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SPATIAL RELATIONS OF WEED MANAGEMENT PRACTICES AND AGROECOLOGICALLY DOMINANT WEED SPECIES WITH ORGANIC DAIRY FARMS IN SOUTHWESTERN WISCONSIN

A Thesis in

Geography

by

Anna M. Shamey

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The thesis of Anna M. Shamey was reviewed and approved* by the following:

Karl Zimmerer
Professor of Geography
Head of Department of Geography
Thesis Advisor

Douglas Miller
Associate Professor of Geography

Brent Yarnal
Professor of Geography
Associate Head of Department of Geography

* Signatures are on file in the Graduate School

Abstract

Conservation of biodiversity in organic agriculture has spurred much debate over the role of organic systems in the environment. However, little is known about the relationship between the variations in weed management practices and the biodiversity of weedy species in organic agriculture. Specifically, how does the spatial distribution and diversity of weedy species vary in relation to diversity in weed management practices? Species identification, vegetative samples, and farmer interviews took place on 20 farms in southwestern Wisconsin to explore how the landscape structures spatial variation in weedy species and how weed management practices respond accordingly. Southwestern Wisconsin, known as the driftless region, is an area of unglaciated hilly terrain with a high density of organic farms. Because of the area's topography and landscaped diversity I hypothesize that weedy species would be spatially distributed according to environmental characteristics (e.g. soil type and moisture), as well as land uses (e.g. pasture vs. crop fields). This study finds weed species distribution to be independent of environmental variables, but significantly correlated with field type (pasture vs. corn). This difference may be inherent to the ecology of each field, but more significantly indicates the importance of management. Further research on current weed management techniques and distribution of weedy species on organic farms will enable researchers, extension agents, certifiers, and others to better facilitate the transition to organic agriculture. Successful transitions are paramount in light of continued growth of the organic sector in the U.S. and would not only help farmers produce higher yields (and therefore be economically viable), but also uphold the environmental and social-ecological goals of the organic movement.

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Chapter 1

INTRODUCTION

1.1 Introduction

This chapter covers contextual information for this project starting with an overview of organic agriculture in the U.S. (Section 1.1.2). Section 1.1.3 briefly explores the term 'weed,' which is revisited in section 3.3.2. Section 1.1.4 discusses weed management in agricultural systems and specifically in organic agriculture. Section 1.2 places this project in the larger scope of human-environment geography. Section 1.3 discusses the research goals, justifications, and hypotheses for this project and section 1.3.1 briefly talks about a related project led by Dr. Karl Zimmerer.

1.1.2 Organic Agriculture

The organic agricultural movement emerged from the 1970's environmental movement, picking up momentum through the 80's and 90's with increases in research funding, publications, and establishment of international programs (Watson 2007). In 1972 the International Federation of Organic Agricultural Movements (IFOAM) was established and the journals *Biological Agriculture and Horticulture* and *American Journal of Alternative Agriculture* (now *Renewable Agriculture and Food Systems*) were established in 1982 and 1986, respectively (Watson 2007, IFOAM 2009). In 2002 the USDA National Organic Standards were passed, creating the rules and regulations upon which all organic producers in the U.S. are certified against and held to. The standards define organic production as "A production system that is managed in accordance with the Act and regulations in this part to respond to site-specific conditions by integrating cultural, biological, and mechanical practices that foster cycling of resources, promote ecological balance, and conserve biodiversity" (Title 2009). Likewise, Organic Valley, one of the nation's largest and most recognized organic cooperatives, defines organic as "…a philosophy and system of production that mirrors the natural laws of living organisms with emphasis on the interdependence of all life" (Organic Valley 2009). Organic Valley goes on to say that this definition "…reflects our deep convictions in our role as stewards of the earth….Organic Valley farmers care for the health of the land, the animals, and people who eat their food" (Organic Valley 2009).

Organic agriculture is often touted as being an environmentally sustainable alternative that conserves the natural resources that we depend upon (Nardone et al. 2004, Pimentel et al. 2005). In support of this, many research studies have shown that organic methods of production enhance environmental characteristics, such as soil and water quality (Birkholfer et al. 2008, Bulluck III et al. 2002, Poudel et al. 2002, Oquist et al. 2007). Economically, farmers enjoy the benefit of price premiums for their products once they are certified, often resulting in higher returns than conventional producers (Bulluck III et al. 2002, Pimentel et al. 2005). It is no surprise then that economic rationales (Turner et al. 2007, Bulluck III et al. 2002) and ethical or environmental concerns (Turner et al. 2007, Morgan & Murdoch 2000, Bulluck III et al. 2002) are the top reasons for farmers to switch to organic agriculture. The transition process to organic agriculture is a 1- to 3-year process in which farmers change their management practices to be in accordance with the National Organic Standards. During this time, specified external inputs can no longer be used and the product will not be certified as organic until a minimum period of time has passed (36 months for cropland and 12 months for livestock) (MOSES 2009).

Today, organic farming has become the fastest growing sector in U.S. agriculture, with food and beverage sales growing from $1 billion in 1990 to $24.8 billion in 2009 (OTA 2010). Organic food sales (fruits and vegetables) also account for 11.4% of all U.S. fruit and vegetable sales (OTA 2010). Land under certified organic production has also increased dramatically over the last decade. In 1995 there were less than 1 million acres in certified organic production in the U.S, and by 2008 there were almost 5 million acres in certified organic production (USDA-ERS 2010). The USDA also conducted its first-ever organic production survey in conjunction with the latest agricultural census (2007). The census has been conducted every 5 years since 1992 and every ten years starting in 1840 (USDA-NASS 2010a). In the survey, 44% of the respondents indicated plans to maintain current levels of organic production over the next five years, while 35% indicated plans to increase organic production (USDA-NASS 2010b). With a continued high rate of growth, issues concerning organic systems are extremely important.

1.1.3 Weeds

Weeds are a frequently cited obstacle to the adoption of organic agriculture (Cavigelli et al. 2008, Barberi 2002, Padel 2001, Bond & Grundy 2001, Turner et al. 2007, Pimentel et al. 2005). Before I go further, however, it is necessary to examine our use of the term ‘weed.’ Language as a social structure is extremely important in this project because it allows the expression and thinking of some things and not others.

Language is highly problematic in this way because it shapes what we see as problems, and how we think of addressing those problems.

Weeds or weedy species are terms and categorizations applied to various species in various areas for various reasons. Currently, there is no standard vocabulary in ecology. The dispute over standardized terminology has been ongoing since the mid-1800's when English botanist Hewett Cottrell Watson first brought up the issue of standardized terminology for describing plant species with differing geographic histories (Davis 2009). Watson suggested five terms for species in a British context: native, denizen, colonist, incognita, and hibernian (Davis 2009). Unfortunately, the number of terms has only expanded since then. In a non-extensive search, Colautti and MacIsaac (2004) identified 32 terms used in invasion ecology literature, many being used interchangeably or inconsistently. The lack of standardized terminology in the field has large implications for miscommunication between researchers, land managers, and policy makers; however, some researchers have also argued that standardized terminology can limit the flexibility and development of a field (Davis 2009). A complete discussion of terminology within invasion ecology is far beyond the scope of this paper, but Colautti and MacIsaac (2004) have brought up three important points concerning the terminology that relies on human-environment interaction:

1) Definitions can vary dramatically, describing different aspects of a species

2) Species may be considered a nuisance (or weed, invasive, etc.) in areas where they have little or no impact simply because they have been classified as such somewhere else. In this case, the terminology has been used as a taxonomic description rather than to describe an ecological phenomenon.

3) A particular species can have both beneficial and detrimental effects. Because of the wide range of subjective criteria used to classify species with various terms, words like 'weed' may have more to do with human perception than with any inherent ecological characteristics (Colautti and MacIsaac 2004). Likewise, an individual's understanding or usage of these terms greatly affects their perception of how problematic a species is and how they make management decisions regarding that species.

A call for re-defining how we think of and perceive weeds is currently taking place in some European countries. The redefining of weedy species to 'accompanying herb' (Beikraut) as adopted by organic practitioners in Germany (Rist 2009), re-shapes not only our language structure and how we think of 'weeds,' but also organic agricultural structures regarding management practices. This simultaneous re-structuring of language and management may make new policies surrounding weeds more successful because the language and concepts surrounding weeds has been broadened, allowing for new and more creative ways of addressing weed management.

1.1.4 Weed Management

Current weed management in conventional agriculture relies heavily on herbicides, with over 95% of the U.S. Corn Belt treated with herbicides each year (Chee-Sanford & Williams II 2004, Pimentel et al. 2005). Reliance on herbicides is largely due to them being both cheap and effective (Mortensen et al. 2000). However, with this reliance comes a lack of both knowledge and experience with other forms of weed management. Since the USDA National Organic Standards prohibits the use of herbicides for weed management, there has been increased attention on research exploring alternative management strategies (Barberi 2002, Bond & Grundy 2001, Mortensen et al. 2000, Gallandt 2006, Hatcher & Melander 2003).

Options for weed management in organic agriculture are quite large, as the National Organic Standards specifically states what cannot be performed regarding weed management, but is rather open ended as to what can be performed for weed management. Some suggestions from the National Organic Standards include mowing, livestock grazing, flame-heat, and mulching (Title 2009). Researchers have also explored a variety of management practices which they lump into two categories, curative and cultural-ecological methods (Bastiaans et al. 2008, Turner et al. 2007).

Curative control tends to target weed seedlings and focus on that specific stage of the plant life cycle, whether through biological or mechanical means (Hatcher & Melander 2003, Turner et al. 2007). Cultural or ecological measures, on the other hand, are oriented towards long-term management of weed populations, implying that any stage in the plant's life cycle may be targeted (Gallandt 1996, Mortensen et al. 2000, Turner et al. 2007).

Curative control methods take direct action on a plant, to either kill or remove it from an area (Hatcher & Melander 2003). A biological curative control method is the use of bioherbicides; unfortunately they are not reliable in terms of their efficacy (Hallett 2005). Mechanical curative control methods are the classical weeding technologies, such as hand weeding and anything else that stirs up the soil to uproot weeds, as well as more recent methods such as flaming (Barberi 2002, Hatcher & Melander 2003). The down side of these methods is their disturbance of the soil structure and the possibility of moving seeds in the seedbank closer to the surface (Barberi 2002).

