WEED MANAGEMENT PRACTICE SELECTION AMONG MIDWEST U.S. ORGANIC GROWERS

BY

JAMES J. DEDECKER

THESIS

Submitted in partial fulfillment of the requirements
for the degree of Master of Science in Crop Sciences
in the Graduate College of the
University of Illinois at Urbana-Champaign, 2012

Urbana, Illinois

Adviser:

Professor John B. Masiunas

ABSTRACT

Weeds are the most costly of all agricultural pests, reducing crop yields, quality and harvestability while simultaneously increasing management expenses. Restriction of synthetic herbicide use in organic agricultural systems increases the complexity of weed management, leading organic farmers to cite weed management as the greatest barrier to organic production. Integrated Weed Management (IWM) systems have been developed to address the ecological implications of weeds and weed management in cropping systems, but adoption is minimal. Organic agriculture may be the most promising context for application of IWM due to philosophical similarities between these two approaches to the “ecologization” of agriculture. However, adoption of IWM on organic farms is poorly understood due to limited data on weed management practices employed, the lack of any agreed-upon IWM metric, and insufficient consideration given to the unique farming contexts within which weed management decisions are made. Therefore, this study aimed to facilitate more successful weed management on organic farms by (i) characterizing organic weed management systems; (ii) identifying motivations for, and barriers to, selection of weed management practices; and (iii) generating guiding principles for effective targeting of weed management outreach. To this end, we used a survey of Midwestern organic growers and nine on-farm interviews to determine how specified psychosocial, demographic and farm structure factors influence selection of weed management practices. Cluster analysis of the data identified three disparate, yet scaled, approaches to organic weed management. Clusters were distinguished by philosophical perspective regarding weeds and the number of weed management practices used. Categorization of individual farms within the identified approaches was influenced by what a farm produces as well as farmer education, years farming and information seeking behavior. Farmer interviews largely supported findings of the survey. The proposed model allows weed management educators to target outreach for enhanced compatibility of farming contexts and weed management technologies.

ACKNOWLEDGMENTS

I would especially like to thank my advisor Dr. John B. Masiunas for hosting me as his graduate student, and committee members Dr. Adam Davis and Dr. Courtney Flint for guiding me through the research process. I would also like to thank Dan Anderson, Dr. Maria Villamil, my labmates, and my family for all of their support and encouragement. Finally, my gratitude is also extended to the farmers who opened themselves and their operations to my work.

"In the context of a "war on weeds", then, a call to "eradicate" weeds demonstrates a social/political belief that humans have grown powerful enough to actively suppress natures' dangerous attempts to reject our industrial uses of ecosystem services… The term "weed" is, in the above sense, an affectively loaded designation for undesired or "dis-esteemed" human relationships with plants…The term weed may be more a psychological category than a botanical or ecological one. What is perhaps even more prosaic in this context is that people's thinking is part of the process. Human thinking and plant behaviour are both part of the same eco-semiotic reality – a common domain within which the symbolic domain of exchange value is extended into the activities of epistemic cultures usually considered to be "objective" or "scientific". In this eco-semiotic frame, a "war on weeds" is therefore a war being waged against the very frameworks that enable us to care about, and take responsibility for, plants."

Low and Peric, 2011

TABLE OF CONTENTS

INTRODUCTION

Restriction of synthetic herbicide use in organic agricultural systems increases the complexity of weed management (Bastiaans et al., 2008; Pannell et al., 2006; Vanclay, 2004), leading organic farmers to cite weeds as the greatest barrier to organic production (Ryan et al., 2007; Walz, 1999). Research indicates that ecological or integrated approaches to weed management have the potential to suppress weed growth with reduced reliance on herbicides (Bicksler and Masiunas, 2009; Burger et al., 2008; Gibson et al., 2011; Hoeft et al., 2001). However, application of IWM theory is complicated by short-term complexity in the level of agroecological knowledge required for integrated management (Llewellyn et al., 2005), as well as the fact that benefits of IWM are largely realized in the long-term compared to the immediate results of direct weed control (Buhler et al., 2000). Few growers have adopted IWM as their approach to weeds on the farm (Czapar et al., 1995; Doohan et al., 2010; Wilson et al., 2009).

Organic agriculture may represent an ideal farming context for the application and study of IWM. Both philosophies are motivated by concern for environmental quality and agricultural sustainability, and both seek solutions through the "ecologization of agriculture" (Lamine, 2011). The IWM concept has been incorporated into the organic pest management standard through emphasis on weed prevention, recognition of multiple control tactics, and relegation of herbicide-based control to last resort status (e-CFR, 2012). Organic growers have proven more likely to adopt individual weed management innovations, such as crop rotation and cover crops, than conventional farmers (McCann et al., 1997). Organic agriculture, by definition, avoids chemical inputs and the associated barriers to IWM adoption cited by proponents (Liebman et al., 2001).

However, adoption of IWM on organic farms is poorly understood due to limited data on weed management practices employed, the lack of any agreed-upon IWM metric (Hammond et al., 2006; Jasinski et al., 2001; Malone et al., 2004; McDonald and Glynn, 1994; Puente et al., 2011; Robertson et al., 2005; Samiee et al., 2009; Shennan et al., 2001)., and insufficient consideration given to the unique farming contexts within which weed management decisions are made. Research indicates that most U.S. organic farmers manage weeds using a limited suite of mechanical controls supported by cultural management such as crop rotation and delayed planting (Ryan et al, 2007; Walz, 1999). According to the available data, organic weed management systems may not include many of the information-intensive practices, such as prevention, economic thresholds and biological control that IWM promotes.

Therefore, this study aimed to (i) characterize organic weed management systems; (ii) identify motivations for, and barriers to, selection of weed management practices; and (iii) generate guiding principles for effective targeting of weed management outreach. Chapter one reviews the literature on organic agriculture and integrated pest management from a historical and philosophical perspective. Chapter two is a manuscript based on data collected by the Midwest U.S. Organic Weed Management Survey. Chapter three presents farmer case studies developed from interviews, which contextualize the survey results.

<u>CHAPTER ONE</u>: LITERATURE REVIEW

Organic Agriculture

The term *organic agriculture* refers to a farm system which "integrates cultural, biological, and mechanical practices that foster cycling of resources, promote ecological balance, and conserve biodiversity" (USDA, 2010). As this definition implies, organic agricultural philosophy views natural systems as a model for farm systems which are holistically successful, maintaining productivity and ecosystem health in the long-term. Practices such as diverse crop rotations, addition of organic matter to soils and incorporation of livestock into farm systems are promoted as methods for building soil fertility through the management of biological systems (Howard, 1943; Rodale, 1948). While this is true, organic agriculture is often defined instead by what it is not, citing the exclusion of most synthetic inputs and genetically modified organisms that are considered deleterious to its ecological goals (Gomiero et al., 2011).

Many consider the philosophical foundation of organic agriculture to be the work of Sir Albert Howard, Lady Eve Balfour and Jerome I. Rodale who were among the first to publicly challenge the value of agricultural intensification through synthetic inputs and promote farming based on the principles of ecology, health and permanence during the period from 1920 through 1950 (Gomiero et al., 2011, Lockeretz, 2007). "These chemicals and these machines can do nothing to keep the soil in good heart. By their use the processes of growth can never be balanced by the processes of decay. All that they can accomplish is the transfer of the soil's capital to current account." (Howard, 1943). However, views regarding the state of agriculture expressed by the mothers and fathers of organic were linked to larger social shifts occurring in their time.

The preservation and conservation movements of the late 19th and early 20th centuries developed a nature centered, or ecocentric, ethical system in response to environmental degradation resulting from new industrial systems (Baxter, 1996; Hoffman and Sandelands, 2005). Ecocentric ethics were perhaps best characterized by Wisconsin naturalist Aldo Leopold in his "land ethic". "A thing is right if it tends to preserve the stability, integrity, and beauty of the biotic community. It is wrong if it tends otherwise." (Leopold 1949). Leopold's biotic community is a holistic conception of nature in its entirety. Ecocentrism values all living and nonliving things for their broad contributions to species or ecosystem rather than as resources or individuals with only economic value (Baxter, 1996). This serves the purpose of highlighting the environmental and social impacts of individual actions that are often externalized or hidden in conventional systems.

Ecocentric ethics locate the center of moral value in specific sates of the all-encompassing biotic community like stability, health, or "balance" in the case of USDA's definition of organic agriculture. These value-based goals represent a form of virtue ethics (de Groot et al., 2011). Virtue ethics are useful for analysis of environmental problems because they are flexible enough to be context specific (de Groot et al., 2011; Sandler, 2010). Due to the complexity of natural systems "balance", for example, cannot likely be achieved in the same way, and may mean very different things, for two distinct ecosystems. Likewise, organic agriculture does mean the same prescription for two different farms, but instead works toward nutrient cycling, biodiversity, and ecological balance as virtuous goals. This can be compared to the nature of the sustainability concept in agriculture. In the words of the organic agriculture pioneer Robert Rodale, "Sustainability is a question rather than an answer" (Ikerd, 2008). Using values as goals and measures for organic agriculture allows for vital place-based solutions.

Organic agriculture also strongly emphasizes intergenerational responsibility (Ikerd, 2005; Rodale, 1948). Intergenerational responsibility refers to the duty of each generation to leave the world in a state that allows coming generations the same opportunities as the preceding generation. Organic agriculture strives to build farm systems that require little external input of nonrenewable resources and instead operate through the internal cycling of nutrients (Howard, 1943; USDA, 2010). It is believed that in this way the world can be conserved in a state which provides opportunity and hope for the indefinite future. "As a patriotic duty, he [the farmer] assumes an obligation to preserve the fertility of the soil, a precious heritage that he must pass on, undefiled and even enriched, to subsequent generations." (Rodale, 1948).

First use of the term *organic* in the context of agricultural philosophy is attributed to both the Englishman Walter Northbourne who wrote of "the farm as organism" and management of the "organic whole" in his 1940 book *Look to the Land*, and American author Jerome I. Rodale who wrote of "organic agriculture" practices like crop rotation and mulching in his 1940 article published in *Fact Digest* (Gomiero et al., 2011). From 1940 through the 1980s organic agriculture expanded as a grassroots movement, with ongoing debate among producer organizations and consumers over what production practices and inputs contribute to its value-based goals (Lockeretz, 2007; Lotter, 2003). However, pest management based on mechanical and cultural controls have always been a hallmark of the organic standard.

Organic Pest Management

Today, organic agriculture is regulated by international and national institutional bodies which set standards for production, handling and processing. In the United States, an arm of U.S. Department of Agriculture (USDA) known as the National Organic Program (NOP) regulates organic farming according to national standards mandated by the Organic Foods

Production Act of 1990. Products labeled or marketed as organic must be produced and handled according to the national standard within operations certified by a USDA accredited agency. **Figure 1.1** displays Section 205.206 of the national organic standard, which dictates the approach to pest management that organic farmers should take.

The organic pest management standard has three key characteristics that differentiate it from the dominant approach to pest control. First, organic pest management is to be based on prevention through crop rotation, sanitation, and other cultural practices. Secondly, organic pest control is to be achieved using primarily mechanical, physical, and biological means. Finally, a "biological or botanical substance", an approved pesticide, can only be applied for pest prevention or control when other documented practices have failed to control a pest. Organic pest management is thus in stark contrast to pesticide-focused control which dominates American agriculture today. Organic solons borrowed this alternative approach to pest management from a related movement which largely paralleled the development of organic agriculture. A paradigm shift in pest management science, known as integrated pest management (IPM), began in the 1950's as a specific reaction to one of the many concerns that inspired organic agriculture, over-reliance on pesticides and its impacts on ecological health (Thill et al., 1991).

Integrated Pest Management:
Theory and History

The concept of IPM first developed during the 1950's and 60's out of concern among entomologists and the public that overreliance on pesticides was creating secondary pest management and environmental problems (Kogan, 1998; Thill et al., 1991). Pesticide efficacy was limited by the evolution of resistance among target species. Local populations of pest species, under the strong selection pressure provided by repeated use of single-mode-of-action pesticides, evolved the ability to survive pesticide applications. Concurrently, incidence of applicator injury and damage to non-target crops and livestock pushed the risks associated with pesticide use to the forefront of public consciousness (Flora, 1990). These relatively isolated concerns were extended to consider broad long-term environmental health impacts of pesticides with the publication of Rachel Carson's *Silent Spring* (1962) (Coppin et al., 2002; Flora, 1990). "Can anyone believe it is possible to lay down such a barrage of poisons on the surface of the earth without making it unfit for all life? They should not be called "insecticides," but "biocides." (Carson, 1962).

Despite evaluation and regulation by USDA, the U.S. Environmental Protection Agency (EPA), and state departments of agriculture unintended consequences of pesticide use persist (Heap, 2012; Calvert et al., 2003). The dilemma of pesticide resistance has only grown in the last half century. Today one hundred and eighty-four herbicide resistant weed biotypes exist in the twelve states of the Midwest U.S. (Heap, 2012). Applicators and others also continue to be injured. A large study funded by the EPA and Centers for Disease Control and Prevention identified 1,009 cases of acute pesticide related illness, including nervous, gastrointestinal, reparatory, eye and skin effects, across seven U.S. states from 1998-1999 (California, Texas, Oregon, New York, Florida, Louisiana, and Arizona) (Calvert et al., 2003). Islam and Anderson (2006) found that 39 cases of acute occupational pesticide poisoning were reported to Wisconsin poison control centers in 2001. These numbers do not reflect any non-occupational, chronic, or unreported illnesses occurring during the studies, and thus drastically underestimate the actual health impacts of pesticides (Calvert et al., 2003; Islam and Anderson, 2006).

Further, debate exists regarding the full environmental risks of pesticide use (Cooper and Dobson, 2009; Damalas, 2009; Flora, 1990; Macfarlane, 2002; Mertz et al., 1998). Legal scientific judgments on the risks of pesticides are made using combined data from two classes of evaluation. Toxicity is determined by number of measures related to acute illness, cancer, and mortality caused by active ingredients of pesticides administered to “representative” plant and animal species (EPA, 2012, Suhre, 2000, Judson et al., 2009). Environmental fate is assessed by standardized measurements of an active ingredient’s interactions with soil, water, air, and food (EPA, 2012, McLean et al., 1988; Varshney et al., 1993). Cumulative effects are only considered for chemicals having similar mechanisms of toxicity (EPA, 2012; Gennings et al., 2004, Wilkinson et al., 2000). Evaluations are performed by product manufacturers and submitted to the EPA for evaluation (EPA, 2012). A product is registered if the mathematical risk calculated using this data is below a particular threshold (EPA, 2012; Williams et al, 2009). However, scientific uncertainty exists regarding broader health implications of chronic exposure to multiple pesticides altered and combined in the environment (Damalas, 2009; Macfarlane, 2002; van Dijk et al., 2008). For example, the toxic effects of certain chemicals do not interact as expected, multiplying rather than working additively when combined in water or soil after application (Gennings et al., 2004)

For the public pesticides represent a unique type of risk, where impacts are diffuse among a population that has little control over the causal agents (Flora, 1990; Macfarlane, 2002). Pesticides can not be seen and exposure, even among non-users, is inevitable through food, water, or air. Such ungovernable risks are often viewed as “insidious”, more dangerous though the mathematical risk may be equal to commonly accepted activities (Coppin et al., 2002). Thus, the unintended and unknown costs of pesticide use have degraded its social acceptability (Chipman et al., 1995; Coppin et al., 2002; Dunlap and Beus, 1992; Van Tassell et al., 1999; Williams and Hammitt, 2001), and encouraged some scientists and to challenge their traditional control oriented, pesticide-based approach to pests (Hoskins et al., 1939; Liebman et al., 2001; Michelbacher and Bacon, 1952; Smith and Allen, 1954; Smith 1969; Zimdahl, 2011). The work of such scientists inspired authors of the U.S. organic agriculture standard. Since its beginning in the 1960's, IPM has continued to represent a philosophical move beyond traditional pest control for scientists and growers, seeking to minimize, through intensive management, both risks associated with agricultural pests *and* the negative implications of pest control strategies.

What is IPM?

No single agreed-upon definition of IPM exists, though many have been proposed (Buhler et al., 2000). Rather, the theory of IPM is united across disciplines by a deceptively simple set of goals including i) viable pest control based upon determined economic injury levels rather than eradication; ii) curbing overreliance on pesticides through the application of agroecological knowledge in the integrated use of a suite of preventative, cultural, physical, biological and information management practices; and iii) minimized negative social and environmental impacts (Buhler et al., 2000; Thill et al., 1991). The goals-based definition of IPM is similar to the virtue oriented definition of organic agriculture, with the same advantages of flexibility and site specificity. Also reminiscent of organic agriculture, IPM emphasizes the importance of ecology in agricultural management (Lamine, 2011)

The pursuit of IPM goals involves relearning of some traditional approaches to pest management, such as cultivation for weeds, which were popular prior to pesticides-based control. This aspect of IPM has created confusion among potential practitioners, many of whom view IPM as a fancy new term for regression in pest control (Walker and Buchanan, 1982). However, crop protection scientists stress the *integrated* and *management* components of IPM, which suggest a novel long-term, systems-based approach (Liebman and Gallandt, 1997).

Cardina et al. (1999), following Elmore (1996), proposed that, in order to be successful and sustainable, IPM should achieve three embedded levels of integration. First, integrated knowledge of individual pest and farm system ecology must be applied to the selection of pest management technologies. Second, selected pest management technologies, each exhibiting relatively weak individual selection pressure, need to be integrated into a suite of practices which provides economically viable pest control without contributing to the development of resistance or environmental degradation. Finally, pest management must be integrated into day-to-day management of the farm system as a whole.

IPM also implies a management, rather than control, approach to pests. Modern use of pest *control* is referential to our “War on Weeds” (Kogan, 1998; Low and Peric, 2011). It suggests human domination of pests through eradication and is often used to refer to actions taken to address an existing pest problem (Buhler, 1996; Low and Peric, 2011). Some control strategies, such as preemergent herbicides, are activated prior to a pest infestation. Still, they are designed to kill as many weeds as possible in the relative short-term. Pest *management*, on the other hand, emphasizes a long-term systems-based approach including prevention of pest infestation, information management, and ultimately a new paradigm based on the understanding that pest species should continue to exist below economic thresholds as natural and important components of agroecosystems (Buhler et al., 2000; Kogan, 1998; Zimdahl, 2011).

Integrated Weed Management

Initially, the majority of progress in IPM applied only to insect pest control. This was likely due to a time lag, and thus motivation delay, between the first documented cases of insecticide resistance in 1947 (houseflies resistant to DDT) and herbicide resistance in 1968 (triazine resistant common groundsel (*Senecio vulgaris*) (Barber, 1949; Ryan, 1970). The 1960’s also saw increased public concern regarding the environmental impacts of pesticides (Coppin et al., 2002; Flora, 1990). By the early 1970's motivations for reducing reliance on herbicides were becoming apparent and were reflected in wide spread acceptance of the term *integrated weed management* (IWM) among weed scientists (Walker and Buchanan, 1982).

In 1980 Baldwin and Santelmann published *Weed Science in Integrated Pest Management.* The authors insisted that herbicides will continue to be an important component of weed management systems. Yet, their paper also acknowledged the basic value of cultural and information management practices, such as cover cropping, weed scouting, and thresholds, supporting herbicide use. However, they concluded that, at that time, the goal of IWM lay beyond reach because;

> "The present knowledge base in weed science is inadequate… Until some of these problem areas have been studied in great depth, research on the influence of integration of multiple control practices on a crop as related to specific crop systems or sequences and locations will be difficult."
>
> (Baldwin and Santelmann, 1980)

In 1981 the Weed Science Society of America (WSSA) hosted a symposium entitled *Integrated Weed Management Systems Technology for Crop Production and Protection* where papers on topics such as weed biology, biological control and IWM research needs were presented (WSSA, 1982). A supplement published in 1982 by McWhorter and Shaw urged weed scientists to pursue research in weed-crop ecology that can be applied to management, as well as interdisciplinary work with other plant protection disciplines toward "total production" IPM systems that manage beyond individual pest complexes. Looking toward the future, WSSA entered the mid 1980s with an aggressive goal for IWM outreach, promising that every farmer would have an IWM program available to them by 1990 (Thill et al., 1991). The society's efforts were supported by USDA in 1993 with the establishment of its goal to have three-quarters of the nation's cropland under IPM by the year 2000 (Jacobsen, 1996).

Is IWM Working?

Research indicates that ecological and integrated approaches to weed management have the potential to suppress weed growth with reduced reliance on herbicides (Bicksler and Masiunas, 2009; Burger et al., 2008; Creamer et al., 1996; Gibson et al., 2011; Hoeft et al., 2001; Liebman and Dyck, 1993). Yet, IPM for weeds remains less developed than IPM for insects (Buhler et al., 2000; Samiee et al., 2009; Thill et al., 1991). Few growers have adopted IWM as their approach to weeds on the farm (Czapar et al., 1995; Doohan et al., 2010; Wilson et al., 2009). Buhler (2000) suggests this is largely due to a lack of basic scientific knowledge regarding crop-weed ecology, as well as differences in insect and weed ecology that complicate the transfer of strategies from IPM for insects to IWM. For example, rotating host and non host crop species can be an effective tool for the management of insects, which are obligate consumers. However, this approach cannot be directly applied to the management of weeds without some modification. Crop selection impacts weed growth variably through competition for resources. However, as primary producers weeds are not dependant on a specific host, and some individuals will likely survive rotation into even the most competitively aggressive crop.

Others argue that development of IWM has been stifled by the history and dominant philosophical position of weed science (Low and Peric, 2011; Zimdahl, 2011). Zimdahl (2011) offers a comparative history of entomology and plant pathology vs. weed science to suggest that while other plant protection disciplines began with the study of pest taxonomy and ecology, weed science was founded on the concept of control. Our history has cultivated what he calls a "pesticide paradigm" within weed science, which narrowly defines the field as technocratic pursuit of a mythological future defined by absolute weed control through ever-improved herbicides. This paradigm is fostered by anthropocentric definitions of weeds as unwanted objects to be controlled, and maintained through the semiotics of our "war on weeds" (Low and Peric, 2011).

Yet, advancements have been made toward a new weed science that, "addresses both society's perception of safety and the scientific community's perception of risk" (Naegele, 1993). In 1999 Buhler published *Expanding the context of Weed Management,* which offers twelve chapters on topics ranging from the identification of economic weed thresholds to soil microorganisms for weed management. Still, in the last chapter Cardina et al. (1999), in constructing a model of IWM integration, argue that although many farmers were using multiple weed management tactics at the time of publication, IWM was still early in its development. For example, weed science had not designed entire integrated farm systems that resist weeds (Cardina et al., 1999).

In 2001 Ohio State University released IPM definitions for over twenty major crops (Jasinski et al., 2001). Their definitions, following the model of Cornell University, represent some of the first comprehensive IPM system designs, providing clear criteria for evaluation of IPM adoption in the context of a specific crop (Jasinski et al., 2001). That same year Liebman, Mohler and Staver (2001) published *Ecological Management of Agricultural Weeds*. Their work advanced IWM through synthesis of the ecological weed management and weed ecology literature published as of that year into a well evidenced, illustrative and applicable text. The authors called for a new ecological paradigm in weed science, and emphasized the application of ecological knowledge to management through topics including vulnerabilities in weed life histories, managing weeds with insects and pathogens, and the human dimensions of weed management knowledge.

In attempting to explain inadequate IWM development the approach of Liebman et al. (2001) differs from Buhler (2000). Where Buhler (2000) implicated the limited extent of IWM science, Liebman et al. (2001) blame "i) the apparent ease and low risk of chemical weed management, ii) the aggressive marketing of chemical solutions to weed management problems, coupled with a lack of widely available information concerning alternatives, iii) the externalization of environmental and human health costs of agrichemical technologies, iv) the increasing prevalence of large-scale industrial farms, and v) government policies that foster input intensive agricultural practices." Others have echoed Liebman et al. (2001), suggesting that limited IWM adoption and the causal conditions represent a greater challenge than limited IWM science (Wilson et al, 2009)

Presentation of IWM as an established viable science and an increased focus on its adoption mark a significant development in weed science. McDonald and Glynn (1994) wrote, "IPM is perhaps at an advantage over other alternative agricultures in that the IPM philosophy or approach is clearly spelled out in several areas, including scouting techniques, the use of threshold figures…" While many farmers have access to IWM information through university extension and the philosophy of IWM may be clear, the details of applied weed ecology and systems for pest management integration at the farm or landscape scale remain largely unachieved (Davis and Ngouajio, 2005). Yet, it is important to begin investigation of IWM application on real farms to determine if and how IWM philosophy can translate into viable weed management. Research has indicated that in order to be adopted IWM must be flexibly applied to fit the context and needs of the existing farm system (Huwer et al., 2005; Kaine and Bewsell, 2008). Organic agriculture may represent an ideal farming context for the application of IWM.

Organic Agriculture and Integrated Weed Management

Largely due to its singular focus on pest management and allowance for synthetic pesticides, IPM is often viewed as the intermediate on a sustainability spectrum between agriculture dependant on synthetic inputs and the organic goal of prescribed ecological management of the entire farm system (Baker et al., 2002; Labrie et al., 2003; Swezey et al., 2007; Todd et al., 2011; Turgut et al., 2011). This model is supported by the common assumption that organic weed management is essentially non-chemical (Bond et al., 2003; Parish, 1990; Wei et al., 2010). In the U.K. this is in fact the case. While several organic insecticides are permitted when crop loss is imminent, herbicide use is not (Bond et al, 2003). However, paragraph (e) of the U.S. organic standard quoted above makes an allowance for biological and botanical weed control chemicals when other management practices prove insufficient (e-CFR, 2012). Many chemical weed control technologies, including acetic acid, essential oils, and soaps are permitted. Chemical weed control remains so uncommon among U.S. organic farm operations that the authoritative national survey of organic agriculture did not even include it in questioning (Walz, 1999). Yet, its tolerance within U.S. organic agriculture suggests little philosophical distance between IPM and organic pest management, aside from the synthetic – non-synthetic distinction (Lamine, 2011).

Both philosophies are motivated by concern for environmental quality and agricultural sustainability, and both seek solutions through the “ecologization of agriculture” (Lamine, 2011).

The IPM concept has been incorporated into the organic pest management standard through emphasis on pest prevention, recognition of multiple control tactics, and relegation of pesticide-based control to last resort status. Rather than two different agricultural systems, IPM can be practically considered the pest management philosophy of organic agriculture in the United States. For this reason, organic agriculture may be ideally suited to the study of IPM application. Organic agriculture, by definition, avoids chemical inputs and the associated barriers to IWM adoption cited by Liebman et al. (2001). Organic growers have proven more likely to adopt individual weed management innovations, such as crop rotation and cover crops, than conventional farmers (McCann et al., 1997). IWM may be underdeveloped, but it is the best option organic farmers have. If IWM fits anywhere, it fits in organic agriculture.

Organic Weed Management in Practice

Organic agricultural systems increase the complexity of weed management, thus exacerbating weed problems (Bastiaans et al., 2008). Weed populations are further impacted by increased soil organic matter, crop rotation, and biodiversity associated with organic agricultural systems (Barberi, 2002). Organic farmers consistently cite weeds as one of the greatest barriers to organic production and rank weed management as their number-one research priority (Baker and Smith, 1987; Ryan et al., 2007; Walz, 1999). Research in organic agriculture is limited, particularly so in the applied aspects of pest management (Duram and Larson, 2001; Parish, 1990). Data from two recent surveys of U.S. organic agriculture (Ryan et al, 2007; Walz, 1999) illustrate the state of organic weed management. Walz (1999) published the results of the Third Biennial National Organic Farmer's Survey, which included several items regarding weed management practices. Ryan et al. (2007) surveyed organic growers specifically on weed management behavior, challenges, and attitudes on behalf of the Rodale Institute. **Table 1.1** shows adoption of several weed management innovations among U.S. organic farmers, according to data from these two surveys.

This data indicates that organic weed management is dominated by direct physical control and a few key cultural controls. It explains why scientists cite limited adoption of IWM, and why many practitioners view organic weed management as a return to cultivation dominated control. However, these numbers may also reflect the limited scope of organic weed management behavior studies to date. It is difficult to accurately survey weed management behavior because of what Bond et al. (2003) discuss as the direct/in-direct distinction in weed management innovations.

Some weed management practices, like mechanical cultivation, are motivated by goals for weed management and act directly against weeds, and can thus be considered direct weed controls. Other practices, such as primary tillage and habitat for beneficial organisms, may contribute to weed management but are considered indirect management because they work through broader agricultural impacts which may be more important to a grower (Bond et al., 2003). When a survey respondent indicates use of a particular practice, researchers can not presume to understand their motivation in doing so. For this reason, as well as ease of administration, the surveys cited above limited the number of weed management practices included to direct controls and indirect practices usually motivated by goals for weed control. Yet, if complex and information-intensive practices like economic thresholds and biological controls are not included in surveys we can not know if they are being adopted in any extent.