Cultural or ecological methods are "…any adjustment or modification to the general management of the crop or cropping systems that contributes to the regulation of weed populations and reduces the negative impact of weeds on crop production" (Bastiaans et al. 2008, pg 482). These approaches can be categorized into three groups, each of which targets a different stage of the plant's life cycle (Bastiaans et al. 2008). The first approach is to reduce recruitment of weed seedlings from the seedbank. An example of this is taking away seed stimuli, such as light, so the weed seeds will not germinate. This is done by laying down black plastic or cultivating at night (Bastiaans et al. 2008). Mulching and cover crops also provide a physical barrier for weed seedlings to contend with (Mirsky et al. 2010, Mortensen et al. 2000). The second approach is to alter the weed:crop competitive relations in favor of the crop. Examples of this are transplanting, selective fertilizing, and breeding superior varieties (Barberi 2002). Transplanting involves taking small crop plants from a greenhouse and planting them in the field, giving the crop a size advantage. Selective fertilizing gives crops a spatial advantage by only fertilizing the crops along their rows (Mortensen et al. 2000). The last approach is to gradually reduce the weed seedbank; this can be done by encouraging predation of the weed seeds. Delaying tillage after harvesting a crop or employing a no-till system exposes seeds to predators for a longer time. Predation can also be encouraged by creating favorable shelter and additional food sources (Gallandt 2006).

These approaches have resulted in a wide variety of weed management practices (Bastiaans et al. 2008, Barberi 2002). Unfortunately, none by itself is completely effective, and there is always the risk that a weed will adapt to a particular management practice (Bastiaans et al. 2008). For these reasons, it is encouraged that farmers employ more complex methods of weed management via a combination of cultural and curative control measures (Mortensen et al. 2000, Cavigelli et al. 2008, Bond & Grundy 2001). This is also referred to as Integrated Weed Management (IWM) (Swanton & Weise 1991). Others have also advocated employing complex weed management methods that "…optimize the whole cropping system rather than weed control per se" (Barberi 2002).

Employment of an integrated weed management system is where whole farm management can be seen as influencing weed flora diversity and abundance. While curative control methods directly affect weeds, cultural management can not only reduce weeds, but also benefit other aspects of a farm, such as soil and water quality (Birkholfer et al. 2008, Bulluck III et al. 2002, Poudel et al. 2002, Oquist et al. 2007). Some methods may even benefit both crops and weeds, such as soil amendments of minerals and manure. Here, quantity is key, as the goal is to provide enough of an amendment to support the crop, but not an excess amount that weeds will also be able to put to use (Pysek & Leps 1991). Temporally, land-use histories can affect future weed species diversity and abundance via weed seedbanks (Mortensen et al. 2000). In these ways, a variety of management methods affect both weed diversity and abundance.

In reviewing conventional herbicidal weed control, Bastiaans et al. (2008) show how the proliferation of a cheap and effective measure against weeds has structured dominant weed management practices, both in temporal and spatial scales as well as in relation to the whole farm system. The authors argue that, "It is often the availability of chemical control that allows farmers to envisage the weed problem in such a short-term perspective and in relative isolation from other crop management aspects" (pg 481). The path-dependency stemming from dominant conventional agricultural production systems is likely inhibiting the transformational change to organic agriculture.

1.2 Human-Environment Geography

Situated within human-environment geography, the dual approaches of structure and agency are particularly amenable to this project. Land-use/cover-change science has emphasized an agent framework in understanding land-use/cover change, focusing on decision making behavior in the larger scope of global environmental change; however, there has been a push to combine agency with structural (political-economic) approaches used in political ecology (Chowdhury and Turner 2006). Within this project I am particularly interested in the political, linguistic, and social structures of organic agriculture in the U.S. and the agency of various actors working within those systems that enable the spread of weedy species.

Anthony Giddens' development of *structuration* as a theoretical approach combined the original conceptualization from Ferdinand de Saussure and parallel interests in Marxism (Johnston & Sidaway 2004). Giddens' *structuration* is a way to "…account for the ways in which people learn about and transform social structures" (Johnston & Sidaway 2004, 242). His approach is a spatially and temporally bound process where one's context is a significant influence on one's development (Johnston & Sidaway 2004). In this way, spatial structure is not just the system within which social life takes place, but also the "…medium through which social relations are produced" (Johnston & Sidaway 2004, 243). The structure-agency debate, acknowledged in

Giddens' concept of the 'duality of structure,' is the "…inter-dependant relationships among structure and agency" (Johnston & Sidaway 2004, 243). Utilized by Moos and Dear in their 1986 article *Structuration theory in urban analysis: I. theoretical exegesis*, the authors laid out the structure-agency debate as two levels of analysis: (1) the "…individuals involved in the production of a particular event"; and (2) the "…structural properties within which those agents are operating" (Johnston & Sidaway 2004, 243). These concepts have mostly been used as organizing frameworks for empirical work, rather than methodological protocols themselves (Johnston & Sidaway 2004). Taking this approach, places are the social systems that provide the context that is simultaneously enabling and constraining (Johnston & Sidaway 2004). Actions reproduce local knowledge, ensuring "…that the social system continues to constrain and enable further actions" (Johnston & Sidaway 2004, 244). However, agency emerges through the actions and choices that create slightly different sets of "…enabling and constraining conditions for future action" (Johnston & Sidaway 2004, 244).

More specific to my project and perhaps more explanatory of the agency side of the structure-agency debate, is Paul Robbins' concept of socio-biological invasive networks (2004). Robbins suggests that "It is not species, but socio-biological networks that are invasive" (Robbins 2004, 139), and he likens these networks of human and nonhuman actors to actor-network theory, where agency is an emergent property and an object's capacity is endowed only through its relative position among other elements in the network (Robbins 2004). In this way, a weedy species invasion can be seen as the outcome of a particular system involving various social and biological pieces, but if pieced together differently, may have a different result. Harlan (1992) echoes this sentiment by noting that “Some weedy species might have been rather uncommon before man began to churn up the landscape, but when the agricultural ‘revolution’ reached them their ecological niches were suddenly expanded and they prospered enormously as a result” (89).

Complimentary to socio-biological networks is hybridity and hybrid landscapes (Swyngedouw 1999, White 2004). A hybrid is a part social, part natural intermediary subject that embodies and expresses both nature and society (Swyngedouw 1999). Agricultural landscapes seem to epitomize this description of a socio-natural expression, due to the inherent characteristics of agricultural systems and the actors involved. Organic agriculture is especially amenable to both concepts of hybridity and socio-biological networks due to its institutionalization of holistic and philosophical approaches to food, community, and the environment (Organic Valley 2009). Through the structures of language and the U.S. organic agricultural system, how do agencies of individuals and nature come together to create an enabling context for a weedy species to emerge?

1.3 Research Goals & Hypothesis

With the continued growth of organic farms in the U.S., issues pertaining to it are increasingly important. My question is ‘what is the relationship between variations in weed management and biodiversity of weeds?’ Clarifying the relationship between weeds and weed management enables a better understanding of (1) why farmers chose certain management methods, (2) why what they are doing is or is not successful both in terms of managing their weeds and supporting other aspects of environmental sustainability, and (3) how their actions enable researchers, extension agents, certifiers, and others to facilitate transitions to organic agriculture, ensuring that the proliferation of organic farms upholds its environmental sustainability objectives. My hypothesis is that weedy species will be spatially distributed according to environmental characteristics (e.g. soil type and moisture), as well as land uses (e.g. pasture vs. crop fields).

1.3.1 Wisconsin NSF Project

This project is related to work being done by Dr. Karl Zimmerer and collaborators at the University of Wisconsin – Madison that seeks to better understand the factors that lead to spatial clustering of organic dairy production in southwestern Wisconsin, with special attention to farmer-farmer and farmer-institution interactions (Zimmerer 2007). The group hypothesizes that "…decentralized farmer decisions to convert to organic methods will tend to create and reinforce land use clustering" (Zimmerer 2007). The project will not only add to our understandings of the complex ways that farmers interact with each other and with institutions, but also help inform "…the design and development of management policies that require understanding the basic human-social dynamics of spatial interactions in farming systems" (Zimmerer 2007). While this project explores a variety of human-social interactions, there is no explicit analysis of the role of environmental characteristics in farmer decision-making when transitioning to organic agriculture. Here, my project will fill the gap by considering the relationship between variations in weed management practices and the biodiversity of weedy species in organic systems.

Chapter 2

METHODS & ANALYSIS

2.1 Introduction

This chapter is focused on the methods and analyses employed in this project. Section 2.2 addresses the selection of the study area as well as individual farms and farmers. Section 2.3 covers the various data sources and research methods used in this study. Section 2.4 describes the research analyses employed on the full and original dataset, while section 2.5 explores the various analyses employed on the field-level datasets.

2.2 Study Area

The study area selection was influenced the aforementioned related research being conducted by Zimmerer and collaborators. Specifically, their research includes the counties of LaCrosse, Monroe, Crawford, Grant, Juneau, Richland, and Vernon (Figure 2.1). These counties are in a region known as the Driftless Region, which encompasses portions of Wisconsin, Illinois, Iowa, and Minnesota (Figure 2.2). This area escaped glaciation in the last ice age, resulting in a highly variable terrain where elevation ranges from ~ 600 to 1,450 feet above sea level (Albert 1995). The area is also home to the Kickapoo River, one of the oldest rivers in the U.S. maintaining its original path (KVA 2008) and the largest tributary of the Wisconsin River (USDA-NRCS 2008). The Kickapoo River watershed covers nearly 500,000 acres of southwestern Wisconsin (in Monroe, Richland, Vernon, and Crawford counties) (USDA-NRCS 2008) (Figure 2.3).

The area is also sometimes referred to as the Kickapoo Region because of the large impact this river has on the area; topologically, the Kickapoo River has carved its way throughout the study area forming the distinct coulees in the landscape. Historically, the Kickapoo River is also known for flooding, the most recent of which was in August of 2008 (Brown 2008).

The variable landscape and fertile soils are thought to be two reasons for the regions burgeoning organic farms (Riely 2005). The Driftless Region is home to a large number of organic producers, companies, and support agencies such as Organic Valley (and their adjacent certifying organization CROPP), Midwest Organic Services Association (MOSA), Organic Prairie, and Midwest Organic and Sustainable Education Services (MOSES), all of which are located (headquartered) in the seven-county study area. Due to the sheer density of organic farms and the variable landscape upon which they are located, this area provided an ideal location for examination of interactions between weed management practices, the environmental landscape, and agroecologically dominant weed species.

Initial farm selection was random and then a snowball method was used for additional farm selection. Farms were contacted for this study via phone calls, referrals from other organic dairy farmers, organic certifying agents, and word of mouth. Contact information for some farmers were obtained via a master list of organic farmers in the region from Zimmerer's project as well as from publicly available lists from the certifying agent Midwest Organic Services Association (MOSA).

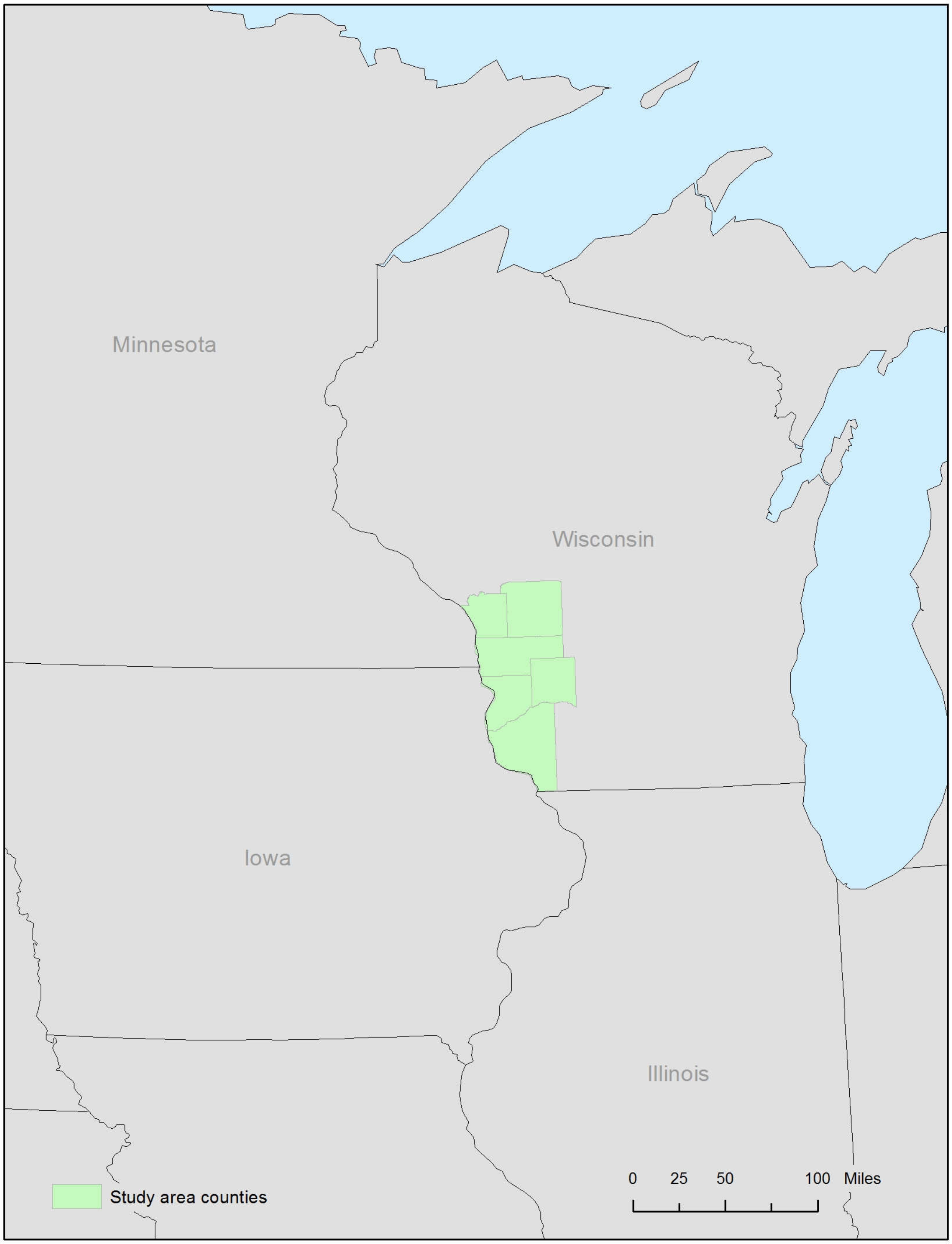


Figure 2.1 Study area.

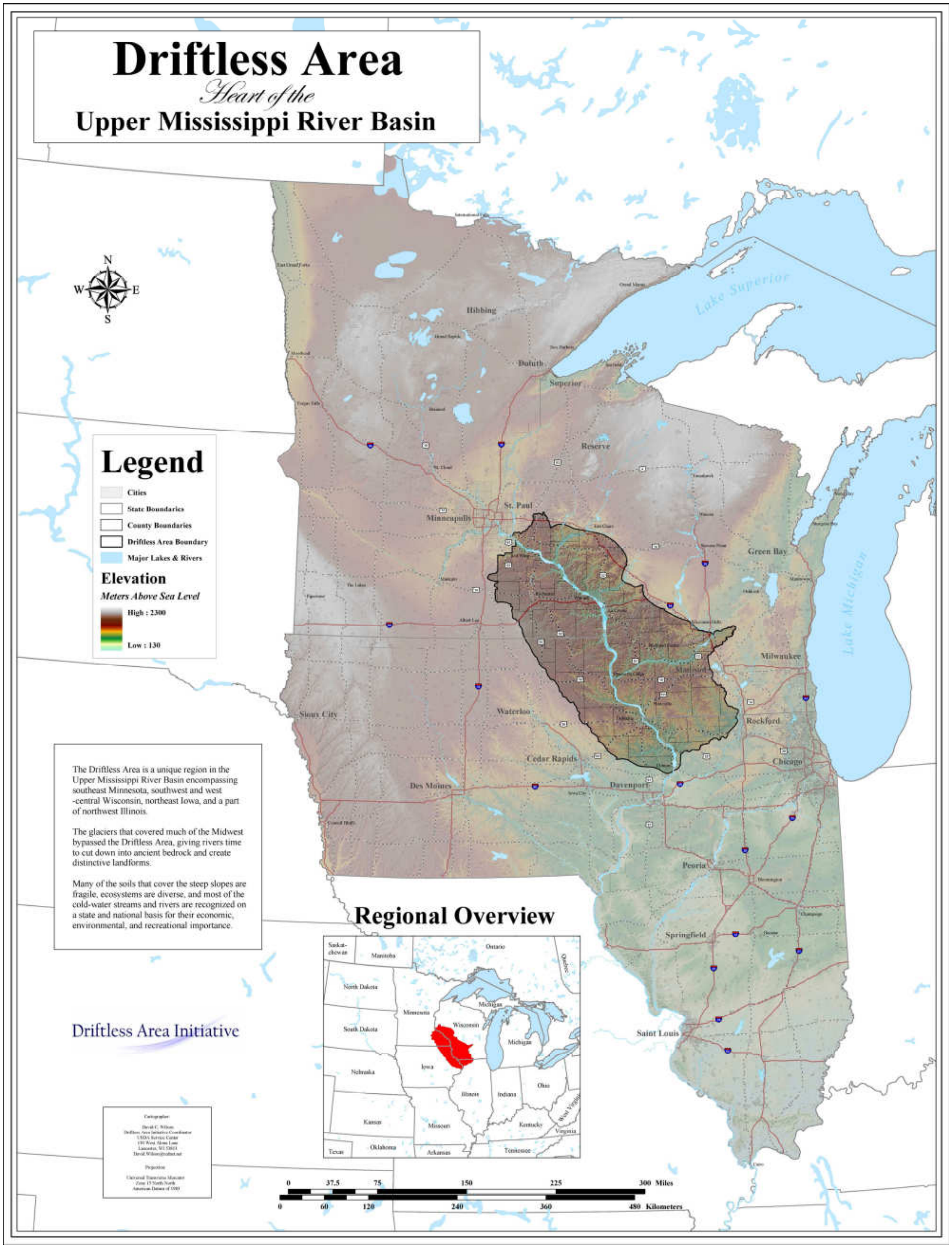


Figure 2.2 The Driftless Region (DAI 2007).