Hand weeding ranks first as the most used practice nationally (77%). Mechanical tillage came in second, used by 72% of growers. Hand weeding and mechanical weed control involve the selective physical destruction of growing weed tissue, or disturbance of soil with the goal of uprooting and/or burying weeds. They represent the oldest approach to direct weed control, progressing historically from hand-pulling to a wide variety of specialized hand implements, harrows, inter / intra-row cultivators, and mowers (Liebman et al., 2001). Bowman (1997) provides an excellent reference to tractor driven mechanical weed management tools and their application. Tool choice, timing, intensity, and frequency largely determine efficacy of mechanical control on a crop specific basis (Rueda-Ayala et al., 2010).

The next most popular practices are indirect cultural controls including crop rotations, cover crops, and mulches. Crop rotations and cover crops were used by 58 and 57% of respondents respectively. Diverse crop rotations including cover crops and/or intercrops can combat weeds by creating dynamic patterns of soil disturbance, resource competition, and opportunities for direct control (Liebman and Davis, 2000). Crop rotation represents one of the farmers' best tools for manipulating weed-crop competition (Koocheki et al. 2009; Liebman and Davis, 2000). Some crops are more competitive than others, and more readily facilitate direct weed control. Johnson et al. (2010) found that organic weed management was feasible in snap bean because it is a short season crop that is competitive with weeds. Conversely, sweet corn did not compete well with weeds in the row, making mechanical weed management more difficult.

Choosing the right crops and length for rotations is important. Lundkvist et al. (2008) determined that an appropriately designed crop rotation was able to maintain weed density and diversity at prior herbicide controlled levels during a fifteen year organic transition. Cavigelli et al. (2008) compared conventional and no-till farm systems to three organic rotations, indicating that rotation length influences weed cover. Short two-year organic corn-soybean rotations were found to have higher weed cover than both conventional and longer organic rotations. However, a four year organic corn-soybean-wheat-hay rotation significantly reduced weed cover compared to the shorter organic rotations, but failed to achieve weed control or yields comparable to the herbicide-based systems. The authors cited weather related interference with timely cultivation as a barrier to weed control in organic systems. Eyre et al. (2011) found that organic management, consisting of mechanical weed control and organic fertility, significantly increased weed cover over conventional management. However, similar to Cavigelli et al. (2008) the authors also showed that preceding crops and crop sequence had more of an impact on weeds than weed management approach, and could be adjusted to minimize the weediness of organically managed plots.

Fifty-two percent of growers indicated that they mulch. Mulching uses organic or synthetic material placed over the soil surface surrounding crop plants to suppress weed germination and seedling growth by acting as a physical barrier and limiting light. Organic mulches come in the form of various applied organic materials, killed cover crops, and living mulches. Straw may be the most popular applied organic mulch, and has been shown to effectively suppress weeds in many crops, increasing yield in melons and bell peppers (Johnson et al., 2004; Wang et al., 2010). Whatever the material, organic mulches may immobilize soil nitrogen if their C:N ratio at application is too high (Doring et al., 2005). Killed cover crops, like Cereal rye (*Secale cereale* L.) treated with a roller-crimper, can be planted without primary tillage to remain on the soil surface as mulch with the added benefit of allelopathic weed suppression (Creamer et al., 1996; Smith et al., 2011). Living mulches grown among crop plants, particularly white clover, can provide excellent weed control and other benefits like erosion control and nitrogen fixation. However, they also compete with crop plants and often reduce yield (Creamer et al., 1996; Feil and Liedgens, 2001). Synthetic mulching most often taken the form of plastic or plant-based biodegradable films placed over raised soil beds.

Synthetic mulches have been shown to provide more consistent weed control than organic mulches, and increase crop yields by warming the soil (Bond et al., 2003; Majahan et al., 2007).

Flaming was only used by 19% of growers. Thermal weed control (flaming) uses 60-70 degree C heat generated by fossil fuel, mainly propane, burners to rupture plant cells (Ascard et al., 2007). Flaming can be used nonselectively or selectively by manipulating crop-weed differences in size, maturity, and/or achitecture (Bond et al., 2003). Flaming is more effective against broadleaf weeds than grasses because the growing point of a grass is protected by older leaves (Cisneros and Zandstra, 2008). Flame weeding may only be profitable above a certain scale threshold due to high machinery and fuel costs (Nemming, 1994).

Only 18% of organic growers indicated use of approved herbicides. Investigations into the efficacy of organic herbicides have produced contradictory results. James and Rahman (2005) compared several botanical organic herbicides to various glyphosate formulations (all 360 g ai/litre at 400 litres/ha) in a controlled setting, concluding that the organic herbicides provided sufficient control of annual ryegrass and white clover ranging from 89 to 97% and comparable to the greater than 96% control provided by all glyphosate formulations. Ferguson (2004) compared citric acid, clove oil, and thyme/clove oil to glyphosate in the field, finding that weed control provided by the organic herbicides ranged from 10-40% while glyphosate provided 100% control. Organic herbicides provided better control when weeds were less than ten centimeters tall, restricting their effective use within the cropping cycle.

Most organic herbicides are plant desiccants that lack selectivity. This characteristic also severely limits their usefulness (James and Rahman, 2005). Evans et al. (2011) evaluated integration of vinegar for in-row weed control in transplanted bell pepper and broccoli. Vinegar was found to provide weed control greater than 96%. However, despite the tedious application of stem protectants, crop plants were injured resulting in significant yield loss. Organic herbicides are also more expensive than synthetic chemicals (Ferguson, 2004).

Only one biological control, grazing, showed significant use nationally (16%). Biological weed control exploits ecological relationships, using herbivory (insects or grazing animals) and disease-host relationships to limit weed growth. Biological weed control takes three main forms including *conservation, inoculation* and *innundation*, the latter two of which can be classified as direct control innovations: *Conservation* biocontrol conserves habitat for beneficial organisms including those that damage weeds. *Inoculation* biocontrol involves introduction of a relatively small number of beneficial organisms to damage a target weed species, and *inundation* biocontrol introduces large numbers of beneficial organisms with the goal of quick control (Liebman et al., 2001).

The theory of biological weed control is attractive, but its direct application is complex. Potential biological control agents must be thoroughly evaluated prior to introduction to minimize impacts on non-target species (Sutherland and Hill, 1990). Hundreds of agents, targeting weed species all over the world, have proven effective in trials (Bond et al., 2003). Still, field efficacy of biological weed control is often "occasional" or "partial" and adoption remains limited (Liebman et al., 2001). Several sources suggest that direct biological control may be the last portion of the IWM package to diffuse among weed managers, or may simply be rejected as overly complex and risky (Lamine, 2011; Puente et al., 2011; Thill et al., 1991).

Therefore, organic weed management systems significantly reduce herbicide use through the application of direct physical weed control supported by cultural methods such as crop rotation and cover cropping. According to the limited available data, organic weed management systems may not include many of the information-intensive practices, such as economic action thresholds and biological controls that IWM promotes. However, is organic weed management nonetheless achieving the IWM goal of viable pest control based upon determined economic injury levels?

Organic Weed Management Outcomes:
Weed Cover, Biomass & Diversity

Organic weed management, with its affinity for mechanical and cultural controls, contributes to increased weed abundance and diversity at both the field and landscape scale (Gruber et al., 2000; Roschewitz et al., 2005; Rydberg and Milberg, 2000). Roschewitz et al. (2005) compared the weed flora of conventional and certified organic farms, finding that the alpha and beta diversities of weed communities on organic farms were significantly greater. Koocheki et al. (2009) determined that weed communities in an experimental high-input system (synthetic fertilizer and herbicide) was 11 species with 66 plants per square meter. Whereas in organic systems with cultivation based weed control, the weed community was13 species with 220 plants per meter squared. Belde et al. (2000) found that the number of individual weeds, biomass, and number of weed seeds in the soil increased significantly under organic management consisting of a diversified crop rotation and mechanical controls. Hiltbrunner et al. (2008) compared the weed community dynamics of integrated and organic treatments in a long term Swiss farm systems comparison. Their data indicated that mechanical weed management alone resulted in seven to fifteen times the weed density of integrated systems using herbicides and cultivation.

Seed Bank Dynamics

The diversity and density of weed seedbanks follow a similar pattern to emerged weeds, increasing with decreased herbicide use and a focus on cultural and mechanical controls (Mayor and Dessaint, 1998; Menalled et al., 2001; Wortman et al., 2010). Wortman et al. (2010)

determined that weed seedbank diversity was higher in an organic green manure system including alfalfa in rotation than manure-based organic and conventional treatments without a forage phase. In a Scottish study comparing weed management on one hundred conventional, integrated, and organic farms Hawes et al. (2010) demonstrated that decreased management intensity, measured as synthetic pesticide and fertilizer use, increased density and diversity of the weed seed bank, as well as emerged weed flora. Organic farms, with limited use of synthetic inputs, had significantly higher weed pressure. The authors also suggest, corroborating Davis et al. (2005), Menalled et al. (2001), and Rydberg and Milberg (2000) that weed communities tend to shift under organic management from grasses, herbicide tolerant, and nitrophilous species that often dominate conventional systems to spring germinating, herbicide susceptible, less nitrophilous, and dicotyledonous species. Also similar to emerged weeds, longer and more diverse crop rotations can reduce weed seedbank populations (Teasdale et al., 2004).

Economic Return to Management

Organic management clearly appears to result in more weeds of greater variety, which can limit net farm income due to decreased yields (Pardo et al., 2008). However, research indicates that crop yield is determined only in part by direct weed-crop competition (Zimdahl, 2004). As primary producers, biodiversity among weed species fosters biodiversity in birds, predatory insects, and soil fauna (Bengtsson et al., 2005, Marshall et al., 2003; Pfiffner et al., 2001; Swezey et al., 2007; Todd et al., 2011). It is difficult to quantify the impacts of increased biodiversity at the ecosystem level on farm variables including weed management, yield and net income (Pimentel et al., 1997; Gomiero et al., 2011). In some cases, organic weed management results in dramatic yield loss. Cavigelli et al. (2008) found that organic systems yielded 24-41% less than herbicide-based systems. The authors cited weather related interference with timely cultivation as a barrier to weed control in organic systems. Hawes et al. (2010) determined that organic yields averaged 50% of conventional treatments partially due to poor weed control.

Yet in other cases indirect benefits of organic agriculture paired with innovative weed management can preserve yield and net farm income (Liebman and Davis, 2000; Stonehouse et al., 1996). Johnson et al. (2010) demonstrated that tactics such as stale seedbed, rotary hoeing, and inter-row cultivation can provide adequate weed control in snap beans. Peruzzi et al. (2007) designed an innovative and effective IWM system for carrot production that enhanced yield. Belde et al. (2000) found that cereal crop yield improved under organic management despite increased weed pressure. The authors suggested that both crops and weeds benefited from increased soil organic matter, enabling the crops to compete effectively. Case studies of twenty-five Ontario farmers found that organic farms spent most of their time and money on weed management, but maintained higher average crop gross margins and net farm incomes due to lower overhead and price premiums (Stonehouse et al., 1996). Hiltbrunner et al. (2008) found that organic maize and winter wheat yields remained comparable to integrated systems, citing favorable site conditions and skill in mechanical weed control developed over the extensive study period. Though more weeds were present at the end of the growing season, over time the managers had become expert at controlling weeds during the critical period of growth that determines yield.

Organic agricultural systems are especially equipped to maintain long-term cropping stability (Pimentel et al., 2005; Rodale, 2011). Data from the Wisconsin Integrated Cropping Systems Trials indicates that organic yields average 90% of conventional. Thirty-four percent of the time weather interfered with mechanical weed control limiting organic grain yields to 74% of conventional systems. However, 66% of the time mechanical weed control was effective and organic yields ranged from 90-99% of conventional (Posner et al., 2008). Thirty years of the Rodale Institute's Farming Systems Trial show that yields in long-term organic systems can be comparable to conventional systems, despite higher weed pressure (Rodale, 2011). Ryan et al. (2009) suggest that organic fertility management results in lower weed –crop competition. Further, in years of drought increased soil organic matter and water holding capacity allow organic crops to maintain yield while conventional systems suffer (Pimentel et al., 2005). In this way ecological agriculture buffers itself against adversity for long-term resilience.

Is this IWM?

Unfortunately, little investigation of IWM adoption in organic agriculture has occurred. Most work to date has considered IPM as a generally insect-focused package technology, and attempted to measure its adoption on non-organic farms. This, again, relates to the common conception of IPM as an intermediate between conventional and organic agriculture (Baker et al., 2002; Labrie et al., 2003; Swezey et al., 2007; Todd et al., 2011; Turgut et al., 2011). Still, organic and conventional farm systems and the decision-making of growers in those systems are similar, and studies of IPM adoption on conventional farms are valuable in attempting to understand organic weed management behavior.

How do we know?

Many IPM metrics have been designed, some attempting the measure of farm scale IPM adoption, others aimed at one pest complex or specific suite of technologies. Several researchers have counted the number of pest management technologies or practices a grower uses to calculate an IPM score (McDonald and Glynn, 1994; Shennan et al., 2001; Jasinski et al., 2001; Malone et al., 2004; Robertson et al., 2005). Some studies have weighted practices based on their complexity or perceived importance to IPM (McDonald and Glynn, 1994; Robertson et al., 2005; Samiee et al., 2009). Others have attempted to identify practices most indicative of IPM, and construct IPM indices (Hammond et al., 2006; Puente et al., 2011). A few have gone as far as designing complex crop-specific IPM protocols to measure behavior against (Jasinski et al., 2001).

Scientists disagree on the usefulness of various measures. The literature suggests that rather than adopting IPM as a complete philosophy, farmers select individual technologies that fit their farming context in a "piece-meal" or "selective" approach (Wearing, 1988; Ridgley and Brush, 1992, Sorensen, 1991). Basic count-based metrics are useful, but considering the adoption of additional technologies as progress toward IPM neglects the core goal of pest management, pest suppression. Some practices may only add complexity or even conflict with established methods (Bastiaans et al., 2008). For example, nighttime tillage may limit weed germination, but it also drastically alters an operator's schedule (Bond et al., 2003). If a grower can achieve viable IPM with fewer technologies, shouldn't they do so? Also, the large number of technologies included in a fully IPM system are prohibitive of efforts to make survey and interview instruments concise. Thus, practices included in each study or index are subjectively chosen by researchers *a priori* based on perceived importance, resulting in little comparability between IPM measures. Equally thorny is an apparent bias in asking growers directly if they are IPM adopters, or questioning a series of behaviors that are obviously chosen to construct IPM indices, which tend to overestimate adoption (Fernandez-Cornejo et al., 1992; McDonald and Glynn, 1994, Shennan et al., 2001).

The USDA and agricultural extension service measure IPM adoption, with more flexibility, as progress along a continuum from prevention to avoidance, monitoring and biological suppression (PAMS). Growers are considered IPM adopters if they use technologies that can be classified into at least three of the four PAMS categories (Puente et al., 2011). This approach allows for differences in farm system context that largely determine what pest management technologies can be rationally adopted (Kaine and Bewsell, 2008). It also incorporates IPM philosophy through an emphasis on multiple integrated approaches to pest management in the context of a specific agroecosystem.

Still, “there is such variability from one farm to another that no single adoption measure will provide information about the extent of true adoption” (Kaine and Bewsell, 2008; Puente et al., 2011). As a result, measurement of whole IPM adoption is very difficult, if not impossible (Wearing, 1988). Therefore discrepancies in adoption measurement should be kept in mind during critical analysis and categorization of pest management practices used by farmers.

Further, understanding of technology diffusion is plagued by oversimplification of the adoption process. Most research treats adoption as a binary event where farmers either use an IPM technology, or they do not (Puente et al., 2011). Yet, Llewellyn et al. (2005) and van der Meulen et al. (2007) suggest otherwise, defining technology adoption as a “dynamic learning process”, where potential adopters develop perceptions of an innovations relative utility in their unique farming context.

Farmer Decision-making

Traditional economic theory suggests that human beings make choices that are expected to maximize utility, or the decision-maker’s well-being (Edwards-Jones, 2006). Financial gain is often assumed to represent utility, and thus farmers are frequently represented as rational profit maximizers (Feder and Umali, 1993). From this theoretical position, economists have developed complex models of farmer decision-making that have significant power to predict decisions with strong business or financial components (Edwards-Jones, 2006; Feder and Umali, 1993).

However, there is evidence that many farmers have developed a “post-productivist” self-identity (Burton and Wilson, 2006). Other factors beyond financial status influence farming utility, and many economic models break down when attempting to predict systems-level decisions where anticipated changes in utility are only partially related to finances.

Many factors, less quantifiable than finances, such as health, happiness, and balance can contribute to conceptions of human well-being. In addition, the rationality of human choice is augmented in several ways. Rationality could perhaps be better described as subjective or “bounded” rationality (Simon, 1990). Human choice occurs under uncertainty. Decisions are based upon limited information formulated into beliefs about the available options, which may be more or less correct. Because humans must base decisions on such limited information and because our analytic powers are also limited we tend to take short-cuts (Gintis, 2009).

First in any decision process, several possible choices are discarded in unconscious, or preattentive, processing based on assumptions regarding the system at hand. Secondly, we develop and apply heuristic rules to guide decision-making under uncertainty, often based on past experience or referring to what the neighbors have chosen (Gintis, 2009; Gladwin and Murtaugh in Barlett, 1980). Decision-making does not take place in exclusive space where only the decision-maker and options resound. Decision-makers gather information not only from their own experience but also from the experiences of those around them, in a process termed social learning (Bandura, 1986). Social relationships also evoke cultural norms like compassion that may lead an individual to make seemingly irrational decisions. However, rationality does not necessarily imply direct self interest (Gintis, 2009). A decision-maker could choose to give money away, for example, for many rational reasons including the expectation of reciprocity or other positive social, psychological, and emotional benefits of philanthropy.

Further, farmers are known to have particular decision-making tendencies that differ from other agriculture stakeholders like scientists and extension agents (Litsinger et al., 2009; Wilson et al, 2009). Many farmers demonstrate particularly risk-averse decision-making (Wilson et al., 2008). For example, direct weed control measures have relatively predictable efficacy, are thus perceived as low risk, and adopted much more readily than preventative measures or biological control (Czapar et al., 1995; Wilson et al., 2009). Related to risk aversion is what Gintis (2009) called "time-inconsistency" in decision making. Farmers discount long-term risks, like environmental impacts of herbicide use, and maximize short-term utility, as in direct weed control (Doohan et al., 2010). Farmers also exhibit a significant preference for accessing information through personal experience, or the experience of other farmers (Eckert and Bell, 2006; Walz, 1999). This characteristic fosters discrepancies between the world-views, or mental models, of farmers and agricultural scientists, particularly regarding weed management (Wilson et al, 2009). For example, Wilson et al. (2009) found that farmers tend to highlight causes of weed problems beyond their control, like seed introduction from neighbors' fields, over dispersal mechanisms mentioned by weed scientists, including machinery spreading seed across the farm. As society's land managers, farmers' decisions, particularly regarding pest management, are also disproportionately impacted by public policy (Ikerd, 1996).

Organic growers differ as well in decision-making from other farm managers. Some farmers pursue organic management only to maximize profit through price premiums. However, a larger percentage of organic farmers are also motivated to attempt ecological farm management by concern for the environmental degradation (Fairweather and Campbell, 1996). This key difference in basic motivations for farming translates into pest management decision-making; growers are more willing to incur short-term pest management risk for future benefits (McCann et al., 1997). As a result, farmers who are motivated by environmental protection appear more likely to adopt IPM systems, which benefit the environment, but may not always prove profitable in the short-term (McDonald and Glynn, 1994; Pannell et al., 2006; Vanclay, 2004; Wearing, 1988).

Yet, research has indicated a lack of weed knowledge among organic farmers. Weed biology and taxonomy were generally less salient among organic farmers than conventional in mental models developed by Doohan et al. (2010). More Ohio organic farmers could not identify weeds and did not understand their mechanisms of competition with crops (Canales et al., 2008; Wszelaki and Doohan, 2003). This may be related to obligatory training for pesticide applicators, which organic farmers generally do not participate in (Doohan, et al., 2010). It may also be related to a relative lack of agricultural background among organic farmers compared to conventional. Either way, environmental concern driving organic agriculture and application of IPM will not be successful without basic knowledge of weed ecology.

Finally, many organic farmers view themselves as part of a counterculture movement (Haydu, 2011; Howard, 1943). Organic agriculture is seen as a righteous alternative to the ills of our industrial food system, a system developed and promoted by the scientific establishment. Therefore, some organic farmers do not trust university recommendations and exhibit an even greater preference for user generated pest management information than conventional farmers (Howard, 1943; Park and Lohr, 2005). At the same time, organic agriculture proponents have sought empirical verification of their claims.

This tenuous relationship between organic agriculture and agricultural science has supported the development of some pseudoscientific concepts within organic circles. One example is the theory of base-cation saturation ratios (BCSR), popularized by William Albrecht, Charles Walters and ACRES USA. The theory of BCSR posits that ideal ratios of soil cations exist, and if achieved contribute to increased crop yield. The theory was extended by Jay L. McCaman in his 1994 book *Weeds and Why They Grow* to suggest that "balancing" cation ratios can limit weed growth. Soil cations can certainly influence crop yield and the composition of emerged weed communities. However, since 1916 research has refuted the BCSR theory, determining that nutrient availability and pH have a much greater impact on crop and weed growth than specific cation ratios (Kelling et al., 1996; Lipman, 1916; Schonbeck, 2000). Still, the BCSR theory maintains a large following within the organic agriculture community (Padgham, 2011).

Technology Adoption

Farmer decision-making is thus an incredibly complex process that is difficult to model or predict. However, technology adoption research has made significant progress in application of decision theory to other innovations like Green Revolution seeds. Three main tenants of technology adoption and diffusion theories were summarized by Straub (2009) including "i) technology adoption is a complex, inherently social, developmental process; ii) individuals construct unique (but malleable) perceptions of technology that influence the adoption process; and iii) successfully facilitating a technology adoption needs to address cognitive, emotional, and contextual concerns".

The theory of technology adoption that has guided much of U.S. agricultural outreach, including efforts to increase adoption of IPM, is Roger's Innovation Diffusion Theory (IDT) (Rogers, 2003; Wilson et al., 2009). Rogers (2003) described an innovation as "an idea, practice or object that is perceived as new by an individual or other unit of adoption". An innovation can be a hard technology like a new cultivator, a soft technology like a novel scouting procedure, or a package of both like IPM (Doohan et al., 2010). Diffusion is the process by which innovations are spread through a population in the form of individual adoption events that first reach early adopters, then the bulk of a population, and finally laggards (Rogers, 2003; Straub, 2009). An innovation should not be assumed to be better or capable of maximizing utility simply because it is new. However IDT, like most technology adoption theory, contradictorily exhibits a strong pro-adoption bias assuming that the goals of diffusion and adoption represent success or moral goods (Straub, 2009). IPM, for example, is viewed as a viable approach to minimization of risks associated with weeds and weed management that can benefit farmers, society, and ecology.

Adoption is conceptualized as an individual learning process that occurs within the diffusion of an innovation. It is viewed from the perspective of the adopter, farmer in this case, and involves the collection and processing of information regarding an innovation as well as integration of the innovation into the existing farm system (Pannell et al., 2006). The adoption process has been broken down into identifiable stages including i) awareness of the problem or opportunity; ii) non-trial information evaluation; iii) trial evaluation; iv) adoption; v) review and modification; and at times vi) disadoption (Pannell et al., 1999; Rogers, 2003; Straub, 2009). Each stage of the adoption process is influenced by a wide variety of economic, social, and structural variables.

Why do farmers manage pests as they do?

Adoption diffusion theories suggest that three variable categories influence use of agricultural innovations, including farm structure, farmer demographics, and perceived characteristics of an innovation (Edwards-Jones, 2006; Rogers, 2003; Straub, 2009). Understanding motivations for adoption will allow identification of weaknesses in IPM theory, highlight decision-making complexities and permit more effective targeting of IPM outreach (Doohan et al., 2010; Wilson et al., 2009).

Farm Structure

The physical, mechanical and ecological context of a farm system sets clear restrictions on what pest management technologies or practices make sense. Variables like farm size have long been used to categorize farm systems, and are also consistently found to influence adoption of IPM technologies (Ridgley and Brush, 1992). Studies have identified a significant positive relationship between farm size and IPM adoption (Ceylan et al., 2010; Chaves and Riley, 2001; Hammond et al., 2006; McDonald and Glynn, 1994; Pannell et al., 2006; Rao et al., 2011). Most of the literature posits that larger farms should provide additional capital for investment in pest management education, technologies, and labor, as well as enhanced ability to bear risk. Larger farms may also magnify any positive returns to IPM adoption through scale (Hammond et al., 2006). For example, investing in IPM education will cost two growers about the same amount of time and money. However, the grower with more acres can apply his knowledge to a wider land base for greater returns.

In a study of Wisconsin dairy and cash grain farms Hammond et al. (2006) found IPM index scores tended to increase with farm size. Operators of large farms sought engagement in pest management decision-making and practice, and had the resources to do so. They owned their own equipment, were more knowledgeable about pest management options, used a more diverse set of pest management technologies, and tended to apply pesticides only when economic thresholds were met. Conversely, small farms in that study tended to have the majority of pest management activities handled by custom applicators due to high relative costs per unit area.

While custom applicators offer many services that could contribute to an IPM program, this did not appear to be their motivation for contracted pest management.

However, other research has indicated that IPM adoption is not restricted to larger farm operations (Fernandez-Cornejo et al., 1992; Samiee et al., 2009; Shennan et al., 2001). In a 2001 phone survey of California farmers Shennan et al. found that relatively small farms and very large farms, rather than midsized farms, were the most intensive users of IPM. Larger farm operations generally have the resources to commit to IPM. Smaller operations that do not hire custom pest managers may have the advantage of less expensive operator or family labor to commit to IPM practices such as intensive pest monitoring (Fernandez-Cornejo et al., 1992; Shennan et al., 2001). Samiee et al. (2009) failed to find a significant association between farm size and IPM adoption, suggesting that available IPM technologies are accessible, diverse and scalable enough to meet the needs of both small and large farms.

Studies have also demonstrated the influence crop choice in pest management (Bastiaans et al., 2008; Hammond et al., 2006; Ridgley and Brush, 1992; Riemens et al., 2010; Turner et al., 2007). Riemens et al. (2010) found that organic farmers aware of the impact of crop choice on weed growth chose more competitive crops. Organic farmers in the U.K. select crop varieties and diversify rotations as a method of cultural weed control (Turner et al., 2007). Hammond et al. (2006) found that cash grain farmers were more likely to adopt IPM practices than dairy farmers in Wisconsin.

Cropping diversity also appears to play a role in pest management decision-making. Research supports the theory that increased crop diversity limits attention to, and flexibility in pest management. IPM is a crop-specific and management intensive technology (Ridgley and Brush, 1992). Bastiaans et al. (2008) note that building pest management systems on integration of several strategies increases system complexity, which is likely the largest general barrier to IPM adoption. Adding IPM to an already complex system, such as a diversified vegetable farm, may test human management capacity.

Carolan (2005), Czapar et al. (1995), and Ridgley & Brush (1992) highlighted the influence of land tenure on IPM adoption. A disproportionately large percentage of agricultural land in the Midwest U.S. is rented (Carolan, 2005). In his 2005 study of sustainable agriculture on rented Iowa farmland, Carolan found that tenants were less likely to invest in sustainable practices, like an IWM system. They felt social pressure from landlords to keep clean fields, and did not want to invest in long-term management approaches when their tenancy remained uncertain. Ridgley and Brush (1992) suggest that a greater percentage of land owned indicates family, rather than business, oriented operations. They propose the theory that family farmers are more likely to invest time in IPM education and adoption due to their stronger and more complex ties to the land paired with long-term, more certain, investments (Ridgley and Brush, 1992).

According to a 1995 survey by Czapar et al. only nine percent of Central Illinois farmers used economic thresholds to make weed management decisions, compared to thirty-four percent for insect management. Respondents cited landlord perception of field cleanliness as one reason for failure to adopt IWM economic thresholds. An impressive seventy-five percent of respondents had fields scouted for pests at least twice per season, but most of the scouting was done by hired consultants or custom applicators. Yet, farmers indicated moderate to high concern regarding key IPM issues including effects of pesticides on water quality and applicator health.