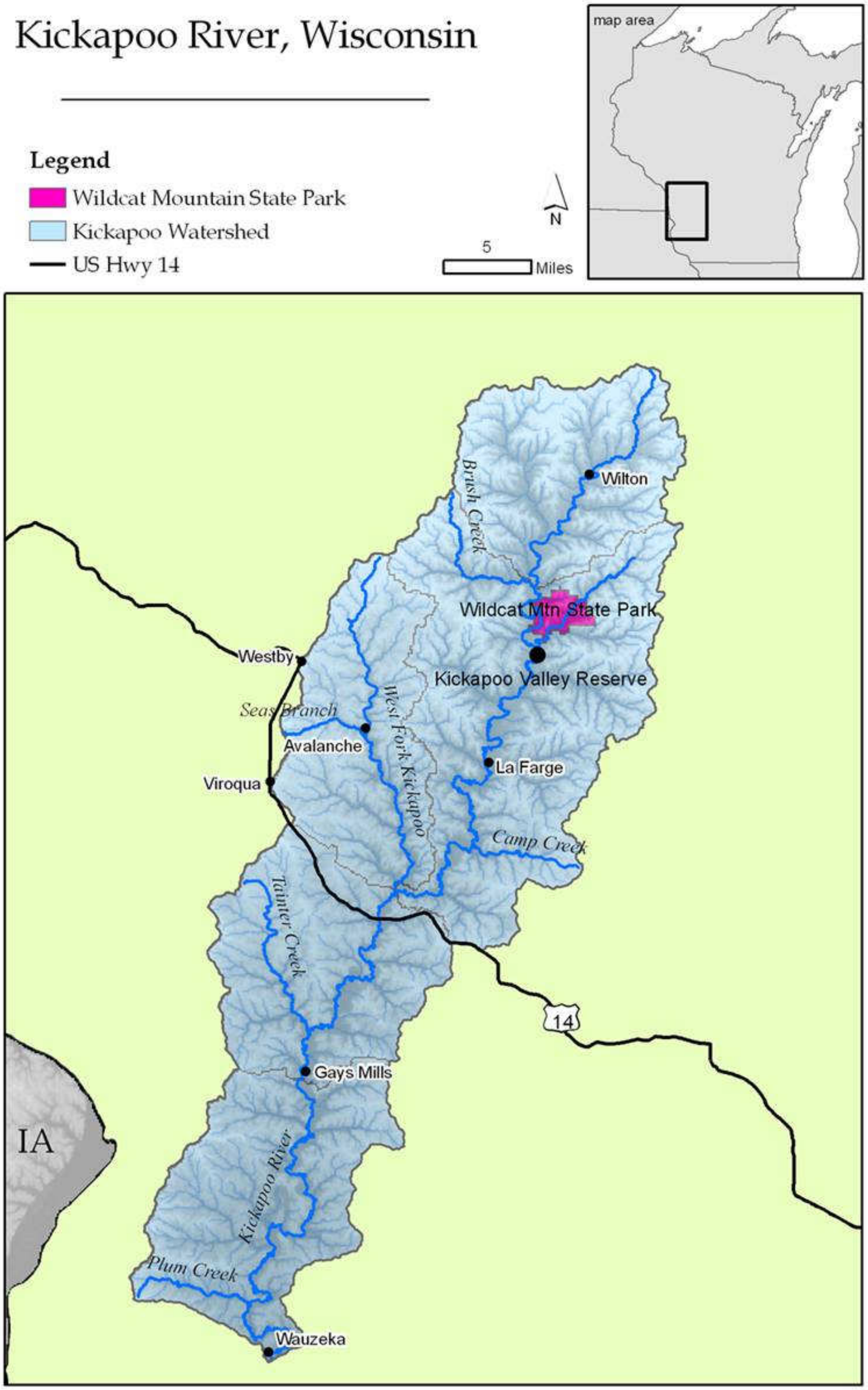


Figure 2.3 The Kickapoo River watershed (USDA-NRCS 2008).

2.3 Data

Both digital environmental spatial data and field data were utilized in this study. A large portion of the environmental spatial data had been previously collected or created for the Zimmerer's NSF project. Field data included vegetative identification, collection, and censusing as well as interviews with farmers.

2.3.1 Environmental Spatial Data

Digital environmental spatial data utilized in this study are summarized in Table 2.1. These data were used to help characterize the farms studied by finding the mean value for each variable listed in Table 2.1 (except slope where minimum and maximum values were also found). The minimum, maximum, mean and standard deviation of mean values across all farms are listed in Table 2.2. The small range in means for all variables suggests environmental similarity among the sampled farms. However, minimal variation may also be a relic of the small study sample (n = 19).

For climatic representation, 'climate divisions' were identified, assigned to participating study farms, and then included in statistical analyses. While available by individual weather stations, the U.S. Department of Agriculture (USDA) and National Oceanic & Atmospheric Administration (NOAA) often portray Palmer Drought Severity Index (PDSI) values along with other climatic information (e.g. temperature and precipitation) by climate divisions. For example, during the growing season, the USDA publishes a *Weekly Weather and Crop Bulletin* showing PDSI values by climate divisions (USDA 2007).

Originally developed by Palmer (1965) as a way to measure drought severity, the Palmer Drought Severity Index (PDSI) is a moisture index that takes into account precipitation, evapotranspiration and soil moisture conditions (Palmer 1965, Alley 1984, Heddinghaus & Sabol 1991). PDSI values have a mean of zero, with negative values indicating increasingly dry conditions, and positive numbers indicating increasingly wet conditions (Alley 1984). The PDSI is standardized such that direct comparisons of PDSI values can be made between different locations (Alley 1984).

Climate divisions subdivide states (usually along county boundaries), and were adopted by the U.S. Weather Bureau in 1949 from the U.S. Department of Agriculture (Guttman & Quayle 1996). These divisions originally corresponded to the USDA's Bureau of Agricultural Economics Crop Reporting Districts, which were based on dominant crop type in any given area (Guttman & Quayle 1996). In the mid-1950s and then again in the early 1960s, divisional boundaries for many areas were realigned to better suit the Weather Bureau's needs. In the west, these realignments were based on drainage basins (due to the interest in water resource issues) (Guttman & Quayle 1996). In other areas, climate divisions were realigned to be "…more climatically homogeneous, with respect to the relationship between climate and the dominant crops grown in the area" (Guttman & Quayle 1996, pg 295). Within each division, weather station values for various climatic data are averaged to produce values for the climatic division as a whole (Wolter & Allured 2007). Climate division values are then averaged (weighted by area) to the state level (NOAA 2011) to aide in decision-making as well as for dissemination to the public. Critics of the climate divisions note that divisions were made on a state-by-state basis and therefore values are not necessarily representative at larger (esp. regional) scales (Wolter & Allured 2007). In an attempt to re-draw these boundaries Wolter & Allured (2007) produced new climatic divisions based on temperature and precipitation that, for my study area, remained essentially the same.

Climate divisions were used in this study as indicators of climatic homogeneity within the study area. The counties comprising each climate division in Wisconsin was found on NOAA's website (NOAA 2005). Each study county was then assigned a number that corresponded with a climate division for Wisconsin. Based on the county within which each farm was located, farms were then assigned climate division numbers. All study farms were within divisions 4 ('West Central', including St. Croix, Pierce, Dunn, Pepin, Eau Claire, Buffalo, Trempealeau, Jackson, La Crosse, and Monroe counties) and 7 ('Southwest', including Vernon, Crawford, Richland, Sauk, Grant, Iowa, and Lafayette counties), with the majority of farms located in division 7. The lack of variation suggests minimal climatic variation among study farms; however, to determine their significance, joint plot overlays (on Bray-Curtis ordinations) were run with all environmental variables in PC-ORD (McCune & Mefford 2006). Environmental variables were determined to be significant if $R^2 \geq 0.20$.

Data	**Information**
National Elevation Dataset - Wisconsin 10m (2009)	Elevation, slope
SSURGO 2.2 (2005)	% sand, silt, clay, pH, organic matter
Palmer Drought Severity Index - NOAA Climate Prediction Center	Wisconsin PDSI divisions

Table 2.1 Data sources and information.

	SAND	SILT	CLAY	OM	PH	ELEV	MIN_S	MAX_S	MEAN_S
min	7.00	41.00	14.00	2.00	6.00	266.78	0.01	13.33	2.84
mean	12.80	63.59	21.02	2.48	6.12	364.30	0.10	55.20	11.79
max	27.00	71.00	31.00	5.00	7.00	411.07	0.36	128.06	20.42
std	5.60	9.12	3.91	0.66	0.24	30.51	0.06	27.90	4.54

Table 2.2 Environmental variables (statistics of means). Sand is soil percent sand. Silt is soil percent silt. Clay is soil percent clay. OM is soil organic matter. PH is soil pH. ELEV is elevation. MIN_S is minimum slope. MAX_S is maximum slope. MEAN_S is mean slope.

2.3.2 Field Data

Vegetative identification, collection, and sampling of field weeds were conducted on 20 farms – 18 were USDA certified organic, 2 were not. Both non-certified farms did selective spraying, leaving some pastures untouched. Fields free of herbicides and pesticides were sampled and included in this study. Although 20 farms and farmers took part in this study, data were only reported for 19 due to changes in sampling technique after the first farm visit (Figure 2.4). Pasture fields are required for every dairy farm under organic certification; however, on-farm corn production is not required. Effective as of 2010, the National Organic Standards mandated that "…a minimum of 30 percent of a ruminant's dry matter intake (DMI), on average, over the course of the grazing season" be provided by pasture (NOS 2010). On smaller farms this caused some farmers to switch all their fields to pasture to meet the new requirements. These requirements, combined with the two non-certified farms (as explained above), account for the difference in cornfields and pastures sampled (n=14 and n=19, respectively). General farm information such as location, address, and operator were also collected. Some of this information was gathered prior to going into the field.

A research design based on one sector of organic agriculture helped control for variation of weeds and weed management practices. This variation is expected to be less than would occur, for example, between dairy farms and vegetable farms. Dairy farms are mainly comprised of two land uses – pasture and grain crops. I conducted vegetative sampling in pasture and cornfields only.

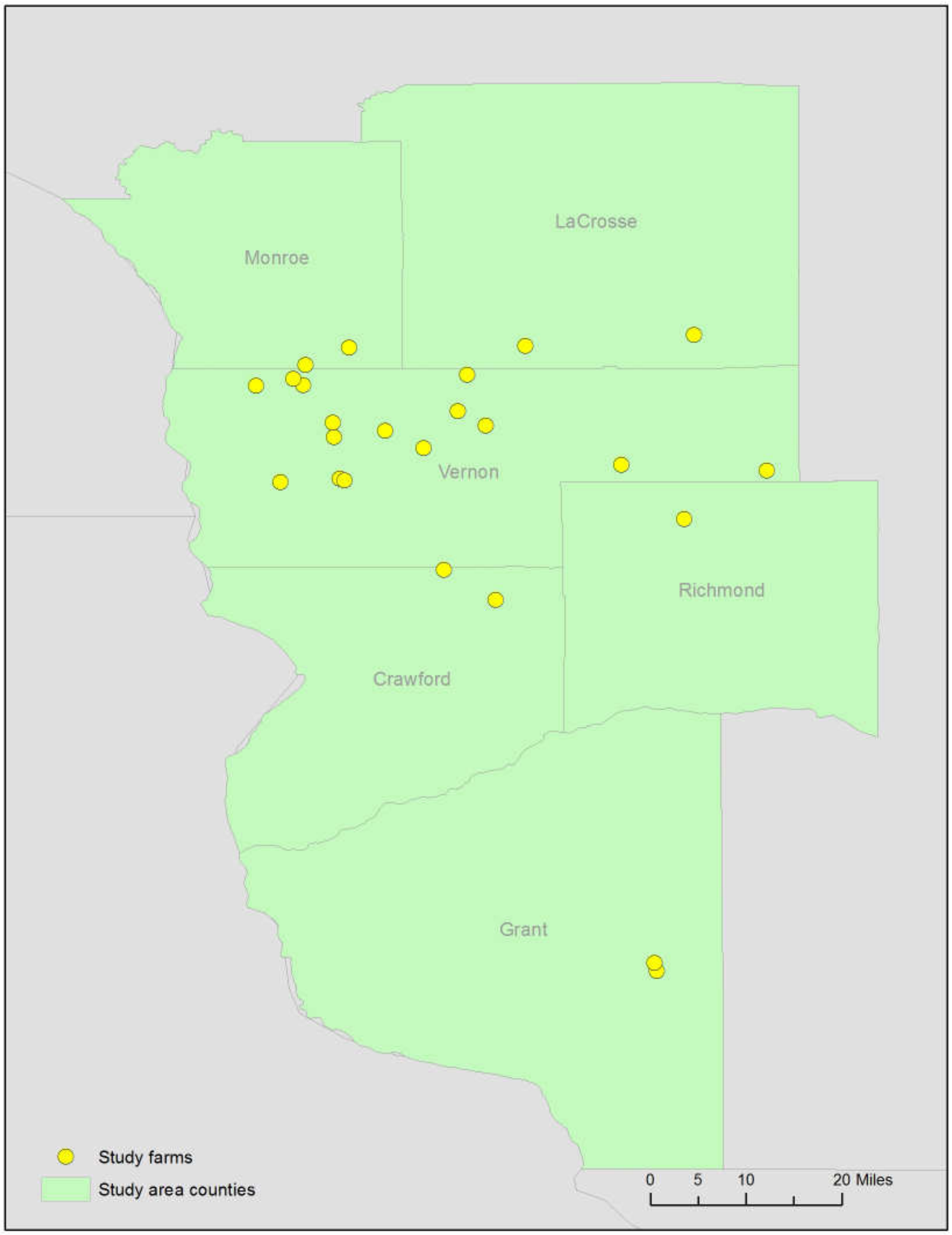


Figure 2.4 Study area with participating farms.

2.3.3 Vegetation Sampling

To conduct vegetative sampling I located three transects in each field type to control for variation in weed species and weed management practices between land uses. This was done using a combination of line transects and quadrat sampling to get a sufficiently representative picture of weed species diversity and abundance on individual farms (Keith 2000).

A staggered layout was used to position three 50m interrupted belt transects in each field type (Herrick et al. 2005, Keith 2000). Transects were evenly spaced throughout each field to cover as large and diverse an area as possible (Figure 2.5). Along each transect were five $1m^2$ quadrats spaced 10m apart (Figure 2.6). Walking each transect, all non-crop plant species that intersected the line were identified and recorded (i.e. the line-intercept method) (Herrick et al. 2005, Keith 2000) (Table 2.3). Within each quadrat all non-crop species were also identified, recorded, and visually estimated for percent coverage (Herrick et al. 2005, Keith 2000) (Table 2.4).

Unknown species encountered in the sampling process were recorded as such by naming each unknown with a number (e.g. 'unknown 1' or 'unknown 2'). Whenever that same unknown was encountered on that farm, it was recorded the same as its initial entry. Notes were often made in the side margins of field sheets to describe the unknown species, and sometimes included sketches. An individual of that species was then collected and placed in a bag labeled with the appropriate field type, transect, and/or quadrat number where it was first encountered on that farm. Species samples collected in the field were then placed in a plant press and labeled with the farm, field type, transect and/or quadrat it was first found in, along with the name (unknown #) it was recorded as on the field sheets. Unknowns were then identified using multiple field guides and online guides. Identification of some individuals remained elusive, but where genus was easily identified, the species was reported as such and included in data analysis (e.g. goldenrod (*Solidago spp*)).

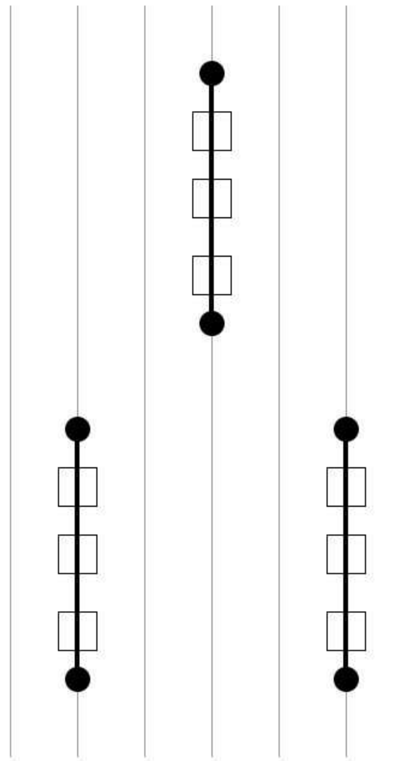


Figure 2.5 Alternating transect layout (vertical lines are crop rows)

Figure 2.6 Transect layout, with five 1 m^2 quadrats

Transects	
Operator ID:	Date
Land use: Corn Pasture	
Pasture description:	
Field center (GPS):	
Transect: 1 2 3	End-point (GPS):

SPECIES	(tally marks)

Table 2.3 Transects field sheet.

Quadrats	
Operator ID:	Date
Land use: Corn Pasture	
Pasture description:	
Field center (GPS):	
Transect: 1 2 3	End-point (GPS)
Quadrat: 1 2 3 4 5	

SPECIES	(tally marks)

Table 2.4 Quadrats field sheet.

2.3.4 Farm-Level Interviews

Interview questions were focused on three aspects of weeds and weed management on dairy farms: (1) farmer perception of weed diversity, (2) farmer perception of weed abundance, and (3) weed management. Within each category, questions were further directed at understanding how each changed over time from being conventional to their current organic status (Appendix A). Background information gathered from the interviews was aimed at creating a general profile of each farmer and the farmer's potential agricultural knowledge based on the length of time they had been farming (both conventionally and organic). Questions on weed abundance and type were aimed at not only getting a sense of what weedy species were on each farm, but also each farmer's perceptions of weeds. These questions often clarified each farmer's stance on weeds and how weeds fit into the whole farm system. Weed management questions were aimed at gathering information on the type of weed management that farmers carried out on their farms (in typical years as well as in this 'off' year) in both cornfields and pastures. Questions on learning about weed management methods were aimed at gathering information on how farmers came to their current weed management system and if and how they decided to change their weed management system. Part of this section was also aimed at understanding how farmers gathered information and learned about new management techniques – i.e. their knowledge networks. Finally, I was interested in how much time farmers spent on their weed management.

Select information from these interviews was then used in joint plot overlays in Bray-Curtis ordinations run in PC-ORD (McCune & Mefford 2006). Farm management variables used in joint plot overlays were years farming (the number of years a farmer has been farming; when answers were ‘all my life,’ 25 was entered for the number of years), years organic (the number of years that farmer has been USDA certified organic), certifier (the certifying agent the farmer is certified through), total acres (the total acres of his/her farm), number crops (the number of crops grown by that farmer, not including pasture as a crop), number common weeds (the number of weed species the farmer identifies as common to his/her farm), number problematic weeds (the number of problematic weed species identified by the farmer), number times field cultivated (the number of times cornfields were cultivated in the 2010 growing season), number times pasture clipped (the number of times pastures were typically clipped in a year; if answer was ‘yes’ then 1 was entered), length of rotation (the length – in years – of a farmer’s crop rotation; if there was a range of years, the longest rotation was used), and number info sources (the number of sources a farmer identified as getting his/her information from regarding farm management).

2.4 Analysis

After field data collection, transect and quadrat data were entered into a Microsoft Excel® (2004) spreadsheet. Transect data were entered either as a 1 or a 0, where 1 indicated the presence of a species along a transect and 0 indicated the absence of a species along a transect. Quadrat data were entered into a separate Microsoft Excel® (2004) spreadsheet where the percent cover of a species was entered as a 1 (0-25%), 2 (25-50%), 3 (50-75%), 4 (75-100%) or 0 (absent). Originally, both spreadsheets contained the same plant species; however, after entering the data into both, species with all zeros (indicating that that species was absent from all transects or quadrats) were deleted from the spreadsheet. The statistical software PC-ORD (McCune & Mefford 2006) was then used to run both two-way cluster analyses and Bray-Curtis ordinations to verify findings.

PC-ORD is a multivariate statistical software program designed for ecological data analyses. The program focuses on nonparametric tools of analysis, creating publishable visual graphics, randomization tests, and bootstrapped confidence intervals for analysis of community data (McCune & Mefford 2006). PC-ORD was chosen to conduct the analysis of this study's data because it offered several ordination and classification techniques not available in typical statistical software programs, including two-way clustering, Bray-Curtis ordination, and joint plot ordination overlays, all of which were utilized in my analyses.

Cluster analyses are used to define groups of items based on their similarities. Two-way clustering in PC-ORD is a hierarchical agglomerative action that joins smaller clusters to make larger clusters and refers to doing a cluster analysis on both the rows and columns simultaneously (as opposed to one at a time). Two-way clustering was chosen as a first step of analysis for this study because it graphically shows the relationship between clusters and individual data points (in this case species and their presence and/or coverage on a transect or in a quadrat). Species abbreviations in two-way cluster analyses are constant throughout the study and explained in Appendix B. Two-way cluster analysis graphs clearly depict similarities and differences between rows in the same group, rows in different groups, columns in the same group, and columns in different groups; thus clarifying how groups of rows and columns relate to each other (McCune & Mefford 2006). This type of analysis does not, however, reveal the driving forces of these relationships. To verify the results of the two-way cluster analyses, Bray-Curtis ordinations were run. Joint plots (on Bray-Curtis ordinations) of environmental and farm management variables were then run to uncover some of the driving forces of the relationships seen in the two-way clustering and Bray-Curtis ordinations.

Ordinations are a method of analysis that order objects along axes according to their resemblances, where objects placed closer together are more similar and objects farther apart are less similar. The Bray-Curtis ordination (also known as a polar ordination) in PC-ORD allows for selection of distance measure and endpoint selection method. Joint plot overlays on Bray-Curtis ordinations are a way of showing the relationship between a set of variables and ordination scores by way of a diagram of radiating lines originating at the centroid of the ordination scores (i.e. the center of the graph). The angle and length of each line indicates the direction and strength of the relationship, where longer lines indicate stronger relationships.

2.4.1 Weed Samples Along Transects (Line-Intercept Method)

In PC-ORD, transect data were first run through a two-way cluster analysis to determine if any species or transects were related to one another. Results showed distinct groupings of species for both pasture and cornfields, as well as species that were equally present in both field types (Figure 2.7). Figure 2.7 shows the relatedness of weed species and transects in cornfields and pastures, where columns are a weed species and rows are a transect. This leads to each square representing the presence (if filled in) or absence (if hollow) of a species on a particular transect.