Thus, many aspects of farm structure impact pest management decision-making and the adoption of an IPM operating philosophy. Still, the farm itself is never independent of the human dimension in agricultural systems. Farmer demographics give researchers a sense of growers as people, and contribute to our understanding of their decisions.

Farmer Demographics

Age of an operation's principle manager often correlates with IPM adoption behavior (Ceylan et al., 2010; Chaves and Riley, 2001; McDonald and Glynn, 1994; Pannell et al., 2006; Rao et al., 2011; Shennan et al., 2001; Van der Meulen et al., 2007). Older farmers often utilize a limited set of pest management technologies with adequate efficacy and limited complexity, and tend toward being "stuck in one's ways" (Ceylan et al, 2010). IPM is also a long-term investment, and adoption may not pay-off during an older farmer's tenure. In a survey of apple growers McDonald and Glynn (1994) found that seventeen percent of respondents used economic thresholds to trigger insect and disease control, but older growers were less likely to do so. Rao et al. (2011) corroborated that finding with their data showing that younger Indian farmers were more likely than their elders to adopt IPM practices for pigeon pea, such as cultivation and spraying of Neem extract. This occurring despite increased net returns associated with IPM adoption.

Studies have also demonstrated a strong positive relationship between formal education and IPM adoption (Ceylan et al., 2010; Chaves and Riley, 2001; Lohr and Park, 2002; Park and Lohr, 2005; Rao et al., 2011; Ridgley and Brush, 1992; Shennan et al., 2001; Van der Meulen et al., 2007; Waller et al., 1998). Since the 1970s, formal agricultural education has exposed farmers to ecology-based pest management and the increasing variety of technologies available. Formal education, regardless of the field, also trains students to critically assess information under uncertainty and may indoctrinate a farmer to trust information-intensive scientific concepts generated by university research (Park and Lohr, 2005).

Park and Lohr (2005) found that fifty-eight percent of American organic farmers had a college education. These educated growers were shown significantly more likely to adopt IPM practices, such as crop rotation, cover cropping, and planting date adjustment, suggesting enhanced abilities to incorporate new technology and motivation to experiment with new methods. Waller et al. (1998) found a similar relationship between level of education and adoption of three cultural controls for Colorado potato beetle among Ohio potato growers.

Farming experience, or years with a particular type of operation, has a complex relationship with IPM adoption. Experience exposes growers to the challenges of pest management, teaches pest ecology, and introduces new management technologies (Van der Meulen et al., 2007). Organic farmers, who tend to be younger on average, adopt additional weed and insect management practices as they gain experience in organic agriculture (Lohr and Park, 2002; Park and Lohr, 2005). Lamine (2011) suggests that organic growers move through stages of efficiency, input substitution, and finally system redesign as they gain experience. System redesign can take the form of endless accumulation of innovations, or may culminate in identification of a concise set of effective management practices (Waller et al., 1998). It is difficult to measure the relationship between experience and age because studies often do not determine at what age respondents were introduced to the IPM concept.

Another variable that measures commitment to and dependence upon farming is the percentage of a household’s income generated on and off the farm (Ceylan et al., 2010). Pannell et al (2006) suggest that the freedom to pursue non-farm interests is often a long-term goal of farmers and considered a mark of a successful and stable agricultural career. However, the sources of off-farm income often distract from farm management and decrease adoption of management intensive systems, thus complicating the relationship between income, experience, and IPM adoption. A greater percentage of off-farm income indicates a smaller percentage of time, money, and attention devoted to agriculture and pest management, and thus less incentive to adopt IPM (Ceylan et al., 2010; Pannell et al., 2006; Samiee et al., 2009).

Perceived Innovation Characteristics

Pest managers, like other practitioners, want technology that meets their needs, forwards their objectives, and helps them accomplish their goals in yield, pest control, etc. (Pannell, et al., 1999). Farmers first demand technology that is effective. A tool must control the weeds, insects or diseases at which it is targeted (Bastiaans et al., 2008; Llewellyn et al., 2004, 2005; Pannell et al., 1999; Sattler and Nagel, 2010). Sattler and Nagel (2010) demonstrated that the adoption decisions of German farmers are influenced by their perception of a new technology's effectiveness, largely related to possible risks associated with adoption, such as increased pest problems. Llewellyn et al. (2004) found that all one hundred and seventy-two Australian grain growers in their sample understood IWM theory and used several management practices that could contribute to an IWM system. Interestingly, many of the practices were not adopted principally for weed control, but offered many benefits at the farm system level. However, IWM efficacy was perceived as limited compared to herbicide-based management.

Other work posits that initial costs and perceived economic value drive IPM adoption (Llewellyn et al., 2004, 2005; Pannell, 1999, et al., 2006; Vanclay, 2004; Van der Meulen et al., 2007; Wearing, 1988). Llewellyn et al. (2005) found that Western Australian grain growers who received education regarding the short-term economic value of IWM practices such as increased seeding rates tended to adopt such practices more readily. Another study found that Australian grazers felt constrained by finances in the efforts to adopt IWM practices for pasture (Van der Meulen et al., 2007).

Growers also desire pest management technology that is easy to use. IPM increases the complexity of pest management, and is thus self limiting (Bastiaans et al., 2008; McDonald and Glynn, 1994; Pannell et al., 2006; Vanclay, 2004). Vanclay (2004) suggested that complexity increases the risk associated with adopting a new technology, and farmers act quite rationally selecting less complex technologies (herbicides) over complex systems like IPM. Innovations with a larger "software" component consisting of specialized knowledge, like IPM, may be perceived as more complex than "hardware" heavy technologies due to the complexity of trialing information intensive, systems-oriented practices which may not show results in the short-term (Doohan et al, 2010). Bastiaans et al. (2008) state that management of complex systems, as is attempted in IPM, also often involves the pursuit of human goals, which biologically conflict. For example, the goal of maximizing yield must be balanced against the full internalized costs of pesticide use and goals for environmental health.

Farmers also differ in the information they receive regarding pest management, what sources they trust, and how they access information. The more pest management information a grower seeks out, they more likely they are to adopt IPM practices (Ceylan et al., 2010; Pannell et al., 2006; Park and Lohr, 2005; Samiee et al., 2009; Wyckhuys and O'Neil, 2007). Quantity and diversity of information sources exposes a farmer to more pest management technologies and the IPM concept. For example, Honduran corn farmers who completed IPM training designed to compliment local knowledge could identify more natural enemies of common pests and understood a broader suite of pest management options (Wyckhuys and O'Neil, 2007).

Samiee et al. (2009) found a positive significant correlation between use of information sources and adoption of IPM among Iranian wheat growers.

Many farmers, especially organic growers, trust one another first for pest management information. They value visual assessment and first-hand accounts of experience with pest management technologies, generating and modifying technology, as well as their own knowledge. The adoption of IPM practices remains limited in significant ways. If farmers rely on one another for information, they will likely continue current adoption trends (Llewellyn, 2007; Park and Lohr, 2005; Turner et al., 2007; Van der Meulen et al., 2007; Walz, 1999). Tuner et al. (2007) found that organic farmers in the U.K. especially appreciate learning from other farmers through field days, feeling that it was an effective way to disseminate weed management information. Respondents to a 1998 national survey of organic agriculture ranked other farmers first among preferred information sources (Walz, 1999).

Studies also point to the complex impacts of extension education and farmer perceptions of extension on IPM adoption (Czapar et al., 1995; He et al., 2008; Llewellyn, 2007; Pannell et al., 2006; Ridgley and Brush, 1992; Samiee et al., 2009; Turner et al., 2007; Vanclay, 2004). Extension promotes IPM, but adoption has been limited, suggesting a disconnect between extension and farmers (Vanclay, 2004). He et al. (2008) indicate that participation in extension workshops increased adoption of pasture crop rotation in China. California apple growers who placed higher value on pest management information generated by extension were found more likely to adopt IPM, despite varying levels of actual contact with extension agents (Ridgley and Brush, 1992). Yet, Czapar et al. (1995) found that a very small percentage of Illinois farmers used university recommendations to guide pest management decisions. Vanclay (2004) states that agricultural science and extension do not have automatic credibility. To gain legitimacy among farmers extension should avoid top-down approaches to diffusion of technologies, which are often uncritically promoted as good for the farmer.

Conclusion

Organic agriculture and IWM grew together in the late 20th Century as responses to the negative environmental health impacts of input intensive agriculture. They share similar philosophies regarding the importance of ecology in agricultural management. The organic community has even attempted to codify IPM in its legal pest management standard. Organic agriculture has been successfully applied to real farm management, but scientists suggest that adoption of IWM is limited. Due to their philosophical similarity, organic agriculture may represent the best system to address IWM adoption within.

The present state of organic weed management in the U.S. is both promising and discouraging. Organic farmers are managing weeds with dramatically reduced herbicide use. Still, weed management is seen as a significant barrier to organic production, and is dominated by a few cultural and mechanical controls. More extensive application of ecological knowledge to farm management, as in the use of economic thresholds or biological controls, is largely not occurring. However, data on organic weed management behavior is limited by the lack of published surveys, and the complexity of surveying weed management behavior.

Further, measures of IWM adoption are often inadequate. Farmers adopt innovations piece by piece in an effort to maximize perceived utility in their unique farming context. Perceptions of utility are influenced by farm structure, farmer demographics, and perceived innovation characteristics. Therefore, in order to understand organic weed management behavior we must cast broad nets. Analysis should consider as many aspects of organic weed management systems as possible, including not only direct and indirect management practices, but also measures of diverse independent variables indicated in the literature. In this way, we can more completely address the questions of i) How to organic farmers manage weeds?, ii) Why do they manage weeds as such?, iii) Do we consider organic farmers adopters of IWM?

LITERATURE CITED

Acheson, J., Barlett, P., Bennett, J., Berry, S., Cancian, F., Chibnik, M., . . . Ortiz, S. (1980). In Barlett P. (Ed.), *Agricultural decision making: Anthropological contributions to rural development*. New York: Academic Press.

Ascard, J., Hatcher, P. E., Melander, B., & Upadhyaya, M. K. (2007). In Upadhyaya M.B. (Ed.), *Thermal weed control*. Wallingford; CABI Publishing.

Baker, B. P., & Smith, D. B. (1987). Self identified research needs of New York organic farmers. *American Journal of Alternative Agriculture, 2*(3), 107-113.

Baker, B., Benbrook, C., Groth, E., & Benbrook, K. (2002). Pesticide residues in conventional, integrated pest management (IPM)-grown and organic foods: Insights from three US data sets. *Food Additives and Contaminants, 19*(5), 427-446.

Baldwin, F. L., & Santelmann, P. W. (1980). Weed science in integrated pest management. *Bioscience, 30*(10, Integrated Pest Management), pp. 675-678.

Bandura, A. (1986). *Social foundations of thought and action: A social cognitive theory*. Englewood Cliffs, N.J.: Prentice-Hall.

Barber, G. W., & Schmitt, J. B. (1949). Further studies on resistance to DDT in the housefly. *Journal of Economic Entomology, 42*(2), 287-292.

Barberi, P. (2002). Weed management in organic agriculture: Are we addressing the right issues? *Weed Research, 42*(3), 177-193.

Bastiaans, L., Paolini, R., & Baumann, D. T. (2008). Focus on ecological weed management: What is hindering adoption? *Weed Research, 48*(6), 481-491.

Belde, M., Mattheis, A., Sprenger, B., & Albrecht, H. (2000). Long-term development of yield affecting weeds after the change from conventional to integrated and organic farming. *Zeitschrift Fur Pflanzenkrankheiten Und Pflanzenschutz-Journal of Plant Diseases and Protection,*291-301.

Belzil, C., & Hansen, J. (2003). Structural estimates of the intergenerational education correlation. *Journal of Applied Econometrics, 18*(6)

Bengtsson, J., Ahnstrom, J., & Weibull, A. (2005). The effects of organic agriculture on biodiversity and abundance: A meta-analysis. *Journal of Applied Ecology, 42*(2), 261-269.

Bicksler, A. J., & Masiunas, J. B. (2009). Canada thistle (cirsium arvense) suppression with buckwheat or sudangrass cover crops and mowing. *Weed Technology, 23*(4), 556-563.

Bond, W., Turner, R. J., & Grundy, A. C. (2003). *A review of non-chemical weed management.* Henry Doubleday Research Association.

Bowman, G. (Ed.). (1997). *Steel in the field: A farmer's guide to weed management tools* Sustainable Agriculture Network.

Bridges, D. C. (1994). Impact of weeds on human endeavors. *Weed Technology, 8*(2), 392-395.

Buhler, D. D. (Ed.). (1999). *Expanding the context of weed management*. Binghamton, NY: Food Products Press.

(1995). Influence of tillage systems on weed population-dynamics and management in corn and soybean in the central usa. *Crop Science, 35*(5), 1247-1258.

(1996). Development of alternative weed management strategies. *Journal of Production Agriculture, 9*(4), 501-505.

Buhler, D. D., Liebman, M., & Obrycki, J. J. (2000). Theoretical and practical challenges to an IPM approach to weed management. *Weed Science, 48*(3), 274-280.

Bürger, J., de Mol, F., & Gerowitt, B. (2008). The “necessary extent” of pesticide use—Thoughts about a key term in german pesticide policy. Crop Protection, 27(3–5), 343-351.

Burton, R. J. F., & Wilson, G. A. (2006). Injecting social psychology theory into conceptualisations of agricultural agency: Towards a post-productivist farmer self-identity? Journal of Rural Studies, 22(1), 95-115.

Cabrera, N. L., & Leckie, J. O. (2009). Pesticide risk communication, risk perception, and self-protective behaviors among farmworkers in california's salinas valley. *Hispanic Journal of Behavioral Sciences, 31*(2), 258-272.

Calvert, G., Plate, D., Das, R., Rosales, R., Shafey, O., Thomsen, C., Lackovic, M. (2004). Acute occupational pesticide-related illness in the US, 1998-1999: Surveillance findings from the SENSOR-pesticides program. *American Journal of Industrial Medicine, 45*(1), 14-23.

Canales, E., Parker, J., Wilson, R., Tucker, M., & Doohan, D. (2008). Knowledge, perception and attitudes of organic farmers about weed management. *Proc. North Cent. Weed Sci. Soc., Abstract 138*

Cardina, J., Webster, T. M., Herms, C. P., & Regnier, E. E. (1999). Development of weed IPM: Levels of integration for weed management. *Journal of Crop Production, 2*(1), 239-267.

Carolan, M. S. (2005). Barriers to the adoption of sustainable agriculture on rented land: An examination of contesting social fields. *Rural Sociology, 70*(3), 387-413.

Carson, R. (1962). *Silent spring*. Houghton Mifflin.

Cavigelli, M. A., Teasdale, J. R., & Conklin, A. E. (2008). Long-term agronomic performance of organic and conventional field crops in the mid-atlantic region. *Agronomy Journal, 100*(3), 785-794.

Ceylan, I. C., Koksal, O., & Kutlar, I. (2010). Determination of effective factors on adoption of integrated pest management practices. *Journal of Environmental Protection and Ecology, 11*(2), 709-717.

Chaves, B., & Riley, J. (2001). Determination of factors influencing integrated pest management adoption in coffee berry borer in colombian farms. *Agriculture Ecosystems & Environment, 87*(2), 159-177.

Chipman, H., Kendall, P., Auld, G., Slater, M., & Keefe, T. (1995). Consumer reaction to a risk-benefit option message about agricultural chemicals in the food-supply. *Journal of Consumer Affairs, 29*(1), 144-163.

Cisneros, J. J., & Zandstra, B. H. (2008). Flame weeding effects on several weed species. *Weed Technology, 22*(2), 290-295.

Cooper, J. F., & Dobson, H. M. (2009). Pesticides and humanity: The benefits of using pesticides. Retrieved from http://www.croplife.org/library/documents/Crop%20protection/Pesticides%20and%20humanity%20Version%20A24.pdf

Coppin, D., Eisenhauer, B., & Krannich, R. (2002). Is pesticide use socially acceptable? A comparison between urban and rural settings. *Social Science Quarterly, 83*(1), 379-394.

Creamer, N., Bennett, M., Stinner, B., & Cardina, J. (1996). A comparison of four processing tomato production systems differing in cover crop and chemical inputs. *Journal of the American Society for Horticultural Science, 121*(3), 559-568.

Czapar, G. F., Curry, M. P., & Gray, M. E. (1995). Survey of integrated pest management practices in central illinois. *Journal of Production Agriculture,* 8.

D'Souza, G., & Ikerd, J. (1996). Small farms and sustainable development: is small *more* sustainable?. *Journal of Agricultural and Applied Economics, 28*(1), 73-83.

Damalas, C. A. (2009). Understanding benefits and risks of pesticide use. *Scientific Research and Essays, 4*(10), 945-949.

Davis, A. S., & Ngouajio, M. (2005). Introduction to the symposium beyond thresholds: Applying multiple tactics within integrated weed management systems. *Weed Science, 53*(3), p. 368.

Davis, A., Renner, K., & Gross, K. (2005). Weed seedbank and community shifts in a long-term cropping systems experiment. *Weed Science, 53*(3), 296-306.

de Groot, M., Drenthen, M., & de Groot, W. T. (2011). Public visions of the Human/Nature relationship and their implications for environmental ethics. *Environmental Ethics, 33*(1), 25-44.

Doohan, D., Wilson, R., Canales, E., & Parker, J. (2010). Investigating the human dimension of weed management: New tools of the trade. *Weed Science, 58*(4), pg. 510.

Doring, T., Brandt, M., Hess, J., Finckh, M., & Saucke, H. (2005). Effects of straw mulch on soil nitrate dynamics, weeds, yield and soil erosion in organically grown potatoes. *Field Crops Research, 94*(2-3), 238-249.

Dunlap, R., & Beus, C. (1992). Understanding public concerns about pesticides - an empirical-examination. *Journal of Consumer Affairs, 26*(2), 418-438.

Duram, L., & Larson, K. (2001). Agricultural research and alternative farmers' information needs. *Professional Geographer, 53*(1), 84-96.

Eckert, E., & Bell, A. (2006). Continuity and change: Themes of mental model development among small-scale farmers. *Journal of Extension, 44*(1) Retrieved from http://www.joe.org/joe/2006february/a2.php

Edwards-Jones, G. (2006). Modelling farmer decision-making: Concepts, progress and challenges. *Animal Science, 82*, 783-790.

Electronic Code of Federal Regulations (e-CFR). (2012). *Title 7, subtitle B, chapter 1, subchapter M, part 205: National organic program.* Retrieved, 2012, from http://ecfr.gpoaccess.gov/cgi/t/text/text-idx?c=ecfr&sid=3f34f4c22f9aa8e6d9864cc2683cea02&tpl=/ecfrbrowse/Title07/7cfr205_main_02.tpl

Elmore, C. (1996). A reintroduction to integrated weed management. *Weed Science, 44*(2), 409-412.

Environmental Protection Agency (EPA). (2011). *Overview of risk assessment in the pesticide program.* Retrieved 3/5, 2012, from http://www.epa.gov/pesticides/about/overview_risk_assess.htm

Evans, G. J., Bellinder, R. R., & Hahn, R. R. (2011). Integration of vinegar for in-row weed control in transplanted bell pepper and broccoli. *Weed Technology, 25*(3), 459-465.

Eyre, M. D., Critchley, C. N. R., Leifert, C., & Wilcockson, S. J. (2011). Crop sequence, crop protection and fertility management effects on weed cover in an organic/conventional farm management trial. *European Journal of Agronomy, 34*(3), 153-162.

Fairweather, J. R., & Campbell, H. (1996). *The decision making of organic and conventional agricultural producers.* (No. 233). Canterbury, New Zealand: Agribusiness and Economics Research Unit.

Feder, G., & Umali, D. L. (1993). The adoption of agricultural innovations : A review. *Technological Forecasting and Social Change, 43*(3-4), 215-239.

Feil, B., & Liedgens, M. (2001). Crop production in living mulches - A review. [Pflanzenproduktion in lebenden mulchen - Eine übersicht] *Pflanzenbauwissenschaften, 5*(1), 15-23.

Ferguson, J. (2004). Evaluation of organic herbicides. *HortScience, 39*(4), 876-876.

Fernandez-Cornejo, J., Beach, E. D., & Huang, W. Y. (1992). The adoption of integrated pest management technologies by vegetable growers. *AGES 9228*

Flora, C. (1990). Pesticide risk - making decisions. *Plant Disease*, *74*(2), 105-108.

Gennings, C., Carter, W., Casey, M., Moser, V., Carchman, R., & Simmons, J. (2004). Analysis of functional effects of a mixture of five pesticides using a ray design. *Environmental Toxicology and Pharmacology, 18*(2), 115-125.

Gibson, K. D., McMillan, J., Hallett, S. G., Jordan, T., & Weller, S. C. (2011). Effect of a living mulch on weed seed banks in tomato. *Weed Technology*, *25*(2), 245-251.

Gintis, H. (2009). Decision theory and human behavior. In *The bounds of reason: Game theory and the unification of the behavioral sciences* (pp. 1-26). Princeton, New Jersey: Princeton University Press.

Gomiero, T., Pimentel, D., & Paoletti, M. G. (2011). Environmental impact of different agricultural management practices: Conventional vs. organic agriculture. *Critical Reviews in Plant Sciences, 30*(1-2), 95-124.

Gruber, H., Handel, K., & Broschewitz, B. (2000). Influence of farming system on weeds in thresh crops of a six-year crop rotation. *Zeitschrift Fur Pflanzenkrankheiten Und Pflanzenschutz-Journal of Plant Diseases and Protection,* 33-40.

Hammond, C. M., Luschei, E. C., Boerboom, C. M., & Nowak, P. J. (2006). Adoption of integrated pest management tactics by wisconsin farmers. *Weed Technology, 20*(3), 756-767.

Hawes, C., Squire, G. R., Hallett, P. D., Watson, C. A., & Young, M. (2010). Arable plant communities as indicators of farming practice. *Agriculture Ecosystems & Environment, 138*(1-2), 17-26.

Haydu, J. (2011). Cultural modeling in two eras of US food protest: Grahamites (1830s) and organic advocates (1960s-70s). *Social Problems, 58*(3), 461-487.

He, X., Cao, H., & Li, F. (2008). Factors influencing the adoption of pasture crop rotation in the semiarid area of china's loess plateau. *Journal of Sustainable Agriculture*, *32*(1), 161-180.

Heap, I. (2012). *The international survey of herbicide resistant weeds.* Retrieved, 2012, from http://www.weedscience.org/In.asp

Hiltbrunner, J., Scherrer, C., Streit, B., Jeanneret, P., Zihlmann, U., & Tschachtli, R. (2008). Long-term weed community dynamics in swiss organic and integrated farming systems. *Weed Research, 48*(4), 360-369.

Hoeft, E., Jordan, N., & Zhang, J. (2001). Integrated cultural and biological control of canada thistle in conservation tillage soybean. *Weed Science, 49*(5), 642-646.

Hoffman, A., & Sandelands, L. (2005). Getting right with nature - anthropocentrism, ecocentrism, and theocentrism. *Organization & Environment, 18*(2), 141-162.

Hoskins, W. M., Borden, A. D., & Michelbacher, A. E. (1939). Recommendations for a more discriminating use of insecticides. *Proc. 6th Pac. Sci. Congr. 5, 5*, 119-123.

Howard, A. (1943). *An agricultural testament*. New York and London: Oxford University Press.

Huwer, R. K., Briese, D. T., Dowling, P. M., Kemp, D. R., Lonsdale, W. M., Michalk, D. L., Woodburn, T. L. (2005). Can an integrated management approach provide a basis for long-term prevention of weed dominance in australian pasture systems? *Weed Research, 45*(3), 175-192.

Ikerd, J. (2005). “Sustaining people through agriculture series": Is organic farming necessary for sustainability? *Small Farm Today Magazine, September-October*

Ikerd, J. E. (2008). *Crisis & opportunity: Sustainability in american agriculture*. Board of Regents of the University of Nebraska.

Islam, K. M. M., & Anderson, H. A. (2006). Status of work-related diseases in wisconsin: Five occupational health indicators. *Wisconsin Medical Journal, 105*(2), 26-31.

Jacobsen, B. J. (1996). USDA integrated pest management initiative. In E. B. Radcliffe, & W. D. Hutchison (Eds.), *Radcliffe's IPM world textbook*. St. Paul, MN: University of Minnesota.

James, T. K., & Rahman, A. (2005). Efficacy of several organic herbicides and glyphosate formulations under simulated rainfall. *New Zealand Plant Protection, 58*

Jasinski, J., Eisley, B., Gastier, T., & Kovach, J. (2001). Scoring IPM adoption in ohio: It really adds up. *Journal of Extension, 39*(5)

Johnson, H. J., Colquhoun, J. B., Bussan, A. J., & Rittmeyer, R. A. (2010). Feasibility of organic weed management in sweet corn and snap bean for processing. *Weed Technology, 24*(4), 544-550.

Johnson, J., Hough-Goldstein, J., & Vangessel, M. (2004). Effects of straw mulch on pest insects, predators, and weeds in watermelons and potatoes. *Environmental Entomology, 33*(6), 1632-1643.

Judson, R., Richard, A., Dix, D. J., Houck, K., Martin, M., Kavlock, R., Smith, E. (2009). The toxicity data landscape for environmental chemicals. *Environmental Health Perspectives, 117*(5), 685-695.

Kaine, G., & Bewsell, D. (2008). Adoption of integrated pest management by apple growers: The role of context. *International Journal of Pest Management, 54*(3), 255-265.

Kelling, K. A., Schulte, & Peters. (1996). One hundred years of ca:mg ratio research. *New Horiz. in Soil Ser., 8*

Kogan, M. (1998). Integrated pest management: Historical perspectives and contemporary developments. *Annual Review of Entomology, 43*, 243-270.

Koocheki, A., Nassiri, M., Alimoradi, L., & Ghorbani, R. (2009). Effect of cropping systems and crop rotations on weeds. *Agronomy for Sustainable Development, 29*(2), 401-408.

Labrie, G., Prince, C., & Bergeron, J. (2003). Abundance and developmental stability of pterostichus melanarius (coleoptera : Carabidae) in organic and integrated pest management orchards of quebec, canada. *Environmental Entomology, 32*(1), 123-132.

Lamine, C. (2011). Transition pathways towards a robust ecologization of agriculture and the need for system redesign. cases from organic farming and IPM. *Journal of Rural Studies, 27*(2), 209-219.

Leopold, A. (1949). *A sand county almanac*. Oxford, U.K.: Oxford University Press.

Liebman, M., & Gallandt, E. R. (1997). Many little hammers: Ecological management of crop-weed interactions. In L. Jackson (Ed.), *Ecology in agriculture* (pp. 291-341) New York: Academic Press.

Liebman, M., Mohler, C., & Staver, C. (Eds.). (2001). *Ecological management of agricultural weeds* Cambridge University Press.

Liebman, M., & Davis, A. (2000). Integration of soil, crop and weed management in low-external-input farming systems. *Weed Research, 40*(1), 27-47.

Liebman, M., & Dyck, E. (1993). Crop-rotation and intercropping strategies for weed management. *Ecological Applications, 3*(1), 92-122.

Lipmann, C. B. (1916). A critique of the hypothesis of the lime/magnesia ratio. *Plant World, 19*

Litsinger, J. A., Libetario, E. M., & Canapi, B. L. (2009). Eliciting farmer knowledge, attitudes, and~Practices in the development of integrated pest management programs for rice in asia. In *Integrated pest management: Dissemination and impact* (pp. 119-273) Springer Netherlands.

Llewellyn, R. S., Lindner, R. K., Pannell, D. J., & Powles, S. B. (2004). Grain grower perceptions and use of integrated weed management. *Australian Journal of Experimental Agriculture, 44*(10), 993-1001.

Llewellyn, R. S., Pannell, D. J., Lindner, R. K., & Powles, S. B. (2005). Targeting key perceptions when planning and evaluating extension. *Australian Journal of Experimental Agriculture, 45*(12), 1627-1633.

Lockeretz W. (Ed.) (2007). *Organic farming: An international history*. Cambridge, MA: CABI.

Lohr, L., & Park, T. (2002). Choice of insect management portfolios by organic farmers: Lessons and comparative analysis. *Ecological Economics, 43*(1), 87-99.

Lotter, D. W. (2003). Organic agriculture. *Journal of Sustainable Agriculture, 21*(4)

Low, D. W., & Peric, Z. (2011). An ecosemiotic approach to weed biosecurity. *Proceedings of the 23rd Asian-Pacific Weed Science Society Conference, 2*

Lundkvist, A., Salomonsson, L., Karlsson, L., & Gustavssone, A. D. (2008). Effects of organic farming on weed flora composition in a long term perspective. *European Journal of Agronomy, 28*(4), 570-578.

Macfarlane, R. (2002). Integrating the consumer interest in food safety: The role of science and other factors. *Food Policy, 27*(1), 65-80.

Magkos, F., Arvaniti, F., & Zampelas, A. (2003). Putting the safety of organic food into perspective. *Nutrition Research Reviews, 16*(2), 211-222.

Mahajan, G., Sharda, R., Kumar, A., & Singh, K. G. (2007). Effect of plastic mulch on economizing irrigation water and weed control in baby corn sown by different methods. *African Journal of Agricultural Research, 2*(1), 19-26.

Malone, S., Ames Herbert Jr., D., & Pheasant, S. (2004). Determining adoption of integrated pest management practices by grains farmers in virginia. *Journal of Extension, 42*(4)

Marshall, E., Brown, V., Boatman, N., Lutman, P., Squire, G., & Ward, L. (2003). The role of weeds in supporting biological diversity within crop fields. *Weed Research, 43*(2), 77-89.

Mayor, J. P., & Dessaint, F. (1998). Influence of weed management strategies on soil seedbank diversity. *Weed Research, 38*(2), 95-105.

McCaman, J. L. (1994). *Weeds and why they grow.* Self published.

McCann, E., Sullivan, S., Erickson, D., & DeYoung, R. (1997). Environmental awareness, economic orientation, and farming practices: A comparison of organic and conventional farmers. *Environmental Management, 21*(5), 747-758.

McCann, E., Sullivan, S., Erickson, D., & DeYoung, R. (1997). Environmental awareness, economic orientation, and farming practices: A comparison of organic and conventional farmers. *Environmental Management, 21*(5), 747-758.

Mcdonald, D., & Glynn, C. (1994). Difficulties in measuring adoption of apple ipm - a case-study. *Agriculture Ecosystems & Environment, 48*(3), 219-230.

McLean, J. E., Sims, R. C., Doucette, W. J., Caupp, C. R., & Grenney, W. J. (1988). Evaluation of mobility of pesticides in soil using U.S. EPA methodology. *Journal of Environmental Engineering, 114*(3), 689-703.

Menalled, F. D., Gross, K. L., & Hammond, M. (2001). Weed aboveground and seedbank community responses to agricultural management systems. *Ecological Applications, 11*(6), 1586-1601.

Mertz, C. K., Slovic, P., & Purchase, I. F. H. (1998). Judgments of chemical risks: Comparisons among senior managers, toxicologists, and the public. *Risk Analysis, 18*(4), 391-404.

Michelbacher, A. E., & Bacon, O. G. (1952). Walnut insect and spider mite control in northern california. *Journal of Economic Entomology, 45*, 1020.

Naegele, J. (1993). Preface In *Zimdahl, R.L. 1993. weed science - A plea for thought.*

National Center for Education Statistics (NCES). (2010). *Percentage of persons age 25 and over and 25 to 29, by race/ethnicity, years of school completed, and sex: Selected years, 1910 through 2010.* Retrieved 2/13, 2012, from http://nces.ed.gov/programs/digest/d10/tables/dt10_008.asp

Nemming, A. (1994). *Acta Horticulturae,* (372), 205-212.

Nord, E. A., Curran, W. S., Mortensen, D. A., Mirsky, S. B., & Jones, B. P. (2011). Integrating multiple tactics for managing weeds in high residue no-till soybean. *Agronomy Journal, 103*(5), 1542-1551.

Pannell, D. J. (1999). Social and economic challenges in the development of complex farming systems. *Agroforestry Systems, 45*(1-3), 393-409.

Pannell, D. J., Marshall, G. R., Barr, N., Curtis, A., Vanclay, F., & Wilkinson, R. (2006). Understanding and promoting adoption of conservation practices by rural landholders. *Australian Journal of Experimental Agriculture, 46*(11), 1407-1424.

Pardo, G., Riravololona, M. J., Petit, M. S., Farcy, P., & Munier-Jolain, N. (2008). Effects of integrated weed control on labour organization and economic profitability of farms. *Itea-Informacion Tecnica Economica Agraria, 104*(4), 448-471.

Parish, S. (1990). A review of nonchemical weed-control techniques. *Biological Agriculture & Horticulture, 7*(2), 117-137.

Park, T. A., & Lohr, L. (2005). Organic pest management decisions: A systems approach to technology adoption. *Agricultural Economics, 33*(3), 467-478.

Peruzzi, A., Ginanni, M., Fontanelli, M., Raffaelli, M., & Barberi, P. (2007). Innovative strategies for on-farm weed management in organic carrot. *Renewable Agriculture and Food Systems, 22*(4), 246-259.

Pfiffner, L., H¨aring, A., Dabbert, S., Stolze, M., & Piorr, A. (2001). *Contributions of organic farming to a sustainable environment*.

Pimentel, D., Wilson, C., McCullum, C., Huang, R., Dwen, P., Flack, J., Cliff, B. (1997). Economic and environmental benefits of biodiversity. *Bioscience, 47*(11), 747-757.

Posner, J. L., Baldock, J. O., & Hedtcke, J. L. (2008). Organic and conventional production systems in the wisconsin integrated cropping systems trials: I. productivity 1990-2002. *Agronomy Journal, 100*(2), 253-260.

Puente, M., Darnall, N., & Forkner, R. E. (2011). Assessing integrated pest management adoption: Measurement problems and policy implications. *Environmental Management, 48*(5), 1013-1023.

Rao, C. A. R., Rao, M. S., Srinivas, K., Patibanda, A. K., & Sudhakar, C. (2011). Adoption, impact and discontinuance of integrated pest management technologies for pigeon pea in south india. *Outlook on Agriculture, 40*(3), 245-250.

Renner, K., & Sprague, C. (2005). *Integrated weed management: One year's seeding.* (No. E2931).Michigan State University Extension.

Ridgley, A. M., & Brush, S. B. (1992). Social-factors and selective technology adoption - the case of integrated pest-management. *Human Organization*, *51*(4), 367-378.

Riemens, M. M., Groeneveld, R. M. W., Kropff, M. J. J., Lotz, L. A. P., Renes, R. J., Sukkel, W., & van der Weide, R. Y. (2010). Linking farmer weed management behavior with weed pressure: More than just technology. *Weed Science*, *58*(4), 496.

Robertson, M. J., Zehnder, G. W., & Hammig, M. D. (2005). Adoption of integrated pest management practices by south carolina cotton growers . *Journal of Extension, 43*(6)

Rodale (2011). *The farming systems trial: Celebrating 30 years*. Kutztown, PA: Rodale Institute.

Rodale, J. I. (1948). The organiculturist's creed. In *The organic front*. Emmaus, PA: Rodale Press.

Rogers, E. M. (2003). *Diffusion of innovations* (5th ed.). New York, NY: Free Press.

Roschewitz, I., Gabriel, D., Tscharntke, T., & Thies, C. (2005). The effects of landscape complexity on arable weed species diversity in organic and conventional farming. *Journal of Applied Ecology, 42*(5), 873-882.

Rueda-Ayala, V., Rasmussen, J., & Gerhards, R. (2010). In Oerke, EC Gerhards, R Menz, G Sikora,R. A. (Ed.), *Mechanical weed control*. New York, NY.

Ryan, M., Duh, S., Wilson, D. & Hepperly, P. (2007). *The skinny on a big problem...weeds: NewFarm.org readers respond to a web-based survey about weed management and tell how they deal with their weeds.*. Retrieved 10/7, 2011, from http://www.rodaleinstitute.org/the_skinny_on_a_big_problem_weeds

Ryan, G. (1970). Resistance of common groundsel to simazine and atrazine. *Weed Science, 18*(5), 614.

Rydberg, N., & Milberg, P. (2000). A survey of weeds in organic farming in sweden. *Biological Agriculture & Horticulture, 18*(2), 175-185.

Samiee, A., Rezvanfar, A., & Faham, E. (2009). Factors influencing the adoption of integrated pest management (IPM) by wheat growers in varamin county, iran. *African Journal of Agricultural Research, 4*(5), 491-497.

Sandler, R. (2010). Ethical theory and the problem of inconsequentialism: Why environmental ethicists should be virtue-oriented ethicists. *Journal of Agricultural & Environmental Ethics, 23*(1-2), 167-183.

Sattler, C., & Nagel, U. J. (2010). Factors affecting farmers' acceptance of conservation measures-A case study from north-eastern germany. *Land use Policy*, *27*(1) 70-77.

Schonbeck, M. (2000). Balancing soil nutrients in organic vegetable production systems: Testing albrecht's base saturation theory in southeastern soils.*Inf. Bull. 10:17*

Shennan, C., Cecchettini, C., Goldman, G., & Zalom, F. (2001). Profiles of california farmers by degree of IPM use as indicated by self-descriptions in a phone survey. *Agriculture Ecosystems & Environment, 84*(3), 267-275.

Simon, H. (1990). Bounded rationality. In *Utility and probability* (pp. 15) Eatwell, J.; Milgate, M.; Newman, P.

Smith, R. F. (1969). The new and the old in pest control. *Accad. Naz. Lincei, 128*, 21-30.

Smith, A. N., Reberg-Horton, C., Place, G. T., Meijer, A. D., Arellano, C., & Mueller, J. P. (2011). Rolled rye mulch for weed suppression in organic no-tillage soybeans. *Weed Science*, *59*(2), 224-231.

Sorensen, A. A. (1991). *IPM and growers: An evolution in thinking*.

Stonehouse, D. P., Weise, S. F., Sheardown, T., Gill, R. S., & Swanton, C. J. (1996). A case study approach to comparing weed management strategies under alternative farming systems in ontario. *Canadian Journal of Agricultural Economics-Revue Canadienne D Economie Rurale, 44*(1), 81-99.

Straub, E. T. (2009). Understanding technology adoption: Theory and future directions for informal learning. *Review of Educational Research, 79*(2), 625-649.

Sutherland, O. R. W., & Hill, R. L. (1990). History and protocols for biological control of weeds in new zealand. *FRI Bulletin - New Zealand Ministry of Forestry, Forest Research Institute, 155*, 18-24.

Swezey, S. L., Goldman, P., Bryer, J., & Nieto, D. (2007). Six-year comparison between organic, IPM and conventional cotton production systems in the northern san joaquin valley, california. *Renewable Agriculture and Food Systems, 22*(1), 30-40.

Taylor, E., Renner, K. A., & Sprague, C. (2008). *Integrated weed management: Fine tuning the system.* (No. E-2931).Michigan State University Extension.

Teasdale, J., Mangum, R., Radhakrishnan, J., & Cavigelli, M. (2004). Weed seedbank dynamics in three organic farming crop rotations. *Agronomy Journal, 96*(5), 1429-1435.

Thill, D. C., Lish, J. M., Callihan, R. H., & Bechinski, E. J. (1991). Integrated weed management-a component of integrated pest-management - a critical-review. *Weed Technology, 5*(3), 648-656.

Todd, J. H., Malone, L. A., McArdle, B. H., Benge, J., Poulton, J., Thorpe, S., & Beggs, J. R. (2011). Invertebrate community richness in new zealand kiwifruit orchards under organic or integrated pest management. *Agriculture Ecosystems & Environment, 141*(1-2), 32-38.

Travlos, I. S., & Economou, G. (2010). In Nardali E. (Ed.), *Effects of no-till farming on global weed-related problems and weed communities of greece and the ongoing challenges of integrated weed and crop management*. Haupauge, NY. Nova Science Publishers, Inc.

Turgut, C., Ornek, H., & Cutright, T. J. (2011). Determination of pesticide residues in turkey's table grapes: The effect of integrated pest management, organic farming, and conventional farming. *Environmental Monitoring and Assessment, 173*(1-4), 315-323.

Turner, R. J., Davies, G., Moore, H., Grundy, A. C., & Mead, A. (2007). Organic weed management: A review of the current UK farmer perspective. *Crop Protection, , 26*(3) 377-382.

USDA, & NASS. (2010). *Organic production survey (2008).* (No. AC-07-SS-2).

van der Meulen, A. W., Reeve, I. J., & Sindel, B. M. (2007). Weed management on grazing properties: A survey of livestock producers in new south wales and victoria. *Australian Journal of Experimental Agriculture, 47*(12), 1415-1421.

van Dijk, H., Houghton, J., van Kleef, E., van der Lans, I., Rowe, G., & Frewer, L. (2008). Consumer responses to communication about food risk management. *Appetite, 50*(2-3), 340-352.

Van Tassell, L., Ferrell, M., Yang, B., Legg, D., & Lloyd, J. (1999). Pesticide practices and perceptions of wyoming farmers and ranchers. *Journal of Soil and Water Conservation, 54*(1), 410-414.

Vanclay, F. (2004). Social principles for agricultural extension to assist in the promotion of natural resource management. *Australian Journal of Experimental Agriculture, 44*(3), 213-222.

Varshney, P., Tim, U. S., & Anderson, C. E. (1993). Risk-based evaluation of ground-water contamination by agricultural pesticides. *Ground Water, 31*(3), 356-362.

Walker, R. H., & Buchanan, G. A. (1982). Crop manipulation in integrated weed management systems. *Weed Science, 30, Supplement 1: Integrated Weed Management Systems Technology for Crop Production and Protection*. Proceedings of a Symposium of the Weed Science Society of America. February 19, 1981. Las Vegas, Nevada, pp. 17-24.

Waller, B., Hoy, C., Henderson, J., Stinner, B., & Welty, C. (1998). Matching innovations with potential users, a case study of potato IPM practices. *Agriculture Ecosystems & Environment, 70*(2-3), 203-215.

Walz, E. (1999). *Third biennial national organic farmer's survey*. Santa Cruz, California: Organic Farming Research Foundation.

Wang, Q., Klassen, W., Evans, E. A., Li, Y., & Codallo, M. (2010). Combination of organic and plastic mulches to improve the yield and quality of winter fresh market bell peppers (capsicum annuum L.). *HortScience, 45*(4), 701-706.

Wearing, C. H. (1988). Evaluating the ipm implementation process. *Annual Review of Entomology, 33*, 17-38.

Weed Science Society of America (WSSA). (1982). *Integrated weed management systems: Technology for crop production and protection*

Wei, D., Liping, C., Zhijun, M., Guangwei, W., & Ruirui, Z. (2010). Review of non-chemical weed management for green agriculture. *International Journal of Agricultural and Biological Engineering, 3*(4), 52-60.

Wilkinson, C., Christoph, G., Julien, E., Kelley, J., Kronenberg, J., McCarthy, J., & Reiss, R. (2000). Assessing the risks of exposures to multiple chemicals with a common mechanism of toxicity: How to cumulate? *Regulatory Toxicology and Pharmacology, 31*(1), 30-43.

Williams, P., & Hammitt, J. (2001). Perceived risks of conventional and organic produce: Pesticides, pathogens, and natural toxins. *Risk Analysis*, *21*(2), 319-330.

Williams, W. M., Hendley, P., Jackson, S. H., Ritter, A. M., Cheplick, J. M., & Holmes, C. M. (2009). Is the US environmental protection agency's pesticide aquatic risk assessment process protective? *Abstracts of Papers of the American Chemical Society, 238,* 555.

Wilson, R. S., Hooker, N., Tucker, M., LeJeune, J., & Doohan, D. (2009). Targeting the farmer decision making process: A pathway to increased adoption of integrated weed management. *Crop Protection, 28*(9), 756-764.

Wilson, R. S., Tucker, M. A., Hooker, N. H., LeJeune, J. T., & Doohan, D. (2008). Perceptions and beliefs about weed management: Perspectives of ohio grain and produce farmers. *Weed Technology, 22*(2), 350.

Wortman, S. E., Lindquist, J. L., Haar, M. J., & Francis, C. A. (2010). Increased weed diversity, density and above-ground biomass in long-term organic crop rotations. *Renewable Agriculture and Food Systems*, *25*(4), 281-295.

Wszelaki, A., & Doohan, D. (2003). Comparing weed communities in organic and conventional vegetable farms across ohio. *Proceedings of the OFFER Horticulture Workshop: 24th Annual OEFFA Conference, March 8–9, 2003.*

Wyckhuys, K. A. G., & O'Neil, R. J. (2007). Local agro-ecological knowledge and its relationship to farmers' pest management decision making in rural Honduras. *Agriculture and Human Values*, *24*(3)

Zimdahl, R. (2004). *Weed-crop competition: a review*. John Wiley & Sons.

Zimdahl, R. (2011). *Weed science - A plea for thought - revisited*

TABLES AND FIGURES

§ 205.206   Crop pest, weed, and disease management practice standard.

(a) The producer must use management practices to prevent crop pests, weeds, and diseases including but not limited to:

(1) Crop rotation and soil and crop nutrient management practices, as provided for in §§205.203 and 205.205;

(2) Sanitation measures to remove disease vectors, weed seeds, and habitat for pest organisms; and

(3) Cultural practices that enhance crop health, including selection of plant species and varieties with regard to suitability to site-specific conditions and resistance to prevalent pests, weeds, and diseases.

(b) Pest problems may be controlled through mechanical or physical methods including but not limited to:

(1) Augmentation or introduction of predators or parasites of the pest species;

(2) Development of habitat for natural enemies of pests;

(3) Nonsynthetic controls such as lures, traps, and repellents.

(c) Weed problems may be controlled through:

(1) Mulching with fully biodegradable materials;

(2) Mowing;

(3) Livestock grazing;

(4) Hand weeding and mechanical cultivation;

(5) Flame, heat, or electrical means; or

(6) Plastic or other synthetic mulches: *Provided,* That, they are removed from the field at the end of the growing or harvest season.

Figure 1.1. The legal U.S. organic pest management standard (e-CFR, 2012)

(d) Disease problems may be controlled through:

(1) Management practices which suppress the spread of disease organisms; or

(2) Application of nonsynthetic biological, botanical, or mineral inputs.

(e) When the practices provided for in paragraphs (a) through (d) of this section are insufficient to prevent or control crop pests, weeds, and diseases, a biological or botanical substance or a substance included on the National List of synthetic substances allowed for use in organic crop production may be applied to prevent, suppress, or control pests, weeds, or diseases: *Provided*, That, the conditions for using the substance are documented in the organic system plan.

(f) The producer must not use lumber treated with arsenate or other prohibited materials for new installations or replacement purposes in contact with soil or livestock.

Figure 1.1. (cont.) The legal U.S. organic pest management standard (e-CFR, 2012)

Weed Management Innovation	Percent of Respondents Using	
	Ryan et al., 2007	Walz, 1999
Weeding by hand or with hand implements	78%	75%
Mechanical Tillage	69%	75%
Crop Rotations	40%	75%
Cover Crops	56%	58%
Mulches	60%	44%
Fallow	31%	*
Fertility Management	29%	*
Planting Date Adjustment	23%	29%
Row Width Adjustment	30%	20%
Smother Crops	*	23%
Flaming or Burning	27%	11%
Stale Seedbed	18%	*
Herbicide	18%	*
Grazing	*	16%
Tolerant Cultivar	9%	*
Ridge Tillage	*	8%
Solarization	10%	3%

*indicates a practice not included in the survey

Table 1.1. Use of seventeen weed management practices by U.S. organic farmers as measured by Ryan et al., 2007 and Walz, 1999

CHAPTER TWO:

MIDWEST U.S. ORGANIC WEED MANAGEMENT SURVEY

ABSTRACT

Organic agricultural systems increase the complexity of weed management, leading organic farmers to cite weeds as the greatest barrier to organic production. Integrated Weed Management (IWM) systems have been developed to address the ecological implications of weeds and weed management in cropping systems, but adoption is minimal. Organic agriculture may be the most promising context for application of IWM due to philosophical similarities between these two approaches to the "ecologization" of agriculture. However, adoption of IWM on organic farms is poorly understood due to limited data on weed management practices employed, the lack of any agreed-upon IWM metric, and insufficient consideration given to the unique farming contexts within which weed management decisions are made. Therefore, this study aimed to (i) characterize organic weed management systems; (ii) identify motivations for, and barriers to, selection of weed management practices; and (iii) generate guiding principles for effective targeting of weed management outreach. We used a survey of Midwestern organic growers to determine how specified psychosocial, demographic and farm structure factors influence selection of weed management practices. Cluster analysis of the data identified three disparate, yet scaled, approaches to organic weed management. Clusters were distinguished by philosophical perspective regarding weeds and the number of weed management practices used. Categorization of individual farms within the identified approaches was influenced by what a farm produces as well as farmer education, years farming and information seeking behavior. The

proposed model allows weed management educators to target outreach for enhanced compatibility of farming contexts and weed management technologies.

INTRODUCTION

Restriction of synthetic herbicide use in organic agricultural systems increases the complexity of weed management (Bastiaans et al., 2008; Pannell et al., 2006; Vanclay, 2004), leading organic farmers to cite weeds as the greatest barrier to organic production (Ryan et al., 2007; Walz, 1999). Research indicates that ecological or integrated approaches to weed management have the potential to suppress weed growth with reduced reliance on herbicides (Bicksler and Masiunas, 2009; Burger et al., 2008; Gibson et al., 2011; Hoeft et al., 2001). However, application of IWM theory is complicated by short-term complexity in the level of agroecological knowledge required for integrated management (Llewellyn et al., 2005), as well as the fact that benefits of IWM are largely realized in the long-term compared to the immediate results of direct weed control (Buhler et al., 2000). Few growers have adopted IWM as their approach to weeds on the farm (Czapar et al., 1995; Doohan et al., 2010; Wilson et al., 2009).

Organic agriculture may represent an ideal farming context for the application and study of IWM. Both philosophies are motivated by concern for environmental quality and agricultural sustainability, and both seek solutions through the "ecologization of agriculture" (Lamine, 2011). The IWM concept has been incorporated into the organic pest management standard through emphasis on weed prevention, recognition of multiple control tactics, and relegation of herbicide-based control to last resort status (e-CFR, 2012). Organic growers have proven more likely to adopt individual weed management innovations, such as crop rotation and cover crops, than conventional farmers (McCann et al., 1997). Organic agriculture, by definition, avoids chemical inputs and the associated barriers to IWM adoption cited by proponents (Liebman et al., 2001).

However, adoption of IWM on organic farms is poorly understood due to limited data on weed management practices employed, the lack of any agreed-upon IWM metric (Hammond et al., 2006; Jasinski et al., 2001; Malone et al., 2004; McDonald and Glynn, 1994; Puente et al., 2011; Robertson et al., 2005; Samiee et al., 2009; Shennan et al., 2001)., and insufficient consideration given to the unique farming contexts within which weed management decisions are made. Research indicates that most U.S. organic farmers manage weeds using a limited suite of mechanical controls supported by cultural management such as crop rotation and delayed planting (Ryan et al, 2007; Walz, 1999). According to the available data, organic weed management systems may not include many of the information-intensive practices, such as prevention, economic thresholds and biological control that IWM promotes. Therefore, it is important to quantify IWM application on working organic farms to determine if and how IWM philosophy can translate into viable organic weed management.

Farmer Decision-making

Traditional economic theory suggests that human beings make choices that are expected to maximize utility, or the decision-maker’s well-being (Edwards-Jones, 2006). Financial gain is often assumed to represent utility, and thus farmers are frequently represented as rational profit maximizers (Feder and Umali, 1993). However, there is evidence that many farmers have developed a “post-productivist” self-identity (Burton and Wilson, 2006). Other “lifestyle” factors beyond financial status, such as health and happiness, influence farming utility. In addition, the rationality of human choice is augmented in several ways. Rationality could perhaps be better described as subjective or “bounded” rationality (Simon, 1990) constructed using limited information (Gintis, 2009) within influential social networks (Bandura, 1986).

Further, farmers are known to have particular decision-making tendencies that differ from other agriculture stakeholders like scientists and extension agents (Litsinger et al., 2009; Wilson et al, 2009). Many farmers demonstrate particularly risk-averse decision-making (Wilson et al., 2008). Related to risk aversion is what Gintis (2009) called "time-inconsistency" in decision making. Farmers tend to discount long-term risks, like environmental impacts of herbicide use, and maximize short-term utility, as in direct weed control (Doohan et al., 2010). Farmers also exhibit a significant preference for accessing information through personal experience, or the experience of other farmers (Eckert and Bell, 2006; Walz, 1999).

Organic growers differ as well in decision-making from other farm managers. Many organic farmers are motivated to attempt ecological farm management by concern for the environmental degradation (Fairweather and Campbell, 1996). This key difference in basic motivations for farming translates into pest management decision-making; organic growers are more willing to incur short-term pest management risk for future benefits (McCann et al., 1997). As a result, farmers who are motivated by environmental protection appear more likely to adopt IPM systems, which benefit the environment, but may not always prove profitable in the short-term (McDonald and Glynn, 1994; Pannell et al., 2006; Vanclay, 2004).

In addition, many organic farmers view themselves as part of a counterculture movement (Haydu, 2011; Howard, 1943). Organic agriculture is seen as a righteous alternative to the ills of our industrial food system, a system developed and promoted by the scientific establishment. Therefore, some organic farmers do not trust university recommendations and exhibit an even greater preference for user generated pest management information than conventional farmers (Howard, 1943; Park and Lohr, 2005). At the same time, organic agriculture proponents have sought empirical verification of their claims. This tenuous relationship between organic agriculture and agricultural science has supported the development of some pseudoscientific concepts within organic circles, such as the base-cation saturation ratio (BCSR) theory of soil fertility and weed management (Padgham, 2011), and likely limits IWM adoption.

Why do farmers manage weeds as they do?

Farmer decision-making is thus an incredibly complex process that is difficult to model or predict. However, technology adoption research has made significant progress in the application of decision theory. Technology adoption is defined as a "dynamic learning process", where potential adopters develop perceptions of an innovations relative utility in their unique farming context (Llewellyn et al., 2005; van der Meulen et al., 2007). Farmers select individual technologies that fit their farming context in a "piece-meal" or "selective" approach (Ridgley and Brush, 1992). Adoption diffusion theory suggests that three variable categories influence this learning process, including farm structure, farmer demographics, and perceived characteristics of an innovation (Edwards-Jones, 2006; Rogers, 2003; Straub, 2009).

The physical, mechanical and ecological context of a farm system sets clear restrictions on what pest management technologies or practices make sense. Farm size, crop choice, cropping diversity, and land tenure may all impact IWM adoption (Bastiaans et al., 2008; Carolan, 2005; Ceylan et al., 2010; Czapar et al., 1995; Hammond et al., 2006; Rao et al., 2011; Riemens et al., 2010). Characteristics of farm managers also influence decision-making for pest management. Age of an operation's principle manager, formal education, and farming experience are all potential independent variables (Ceylan et al., 2010; Chaves and Riley, 2001; Pannell et al., 2006; Rao et al., 2011; Shennan et al., 2001; van der Meulen et al., 2007). Further, pest managers, like other practitioners, want technology that meets their needs, forwards their objectives, and helps them accomplish their goals in yield, pest control, etc. (Pannell, et al., 1999). Efficacy, initial costs and perceived economic value, as well as ease of use can shape farmers' perceptions of an innovation's utility (Bastiaans et al., 2008; Pannell et al., 2006; Sattler and Nagel, 2010; van der Meulen et al., 2007). Farmers also differ in the information they receive regarding pest management, what sources they trust, and how they access information. The more pest management information a grower seeks out, they more likely they are to adopt IPM practices (Ceylan et al., 2010; Pannell et al., 2006; Park and Lohr, 2005; Samiee et al., 2009; Wyckhuys and O'Neil, 2007). Research indicates inconsistent impacts of extension education and farmer perceptions of extension on IPM adoption (Czapar et al., 1995; Llewellyn, 2007; Pannell et al., 2006; Ridgley and Brush, 1992; Samiee et al., 2009; Turner et al., 2007; Vanclay, 2004).

Research Objectives

Organic agriculture has been successfully applied to farm management, but scientists suggest that adoption of IWM is limited. Due to their philosophical similarity, organic agriculture may represent the best system to address IWM adoption within. The present state of organic weed management in the U.S. is both promising and discouraging. Organic farmers are managing weeds with dramatically reduced herbicide use. Still, weed management is seen as a significant barrier to organic production, and is dominated by a few cultural and mechanical controls. However, data on organic weed management behavior is limited by the lack of published surveys and the complexity of quantifying weed management behavior.

Therefore, this study aimed to (i) characterize organic weed management systems; (ii) identify motivations for, and barriers to, selection of weed management practices; and (iii) generate guiding principles for effective targeting of weed management outreach. Given the aforementioned complexity, and contextual importance, of the farmer decision-making processes, we considered as many aspects of organic weed management systems as possible, including not only direct and indirect management practices, but also measures of diverse independent variables related to the unique farming contexts within which weed management decisions are made.