Common and associate species were determined for each field type and are listed in Table 2.5. Species were defined as ‘common’ to a particular field type if they were present in at least two thirds of transects for that field type and also in twice as many transects for that field type as compared to transects from the other field type. There were six common species in both cornfields and pastures. Species were defined as ‘associate’ to a particular field type if they were in at least a sixth of transects for that field type and also in at least one-and-a-half times as many transects in that field type as compared to transects from the other field type. There were 12 associate species in both cornfields and pastures. Neutral species were also identified and are listed in Table 2.5. Neutral species were defined as those species present in at least one sixth of transects for either field type, but present in less than one-and-a-half times as many transects as the other field type (i.e. species who met either presence cutoff but did not clearly preference one field type over the other). There were four neutral species to both cornfields and pastures.

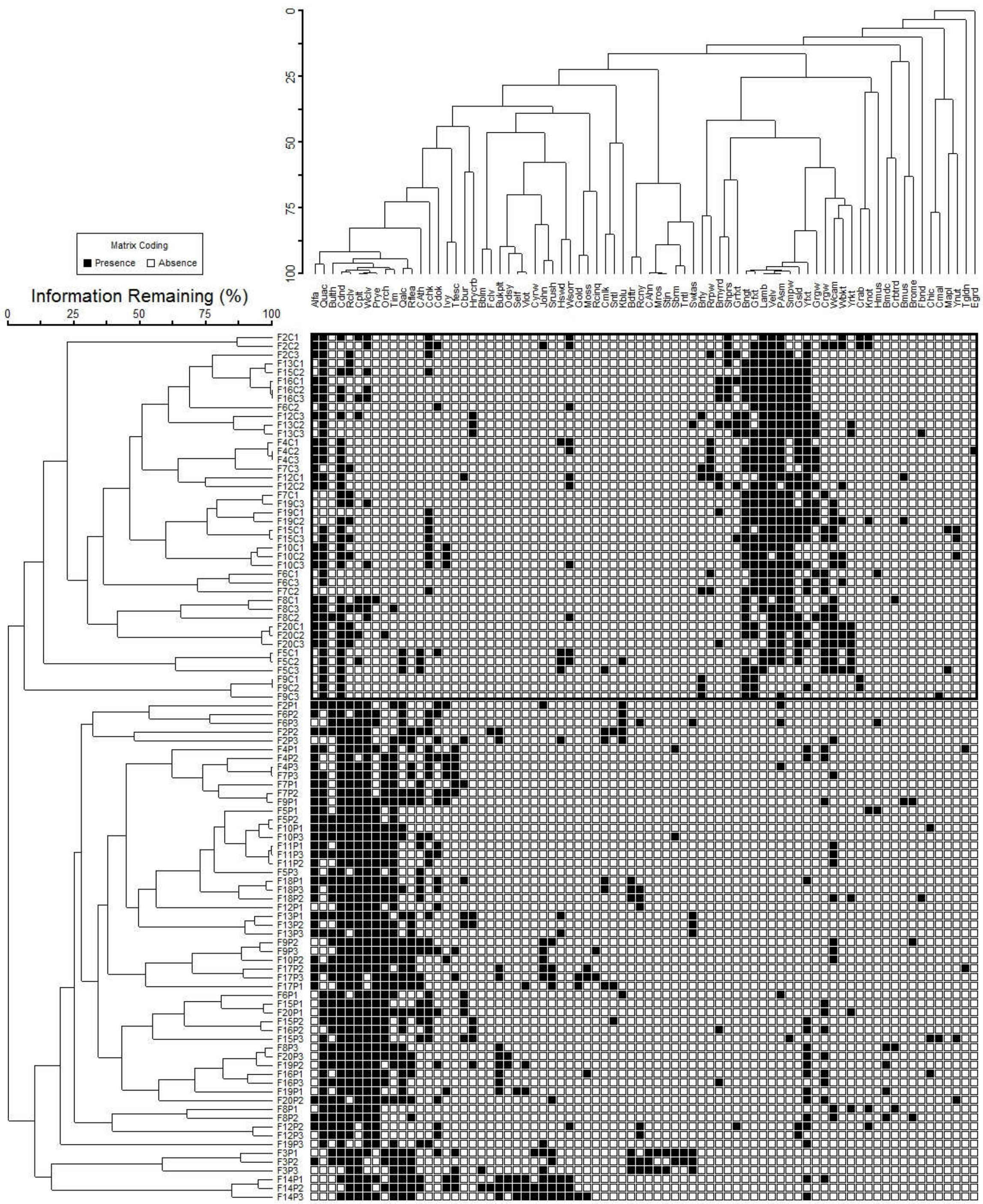


Figure 2.7 Results of two-way cluster analysis showing relatedness of weed species and transects in cornfields and pastures. Columns are species and rows are transects. The outline around the top of the image delineates corn from pasture transects, where corn transects are in the upper half of the image and pasture transects are in the lower half of the image.

Common Weeds (Present in min. 2/3 transects & 2x as many as other field type)		
Common Name	**Scientific Name**	**Field Type**
Black nightshade	*Solanum americanum*	Corn
Giant foxtail	*Sateria faberi*	Corn
Lambsquarter	*Chenopodium album*	Corn
Velvetleaf	*Abutilon theophrastii*	Corn
Pennsylvania smartweed	*Polygonum pennsylvanicum*	Corn
Smooth pigweed	*Amaranthus hybridus*	Corn
Red clover	*Trifolium pratense*	Pasture
Common plantain	*Plantago major*	Pasture
White clover	*Trifolium repens*	Pasture
Perennial rye	*Lolium perenne*	Pasture
Orchard grass	*Dactylis glomerata*	Pasture
Timothy grass	*Phleum pratense*	Pasture
Associate Weeds (Present in min. 1/6 transects & 1.5x as many as other field type)		
Wood sorrel	*Oxalis stricta*	Corn
Giant ragweed	*Ambrosia trifida*	Corn
White campion	*Silene latifolia*	Corn
Wild buckwheat	*Polygonum convolvulus*	Corn
Barley	*Hordeum vulgare*	Corn
Barnyard grass	*Echinochloa crus-galli*	Corn
Gallant soldier	*Galinsoga parviflora*	Corn
Green foxtail	*Setaria viridis*	Corn
Red root pigweed	*Amaranthus retroflexus*	Corn
Shepherd’s purse	*Capsella bursa-pastoris*	Corn
Yellow foxtail	*Setaria lutescens*	Corn
Yellow rocket	*Barbarea vulgaris*	Corn
Queen anne’s lace	*Daucus carota*	Pasture
Rough fleabane	*Erigeron glabellus*	Pasture
Canada thistle	*Cirsium arvense*	Pasture
Curly dock	*Rumex crispus*	Pasture
Ground ivy	*Glechoma hederacea*	Pasture
Tall fescue	*Festuca arundinacea*	Pasture
Common burdock	*Arctium minus*	Pasture
Buckhorn plantain	*Plantago lanceolata*	Pasture
Johnson grass	*Sorghum halepense*	Pasture
Bull thistle	*Cirsium vulgare*	Pasture
Common chickweed	*Stellaria media*	Pasture
Slender rush	*Juncus tenius*	Pasture
Neutral Weeds (Present in min. 1/6 transects & less than 1.5x as many transects as other field type)		
Alfalfa	*Medicago sativa*	Both
Quackgrass	*Elytrigia repens*	Both
Common dandelion	*Taraxacum officinale*	Both
Common ragweed	*Ambrosia artemisiifolia*	Both

Table 2.5 Biogeographic distribution of major (common, associate and neutral) weed species along transects within cornfields and pastures (see definitions in section 2.4.1).

To verify the findings from the two-way cluster analysis and to better understand what might be driving these clusters, a Bray-Curtis ordination was run. The ordination was run with a Sorensen distance measure and used variance-regression as the endpoint selection method for axes 1 and 2. Results again showed distinct divisions between cornfields and pastures (Figure 2.8) as well as clustering of species (Figure 2.9). While Figure 2.8 shows the relatedness of transects with one another, Figure 2.9 shows the relatedness of species with one another. Figure 2.9 shows the results of the Bray-Curtis ordination of transect data transposed to show species relatedness. The dash and dot (top left), solid (bottom left), and dashed (right) circles identify common and associate corn, neutral, and common and associate pasture species, respectively.

I then chose to run a joint plot overlay of environmental variables onto the Bray-Curtis ordination results either to verify or disprove previous findings that suggested environmental similarity among the sampled farms. Results of the joint plot overlay verified that the environmental variables do not contribute to the statistical clustering of species along transects. Standard definitions of ecological significance were used in this study where significance was defined as $R^2 \geq 0.2$.