MATERIALS AND METHODS

Study Region:
The Midwest United States

The Midwest is the most intensively cropped region of the United States consisting of twelve state including North Dakota, South Dakota, Nebraska, Kansas, Minnesota, Iowa, Missouri, Wisconsin, Illinois, Indiana, Michigan, and Ohio. The Midwest is uniquely suited to the study of organic weed management behavior. It is recognized by USDA as the North Central Integrated Pest Management region, sharing a common set of cropping systems and pest species. Approximately 30% of U.S. organic acreage and operations are located here, placing it second after only the Western region, which includes large agricultural states like California (USDA, 2010). Early sociological work considered the Midwest to be representative of “typical” Middle America (Lynd, 1929). However, what may be more valuable to our study is the diversity of agroecosystems present in the region. The Midwest is dominated by grain production, but forage, vegetable, fruit and flower farms are also present. Therefore analysis of organic agriculture in the Midwest U.S. should provide a fairly complete picture of organic weed management in practice, and significant insight into organic at the national level.

Survey Instrument

A questionnaire entitled “Midwest U.S. Organic Weed Management Survey” was developed during the fall and winter of 2009 with the assistance of University of Illinois sociologists and weed scientists specializing in integrated/organic weed management (**Appendix A**). The instrument was designed to assess weed management methods as well as farm structure, demographic, and perceived innovation variables that the literature indicates may influence selection of weed management practices.

Section one of the questionnaire included six questions designed to evaluate the structure of respondents' farm operations. In section two of the questionnaire binary use of sixty-three different weed management practices was measured using a check-off table organized into nine categories: soil preparation, planting, prevention, thresholds, mechanical controls, biological control, cultural controls, chemical controls, and information management. Our goal was to include as many weed management practices available to organic growers as possible in order to develop a comprehensive picture of organic weed management systems. Section three of the questionnaire included five questions regarding factors that may influence growers' perceptions of weed management innovations. The final section of the questionnaire included eight questions designed to assess the impact of farmer demographics on selection of weed management practices.

Survey Pretest

The survey instrument was pretested with a small convenience sample of organic growers (22) January 6-8th, 2010 at the Illinois Specialty Crops, Agritourism, & Organic Conference in Springfield, IL and February 25-27th, 2010 at the Midwest Organic and Sustainable Education Service Organic Farming Conference in La Crosse, WI. Inclusion/exclusion criteria for the pretest limited participation to organic growers over the age of eighteen farming in one of the 12 states of the North Central region (Midwest U.S.). Pretest participants signed a written consent form which was collected separately to maintain respondent anonymity. Oral and written feedback from the pretest sample was used to judge the clarity and validity of individual questions as well as the overall quality of the survey instrument.

Sample Development

Information on the target population (Midwest organic growers) was drawn from the 2010 publically available list of certified organic operations collected by accredited certifying agencies and compiled by U.S.D.A.'s Agricultural Marketing Service (USDA, 2010). Our sample therefore excludes uncertified organic operations and the implications of such systems. Inclusion/exclusion criteria limited the target population to certified organic farm operations located in the Midwest U.S. whose primary scope of certification was listed as crops. Farm operations meeting these criteria were classified by the researcher into mutually exclusive categories using provided information regarding primary crops produced. Categories included grain, grain & forage, vegetable, forage, fruit and diversified (operations producing products in three or more categories). Operations producing primarily livestock or wild crop products, such as maple syrup, were eliminated from the population due to the high likelihood of limited or nonexistent weed management activity in these contexts. A final population of 3,070 farm operations in the North Central Region satisfied all of the above criteria.

A stratified random sample of 500 farm operations was drawn from this target population. Random selection was accomplished using a random number generator, with each member of the target population assigned a numerical code (Haahr, 2012). Stratification occurred by operation class using proportionate allocation due to hypothesized correlation between crops produced and weed management methods (Bastiaans et al., 2008; Hammond et al., 2006; Ridgley and Brush, 1992; Riemens et al., 2010; Turner et al., 2007). This strategy seeks to develop a more representative sample by applying a sampling fraction to each strata that is proportional to that of the entire population (Dillman, 2008). For example, 528, or 17.2%, of the 3,070 farm operations in the target population were classified as grain farms. Therefore, the same proportion of the survey sample (17.2% of 500, or 86 farm operations) was randomly selected for participation from all grain farms in the population. The final sample included 260 (52%) grain & forage farms, 86 (17.2%) grain farms, 56 (11.2%) diversified farms, 46 (9.2%) forage farms, 44 (8.8%) vegetable farms, and 8 (1.6%) fruit farms.

Survey Administration

Administration of the finalized Midwest U.S. Organic Weed Management Survey occurred in January and February of 2011 following a method developed by Pennings et al. (2002) for survey research specifically targeting farmers. The survey was mailed to 500 potential respondents on January 21st, 2011. A follow-up postcard was mailed to all potential respondents on February 17th, 2011 to thank those farmers who had already responded and encourage participation among those that had not.

The survey packet included a cover letter, the survey instrument, a postage-paid return envelope, and a new one-dollar bill as token financial incentive. The cover letter/implied consent form, printed on University letterhead and hand-signed, explained the purpose of the survey and rights of research participants, identified the researchers and provided their contact information, and encouraged participation by emphasizing the project's potential positive impacts on organic weed management outreach (**Appendix A**). The survey instrument was constructed as a standard letter-sized packet consisting of twenty-two questions arranged on eight single-sided pages, including a title page.

Survey Response

Anonymous responses to the survey were received by mail from January 29th, 2011 through March 1st, 2011. Twenty-four survey packets failed to reach potential participants due to address errors or lack of a current forwarding address. This reduced the survey's potential sample size from 500 to 476. 232 completed survey instruments were received. Of these, thirteen respondents indicated that they no longer manage any portion of their farm operation organically. These responses were excluded leaving 219 useable responses for data analysis. As a result, response rate for the survey was 46%. Response rate by stratum was nearly proportional to the fraction of each operation type present in the target population **(Figure 2.1)**. The 219 useable survey responses included 95 (43%) grain & forage farms, 52 (24%) grain farms, 14 (6%) diversified farms, 24 (11%) forage farms, 30 (14%) vegetable farms, and 4 (2%) fruit farms. Distribution of sample cases by state is presented in **Figure 2.2** and was nearly proportional to geographical distribution of the all organic farms in the Midwest. Therefore, our sample should be sufficiently representative of the target population.

Data Analysis

Data generated by the Midwest U.S. Organic Weed Management Survey was analyzed using two statistical methods – hierarchical agglomerative cluster analysis (HACA) and binary logistic regression. Cluster analysis is a data mining technique that seeks to identify meaningful groupings (clusters) within a data set (Tan et al., 2005). Cluster analysis is useful for increased understanding of complex data through classification, but also aids further analysis through data reduction. It has been applied extensively in ecology and sociology, but has also been used to classify farm operations according to pest management behavior (Burger et al., 2012; Kaine and Bewsell, 2008; Michos et al., 2012; Sellmer et al., 2004; van der Meulen et al., 2007).

While cluster analysis can be applied to many different kinds of data, our goal was to identify distinct weed management "types" or approaches based only on the qualitative measure of weed management practices used by survey respondents. To this end, use of each weed management practice included in the survey was coded as a dichotomous binary variable with "1" indicating use of the practice and "0" indicating lack of use. Each case included responses to sixty-three different weed management practices, resulting in a large 223 x 63 binary data set.

A number of distance measures are appropriate for binary data. However, a group of distance measures known collectively as matching coefficients consistently and accurately identify known clusters within binary data sets (Finch, 2005). Of the matching coefficients, we selected the Dice (1945) coefficient because it gives additional weight to cases of positive agreement (e.g. 1, 1) and discounts cases of negative agreement (e.g. 0, 0). Information regarding what weed management practices farmers are *not* using would certainly be important to a wider understanding of weed management technology adoption. However, we chose to focus our work primarily on practices selected.

The resulting Dice coefficient can range from 0 to 1. A coefficient of 1 indicates a perfect match where, in the context of our research, farmers 1 and 2 are using the exact same suite of practices to manage weeds. Conversely, a coefficient of 0 indicates a pairing of cases in which two farmers use entirely different weed management practices. IBM Statistical Package for the Social Sciences, version 19.2 for Windows, was used to calculate Dice coefficients and construct a similarity matrix of all possible case pairings (SPSS Inc., 2011).

The second step in HACA, hierarchical agglomerative clustering itself, uses calculated distance measures to form mutually exclusive groups of cases (clusters) in a hierarchical additive process. The appropriate number of clusters can be determined through examination of the clustering dendrogram and analysis of the agglomerative coefficient (Hair et al., 1992). Various clustering algorithms are available for computation of the distance between clusters as they are formed. We chose to use Ward's (1963) method because previous research suggests it is the most useful algorithm for clustering of binary data using matching coefficients (Hands and Everitt, 1987). Ward's method was originally intended for use with squared Euclidean distance measures. However, its use has been generalized and shown successful in clustering cases using distance measures other than squared Euclidean distances (Batagelj, 1988).

Validation of Cluster Analysis Results

Cluster validation was achieved through internal and external evaluation. Internal evaluation consisted of reliability and homogeneity measures. Reliability of the cluster solution was determined through calculation of Cronbach's alpha to determine if proposed cluster membership is indeed a reliable measure of weed management practices used. Intraclass correlation was calculated for each proposed cluster to measure cluster homogeneity in terms of weed management practices used. In external evaluation clustering results are compared to accepted classifications of the data not used in clustering (Barbaranelli, 2002). Two variables commonly used to classify weed management behavior are operation class (products grown) and number of weed management practices adopted. The categorical measure of operation class was tested against cluster membership using a Monte Carlo simulation (Fishmen, 1995; Spall, 2005) of the Fisher's Exact Test (1922, 1954) (chi-square extended for large contingency tables with small cell frequencies). A categorical measure of the number of weed management practices adopted was also tested against proposed cluster membership using a chi-square test.

Binary Logistic Regression

In an effort to identify other less apparent drivers motivating adoption of particular weed management innovations, and thus proposed cluster membership, a stepwise logistic regression procedure was applied to estimate the impact of several probable independent variables, following the method described by Villamil et al. (2011) (Kutner et al., 2004; SAS 9.0, 2010). Covariates included survey data regarding farm structure, farmer demographics, and psycho-social factors contributing to perceived innovation characteristics. Because each operation class (products grown) occurred in only two of the three proposed clusters, two binary logistic regression models were calculated to describe i) what drives forage and fruit farmers into Cluster

A or Cluster B, and ii) what pushes grain & forage, grain, vegetable, and diversified growers into either Cluster A or Cluster C.

Maximum likelihood estimates of the regression coefficients and their standard errors were computed for each model. Chi-square (χ^2) was employed to test the significance of the regression terms. Using the fitted model, a predicted event (e.g. = *Cluster C (≠ Cluster A)*) odds $(p/1-p)$ can be calculated for all cases in a pair of clusters. If the predicted event odds exceed the cutoff value of 0.5, the farm operation is predicted to be a member of the considered cluster (i.e. Cluster C). If not, the farm operation is predicted to be a member of the default cluster (i.e. Cluster A) (Kutner et al., 2004; Villamil et al., 2011).

Odds ratios were also calculated to express the likelihood of cluster membership under one of two possible conditions, holding all other variables constant (e.g. positive vs. negative attitude toward weeds). If the confidence interval (CI) of the odds ratio for a given parameter in the equation includes 1, there is no difference in the likelihood of cluster membership for the two conditions. If both CI endpoints are greater than 1, membership in the considered cluster (i.e. Cluster C) is more likely under the first condition (positive attitude toward weeds). If both CI endpoints are less than 1, then membership in the considered cluster (i.e. Cluster C) is more likely under the second condition (negative attitude toward weeds). When calculating odds ratios for continuous variables, such as years farming, the likelihood of cluster membership for a grower with x+1 years farming (e.g. 26) is compared with a grower exhibiting x years farming (e.g. 25) (Kutner et al., 2004; Villamil et al., 2011).

RESULTS AND DISCUSSION

Demographics and Descriptive Statistics

Demographic characteristics of the target population are presented in **Table 2.1**. These results largely mirror trends among organic growers at the national level, suggesting that our sample may be representative of not only Midwest organic agriculture, but U.S. organic as a whole (Walz, 2004). The average age of respondents was 51 (22-78) years, the majority (94%) being male. Percentage of female respondents (6%) was lower than the 22% existing nationally (Walz, 2004). This reflects the fact that less than 10% of all farm operators (organic and conventional) in the Midwest are women, compared to greater than 25% female operators in many Western states and parts of New England (USDA, 2009). On average Midwest organic farmers were college educated at the baccalaureate level. Respondents farmed an average of 270 (2-4,000) acres, with approximately 75% certified organic. Growers were experienced averaging 26.6 (2-76) years farming, with 12.1 (1-54) years dedicated to organic production.

Respondents generated an average of 25% of their household income off-farm, and owned approximately 75% of their farm acres. Gross farm incomes averaged $50,000 in 2010, well above the 2001 national average of $25,000 (Walz, 2004). Some of this difference is likely related to inflation over intervening nine years, but other research indicates that the economic value of U.S. agriculture is concentrated in the Midwest and California (USDA, 2009).

When asked to list the most problematic weeds on their farm, respondents most frequently mentioned foxtail (*Setaria faberi* or *Setaria glauca*) (78 times), followed by lambsquarters (*Chenopodium album*) (54 times), Giant ragweed (*Ambrosia trifida*) (40 times), Canadian thistle (*Cirsium arvense*) (36 times), ragweed (*Ambrosia artemisiifolia* var. *elatior*) (35 times), and velvetleaf (*Abutilon theophrasti*) (34 times). The high incidence of lambsquarter, ragweed, and velvetleaf support previously reported shifts toward dicots and less nitrophilous species observed under organic management (Davis et al., 2005; Menalled et al., 2001; Rydberg and Milberg, 2000) However, frequent mention of foxtail (*Setaria faberi* or *Setaria glauca*) does not support a theorized shift away from grasses. If knowledge of weed biology is indeed relatively limited among organic farmers, (Doohan et al., 2010) the free listing of problematic weed species may reflect popular weed names that farmers are aware of rather than the actual species present on their farm. For example, the common name foxtail is used in reference to several different weed species, all of which exist in the Midwest, including yellow foxtail (*Setaria pumila* ssp *.pumila*), bristly foxtail (*Setaria verticillata*), foxtail barley (*Hordeum jubatum*), and foxtail bristlegrass (*Setaria italica*).

Midwest organic farmers used an average of fifteen (1-34) practices that contribute to weed management. This number is higher than any previously reported value, and may be partially related to the relatively large number of practices included in our survey. However, if adoption of IWM is measured as number of weed management practices used, Midwest organic farmers appear to demonstrate more extensive adoption (McDonald and Glynn, 1994; Shennan et al., 2001; Jasinski et al., 2001; Malone et al., 2004; Robertson et al., 2005). Percent of respondents using each surveyed weed management practice is presented by category in **Appendix C**. The ten most commonly adopted practices for the 2010 season were crop rotation (86%) averaging 2-4 crops in sequence, between-row cultivation (78%), primary tillage (76%), cover cropping (66%), delayed planting (65%), green manure (63%) scouting (57%), hand weeding (57%), mowing (52%), and increased planting density (50%). This supports previous work finding that organic weed management is dominated by cultural and direct mechanical controls (Ryan et al, 2007; Walz, 1999). Many growers demonstrated a tolerant or confident attitude toward weeds (47%) best summarized by a quote from one respondent: "There will always be weeds. There will always be weed seeds. Rotate, keeps weeds off balance and minimize crop impact." The remaining fraction of growers split rather evenly between extremely positive (23%) and negative (29%) attitudes toward weeds. Most growers rated weed control on their organic acres as "fair" on a four point poor-excellent scale.

The percentage of famers using each surveyed resource for weed management information is shown in **Table 2.2**. Respondents indicated that they trust other farmers (83%) and interactions with other farmers, such as field days (55%), for quality weed management information before books (46%), university (24%), internet (19%), private consultants (16%), and dealers (11%). This finding corroborates earlier studies showing a strong preference for user generated information among farmers, particularly organic producers (Eckert and Bell, 2006; Park and Lohr, 2005; Walz, 2004). A peer-focused and experience-based information sourcing preference may contribute to differences between farmer and scientist weed management mental models, as well as the related perception among scientists that IWM adoption is limited (Czapar et al., 1995; He et al., 2008; Litsinger et al., 2009; Llewellyn, 2007; Pannell et al., 2006; Ridgley and Brush, 1992; Samiee et al., 2009; Turner et al., 2007; Vanclay, 2004; Wilson et al, 2009). However, education and significant farming experience appear be promoting organic weed management systems that are, on average, quite complex.

Twenty percent of growers surveyed voluntarily mentioned some version of the base-cation saturation ratio (BCSR) theory of soil fertility popularized by ACRES USA. The BCSR theory suggests that "ideal" ratios of soil cations exist, which if achieved contribute to "balanced" soil with lower weed pressure and higher crop yields. Soil cations can certainly influence crop yield and the composition of emerged weed communities. However, empirical evidence generated over the last century has continually refuted the BCSR theory, determining that nutrient availability and pH have a much greater impact on crop and weed growth than specific cation ratios (Kelling et al., 1996; Lipman, 1916; Schonbeck, 2000). Still, the BCSR theory maintains a large following within the organic agriculture community. A book promoting the application of this theory to weed management, *Weeds and Why They Grow* by Jay L. McCaman (1994), remains one of the best-selling books available through the Midwest Organic and Sustainable Education Service (Padgham, 2011).

The popularity of pseudoscientific concepts, such as the BCSR theory, among the organic community may be partially due to organic's political stance as a counterculture movement and subsequent distrust of the scientific establishment (Haydu, 2011; Howard, 1943). Promotion of the BCSR theory has resulted in significant misappropriation of agricultural resources and limited the development of organic weed management systems (Kopittke and Menzies, 2007). Organic weed management outreach must work against such misinformation. This work should begin with the promotion of sound agricultural science that garners trust by addressing popular critiques including reductionism, externalization of environmental and social costs, and biased promotion of the agro-industrial complex.

Cluster Analysis of Weed Management Practices

Figure 2.3 shows the pattern of case clustering in the form of a dendrogram. Analysis of the dendrogram and agglomerative coefficient determined that a solution of three clusters maximized distance between clusters while maintaining homogeneity within. Calculation of Cronbach's alpha considering cluster membership and 61 weed management practices ($\alpha = .744$) suggests that cluster membership as proposed is indeed a reliable measure of weed management practices used. Intraclass correlations for Cluster A (ICC = .589, $P<.0001$) Cluster B (ICC = .707, $P<.0001$), and Cluster C (ICC = .63, $P<.0001$) all approached or exceeded the threshold of .60 and were found to be statistically significant. This suggests satisfactory homogeneity within the proposed clusters in terms of weed management practices used.

The categorical measure of operation class was tested against proposed cluster membership and found to be significantly different from the expected distribution among clusters A, B, and C (X^2 = 150.02, df = 10, P<.0001). Cluster A contains farms from each operation class surveyed. On the contrary, Cluster B and C split the classes. C contains only grain & forage, vegetable, grain, and diversified farms; Cluster B includes only forage and fruit operations. A categorical measure of the number of weed management practices adopted was also tested against cluster membership and found to be significantly different from the expected distribution among clusters (X^2 = 94.11, df = 4, P<.0001). Farm operations in Cluster B used the lowest average number of weed management practices (7), led by Cluster A (13) and ultimately C (21). **Figure 2.4** presents the modeled cluster solution including measures of external evaluation. Aside from validating our typology, external evaluation suggests that operation class (Bastiaans et al., 2008; Hammond et al., 2006; Ridgley and Brush, 1992; Riemens et al., 2010; Turner et al., 2007) and practice count classifications (Jasinski et al., 2001; Malone et al., 2004; McDonald and Glynn, 1994; Robertson et al., 2005; Shennan et al., 2001) correctly reflect natural variation in organic weed management behavior, and can thus be considered valid measures that aid understanding of IWM adoption. A description of the three identified clusters follows.

The Classic Control Cluster

Cluster A is the largest group comprising 59% (129) of the sample, and contains farms in each of the six identified operation classes including grain & forage (68), grain (34), vegetable (12), forage (6), diversified (5), and fruit (1) (missing (3)). Farms in Cluster A use an average of 13 practices to manage weeds on their farms. Cluster A will be discussed as the "Classic Control" cluster (CCC) due to a strong emphasis among its members on control of existent or inevitable weeds through cultural and mechanical controls. Quotes from members of the CCC asked to describe their attitude toward weeds and weed management reflect this common approach (**Figure 2.5**). Growers in the CCC appear to be driven by efficacy in weed control within the short-term frame of individual growing seasons.

> "Don't plant too early. Till [the] soil good before planting.
> Harrow before [the] crop is up. Don't pack [the] ground too much.
> Cultivate at least three times, and start as soon as possible."
>
> -Anonymous CCC grower

Relative engagement (average number of practices used within a particular category) in the nine surveyed categories of weed management practices among the proposed clusters is presented in **Table 2.3**. The category with the highest level of engagement among the CCC is planting management (34%) followed by mechanical controls (29%) and cultural controls (26%). Adoption of weed management practices among the proposed clusters is also shown in **Appendix C**. Ninety-one percent of growers in the CCC adopted crop rotation, nearly matched by extensive adoption of between-row cultivation (85%), primary tillage (78%), and cover cropping (64%). The CCC represents the legacy of traditional organic weed management; this is the way weeds were managed prior to herbicide-based control (Walker and Buchanan, 1982). Weed management systems in this group are not the most diverse and work from the limited perspective of the cropping cycle, lacking a focus on prevention or long-term management. However, members of the CCC achieve a perceived level of weed control very similar to the other clusters, without investing in information-intensive and risky ecological management.

The Forb Philosophy Cluster

Cluster B is the smallest group comprising 10% (21) of the sample, and contains farms in two operation classes, including forage (16) and fruit (3) (missing (2)) farms. Farms in Cluster B use the lowest average of 7 practices to manage weeds on their farms. Cluster B will be discussed as the "Forb Philosophy" cluster (FPC) due to an alternative weed management philosophy which highlights the value of weeds in perennial farm systems. The term "Forb" is technically defined as, "an herbaceous broadleaved plant, other than cultivated legumes, with forage value" (Barnes et al., 2003). However, its use has been extended by managers of perennial systems to describe any uncultivated plant with beneficial characteristics, such as forage value, nitrogen fixation or pollinator attraction. This more general definition, including grasses, may be more in line with etymology of the term forb, developing from the Greek *phorbē* fodder or food and *pherbein* to graze (Merriam-Webster, 2012).

Many wild plants considered weeds in annual cropping systems are not as problematic in perennial systems. This limits the number of problematic wild plants to toxic and/or noxious weeds that livestock will not eat and weeds that do not respond favorably to mowing. In the context of their systems, members of the FPC view many weeds as contributions to biodiversity and, unlike the CCC driven by short-term efficacy, appear to base their management on goals for health, safety, and environmental protection. Quotes from members of the FPC asked to describe their attitude toward weeds and weed management reflect this common approach (**Figure 2.6**).

"I consider them as forbs. If cows don't eat them they will be
mowed or plowed and make minerals available for the next crop."

-Anonymous FPC grower

Members of the FPC use relatively few weed management practices from only three categories. The category with the highest level of engagement among the FPC is information management (28%) followed closely only by biological controls (17%). The one mechanical control with significant adoption among the FPC was mowing (90%). Other mechanical controls rely on soil disturbance, which is less desirable in perennial systems.

Eighty percent of growers in the FPC adopted mowing, supported by grazing (67%), and weed scouting (45%). Growers in the FPC manage weeds for long-term control at acceptable levels through the information-intensive application of one specialized method of direct mechanical control (mowing) and one flexible biological control (grazing), that are also traditional elements of forage and perennial fruit production systems. In building farm systems that value rather than battle weeds, members of the FPC achieve a level of management integration that escapes the other two groups. Through integration into the production system at a fundamental level, weed management is transformed. Effort is focused on maximization of production *through* longevity, and weed management treated as almost incidental. Design of cropping systems that truly integrate weed management has long been a goal of IWM science (Cardina et al., 1999). However, this goal is not being achieved as the capstone of a progression through ever-increasing diversity and integration in weed management, as some have theorized (Lamine, 2011). It instead appears to be occurring extensively only in the specific context of perennial systems which demonstrate the least diversity in weed management, driven by an alternative view of what a weed is.

The Integrated Management Cluster

Cluster C comprises 32% (69) of the sample, and contains farms in four operation classes, including grain & forage (26), vegetable (18), grain (17), and diversified (7) (missing

(1)). The only farm types not included in Cluster C are forage and fruit farms found in the FPC. Farms in Cluster C use the highest average of 21 practices to manage weeds on their farms. Cluster C will be discussed as the "Integrated Management" cluster (IMC) due to the diverse and information-intensive nature of member management strategies, building on direct control efforts with additional emphasis on prevention, information management, and the application of control thresholds. Members of the IMC, like the CCC, are driven by weed management efficacy, but appear to believe that a more holistic or ecological approach to management is the way to achieve sustainable control. Quotes from members of the IMC asked to describe their attitude toward weeds and weed management reflect this common approach (**Figure 2.7**).

"Prevention. Do not allow production of seed."

-Anonymous IMC grower

"We're not going to kill them all. Keep them under an economic threshold."

-Anonymous IMC grower

The category with the highest level of engagement among the IMC is information management (50%) followed closely by several other categories including planting management (48%), cultural controls (42%), prevention (38%), mechanical controls (35%), and control thresholds (32%). Growers in the IMC have adopted diverse systems composed of a suite of management innovations. Their systems build on cultural and mechanical controls with preventative practices not used by either other cluster, and information management practices not extensively adopted among the CCC.

The diversity of weed management among the IMC suggests adoption of the IWM philosophy, but, as is noted in previous literature, biological controls have not been incorporated into the most diverse organic weed management systems (Lamine, 2011; Puente et al., 2011; Thill et al., 1991). This may be evidence that biological weed controls fit better in perennial farm systems with long-term management outlooks. Perhaps biological control should not be a central strategy in annual cropping systems dependant on high levels of weed control, and thus relatively traditional "weed as enemy" management philosophies.

Logistic Regression Analysis

In an effort to identify other less apparent drivers motivating adoption of particular weed management innovations, and thus proposed cluster membership, a stepwise logistic regression procedure was applied to estimate the impact of several probable independent variables (Kutner et al., 2004). Independent variables included data regarding farm structure, farmer demographics, and perceived innovation characteristics, which the literature suggests influence weed management behavior. Because each operation class (products grown) occurred in only two of the three proposed clusters, two binary logistic regression models were calculated to describe i) what drives forage and fruit farmers into the FPC over the CCC, and ii) what pushes grain & forage, grain, vegetable, and diversified growers into the IMC rather than the CCC.

Results of stepwise logistic regression for the CC and IM Clusters are presented in **Table 2.4**. The selected model achieved 73% percent of correct classification, and the Hosmer-Lemeshow lack-of-fit test indicated a reasonable model fit (X^2 = 3.5, df = 4, P = .57). The resulting equation indicates that years of formal education, years farming, and information seeking (measured as number of resources used) are the most important variables determining whether an organic grain & forage, grain, vegetable, or diversified grower will manage weeds in the pattern of the CCC, or instead diversify weed management as in the IWC. The odds ratio of being a IMC member indicates that each step along our categorical measure of formal education (i) middle school, ii) high school diploma or equivalent, iii) some college, iv) college degree, and v) graduate or professional degree) increases the odds of being in the IMC by 70%, with a confidence interval (CI) for this term ranging from 1.29 to 2.23. This supports other findings suggesting that formal education is correlated with adoption of diverse pest management strategies (Ceylan et al., 2010; Chaves and Riley, 2001; Lohr and Park, 2002; Park and Lohr, 2005; Rao et al., 2011; Shennan et al., 2001; van der Meulen et al., 2007;). Since the 1970s, formal agricultural education has exposed farmers to ecology-based pest management and the increasing variety of technologies available. Formal education, regardless of the field, also trains students to critically assess information under uncertainty and may indoctrinate a farmer to trust information-intensive scientific concepts generated by university research (Park and Lohr, 2005).

Odds of being in the IMC were 21% (CI, 1.01-1.44) higher for each additional resource a grower accessed for weed management information. This finding corroborates previous work highlighting the importance of information sourcing in pest management technology adoption (Ceylan et al., 2010; Pannell et al., 2006; Park and Lohr, 2005; Samiee et al., 2009; Wyckhuys and O'Neil, 2007). Farmers differ in the information they receive regarding pest management, what sources they trust, and how resources are accessed. Increased quantity and diversity in information sources exposes a farmer to more pest management innovations and the IPM concept. The more pest management information a grower seeks out, they more likely they are to adopt various promoted practices.

Lastly, odds of being in the IMC increased by 3% (CI, 1.00-1.05) with each additional year of farming experience a grower had accumulated. Farming experience exposes growers to the challenges of pest management, teaches pest ecology, and introduces new management technologies (van der Meulen et al., 2007). Organic farmers adopt additional weed and insect management practices as they gain experience in agriculture (Lohr and Park, 2002; Park and Lohr, 2005). Grain, grain & forage, vegetable, and diversified growers in our sample tended to add practices to their weed management suite and focus more on prevention and economic thresholds as the gained experience. Interestingly, experience in organic agriculture did not prove significant, suggesting that weed ecology and its implications for management can be observed and learned in organic and conventional farm systems.

Results of logistic regression for the CC and FP Clusters are presented in **Table 2.5.** The resulting equation indicates that years of formal education is the most important variable determining whether an organic forage or fruit grower will manage weeds in the pattern of the CCC, or instead shift their philosophy of weed management to accommodate perennial systems ecology as in the FPC. The odds ratio of being a FPC member indicates that each step along our categorical measure of formal education increases the odds of being in the FPC by 165%, with a confidence interval (CI) ranging from 1.14 to 6.12. This indicates that formal education not only promotes diversification of weed management in line with the IWM concept, but in the context of perennial systems also fosters an alternative philosophy of weed management based on a few integrated mechanical, biological, and information management practices.

CONCLUSIONS

Results of our cluster analysis suggest that organic weed management behavior can be classified into three dominant categories. Classic Control type managers are found in every operation class and represent the dominant approach to organic weed management. They focus weed control within individual growing seasons and use a moderate suite of mechanical and cultural controls. Growers in the CCC tend to have less formal education and experience in agriculture, and access fewer resources for weed management information. Forb Philosophy type managers are fruit and forage growers who have alternative view of weeds and their role in perennial agroecosystems. FP growers manage weeds using information management, mowing and grazing. They tend to have more formal education than their counterparts in the CCC. Integrated weed managers include all operation classes except fruit and forage farms. IMC growers build on cultural and mechanical controls with information intensive practices such as economic action thresholds and prevention. These growers have diversified their weed management systems. This diversification is facilitated by formal education, experience in farming, and additional information sourcing behavior.

If increased adoption of diverse ecological weed management systems is the goal, our findings suggest that i) organic weed management systems are on average quite diverse, ii) what a grower chooses to produce can impact weed management philosophy through clear restrictions on weed management behavior; iii) information availability and sourcing are central to successful diffusion of ecological weed management, and iv) information-intensive weed management innovations (particularly prevention and economic action thresholds) should be targeted at formally educated and experienced growers.

Yet, it is important to note that average perceived level of weed control did not differ significantly between the clusters proposed here. If subjective assessments of weed control can be trusted (Andujar et al., 2010), this raises the unavoidable question of IWM efficacy. Should we promote IWM systems if they do not necessarily result in “better” weed control? The true advantage of IWM may instead be as a transition strategy for growers looking to reduce reliance on a single weed management strategy, like cultivation or herbicides, and promote biodiversity (Labrie et al., 2003; Swezey et al., 2007). In organic agriculture, where herbicides are not a viable option, weed management systems are inherently and necessarily diverse. Now that a model of organic weed management behavior has been proposed, further work is needed to completely understand the relationship between these behavioral types and weed management outcomes in terms of weed control and net return to management.

LITERATURE CITED

Andújar, D., Ribeiro, A., Carmona, R., Fernández-Quintanilla, C., & Dorado, J. (2010). An assessment of the accuracy and consistency of human perception of weed cover. *Weed Research, 50*(6), 638-647.

Bandura, A. (1986). *Social foundations of thought and action: A social cognitive theory*. Englewood Cliffs, N.J.: Prentice-Hall.

Barbaranelli, C. (2002). Evaluating cluster analysis solutions: An application to the italian NEO personality inventory. *European Journal of Personality, 16,* S43-S55.

Barnes, R. F., Nelson, C. J., Collins, M., & Moore, K. J. (Eds.). (2003). *Forages, volume 1: An introduction to grassland agriculture* (6th ed.). Ames, IA: Iowa State Press.

Bastiaans, L., Paolini, R., & Baumann, D. T. (2008). Focus on ecological weed management: What is hindering adoption? *Weed Research, 48*(6), 481-491.

Batagelj, V. (1988). Generalized ward and related clustering problems. In *Classification and related methods of data analysis* (pp. 67-74). B. V., North-Holland.: Elsevier Sci. Publ.

Bicksler, A. J., & Masiunas, J. B. (2009). Canada thistle (cirsium arvense) suppression with buckwheat or sudangrass cover crops and mowing. *Weed Technology, 23*(4), 556-563.

Buhler, D. D., Liebman, M., & Obrycki, J. J. (2000). Theoretical and practical challenges to an IPM approach to weed management. *Weed Science, 48*(3), 274-280.

Bürger, J., de Mol, F., & Gerowitt, B. (2012). Influence of cropping system factors on pesticide use intensity – A multivariate analysis of on-farm data in north east germany. European Journal of Agronomy, 40(0), 54-63.

(2008). The “necessary extent” of pesticide use—Thoughts about a key term in german pesticide policy. *Crop Protection, 27*(3–5), 343-351.

Burton, R. J. F., & Wilson, G. A. (2006). Injecting social psychology theory into conceptualisations of agricultural agency: Towards a post-productivist farmer self-identity? *Journal of Rural Studies, 22*(1), 95-115.

Cardina, J., Webster, T. M., Herms, C. P., & Regnier, E. E. (1999). Development of weed IPM: Levels of integration for weed management. *Journal of Crop Production, 2*(1), 239-267.

Carolan, M. S. (2005). Barriers to the adoption of sustainable agriculture on rented land: An examination of contesting social fields. *Rural Sociology, 70*(3), 387-413.

Ceylan, I. C., Koksal, O., & Kutlar, I. (2010). Determination of effective factors on adoption of integrated pest management practices. *Journal of Environmental Protection and Ecology, 11*(2), 709-717.

Chaves, B., & Riley, J. (2001). Determination of factors influencing integrated pest management adoption in coffee berry borer in colombian farms. *Agriculture Ecosystems & Environment, 87*(2), 159-177.

Czapar, G. F., Curry, M. P., & Gray, M. E. (1995). Survey of integrated pest management practices in central illinois. *Journal of Production Agriculture, 8.*

Davis, A., Renner, K., & Gross, K. (2005). Weed seedbank and community shifts in a long-term cropping systems experiment. *Weed Science, 53*(3), 296-306.

Dice, L. R. (1945). Measures of the amount of ecologic association between species. *Ecology, 26*(3), pp. 297-302.

Dillman, D., Smyth, J. D., & Christian, L. M. (2008). *Internet, mail and mixed-mode surveys* Wiley & Sons.

Doohan, D., Wilson, R., Canales, E., & Parker, J. (2010). Investigating the human dimension of weed management: New tools of the trade. *Weed Science, 58*(4), 510.

Eckert, E., & Bell, A. (2006). Continuity and change: Themes of mental model development among small-scale farmers. *Journal of Extension, 44*(1) Retrieved from http://www.joe.org/joe/2006february/a2.php

Edwards-Jones, G. (2006). Modelling farmer decision-making: Concepts, progress and challenges. *Animal Science, 82*, 783-790. doi:10.1017/ASC2006112

Electronic Code of Federal Regulations (e-CFR). (2012). *Title 7, subtitle B, chapter 1, subchapter M, part 205: National organic program.* Retrieved, 2012, from http://ecfr.gpoaccess.gov/cgi/t/text/text-idx?c=ecfr&sid=3f34f4c22f9aa8e6d9864cc2683cea02&tpl=/ecfrbrowse/Title07/7cfr205_main_02.tpl

Fairweather, J. R., & Campbell, H. (1996). *The decision making of organic and conventional agricultural producers.* (No. 233). Canterbury, New Zealand: Agribusiness and Economics Research Unit.

Feder, G., & Umali, D. L. (1993). The adoption of agricultural innovations : A review. *Technological Forecasting and Social Change, 43*(3-4), 215-239. doi:DOI: 10.1016/0040-1625(93)90053-A

Fernandez-Cornejo, J., Beach, E. D., & Huang, W. Y. (1992). The adoption of integrated pest management technologies by vegetable growers.*AGES 9228*

Finch, H. (2005). Comparison of distance measures in cluster analysis with dichotomous data. *Journal of Data Science, 3*(1), 85-100.

Fisher, R. A. (1922). On the interpretation of χ^2 from contingency tables, and the calculation of P. *Journal of the Royal Statistical Society, 85*(1).

Fisher, R. A. (1954). *Statistical Methods for research workers*. Oliver and Boyd.

Fishmen, G. S. (1995). *Monte carlo: Concepts, algorithms, and applications*. New York: Springer.

Gibson, K. D., McMillan, J., Hallett, S. G., Jordan, T., & Weller, S. C. (2011). Effect of a living mulch on weed seed banks in tomato. *Weed Technology, 25*(2), 245-251.

Gintis, H. (2009). Decision theory and human behavior. In *The bounds of reason: Game theory and the unification of the behavioral sciences* (pp. 1-26). Princeton, New Jersey: Princeton University Press.

Haahr, M. (2012). *Random.org: True random number generator.* Retrieved, 2011, from http://www.random.org/

Hair, J., Anderson, R., Tatham, R., & Black, W. (1992). *Multivariate data analysis* (2nd ed.). New York: Macmillan Publishing Company.

Hammond, C. M., Luschei, E. C., Boerboom, C. M., & Nowak, P. J. (2006). Adoption of integrated pest management tactics by wisconsin farmers. *Weed Technology, 20*(3), 756-767.

Hands, S., & Everitt, B. (1987). A monte carlo study of the recovery of cluster structure in binary data by hierarchical clustering techniques. *Multivariate Behavioral Research, 22*(2), 235.

Haydu, J. (2011). Cultural modeling in two eras of US food protest: Grahamites (1830s) and organic advocates (1960s-70s). *Social Problems, 58*(3), 461-487.

Hoeft, E., Jordan, N., & Zhang, J. (2001). Integrated cultural and biological control of canada thistle in conservation tillage soybean. *Weed Science, 49*(5), 642-646.

Howard, A. (1943). *An agricultural testament*. New York and London: Oxford University Press.

Jasinski, J., Eisley, B., Gastier, T., & Kovach, J. (2001). Scoring IPM adoption in ohio: It really adds up. *Journal of Extension, 39*(5).

Kaine, G., & Bewsell, D. (2008). Adoption of integrated pest management by apple growers: The role of context. *International Journal of Pest Management, 54*(3), 255-265.

Kelling, K. A., Schulte, & Peters. (1996). One hundred years of ca:Mg ratio research. *New Horiz. in Soil Ser., 8.*

Kopittke, P. M., & Menzies, N. W. (2007). A review of the use of the basic cation saturation ratio and the "ideal" soil RID A-6026-2011. *Soil Science Society of America Journal, 71*(2), 259-265.

Kutner, M. H., Nachtsheim, C. J., & Neter, J. (2004). *Applied linear regression models*. New York, NY: Mc Graw Hill Irwin.

Labrie, G., Prince, C., & Bergeron, J. (2003). Abundance and developmental stability of pterostichus melanarius (coleoptera : Carabidae) in organic and integrated pest management orchards of quebec, canada. *Environmental Entomology, 32*(1), 123-132.

Lamine, C. (2011). Transition pathways towards a robust ecologization of agriculture and the need for system redesign. cases from organic farming and IPM. *Journal of Rural Studies, 27*(2), 209-219.

Liebman, M., Mohler, C., & Staver, C. (Eds.). (2001). *Ecological management of agricultural weeds* Cambridge University Press.

Lipmann, C. B. (1916). A critique of the hypothesis of the lime/magnesia ratio. *Plant World, 19*

Litsinger, J. A., Libetario, E. M., & Canapi, B. L. (2009). Eliciting farmer knowledge, attitudes, and~Practices in the development of integrated pest management programs for rice in asia. In *Integrated pest management: Dissemination and impact* (pp. 119-273) Springer Netherlands.

Llewellyn, R. S. (2007). Information quality and effectiveness for more rapid adoption decisions by farmers. *Field Crops Research, 104*(1-3), 148-156.

Llewellyn, R. S., Lindner, R. K., Pannell, D. J., & Powles, S. B. (2004). Grain grower perceptions and use of integrated weed management. *Australian Journal of Experimental Agriculture, 44*(10), 993-1001.

Llewellyn, R. S., Pannell, D. J., Lindner, R. K., & Powles, S. B. (2005). Targeting key perceptions when planning and evaluating extension. *Australian Journal of Experimental Agriculture, 45*(12), 1627-1633.

Lohr, L., & Park, T. (2002). Choice of insect management portfolios by organic farmers: Lessons and comparative analysis. *Ecological Economics, 43*(1), 87-99.

Lynd, R. S., & Lynd, H. M. (1929). *Middletown: A study in contemporary american culture*. Ney York: Harcourt, Brace, and Company.

Malone, S., Ames Herbert Jr., D., & Pheasant, S. (2004). Determining adoption of integrated pest management practices by grains farmers in virginia. *Journal of Extension, 42*(4).

McCaman, J. L. (1994). *Weeds and why they grow.*

McCann, E., Sullivan, S., Erickson, D., & DeYoung, R. (1997). Environmental awareness, economic orientation, and farming practices: A comparison of organic and conventional farmers. *Environmental Management, 21*(5), 747-758.

Mcdonald, D., & Glynn, C. (1994). Difficulties in measuring adoption of apple ipm - a case-study. *Agriculture Ecosystems & Environment, 48*(3), 219-230.

Menalled, F. D., Gross, K. L., & Hammond, M. (2001). Weed aboveground and seedbank community responses to agricultural management systems. *Ecological Applications, 11*(6), 1586-1601.

Merriam-Webster, I. (2012). *Merriam-webster online dictionary: "forb".* Retrieved, 2012, from http://www.merriam-webster.com/dictionary/forb

Michos, M. C., Mamolos, A. P., Menexes, G. C., Tsatsarelis, C. A., Tsirakoglou, V. M., & Kalburtji, K. L. (2012). Energy inputs, outputs and greenhouse gas emissions in organic, integrated and conventional peach orchards. Ecological Indicators, 13(1), 22-28.

Padgham, J. (2011, September-October). Book review: Weeds and why they grow by jay McCaman. *Organic Broadcaster.*

Pannell, D. J., Marshall, G. R., Barr, N., Curtis, A., Vanclay, F., & Wilkinson, R. (2006). Understanding and promoting adoption of conservation practices by rural landholders. *Australian Journal of Experimental Agriculture, 46*(11), 1407-1424.

Pannell, D. J. (1999). Social and economic challenges in the development of complex farming systems. *Agroforestry Systems, 45*(1-3), 393-409.

Park, T. A., & Lohr, L. (2005). Organic pest management decisions: A systems approach to technology adoption. *Agricultural Economics, 33*(3), 467-478.

Pennings, J. M. E., Irwin, S. H., & Good, D. L. (2002). Surveying farmers: A case study. *Review of Agricultural Economics, 24*(1), pp. 266-277.

Puente, M., Darnall, N., & Forkner, R. E. (2011). Assessing integrated pest management adoption: Measurement problems and policy implications. *Environmental Management, 48*(5), 1013-1023.

Rao, C. A. R., Rao, M. S., Srinivas, K., Patibanda, A. K., & Sudhakar, C. (2011). Adoption, impact and discontinuance of integrated pest management technologies for pigeon pea in south india. *Outlook on Agriculture, 40*(3), 245-250.

Ridgley, A. M., & Brush, S. B. (1992). Social-factors and selective technology adoption - the case of integrated pest-management. *Human Organization, 51*(4), 367-378.

Riemens, M. M., Groeneveld, R. M. W., Kropff, M. J. J., Lotz, L. A. P., Renes, R. J., Sukkel, W., & van der Weide, R. Y. (2010). Linking farmer weed management behavior with weed pressure: More than just technology. *Weed Science, 58*(4), 496.

Robertson, M. J., Zehnder, G. W., & Hammig, M. D. (2005). Adoption of integrated pest management practices by south carolina cotton growers . *Journal of Extension, 43*(6)

Rogers, E. M. (2003). *Diffusion of innovations* (5th ed.). New York, NY: Free Press.

Ryan, M., Duh, S., Wilson, D. & Hepperly, P. (2007). *The skinny on a big problem...weeds: NewFarm.org readers respond to a web-based survey about weed management and tell how they deal with their weeds.*. Retrieved 10/7, 2011, from http://www.rodaleinstitute.org/the_skinny_on_a_big_problem_weeds

Rydberg, N., & Milberg, P. (2000). A survey of weeds in organic farming in sweden. *Biological Agriculture & Horticulture, 18*(2), 175-185.

Samiee, A., Rezvanfar, A., & Faham, E. (2009). Factors influencing the adoption of integrated pest management (IPM) by wheat growers in varamin county, iran. *African Journal of Agricultural Research, 4*(5), 491-497.

Sattler, C., & Nagel, U. J. (2010). Factors affecting farmers' acceptance of conservation measures-A case study from north-eastern germany. *Land use Policy, , 27*(1) 70-77.

Schonbeck, M. (2000). Balancing soil nutrients in organic vegetable production systems: Testing albrecht's base saturation theory in southeastern soils.*Inf. Bull. 10:17*

Sellmer, J., Ostiguy, N., Hoover, K., & Kelley, K. (2004). Assessing the integrated pest management practices of pennsylvania nursery operations. HortScience, 39(2), 297-302.

Shennan, C., Cecchettini, C., Goldman, G., & Zalom, F. (2001). Profiles of california farmers by degree of IPM use as indicated by self-descriptions in a phone survey. *Agriculture Ecosystems & Environment, 84*(3), 267-275.

Simon, H. (1990). Bounded rationality. In *Utility and probability* (pp. 15) Eatwell, J.; Milgate, M.; Newman, P.

Spall, J. (2005). Monte carlo computation of the fisher information matrix in nonstandard settings. *Journal of Computational and Graphical Statistics, 14*(4), 889-909.

SPSS Inc. (2011). *SPSS for windows, rel. 19.0.0. 2011*. Chicago

Straub, E. T. (2009). Understanding technology adoption: Theory and future directions for informal learning. *Review of Educational Research, 79*(2), 625-649.

Swezey, S. L., Goldman, P., Bryer, J., & Nieto, D. (2007). Six-year comparison between organic, IPM and conventional cotton production systems in the northern san joaquin valley, california. *Renewable Agriculture and Food Systems, 22*(1), 30-40.

Tan, P. A., Steinbach, M., & Kumar, V. (2005). *Introduction to data mining* Addison-Wesley.

Thill, D. C., Lish, J. M., Callihan, R. H., & Bechinski, E. J. (1991). Integrated weed management-a component of integrated pest-management - a critical-review. *Weed Technology, 5*(3), 648-656.

Turner, R. J., Davies, G., Moore, H., Grundy, A. C., & Mead, A. (2007). Organic weed management: A review of the current UK farmer perspective. *Crop Protection, 26*(3) 377-382.

United States Department of Agriculture (USDA). (2010). *List of certified operations.* Retrieved, 2011, from http://apps.ams.usda.gov/nop/

USDA, & NASS. (2009). *2007 census of agriculture*.

van der Meulen, A. W., Reeve, I. J., & Sindel, B. M. (2007). Weed management on grazing properties: A survey of livestock producers in new south wales and victoria. *Australian Journal of Experimental Agriculture, 47*(12), 1415-1421.

Vanclay, F. (2004). Social principles for agricultural extension to assist in the promotion of natural resource management. *Australian Journal of Experimental Agriculture, 44*(3), 213-222.

Villamil, M. B., Alexander, M., , H. S., A., & Gray, M. E. (2011). Producer perceptions and information needs regarding their adoption of bioenergy crops. *In Press,*

Walz, E. (1999). *Third biennial national organic farmer's survey*. Santa Cruz, California: Organic Farming Research Foundation.

(2004). *Fourth national organic farmer's survey*. Organic Farming Research Foundation.

Ward, J. (1963). Hierarchical grouping to optimize an objective function. *Journal of the American Statistical Association, 58*(301), 236.

Wilson, R. S., Hooker, N., Tucker, M., LeJeune, J., & Doohan, D. (2009). Targeting the farmer decision making process: A pathway to increased adoption of integrated weed management. *Crop Protection, 28*(9), 756-764.

Wilson, R. S., Tucker, M. A., Hooker, N. H., LeJeune, J. T., & Doohan, D. (2008). Perceptions and beliefs about weed management: Perspectives of ohio grain and produce farmers. *Weed Technology, 22*(2), 350.

Wyckhuys, K. A. G., & O'Neil, R. J. (2007). Local agro-ecological knowledge and its relationship to farmers' pest management decision making in rural honduras . *Agriculture and Human Values, 24*(3).

TABLES AND FIGURES

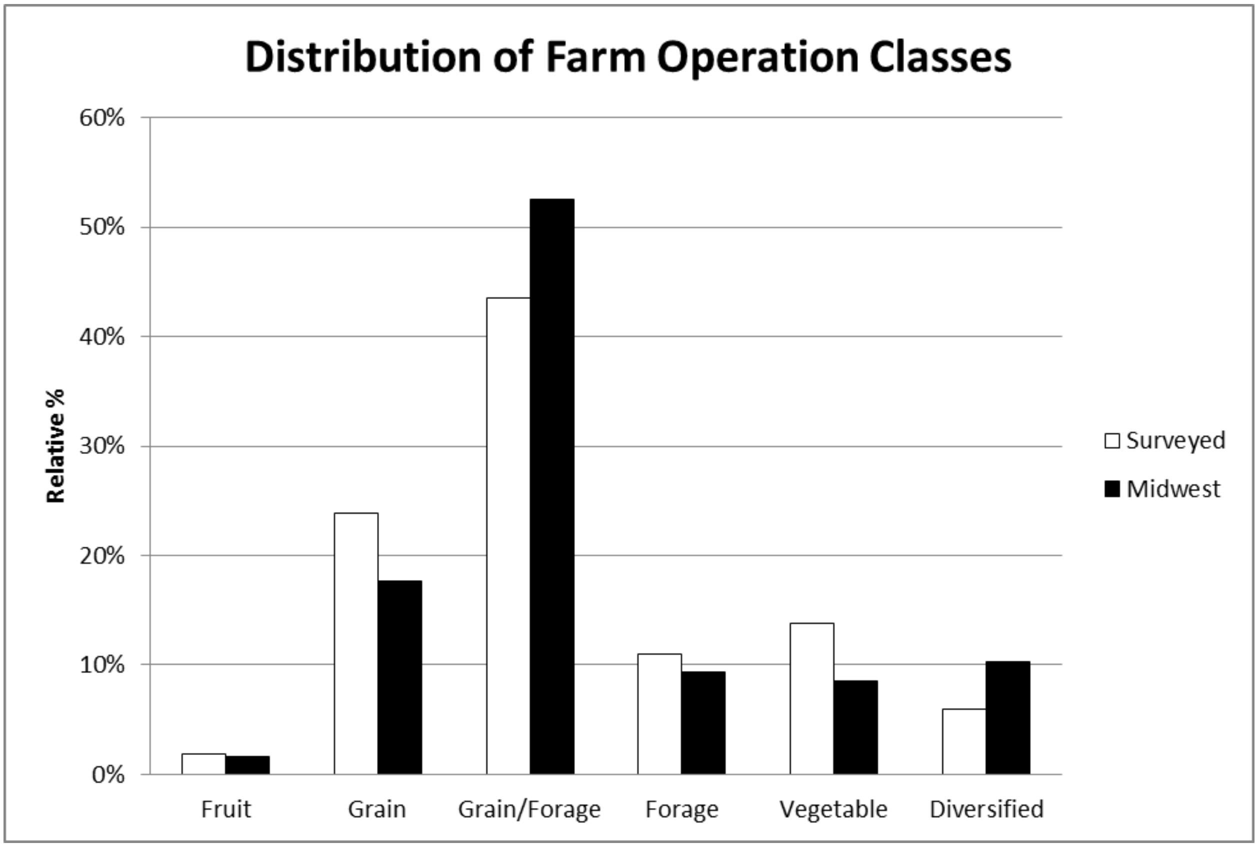


Figure 2.1. Distribution of farm operation classes among the survey sample compared to the target population (USDA, 2010)

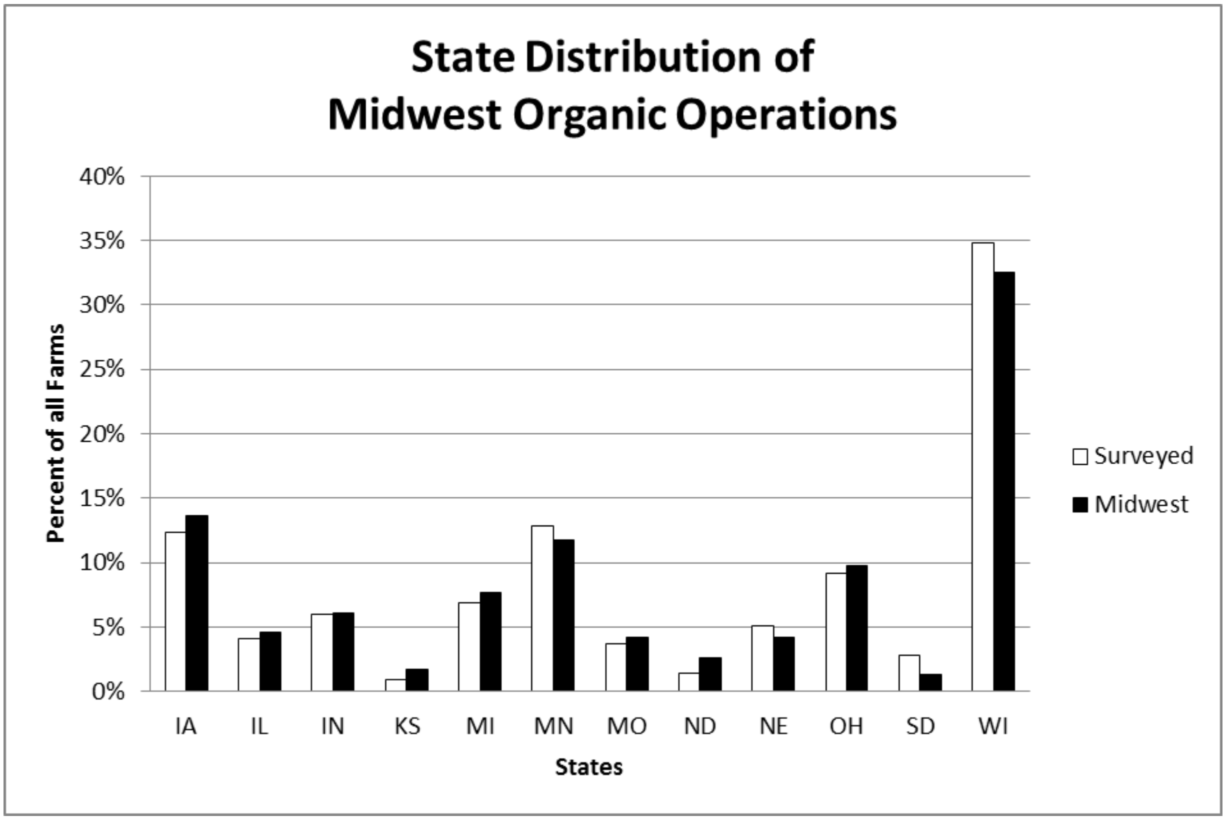


Figure 2.2. Distribution of organic farm operations across states of the Midwest U.S. among the survey sample compared to the target population (USDA, 2010)

Sample Demographics Compared to National Trends

	Acres	Yrs. Farming	Yrs. Organic	Gross Income	Age	Ed.	% Female
Surveyed	270	26.6	12.1	$50,000	51	B.S. or B.A.	6%
U.S.	277	20.4	11.5	$25,000	51	B.S. or B.A.	22%

Table 2.1. Demographics of the survey sample compared to national trends from a mail survey of organic agriculture (Walz, 2001)

Farmers' Weed Management Information Resources

Resource	**% of Respondents Using**
Other Farmers	82.5%
Field Days, Workshops, Conferences	55.3%
Periodicals and/or Newsletters	46.1%
Books	45.6%
University Extension and/or Researchers	24.4%
Internet Sites	18.9%
Trade Organizations	17.1%
Non-university Consultants	15.7%
Natural Resource Conservation Service	12.0%
Equipment or Chemical Dealers	10.6%
Radio or TV	1.9%