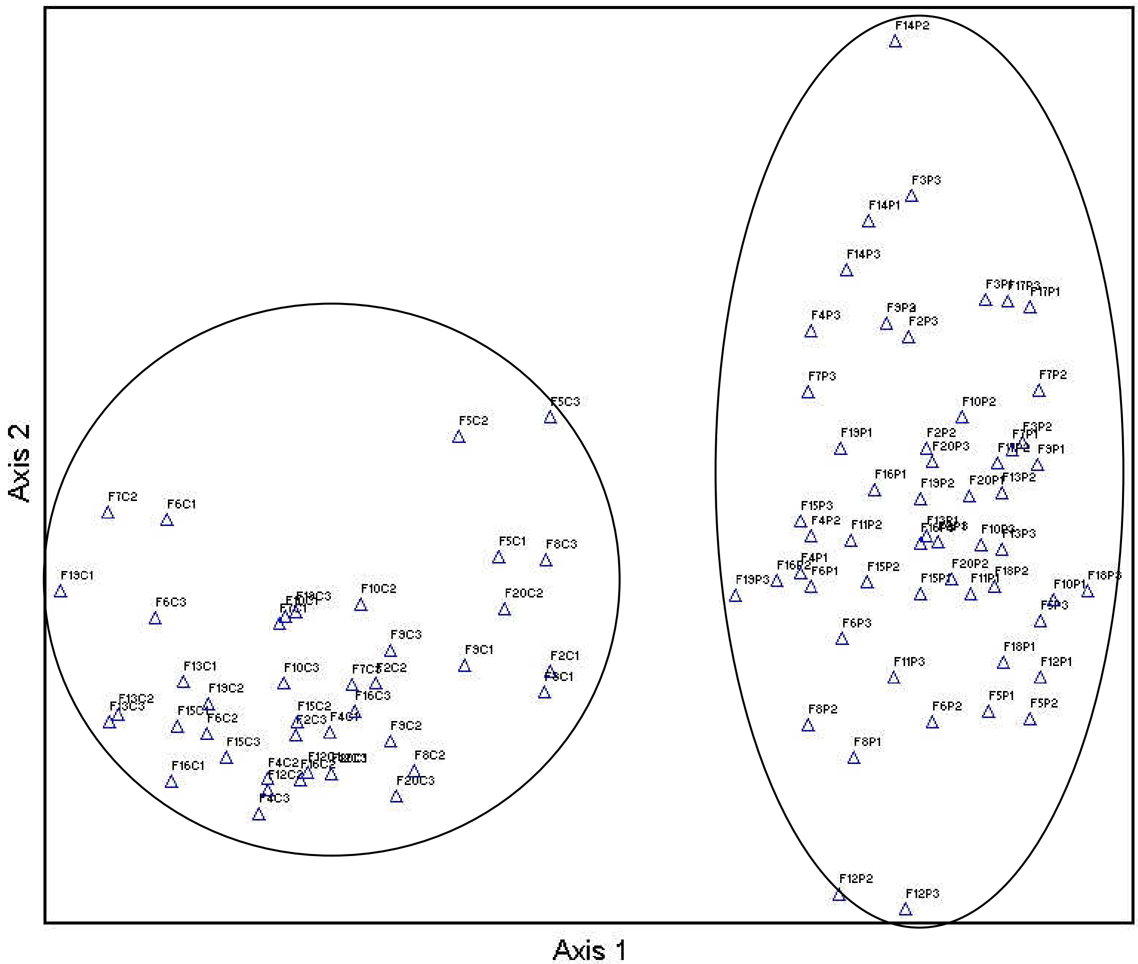


Figure 2.8 Results of Bray-Curtis ordination showing the relatedness of weeds species along transects (n = 99) in cornfields and pastures. Each symbol represents one transect.

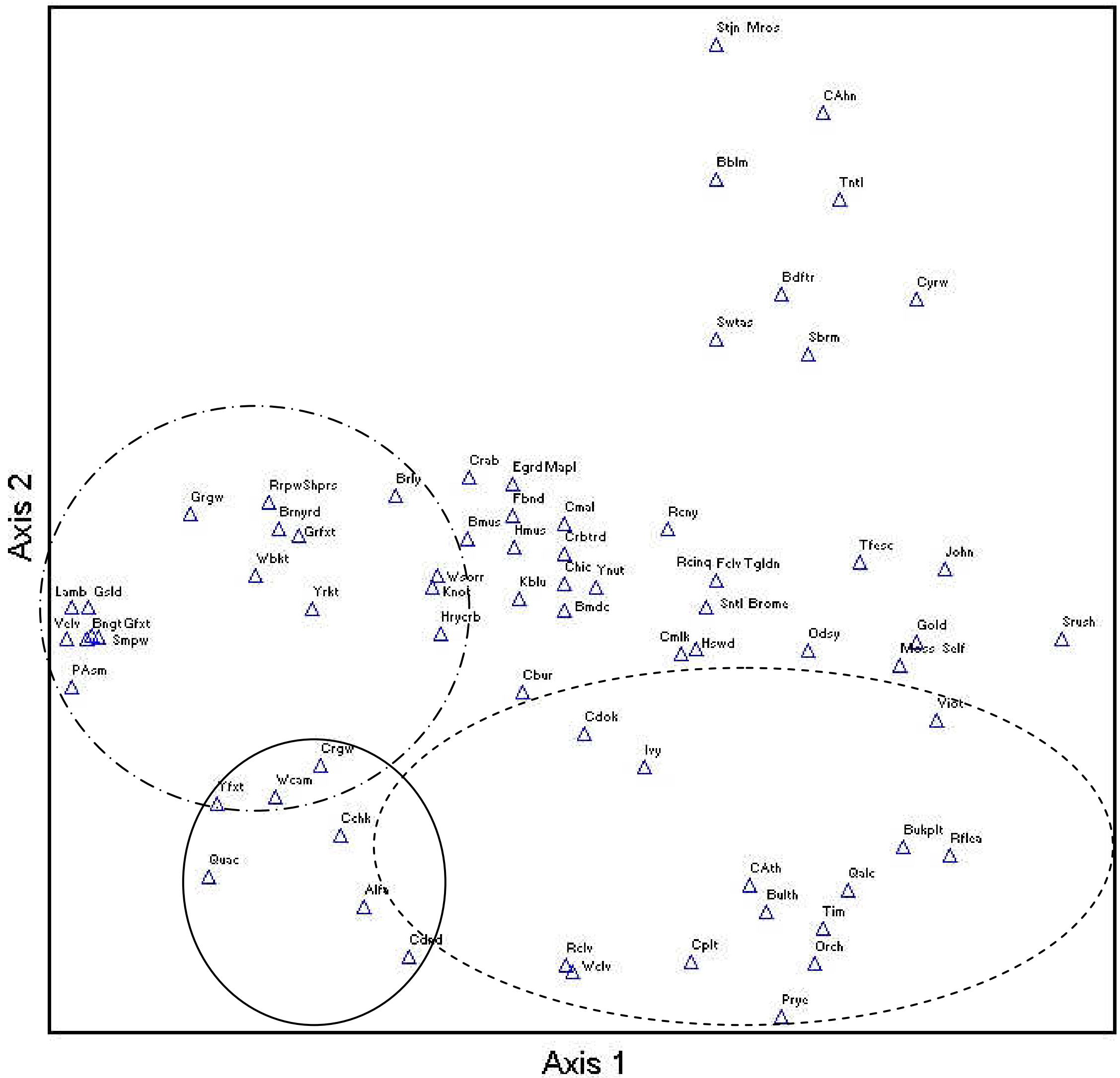


Figure 2.9 Results of Bray-Curtis ordination showing relatedness of weed species (n = 76). The circle of dashes and dots approximates the species common to or associating with cornfields. The circle of dashes approximates the species common to or associating with pastures. The solid circle approximates species neutral to both field types. Species not circled showed indistinct patterns.

A second joint plot analysis with farm management variables was run showing that ‘number of crops’ on a farm was significant ($R^2 = 0.22$) (Figure 2.10). The minimum number of crops (not including pasture) grown on a farm was zero, and the maximum number of crops grown on a farm was five. In Figure 2.10, the variable ‘number of crops' increased along the length of the arrow and appeared to be relating more with cornfields.

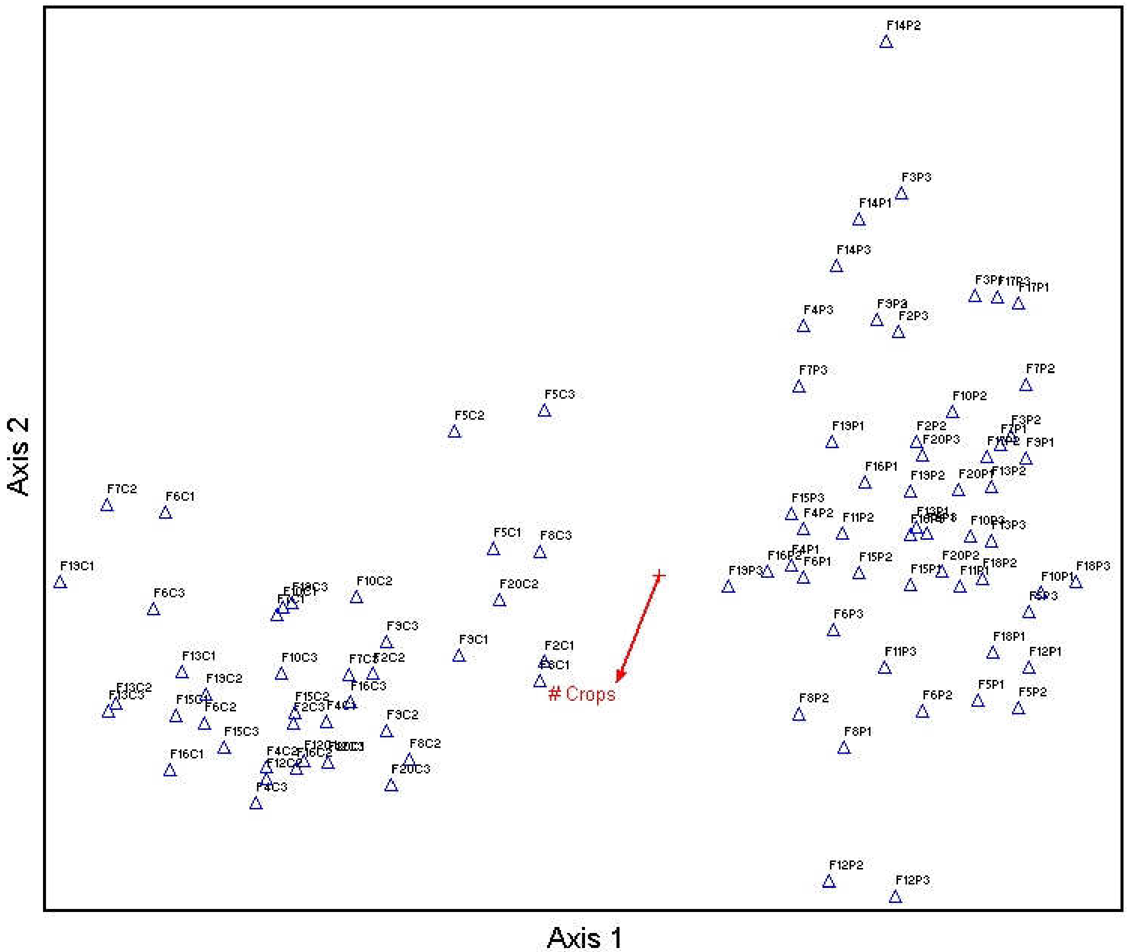
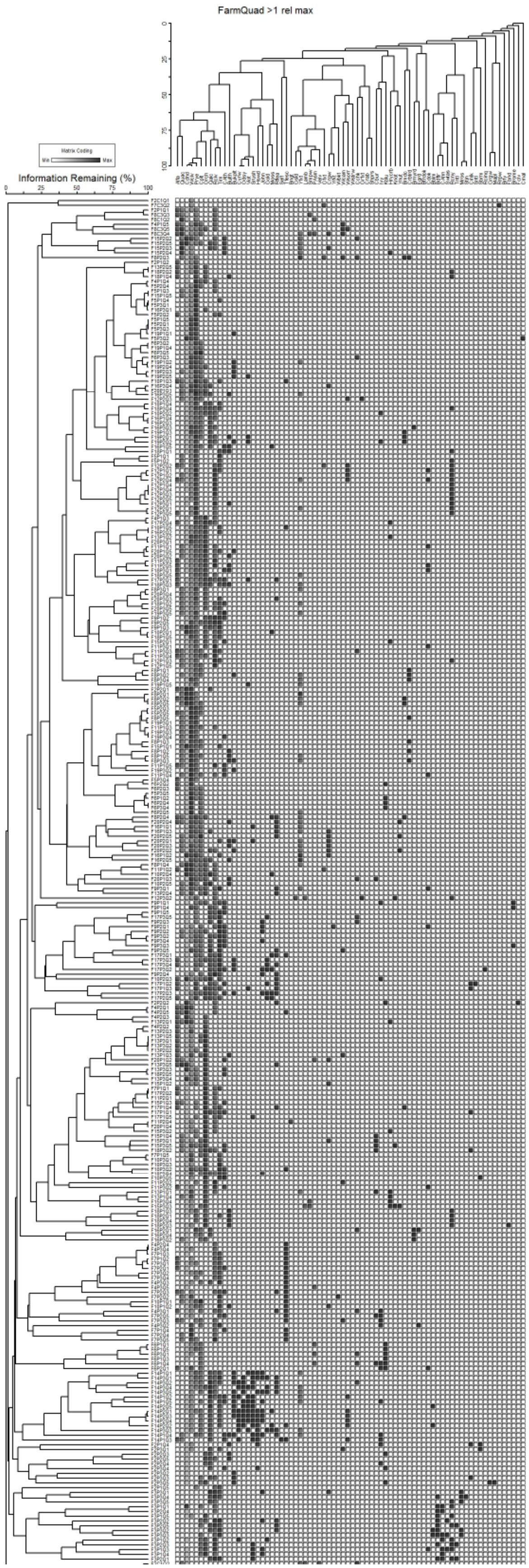