Table 2.2. Percent of respondents indicating use of each weed management information resource surveyed

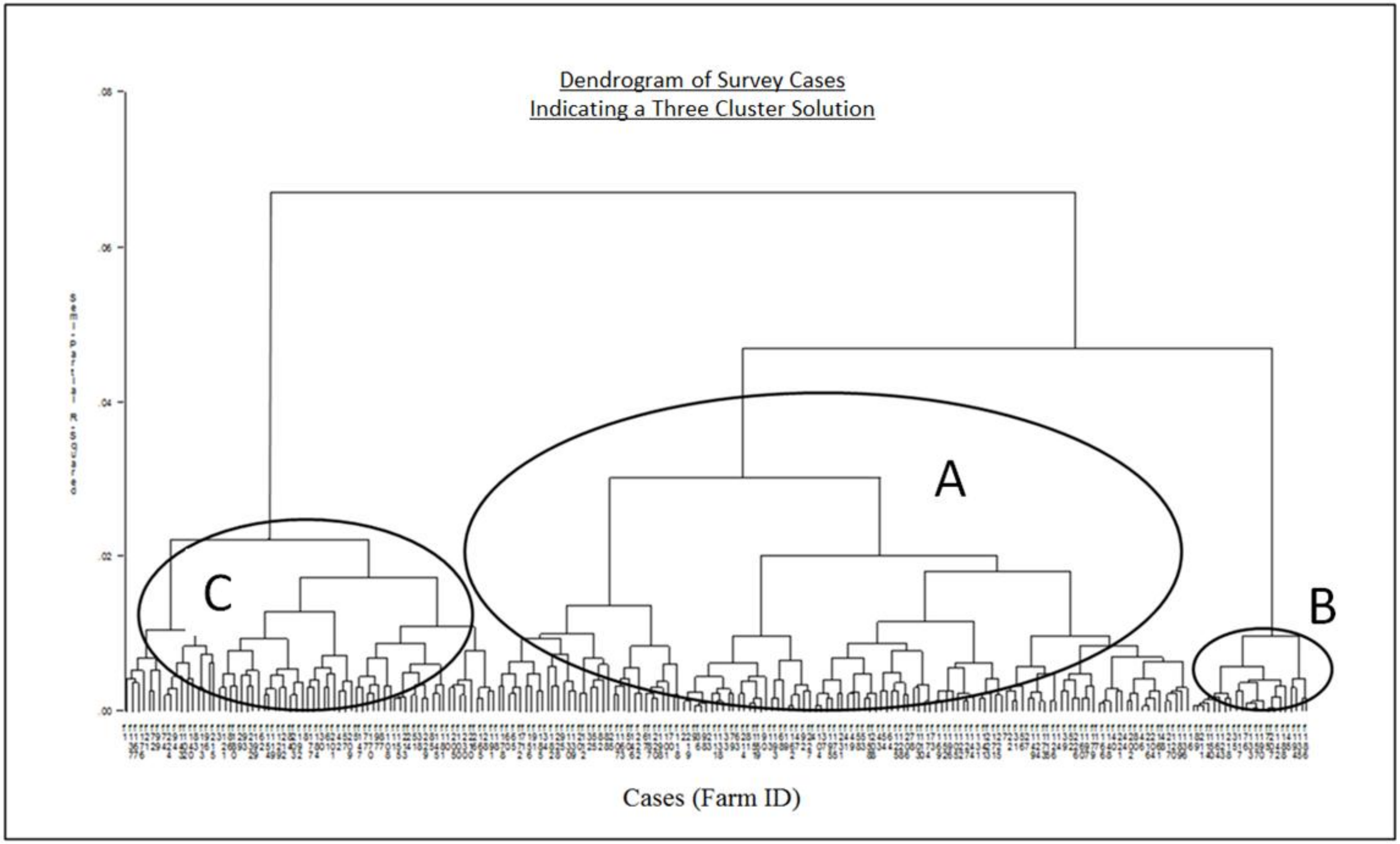


Figure 2.3. Dendrogram of the cluster analysis solution showing individual cases grouped hierarchically into three clusters

Three Distinct Approaches to Organic Weed Management

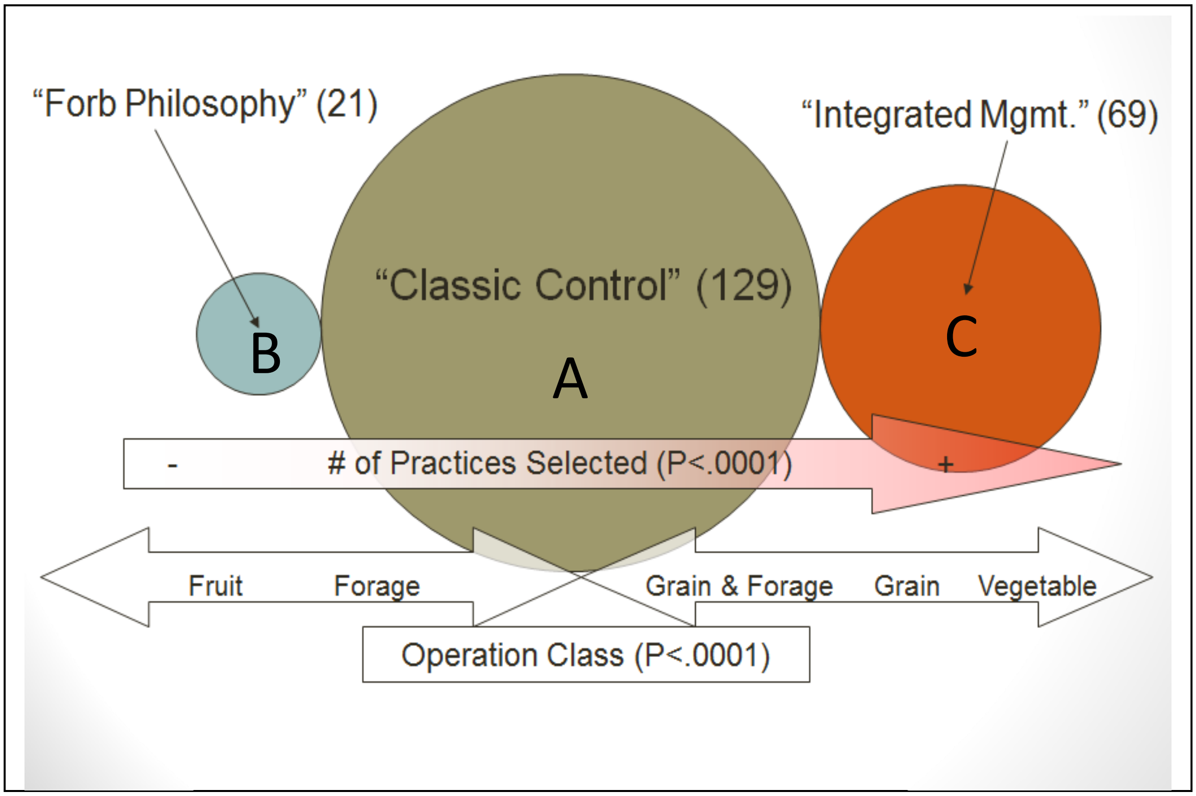


Figure 2.4. Modeled three cluster solution showing measures of external evaluation

Classic Control Cluster Quotes

- "You know they are going to come. Be patient and take control of them."
- "Working on living with annual weeds by cultivating enough to ensure a good crop."
- "(We) use mold board plow, later planting, rotary hoe, and at least two tries of cultivation to manage our weeds."
- "Don't plant too early. Till soil good before planting. Harrow before crop is up. Don't pack ground too much. Cultivate at least three times and start as soon as possible."

Figure 2.5. Quotations from members of the Classic Control Cluster showing an emphasis on cultural and mechanical weed controls

Weed management practice categories	Cluster[a] A (classic control)	B (forb philosophy)	C (integrated)
	Relative engagement[b] (%)		
Planting management	34.6	10.4	49.3
Prevention	16.3	10.1	38.9
Thresholds	15.1	8.7	32.6
Mechanical controls	29.9	11.3	36.3
Biological controls	8.9	17.4	16.6
Cultural controls	25.9	6.5	42.2
Chemical controls	0.0	3.1	2.5
Information management	20.0	29.3	50.7

[a] Management clusters were determined via hierarchical cluster analysis.

[b] Relative engagement is measured as average percent of practices used within a given category

Table 2.3. Engagement in weed management practice categories among management clusters

Forb Philosophy Cluster Quotes

- "I consider them as forbs. If cows don't eat them they will be mowed or plowed and make minerals available for the next crop."
- "Great Feed for cattle!"
- "Not too concerned as long as they (weeds) don't get out of control. It all adds to the biodiversity."
- "Live with a few weed(s) and enjoy life. Use them where possible. Quack grass and foxtail make good feed in a rotational grazing system."
- "Weeds must be maintained. All part of a healthy ecosystem. Proper mowing timed to not reproduce or reseed itself."

Figure 2.6. Quotations from members of the Forb Philosophy Cluster demonstrating their alternative philosophy of weed management

Integrated Management Cluster Quotes

- "Weeds are the indicator of the intersection of soil, climate and management conditions."
- "First you have to be smarter than the weed, then it's all down hill."
- "We're not going to kill them all. Keep them under an economic threshold."
- "Prevention. Do not allow production of seeds!"
- "Take notes and learn your land."

Figure 2.7. Quotations from members of the Integrated Management Cluster demonstrating their information-intensive approach to weed management

Parameter	DF	Estimate	SE	Wald χ^2	Sig	Odds ratio	95% Lower	CI Upper
Intercept	1	-3.42	0.63	28.96	<.0001			
Education	1	0.53	0.14	14.56	.0001	1.70	1.29	2.23
Years Farming	1	0.03	0.01	4.63	0.03	1.03	1.00	1.05
Information Seeking	1	0.19	0.09	4.39	0.04	1.21	1.01	1.44

Table 2.4. Results of stepwise logistic regression for the CC and IM Clusters

Parameter	DF	Estimate	SE	Wald χ^2	Sig	Odds ratio	95% Lower	CI Upper
Intercept	1	-1.87	1.19	2.46	0.12			
Education	1	0.97	0.43	5.17	0.02	2.65	1.14	6.12

Table 2.5. Results of stepwise logistic regression for the CC and FP Clusters

<u>CHAPTER THREE</u>: FARMER CASE STUDIES

INTRODUCTION

Interviewing is a common methodology for collecting data from farmers (Cabrera and Leckie, 2009; Kaine and Bewsell, 2008; Llewellyn et al., 2004; McCann et al., 1997; Pennings et al., 2002; Sattler and Nagel, 2010; Taylor et al., 1992; van der Meulen et al., 2007). Data generated by semi-structured interviews contrasts well with the largely quantitative approach of written surveys. Interviews can capture qualitative human subjects data better than any other methodology, except perhaps participant observation. Interviews allow researchers and respondents to move beyond the basic line of questioning, to ask "Why? For how long?", and "What about the future?". They capture the voice of participants to more accurately reflect the meaning of their statements. For these reasons, interviews are virtually essential to a more complete understanding of organic weed management behavior and IWM adoption.

MATERIALS AND METHODS

Interview Protocol

A semi-structured on-farm interview protocol was developed from the written Midwest U.S. Organic Weed Management Survey in early 2010 with the goal of contextualizing quantitative survey data through the construction of largely qualitative case studies **(Appendix B)**. The interview protocol called for approximately one hour of semi-structured interviewing in a line of questioning drawn from the survey, followed by an unstructured tour of weed management on the farm. All items from the written survey were included in the interview questionnaire, as were additional questions omitted from the written survey due either to their overtly personal nature, or the general effort to control instrument length. Interview questions not included in the written survey included i) How long have you or your family lived in this area?; ii) Do you live on the farm property?; iii) How many years have you or your family farmed the land you currently farm?; iv) Why do you farm organically?; v) Who is your certifier?; vi) Who works on the farm?; vii) Describe the weed pressure and problem weed species on your farm?; viii) How would you describe your attitude toward weeds on the farm? (Why do you feel this way?); ix) Do you consider yourself a user of integrated weed management?; x) How would you describe your weed management goals and/or strategy?; xi) Do you consider last year's weed management a success?; xii) Which weed management methods do you consider effective/ineffective?; xiii) Are you planning to manage weeds differently this season?; xiv) Why do you trust your preferred weed management information source?; xv) Why do you think specified stakeholders have responded as they have to your weed management practices?; and xvi) Do the responses you receive or anticipate from others affect your weed management decisions?

Sample Development

Survey pretest participants contacted at organic agriculture conferences in January and February of 2010 were targeted for involvement in the on-farm interview portion of our research. Each survey pretest administered included an optional interview contact information form, which interested organic farmers submitted at their discretion. Fifteen growers submitted forms indicating their interest and were contacted via telephone in March 2010 to collect basic information on their farm operation and judge the feasibility of an interview. Interview participants were then subjectively selected, based primarily on crops produced, to build a diverse sample of Midwest organic farms. Eight interviews were conducted by the researcher during June and July of 2010, and one by a research assistant in December 2011. Data was collected as research notes, digital audio files, and digital still photographs. Interview participants signed a written consent form permitting the researcher to use their names and other identifying information in written publication. Digital images and audio files were released only for public presentations on the project by the researcher. The nine completed on-farm interviews represent five assorted operation classes (grain, grain & forage, vegetable, fruit and ornamentals) located in Illinois, Minnesota and Wisconsin.

Our method is considered “convenience sampling” and is not a random technique. As a result, our interview sample represents a subset of Midwest organic growers likely to attend educational conferences. Respondents to the Third Biennial National Organic Farmers’ Survey ranked conferences and seminars as the second most useful “place or thing” resource for information regarding organic production, indicating that 64% of respondents attend conferences and seminars an average of 2.1 times per year (Walz, 1999). We therefore expect our interview sample to be somewhat representative of the larger population of organic growers in the Midwest. Still, our sampling bias will likely translate into differences between survey and interview results.

One of these differences may be the level of education among interview participants and its impact on management behavior. Many of our interview participants had high levels of formal education. However, this did not always translate into information intensive weed management systems as our model from the survey data suggests. Conferences are known to attract participants who value opportunities for formal education (Yoo & Zhao, 2010). Therefore, among our biased sample education may be a less valuable predictor of weed management behavior than some other influential variables like farming experience. It appears that many highly educated farmers we interviewed are diversifying their approach to weed management, with additional attention to prevention and economic thresholds, as they gain farming experience. None the less, we have organized the case studies according to our cluster model to illustrate its relevance.

CASE STUDIES

Illustrations of the Classic Control Cluster

Ken Seguine & Jay Gilbertson
Hay River Pumpkin Seed Oil
Prairie Farm, WI

Ken Seguine (54, six years college) and Jay Gilbertson (49, B.A.) own and manage Hay River Pumpkin Seed Oil, headquartered on their farm in Prairie Farm, Wisconsin. Here they raise naked-seeded pumpkins for the production of their value-added product. Now in their seventh year, their growing area has expanded to a total of 20 owned and leased acres. Ken and Jay have managed all of their pumpkin ground organically since 2001, and today certify 30 acres (10 acres unplanted). They are driven by a vision for an enterprise that is environmentally and socially sustainable.

> "We want to make this commercial enterprise work, and make it work organically. We include sustainable for the people. We want to be able to pay people…We also have a deeper motivation, wanting to be really responsible about the way we live on the land…Leave this land a better cleaner place."

According to Ken and Jay the weed community on their farm includes quackgrass (*Elytrigia repens*) and lambsquarters (*Chenopodium album*) that exert high levels of competitive pressure on their pumpkins, despite transplanting. Ken and Jay exhibit a somewhat negative attitude toward weeds ("Die F%#$ers"), but accept them as an inevitability of organic production. Together they are actively compiling a suite of practices to manage weeds, focusing on cultural and mechanical controls augmented by some prevention and weed identification.

In the past they tried plastic mulch, but found it ineffective against the quack grass and difficult to remove. Their current approach includes nine practices. Primary tillage using a rotovator breaks-up the quack grass rhizomes and exposes them to desiccation. The pumpkin plantings are arranged on five-foot centers to ensure adequate spacing and quick canopy fill with their bush varieties. During the main season flat fields are tractor cultivated using a C-tine implement modified with pumpkin knives, and contour strips in sloped fields are mowed. In-row weeds are sometimes topped with a string trimmer. In the future, Ken and Jay hope to implement stale seedbed cultivation. They rate weed control on their farm at a three out of ten.

Ken and Jay have accessed several resources for weed management information, including other growers, conferences, university, private consultants, and books. Neighboring growers have shared a lot of advice, sometimes conflicting. Ken found the MOSES Organic Farming Conference to be the most helpful because it facilitates interaction with more experienced growers. Ken and Jay view IWM as an unachieved goal for their weed management system. "We are oriented there. I think our ignorance and inexperience maybe hampers us. But as we go along, yeah, we are going to get much more sophisticated. So, we want to be [users of IWM]".

Jason and Sarah Shoot
Frontwards Farm
Makanda, IL

Jason Shoot (35, B.A. in English) and his wife Sarah (B.A. in Fiber Arts) own and manage Frontwards farm at their home in Makanda, Illinois. Here on about one acre they raise vegetables, fruit, and poultry for a sixteen member CSA. Jason has gardened and landscaped for fourteen years, but this is only his third year growing food commercially. Jason and Sarah have managed their farm organically since purchasing it in 2006, but it is not certified. Jason is driven by a vision for self sufficiency and health, but also feels compelled to reach out to his community.

> "There has always been this part of me that really wanted to be like Grizzly Adams. "Live off the land" kind of mentality. But, I don't want to be that person…I love the world, and I think there is still a lot of hope…We are feeding other people, but they are also feeding our farm by supporting us."

According to Jason the weed community on his farm is dominated by Johnsongrass (*Sorghum halepense*), curly dock (*Rumex crispus*), and various other perennial grasses. He feels that weed pressure on his farm is medium-high because the soil is newly cultivated, but manageable through preventative mulching. Jason exhibits a strongly ecocentric and scholarly attitude toward weeds, working to learn the ecology of various species for the application of selective control.

> "Before I started doing lawn care and landscaping I never would have thought there was anything good about clover. But of course, a lot of farmers plant clover on purpose. I'm trying to learn about benefits…whether through aeration, or nitrogen fixing, or keeping other weeds down…I am just trying to learn which ones are most important to eliminate…, which ones I can live with for a little bit

> longer, and which ones I may *not* want to eliminate. I am always fighting that drive for aesthetic beauty."

Jason uses a limited suite of practices to manage weeds, focusing on cultural and mechanical controls. Crop rotations including cover crops vary competitive dynamics. Primary tillage using a rototiller breaks-up grass rhizomes and other weeds. Plantings are made at high densities. Due to experience in landscaping, Jason applies various organic mulches like straw, cardboard, or woodchips. During the main season crops are hand weeded or hoed. Jason rates weed control on his farm at a five out of ten.

Jason has accessed few resources for weed management information, focusing mostly on personal experience and other growers. He values these resources because he believes that system context largely determines efficacy in agriculture. Unfortunately, neighboring growers have resisted Jason's efforts as a new grower to build networks. Jason views himself as a user of IWM, but feels that his farm system is only beginning the transition toward a more managed state. His philosophy of weed management indicates that he will likely diversify his weed management behavior with additional vegetable growing experience.

Anthony Kurtz
Kaynick Farms
Wonewoc, WI

Tony Kurtz (43, Master's in International Relations) owns and manages Kaynick Farms in Wonewoc, Wisconsin. Here he raises corn, soybean, wheat, oats and hay for sale to local dairies and feed mills. Tony is in his fifth year farming, since retirement from the military. He has recently added additional leased land to his operation, now totaling 100 acres. Tony has managed all of his ground organically since 2005, and today certifies 75%. Tony farms organically in an effort to make a profit on a small scale, and because of what he perceives as the negative impacts of agricultural chemicals on human and environmental health.

> "One, on a small scale, organically is the only way you are going to make any money at all. Two, I do think there is something to the chemicals that we're putting on the crops…That stuff's got to go somewhere."

According to Tony the weed population on his farm includes lambsquarters (*Chenopodium album*), common ragweed (*Ambrosia artemisiifolia* var. *elatior*), foxtail (*Setaria faberi* or *Setaria glauca*), and redroot pigweed (*Amaranthus retroflexus*) that exert medium levels of competitive pressure on his crops. Tony exhibits a tolerant attitude toward weeds, because he feels that a totally clean field is not a realistic goal for organic systems. Yet, he believes he is making progress in weed management as he gains farming experience and new tools. "I've seen just over the last three years; I'm getting a better handle on the weeds." He is actively experimenting to build a suite of weed management practices, focusing on cultural and mechanical controls supported by scouting and weed identification.

Tony is driven by efficacy and economics in weed management and his current approach includes sixteen practices. He scouts fields, and is learning his weed community. Primary tillage using a chisel plow and disc breaks soil crusting and stimulates weed germination. Four to six crops are rotated to vary competition dynamics. Crop varieties are selected based on their ability to compete with weeds. Planting densities and row spacings are arranged to facilitate cultivation. During early crop growth, the first flush of weeds is cultivated using a Danish tine implement and rotary hoe. During the main season fields are cultivated using a Buffalo row crop cultivator. Tony rates weed control on his farm at a six out of ten.

Tony has accessed several resources for weed management information, including other growers, university, books, and periodicals. One neighboring grower has acted as a mentor, sharing experience and work with Tony. Tony finds internet resources and the book “Integrated Weed Management: One Year’s Seeding” (Davis et al., 2005) by Michigan State Extension to be especially helpful. Tony views himself as a user of IWM and his active education suggests that he will progress in the diversification of his weed management system. Yet, his current system is somewhat limited, likely due to limited experience in agriculture.

Jeanie McKewan
Brightflower Nursery
Stockton, IL

Jeanie McKewan (57, Master’s in Plant Pathology) owns and manages Brightflower Nursery located at her home in Stockton, Illinois. Here she raises cut flowers, as well as potted herbs and vegetables. Her farm totals 1.5 open field acres and 6,000 square feet of greenhouse space. Jeanie has managed her entire operation organically since its establishment in 2006, and is 100% certified. She grows organically to take advantage of the niche market, and believes it is a safer system that keeps growers accountable to a standard of practice.

> “I knew that there were strict rules on record keeping, along with the fact that I wanted to learn a safer system…I very much want to learn to how to farm organically, I knew the only way that I could do that was to force my hand and become certified. I also knew that I am so, so small that it would be another added benefit to get my stuff out.”

According to Jeanie the weed community on her farm includes keek (*Rorippa sylvestris*), quackgrass (*Elytrigia repens*), crabgrass (unidentified *Digitaria* species), docks (*Rumex crispus* and *Arctium minus*), thistles (*Cirsium arvense* and *Cirsium vulgare*), wild carrot (*Daucus carota*), and common ragweed (*Ambrosia artemisiifolia* var. *elatior*) that exert medium levels of competitive pressure on her cut flower crops. Jeanie exhibits a cautiously selective attitude toward weeds. She is committed to preventing seed dispersal, and ideally, beds are clean for events and tours she hosts. "But I only have so much labor to devote to weeding. There are certain plants that I know can handle it longer than others. A certain amount of weeds are fine, in my opinion, but not when the plants are young." Jeanie uses a limited suite of practices to manage weeds, focusing on cultural and mechanical controls.

She prefers weed management innovations that are suited for flower crops, have been trialed by others, and contribute to profitability. Her current approach includes eight practices. Buckwheat and rye cover crops suppress weed growth. Primary tillage using a rototiller breaks sod. Planting densities are increased for quick canopy closure. Perennial plants are mulched with cardboard and woodchips. During the main season annual crops are hand weeded or hoed. Uncropped areas are mowed and clipped with a string trimmer. In the future, Jeanie hopes to increase mechanization of weed management on her farm. She rates weed management on her farm as a six out of ten.

Jeanie has accessed a handful of resources for weed management information, including trade organizations (Association of Cut Flower Growers), periodicals (Growing for Market), and conferences. She found the MOSES Organic Farming Conference to be the most helpful because it facilitates interaction with experienced, intelligent, and like-minded growers. Jeanie feels that her approach to weed management is diverse, but was not entirely familiar with IWM concept.

Harold & Ross Wilken
Wilken Family Farms
Danforth, IL

Harold Wilken (51, three years college) and his son Ross are the fifth and sixth generation of their family to farm near Danforth, Illinois. Together, with the help of a couple employees, they raise corn, soybeans, wheat, oats, hay, and barley on 1,400 acres, of which they own 25%. Harold has farmed his entire life, thirty years independently; Ross joined him officially in 2003. Harold began to manage part of his ground organically in 2000 at the suggestion of a landlord, and today certifies 82% with 250 transitional acres. Their crops are marketed directly to organic and conventional livestock operations and through the Midwest Organic Farm Co-op. Harold farms organically because he believes in intergenerational responsibility and protecting environmental health.

> "Number one was to make a place for the next generation to come back to farm; second was health…With the adaptation of spraying as your only weed control method. It has taken away some of the ability of young people on the farm to participate in the farming operation. Because one way that young people got involved in the farming was to do tillage. When you take away weed control by tillage methods you take away the need for children…The kids that have grown up now, other than Ross…Ross and I have a close working relationship…If I walk to the combine, he walks to the wagon."

The weed community on the Wilken's farm includes foxtail (*Setaria faberi* or *Setaria glauca*), common waterhemp (*Amaranthus rudis*), and some Canada thistle (*Cirsium arvense*). Harold exhibits a tolerant and rational attitude toward weeds, with a goal of reducing weed pressure below economic thresholds. "To totally eradicate weeds on our size of acreage would be cost prohibitive." He actively experiments with weed management innovations, currently relying on cultural and mechanical controls.

Crop rotations are the foundation of the Wilken's weed management system. Cover crop and forage phases out-compete weeds and feed the soil. Primary tillage using a moldboard plow buries weed seed and crop residue. Crops are planted at high densities, and intercrops are worked into rotations. During growth, crops are mechanically cultivated. Harold and Ross have tried custom grazing and flaming, but found them ineffective for weed control. In the future they hope to add site specificity and precision data to cultivation, integrating it with the cropping cycle through GPS mapping technology. They rate weed control on their farm variably by crop. "We have certain fields that had very good control, and there are others that didn't. It all about timing. Eight over all on the soybeans. The corn was anywhere from nine to three. With the number of acres we have…You can only cover so much ground in a day." Harold's weed management decision-making is driven by efficacy and applicability to his specific farm context. He strives for 70% control or higher, but weather and rain can prohibit timeliness. They are also reducing their hay acreage to make more time for row crop cultivation.

Harold has accessed a few resources for weed management information, including other growers, the Rodale Institute, and conferences. He finds information from other growers to be the most helpful because they experience outcomes of management first hand. He rates success in weed management by the reactions of neighboring growers, who were originally critical, but noticed improved control last season. "I'm not in the brotherhood any more. I've stepped away from what everybody considers as acceptable…It holds us accountable. When you start to get acceptance from the older generation of farmers, then you know." Harold also enjoys networking at the MOSES Organic Farming Conference. He views himself as a user of IWM and applies economic threholds, but he also believes that cultivation is the most practical approach to weed management in his grain and forage system.

David Woodruff
W & M Land Corp
Woodstock, IL

David Woodruff (56, M.B.A.) owns and manages W & M Land Corp Organic Nursery, headquartered at his home in Woodstock, IL. He and his employee Erika Klemm raise bedding plants (herbs, flowers and other ornamentals), cut flowers and some produce including tomatoes, peppers, ground cherries and garlic. Products are sold through wholesale, local farmer's markets, and a new retail space. David grew up on a small farm, but is in the seventh year with his current one acre operation. David and Erika have managed all of their ground organically for seven years and today certify half of the acreage, the rest in transition. David grows organically because he believes that input intensive agriculture is not economically or environmentally sustainable.

> "I don't like the chemicals. Having grown up with the land grant colleges and the system that they have pushed forward…We questioned this…I'm not sure organic can feed the world; I'm really am not. Our world has got an awful lot of people in it now days. I *do* believe a system that requires monoculture with huge inputs that are artificially created *cannot* be considered sustainable, by definition. We are depleting the resources. It is economically ridiculous."

According to David the weed population on his farm includes purselane (*Portulaca oleracea*) Canadian thistle (*Cirsium arvense*), and various grasses introduced through horse manure. These weeds compete fiercely with his horticultural crops. David exhibits a tolerant attitude toward weeds and attempts to apply estimated economic action thresholds. He is especially careful to minimize the production and dispersal of seed. David uses a suite of practices to manage weeds, including cultural and mechanical controls supported by management records, weed identification, and a bit of biological control.

David and Erika's current approach includes thirteen practices. Fallow greenhouses are solarized to kill weeds and weed seed. Primary tillage using a rototiller breaks-up sod and buries weed seed. Some plots are no-till cultivated to promote nutrient cycling and minimize annual weed germination. Four to six crops are rotated to vary competitive dynamics. Planting densities are increased to promote quick canopy closure. During the main season plots are hand weeded and hoed. In-row weeds are also suppressed with extensive straw mulching. Edges and non-crop areas mowed or clipped with a string trimmer. Some weeds are fed to tortoises kept in the greenhouse, and others are harvested to include in flower arrangements. David rates weed control on his farm as a six out of ten.

David has accessed several resources for weed management information, including other growers, conferences, university, books, and periodicals. David has found conferences and industry periodicals, particularly Growing for Market, to be the most helpful. David views himself as a user of IWM, but believes his organic status largely restricts weed management to reactionary control. "In terms of IPM, Yeah, you scout, you look horrified, and you try to ignore the problem, and eventually you attack it. Remembering that as organic I am not supposed to be acting before I see the problem, which I disagree with." While prophylactic pest controls are not permitted in organic agriculture, management based on prevention is key. This suggests that the importance of prevention should be stressed in organic weed management outreach.

Illustrations of the Forb Philosophy Cluster

Jim and Barb Lindemann
Gardens of Goodness
McFarland, WI

Jim Lindemann (65, PhD Education Administration) and his wife Barb manage an apple orchard in McFarland, Wisconsin. Their diverse orchard grows on transitional ground, which they rent. All together they manage two owned and forty-eight rented / share cropped acres. Jim hopes to market his apples as alcoholic cider in the near future, and has spent the last two years building and obtaining permits for a small processing facility on-site. They have managed their land organically for 21 years and began marketing their crops ten years ago in 2000. Jim and Barb choose organic management out of concern for human health (farmers, employees, customers), and to maximize profits. "a) It's our own health, b) it's nutrition, and c) it's the health of the people who buy our stuff…and I think number four, although it's not all that important is, if we can break even doing it then that justifies [organic]."

According to Jim the weed community on his farm includes bull thistle (*Cirsium vulgare*), burdock (*Arctium minus*), quackgrass (*Elytrigia repens*)**,** Queen Anne's lace (*Daucus carota*), red clover (*Trifolium pratense*), and comfrey (*Cynoglossum virginianum*). Jim highlights the value of wild plants in his orchard, their contributions to pollination and pest management through attraction of beneficial insects. "A traditional definition of a weed is different than our definition…There's a lot of stuff we don't consider the enemy." As a result, Jim's weed management focuses on extensive application of knowledge regarding weed ecology supported by a few cultural and one mechanical control.

The orchard is mowed only periodically, and a strip of growth is left in the tree row to allow for the growth of beneficial species. In this way Jim is working to implement a push-pull system for insect pest management, known as Swiss Sandwich, which uses wild plants as attractants and repellants. He is aware of weed ecology, mows with an economic threshold in mind, and selectively controls noxious species that do not contribute to his management goals. The apple trees are also mulched with aquatic weed tissue harvested from local lakes by the municipality, and acquired at no cost. Textile mulch was tried around trees, but weeds grew through it over time.

Jim has accessed several resources for weed management information, including other growers, university, books, conferences, and the internet. He finds the internet to be the most helpful resource because it allows him to aggregate what he views as unbiased information from several different resources. Jim is driven by improved fruit production *through* wild plants. He considers himself a user of IWM, but rejects the narrow-mindedness created by classifying farm systems. "You have the so-called conventional, and then you can have IPM…then you can have organic…I don't think to create little boxes is really productive. The issue is how to get these [IWM] concepts out."

Illustrations of the Integrated Management Cluster

Henry Brockman
Henry's Farm
Congerville, IL

Henry Brockman (45, B.A.) owns and manages Henry's Farm, located at his home in Congerville, Illinois. Here he grows over one hundred different vegetable crops sold through a 220 member CSA and the Evanston, IL farmer's market. Henry has spent his life around organic agriculture and is in his eighteenth season as a principal operator. His cultivated ground consists of several hoop houses, 20 bottom land and four upland acres, half of which are fallowed in a two year rotation. The current fallow is in alfalfa, clover and orchard grass. Henry has managed all of his ground organically from the beginning and was certified prior to the implementation of USDA standards in 2000. However, he no longer certifies the farm because he did not notice any change in customer feedback after the initial discontinuation of certification, and believes that his management standards go beyond USDA organic. Henry grows organically because he was raised to value environmental protection and self sufficiency through local sustainable agriculture.

> "For me it's the way I was brought up…We raised pretty much all our own produce, you know eggs, meat, everything. And we did all that organically…I didn't know any other way to raise food actually…I consider myself an environmentalist too. That's part of it. The only way to protect the environment is to raise food organically."

According to Henry the main weed population on his farm is foxtail (*Setaria faberi* or *Setaria glauca*) which exerts intense competitive pressure. However, he exhibits a tolerant and relaxed attitude toward weeds, focusing on specific crop-weed competitive relationships and the precise timing of control.

> "With lettuce, for example. I do almost all my lettuce, except for the first planting, from seed rather than transplants. We have to thin it anyway…So we hoe it and thin it at the same time, and usually that's all we ever have to do. That's all the weeding that's done. There will be some amaranth. But usually by the time they are getting big enough that they are going to shade the lettuce, I've

> already harvested the lettuce, or I'm ready to harvest the lettuce…and I can get in and till those in before those go to seed. Over the years I've learned when certain crops have to be weeded."

Henry also views weeds as contributions to biodiversity on the farm and indicators of soil suitable for the production of vegetables, to which many weed species are related. Henry employs a diverse suite of practices to manage weeds, building on specialized cultural and mechanical controls with information management, and a strong focus on experienced-based economic thresholds.

Henry uses twenty-four practices to manage weeds. He knows his problem weed species, understands when each crop must be weeded, and keeps records of his management behavior. His fallow strategy rotates cropped fields, incorporating cover crops and green manure. The cover crops out compete weeds and are mowed or grazed for additional control. He is experimenting with different mowing regimes to improve foxtail (*Setaria faberi* or *Setaria glauca*) suppression. In the cropped field primary tillage is followed by shallow cultivation in the false seed bed method. Competitive varieties are transplanted and sown late at high densities. Main season control is selectively applied using a wide array of tractor driven cultivation implements, hoes, and hand weeding. Late season control is maintained through the application of straw mulch. Some weed species, such as redroot pigweed (*Amaranthus retroflexus*), are harvested and consumed. Henry rates weed control on his farm as a seven out of ten.

Henry has accessed several resources for weed management information, including other growers, conferences, university, dealers, books, and periodicals. He finds personal experience to be most important in weed management because each individual farm system is unique in motivation and practice. Henry was only initially familiar with IPM not IWM, but after definition views himself as a user of IWM, from the perspective of applying economic control thresholds.

David Massey
Northwoods Organic Produce
Pequot Lakes, MN

David Massey (70, three years college) owns and manages Northwoods Organic Produce located in Pequot Lakes, Minnesota. He and five interns raise 250 varieties of fruits and vegetables marketed through local restaurants, food stores & co-ops, and u-pick. David began gardening in his twenties, and has farmed professionally since retiring from the chemical industry in 1998. Production is concentrated on eight certified organic acres. David is driven by goals for environmental health and intergenerational responsibility. “You want to leave a place better than what you found it.” He views his interns as students, and the farm as an alternative to modern ills.

According to David the most problematic weed species on his farm is Canadian thistle (*Cirsium arvense*). David exhibits an extremely tolerant attitude toward weeds, accepting them as a necessary part of life and source of nutrients for the following crop. However, his intensive management activity appears to effectively minimize weed germination and growth. He has developed a unique system for weed management focusing on extensive mulching supported by other cultural and mechanical controls.

His current approach includes 23 practices. Habitat is conserved for beneficial species. Field borders are mowed. Crop rotations, including cover crops and intercropping, vary competition dynamics. Primary tillage using a rototiller or disc breaks-up the soil, kills weeds, and incorporates aged compost. Polypropylene weed barrier is laid over much of the tilled soil, and high density plantings of crops such as onions, strawberries, and tomatoes are made through it. Transplant holes are covered with newspaper, woodchips, or other materials. Water and fertilizer are applied through drip irrigation to favor crop growth. Stray weeds are hand-pulled or cultivated in unmulched plantings. Some species are harvest and marketed. David rates weed control on his farm by his success in limiting the production of new weed seed. A clean field is not his goal and he declined to rate weed control in terms of field cleanliness.

> "Well I'm not out to eradicate weeds. I'm kind of in a management mode. I'm trying to keep it down so they don't produce so much seed. Because the seed is what causes the problem in subsequent years. [But] clean fields aren't exactly where it's at either, because cultivation destroys carbon."

David has accessed several resources for weed management information including conferences, dealers, books, trade organizations, and periodicals. He has found ACRES USA and the book Weeds and Why They Grow by Jay L. McCaman (1994) to be the most helpful because they provide access to alternative views in weed management from what David calls "academics on the fringe". David was not aware of the IWM concept, but suggested that diversity and innovation are goals for weed management on the farm.

> "Oh yeah. I do lots of those things. I mean you almost have to if you're organic…The big thing is you're moving your food products around every year. Crop rotation. So you got rotations and we've already talked about a number of strategies using weeds, using tillage, or using the weed block or using cover crops,

which give you an alleloopathic effect like rye. I've got cover crops I haven't put in yet this year. I've interplanted some years. I've interplanted between rows."

CONCLUSION

The case studies presented above largely support the model of organic weed management behavior generated by our survey. What a grower chooses to produce can impact weed management philosophy through clear restrictions on weed management behavior. Managers of perennial agricultural systems tend to develop an alternative philosophy of weed management highlighting the values of ruderal vegetation. Growers with less experience in agriculture, accessing fewer information resources tend to manage weeds with a less diverse suite of innovations focused on mechanical controls supported by cultural management. A greater diversity of weed management innovations, including information-intensive practices like prevention and the application of economic action thresholds, are adopted by more educated and experienced growers who actively seek out new weed management information resources.

However, all of the growers interviewed for this study managed weeds with diverse non-chemical approaches that allowed them to harvest a crop and maintain their commercial enterprises. No grower expressed feeling that weeds were an insurmountable obstacle. Those with relatively limited suites of adopted innovations, placing them in the CCC, should not be considered poor managers. On a traditional conventional-IPM-organic spectrum their weed management systems would be considered beyond IWM. Also, all CCC growers interviewed were actively seeking information (even if sources were few) and diversifying their systems with additional experience. As stated above, the way our interview sample was generated, and subsequent above-average education level of our interview participants, likely skewed our data to overestimate the potential for all growers to adopt information-intensive weed management practices.

LITERATURE CITED

Cabrera, N. L., & Leckie, J. O. (2009). Pesticide risk communication, risk perception, and self-protective behaviors among farmworkers in california's salinas valley. *Hispanic Journal of Behavioral Sciences, 31*(2), 258-272.

Davis, A., Renner, K. A., Sprague, C., Dryer, L., & Mutch, D. (2005). Integrated weed management: One year's seeding.

Kaine, G., & Bewsell, D. (2008). Adoption of integrated pest management by apple growers: The role of context. *International Journal of Pest Management, 54*(3), 255-265.

Llewellyn, R. S., Lindner, R. K., Pannell, D. J., & Powles, S. B. (2004). Grain grower perceptions and use of integrated weed management. *Australian Journal of Experimental Agriculture, 44*(10), 993-1001.

McCaman, J. L. (1994). *Weeds and why they grow*

McCann, E., Sullivan, S., Erickson, D., & DeYoung, R. (1997). Environmental awareness, economic orientation, and farming practices: A comparison of organic and conventional farmers. *Environmental Management, 21*(5), 747-758.

Pennings, J. M. E., Irwin, S. H., & Good, D. L. (2002). Surveying farmers: A case study. *Review of Agricultural Economics, 24*(1), pp. 266-277.

Sattler, C., & Nagel, U. J. (2010). Factors affecting farmers' acceptance of conservation measures-A case study from north-eastern germany. *Land use Policy , 27*(1) 70-77.

Taylor, D. C., Dobbs, T. L., & Smolik, J. D. (1992). Beliefs and practices of sustainable farmers in south-dakota. *Journal of Production Agriculture, 5*(4), 545-550.

van der Meulen, A. W., Reeve, I. J., & Sindel, B. M. (2007). Weed management on grazing properties: A survey of livestock producers in new south wales and victoria. *Australian Journal of Experimental Agriculture, 47*(12), 1415-1421.

Walz, E. (1999). *Third biennial national organic farmer’s survey.* . Santa Cruz, California: Organic Farming Research Foundation.

Yoo, J. J., & Zhao, X. (2010). Revisiting determinants of convention participation decision making. *Journal of Travel & Tourism Marketing, 27*(2), 179-192.

APPENDIX A:

MIDWEST U.S. ORGANIC WEED MANAGEMENT SURVEY

UNIVERSITY OF ILLINOIS
AT URBANA-CHAMPAIGN

Department of Crop Sciences
AW-101 Turner Hall
1102 South Goodwin Avenue
Urbana, IL 61801-4798

Dear Organic Grower,

You are invited to participate in a research study on weed management in organically-grown crops. This study is conducted by me, a Masters of Science student, and John Masiunas, Associate Professor, in the Crop Sciences Department at the University of Illinois, Urbana-Champaign. The objective of this research project is to determine what drives organic farmers to adopt particular weed management practices and reject others. You have been randomly selected from a publicly available list of organic crop producers provided by accredited certifiers to the United States Department of Agriculture (U.S.D.A.). Your participation is needed to ensure that future weed management research and outreach can be designed to serve the unique needs of organic growers.

Enclosed with this letter is a brief questionnaire about factors related to your use of weed management practices. Please look over the questionnaire and, if you decide to do so, answer the questions and return it to me in the enclosed postage-paid envelope. Completing the survey should take no more than fifteen minutes of your time and is voluntary, anonymous, and not expected to have any risks beyond those in everyday life. You may skip any questions you do not wish to answer. Your decision to participate, decline, or withdraw from participation will have no effect on your current status or future relations with me, John Masiunas, or the University of Illinois

Your participation in this research will be completely confidential. No information will be requested in the survey that could lead to your personal identification. The data we collect will be averaged and reported in aggregate. Possible outlets of dissemination may include my student thesis, grower publications, peer reviewed journals, and presentations on the research.

Also enclosed is my gift to you of one dollar. The dollar is yours to keep whether or not you decide to participate. However, **I hope you will take a few minutes before February 15th, 2011 to complete and return the questionnaire.**

If you have questions about this project, please contact me at (920) 428-9357 or dedecke2@illinois.edu. You may also contact John Masiunas at (217) 244-4469 or masiunas@illinois.edu. If you have any questions about your rights as a research participant in the study, please contact the University of Illinois Institutional Review Board at 217-333-3670 (collect calls accepted if you identify yourself as a research participant) or via email at irb@illinois.edu.

Sincerely,

James DeDecker, B.S.
Masters Student
Department of Crop Sciences
University of Illinois, Urbana-Champaign

telephone 217-333-3420 • *fax* 217-333-9817
email cropsci@illinois.edu • *url* http://www.cropsci.illinois.edu/

Midwest U.S. Organic Weed Management Survey

Department of Crop Sciences
College of Agricultural, Consumer, and Environmental Sciences
University of Illinois at Urbana-Champaign

To begin we would like to gather some basic information about your farm. Please fill in the blanks or check the box in front of the answer that best describes your operation.

1. Do you manage any portion of your farm organically, regardless of certification status?

   - ☐ If **yes**, proceed to question two
   - ☐ If **no**, please stop the survey and return in enclosed postage-paid envelope.

2. How many years has at least part of your farm been managed organically?

   ____

3. How many tillable acres do you currently farm (both owned and rented)?

   ____

4. Of the total acres you currently farm, what percentage do you own, including those you are in the process of buying?

   - ☐ 0%-24%
   - ☐ 25%-49%
   - ☐ 50%-74%
   - ☐ 75%-100%

5. Of the total acres you currently farm, what percentage is **certified organic** by the guidelines of the USDA's National Organic Standards?

- ☐ 0%-24%
- ☐ 25%-49%
- ☐ 50%-74%
- ☐ 75%-100%

6. Please list up to five of the most profitable organic crops you produce and the **approximate** amounts you harvested last year (2010).

Organic Crop	**Amount Harvested**

In section two we are interested in learning about weed management on your farm. Please fill in the blanks or check the box in front of the answer that best describes your methods.

7. What methods of weed management did you use in your organic crops last season (2010)? (please check all that apply)

Soil Preparation	Planting	Prevention	Thresholds
□ Stale Seed Bed	□ Competitive Varieties	□ Clean Ag. Products	□ Economic Threshold
□ False Seed Bed	□ Increased Seed Size	□ Clean Equipment	□ Weed-Free Threshold
□ Steaming	□ Delayed Planting	□ Clean Field Edges	
□ Biofumigants	□ Increased Planting Density	□ Combine Chaff Screening	
	□ Row spacing	□ Irrigation Water Screening	
		□ Manure Composting	

Mechanical Controls	Biological Controls	Cultural Controls	Rotations
□ Primary Tillage	□ Grazing	□ Crop Rotations **[If Yes]** →	□ 2 Crops
□ Pre Harrowing	□ Weed Damaging Insects	□ Relay Cropping	□ 2-4 Crops
□ Rotary Hoeing	□ Weed Predators/Pathogens	□ Cover Crops	□ 4-6 Crops
□ Rotary Tillage	□ Weed Seed Predators	□ Green Manure	□ 6-8 Crops
□ Post Harrowing	□ Habitat for Beneficials	□ Intercropping	□ 9 + Crops
□ Between-row Cultivation	□ Conservation Biocontrol	□ Mulching	
□ In-row Cultivation	□ Eating/Find a Use	□ Banded Fertilizer	
□ High Residue Cultivation		□ Sidedress Fertilizer	
□ Reduced Tillage		□ Fallow	
□ No Till		□ Water Management	
□ Mowing		□ Solarization	
□ Hand Weeding			
□ Flame Weeding			
□ Hot Water/Steam/Oil			
□ Crushing/Rolling			

Chemical Controls	Info. Management	Other (please specify)
□ Pre-emergent Organic Herbicides	□ Scouting	
□ Post-emergent Organic Herbicides	□ Weed I.D.	
□ Fumigation	□ Mapping	
□ Acetic Acid	□ Past Management Records	
□ Essential Oils		
□ Corn Gluten Meal		

8. How would you rate overall weed control in your organic fields at last harvest?

- ☐ Excellent control (trace or no live weeds)
- ☐ Good control (few weeds remain alive)
- ☐ Fair control (several weeds remain alive)
- ☐ Poor control (most weeds remain alive)

9. Please list up to three of the most problematic weed species present on your farm.

1) ___________________________________
2) ___________________________________
3) ___________________________________

10. What resources do you use to obtain information on weed management? (please check all that apply)

- ☐ Other Farmers
- ☐ Natural Resource Conservation Service
- ☐ University Extension and/or Researchers
- ☐ Non-university Consultants
- ☐ Weed management equipment or chemical Dealers
- ☐ Books
- ☐ Trade Organizations (e.g. Organic Trade Association)
- ☐ Periodicals and/or Newsletters
- ☐ Field days, Workshops, Conferences
- ☐ Internet sites
- ☐ Radio or TV
- ☐ Other (please specify):____________________________________

11. Of the information resources you checked above, which has proven to be the most helpful? Also, please name the specific source or sources.

____
____

12. In a few words, please describe your attitude toward weeds on the farm.

____

____

13. Please rate the importance of each of the following considerations when deciding what weed management methods to use.

	Very Important	**Somewhat Important**	**Not Important**
Ease of Use			
Health and Safety			
Effective Weed Management			
Available Equipment			
Religious / Spiritual Considerations			
Financial Cost			
Environmental Protection			
Information Availability			

14. On the table in question 13, please **circle** the consideration that is **most important** when deciding what weed management methods to use. Please **cross-out** the consideration that is **least important.**

Finally, we want to gather some information about you personally to find correlations between weed management choices and personal characteristics. Please fill in the blanks or check the box in front of the answer that best describes you.

15. What year were you born?

    ____

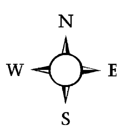
16. What is your gender?

    ☐ Female
    ☐ Male

17. What is the highest level of education you have completed?

    ☐ Middle school
    ☐ High school diploma or equivalent
    ☐ Some college
    ☐ College degree
    ☐ Graduate or professional degree

18. In what state and region do you farm? (please circle region on compass and write state name)



____

19. How many years have you been farming?

    ____

20. How many years have you farmed **organically**?

    ____

21. What percentage of your household income is generated **off-farm**?

- ☐ 0%-24%
- ☐ 25%-49%
- ☐ 50%-74%
- ☐ 75%-100%

22. Which category best represents your annual gross total farm sales last year?

- ☐ less than $25,000
- ☐ $25,000 to $49,999
- ☐ $50,000 to $99,999
- ☐ $100,000 or more

Please use this space to provide us with any information that you want to share, or that you feel will be important for understanding weed management on your farm.

____

____

____

____

____

____

____

____

____

Thank you!

Your completed survey can be submitted by mail using the enclosed postage-paid envelope.

[If you have questions about this project, please contact James DeDecker at (920) 428-9357 or dedecke2@illinois.edu. You may also contact John Masiunas at (217) 244-4469 or masiunas@illinois.edu. If you have any questions about your rights as a research participant in this study, please contact the University of Illinois Institutional Review Board at 217-333-3670 (collect calls accepted if you identify yourself as a research participant) or via email at irb@illinois.edu.]

APPENDIX B: FARMER INTERVIEW PROTOCOL

Factors Influencing Selection of Weed Management Practices Among Organic Growers in the Midwest United States

Interview Protocol

Personal Characteristics

- What is your age?

  ____

- What is the highest level of education you have completed?

  ____

  - How long have you or your family lived in this area?

    ____

  - Do you live on the farm property?

    ____

- How many years have you been farming?

  ____

  - How many years have you or your family farmed the land you currently farm?

    ____

- What percentage of your household income is generated off farm?

  ____

Farm Structure

- How many tillable acres do you farm (both owned and rented)?

  ____

- Of the total acres you farm, what percentage do you own?

  ____

- How many years has at least part of your farm been managed organically?

  ____

  - Of the total acres you farm, what percentage is certified organic by the guidelines of the USDA's National Organic Standards?

    ____

- Why do you farm organically?

  ____

  ____

  ____

- Who works on the farm? (Where does labor come from?)

  ____

  ____

- What organic crops do you produce?

  ____

  ____

  ____

- How do you market your organic crops?

  ____

  ____

Weed Management Methods

- Describe the weed pressure and problem weed species on your farm?

  ____

  ____

  ____

- How would you describe your attitude toward weeds on the farm?

____

____

____

    - Why do you think you feel this way?

    ____

    ____

    ____

- Do you consider yourself a user of integrated weed management?

____

____

- How would you describe your weed management goals and/or strategy?

____

____

____

- What methods of weed management did you use last season?

____

____

____

    - Which methods do you consider most effective?

    ____

    ____

    - Which methods do you consider least effective?

    ____

    ____

    ____

    - Are you planning to do anything differently this season?

    ____

    ____

    ____

- On a scale from 1-10, 1 representing no control and 10 representing a completely clean field, how would you rate overall weed control in your organic fields at last harvest?

  ____

  - Do you consider last year’s weed management a success?

    ____

    ____

Social Context of Weed Management Decision Making

- What resources do you use to obtain information on weed management? (e.g. other farmers, NRCS, University extension and/or researchers, non-university consultants, weed management equipment or chemical dealers, books, trade organizations, periodicals and/or newsletters, field days, workshops, conferences, internet sites, radio, TV)

  ____

  ____

  - Which information source has proven to be the most helpful?

    ____

    ____

  - Why do you trust that information source?

    ____

    ____

    ____

- When you are deciding what weed management methods to use, what do you take into consideration? (e.g. effective weed management, financial profitability, health and safety, environmental protection, ease of use, etc.)

  ____

  ____

  ____

- If you had to choose, what would you say is the most important consideration?

  ____

  ____

- How have other people (e.g. family, friends, neighbors, landlords, other farmers, extension agents, industry professionals) responded to your weed management practices and/or the level of weed control on your farm?

  ____
  ____
  ____

  - Why do you think group X has responded in this way?

    ____
    ____
    ____

  - Do the responses you receive or anticipate from others affect your weed management decisions?

    ____
    ____
    ____

APPENDIX C: WEED MANAGEMENT PRACTICE TABLE

Weed management practices[a]	Overall	Cluster[b] A (classic control)	Cluster[b] B (forb philosophy)	Cluster[b] C (integrated)
	Producer adoption rate (%)			
I. *Planting management*				
biofumigation	0.5	0.8	0.0	0.0
competitive varieties	27.6	22.3	30.4	36.2
delayed planting	65.2	65.4	4.3	84.1
false seedbed	6.8	7.7	0.0	7.2
increased planting density	50.2	46.9	17.4	66.7
increased seed size	3.6	4.6	0.0	2.9
adjusted row spacing	36.7	32.3	0.0	56.5
stale seedbed	22.6	19.2	4.3	34.8
steaming	0.0	0.0	0.0	0.0

Table C.1. Adoption of weed management practices by management clusters and overall

II. *Prevention*				
clean agricultural products	29.0	19.2	4.3	55.1
clean equipment	43.0	33.8	21.7	68.1
clean field margins	30.3	23.1	8.7	50.7
combine chaff screening	6.3	1.5	0.0	17.4
irrigation water screening	1.8	1.5	0.0	2.9
manure composting	25.8	18.5	26.1	39.1
III. *Thresholds*				
economic threshold	29.4	22.3	17.4	46.4
weed-free threshold	10.4	8.5	0.0	18.8
IV. *Mechanical controls*				
between row cultivation	77.8	86.9	0.0	85.5
crushing or rolling	2.3	2.3	0.0	2.9
flaming	17.6	18.5	8.7	18.8

Table C.1. (cont.) Adoption of weed management practices by management clusters and overall

hand weeding	57.0	52.3	39.1	71.0
high-residue cultivation	7.2	6.9	0.0	10.1
hot water	0.5	0.0	4.3	0.0
in-row cultivation	19.0	13.8	0.0	34.8
mowing	52.0	43.8	82.6	56.5
no-till	2.3	0.0	13.0	2.9
post-emergent harrowing	24.9	26.9	0.0	29.0
pre-emergent harrowing	46.2	54.6	0.0	44.9
primary tillage	76.5	79.2	4.3	94.2
reduced tillage	5.4	3.8	4.3	8.7
rotary hoeing	47.1	45.4	4.3	63.8
rotary tillage	13.6	10.0	8.7	21.7
V. *Biological controls*				
conservation bio-control	7.2	3.1	13.0	13.0
eat or use	5.0	3.1	8.7	7.2

Table C.1. (cont.) Adoption of weed management practices by management clusters and overall

grazing	46.2	44.6	69.6	40.6
habitat for beneficial organisms	19.9	7.7	26.1	40.6
herbivorous insects	2.7	1.5	0.0	5.8
other herbivores	1.4	0.8	4.3	1.4
weed seed predators	2.7	0.8	0.0	7.2
VI. *Cultural controls*				
banded fertilizer	7.2	3.8	0.0	15.9
cover cropping	65.6	66.2	17.4	79.7
crop rotation	85.5	91.5	17.4	97.1
fallow	16.7	9.2	13.0	31.9
green manure	63.3	59.2	0.0	91.3
intercropping	11.8	7.7	0.0	23.2
relay cropping	2.7	2.3	0.0	4.3
side-dress fertilizer	10.9	9.2	4.3	15.9

Table C.1. (cont.) Adoption of weed management practices by management clusters and overall

solarization	1.8	0.0	0.0	5.8
water management	7.7	0.0	8.7	21.7
VII. *Chemical controls*				
acetic acid	2.3	0.0	8.7	4.3
corn gluten	0.5	0.0	0.0	1.4
essential oils	0.5	0.0	4.3	0.0
fumigation	0.0	0.0	0.0	0.0
post-emergent herbicide	1.8	0.0	8.7	2.9
pre-emergent herbicide	0.9	0.0	0.0	2.9
VIII. *Information management*				
mapping	7.2	2.3	13.0	14.5
past management records	24.9	16.9	17.4	42.0
scouting	57.0	43.8	47.8	84.1

Table C.1. (cont.) Adoption of weed management practices by management clusters and overall

weed id	33.0	16.2	39.1	62.3

[a] Weed management practices are grouped within major categories of management approach.

[b] Management clusters were determined via hierarchical cluster analysis.

Table C.1. (cont.) Adoption of weed management practices by management clusters and overall