Figure 2.10 Overlay of joint plot analysis on Bray-Curtis ordination results of weed species along transects (n = 99) showing their relationship to the statistically significant management variable 'number of crops.' Weed samples along transects show a statistically significant relation in direction of arrow.

2.4.2 Weed Samples in Quadrats

In PC-ORD, quadrat data were also run through a two-way cluster analysis and then a Bray-Curtis ordination. Results of the two-way cluster analysis showed distinct groups of species in cornfields and pastures, as well as species that appeared to have no preference for either field type (Figure 2.11). Figure 2.11 shows the relatedness of weed species in quadrats in cornfields and pastures, where columns are a weed species and rows are a quadrat. This leads to each square representing the presence (if filled in) or absence (if hollow) of a species in a particular quadrat. These results verify the distinction between cornfield and pasture species as seen in the transect samples (section 2.4.1).

Using the same definitions outlined previously, species were labeled as common, associate or neutral to cornfields and pastures (Table 2.6). Again, species were defined as ‘common’ to a particular field type if they were present in at least two-thirds of the quadrats for that field type and also in twice as many quadrats for that field type as compared to quadrats from the other field type. One species was determined to be common to corn quadrats while four species were common to pasture quadrats. Species were defined as ‘associate’ to a particular field type if they were in at least a sixth of quadrats for that field type and also in at least one-and-a-half times as many quadrats in that field type as compared to quadrats from the other field type. Seven species were associated with each cornfield and pasture quadrat. Neutral species were those that met the minimum presence cutoffs, but were in less than one-and-a-half times as many quadrats as the other field type (i.e. species who met either presence cutoff but did not clearly preference one field type over the other). One species was determined to be neutral to both cornfield and pasture quadrats.


FarmQuad >1 rel max
Matrix Coding
Min
Max
Information Remaining (%)
0
25
50
75
100

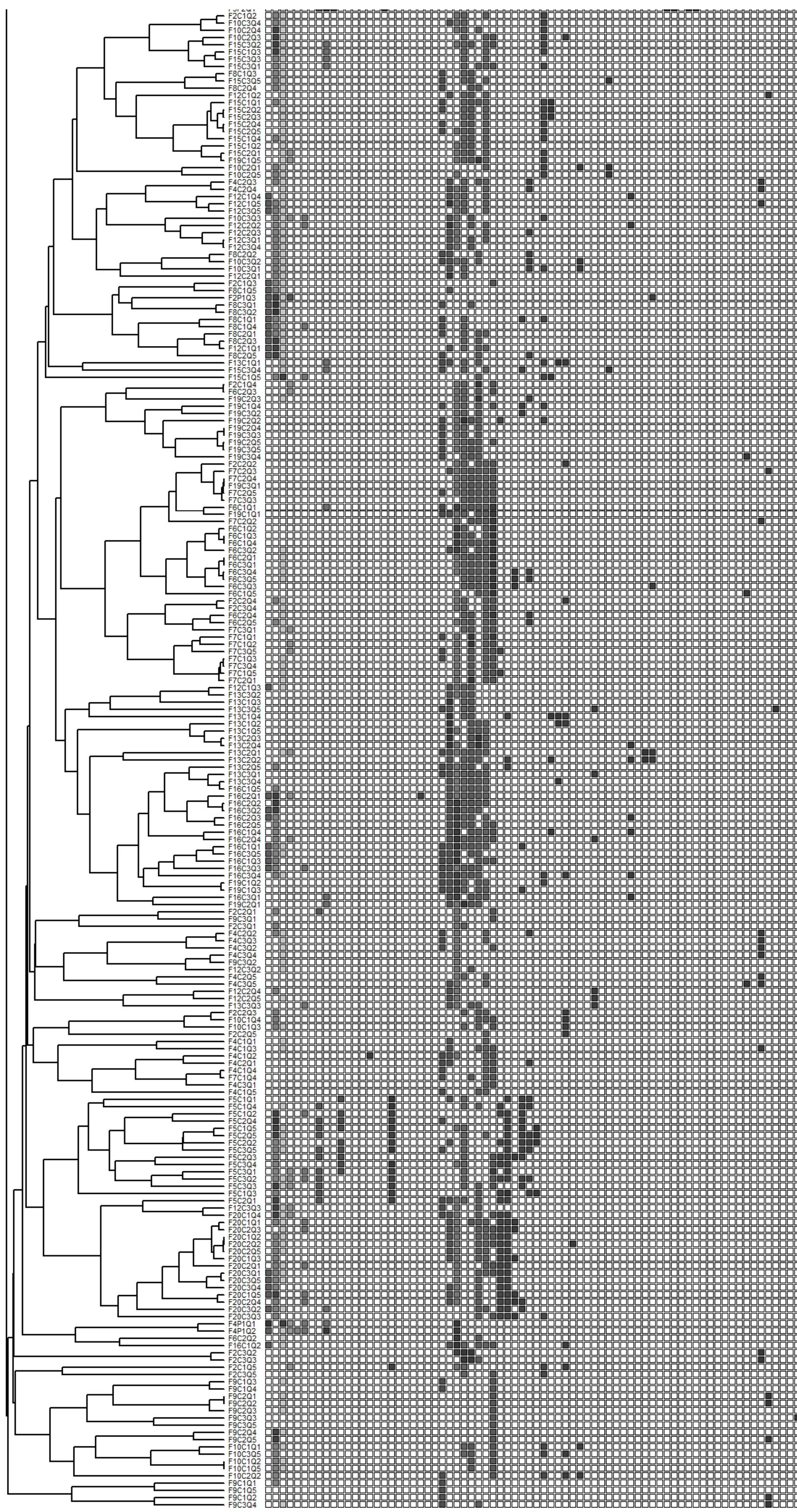


Figure 2.11 Results of two-way cluster analysis showing relatedness of weed species in quadrats in cornfields and pastures. Columns are species and rows are quadrats. The break in the image delineates corn from pasture quadrats, where pasture quadrats are in the upper half of the image and corn quadrats are in the lower half of the image.

Common Name	Scientific Name	Field Type
Common Weeds (Present in min. 2/3 transects & 2x as many as other field type)		
Yellow foxtail	*Setaria lutescens*	Corn
Common dandelion	*Taraxacum officinale*	Pasture
Orchard grass	*Dactylis glomerata*	Pasture
Perennial rye	*Lolium perenne*	Pasture
White clover	*Trifolium repens*	Pasture
Associate Weeds (Present in min. 1/6 transects & 1.5x as many as other field type)		
Giant foxtail	*Setaria faberi*	Corn
Lambsquarter	*Chenopodium album*	Corn
Velvetleaf	*Abutilon theophrastii*	Corn
Black nightshade	*Solanum nigrum*	Corn
Gallant soldier	*Galinsoga parviflora*	Corn
Pennsylvania smartweed	*Polygonum pennsylvanicum*	Corn
Smooth pigweed	*Amaranthus hybridus*	Corn
Alfalfa	*Medicago sativa*	Pasture
Canada thistle	*Cirsium arvense*	Pasture
Queen anne’s lace	*Daucus carota*	Pasture
Tall fescue	*Festuca arundinacea*	Pasture
Common plantain	*Plantago major*	Pasture
Red clover	*Trifolium pratense*	Pasture
Timothy grass	*Phleum pratense*	Pasture
Neutral Weeds (Present in min. 1/6 transects & less than 1.5x as many transects as other field type)		
Quackgrass	*Elytrigia repens*	Both

Table 2.6 Biogeographic distribution of major (common, associate and neutral) weed species in quadrats within cornfields and pastures (see definitions in section 2.4.2).

Again, a Bray-Curtis ordination was run to verify these findings. The ordination was run with a Jaccard distance measure and used variance-regression as the endpoint selection method for axes 1 and 2. The Bray-Curtis ordination verified the separation and clustering of cornfield and pasture quadrats (Figure 2.12). Figure 2.12 shows the relatedness of pasture and cornfield quadrats.

I then chose to run a joint plot overlay of environmental variables onto the Bray-Curtis ordination results either to verify or disprove previous findings that suggested environmental similarity among the sampled farms. Results of the joint plot overlay verified that the environmental variables do not contribute to the statistical clustering of species within quadrats. Likewise, when a joint plot overlay was run with farm management variables, no variables were found to be significant at the $R^2 = 0.2$ level.

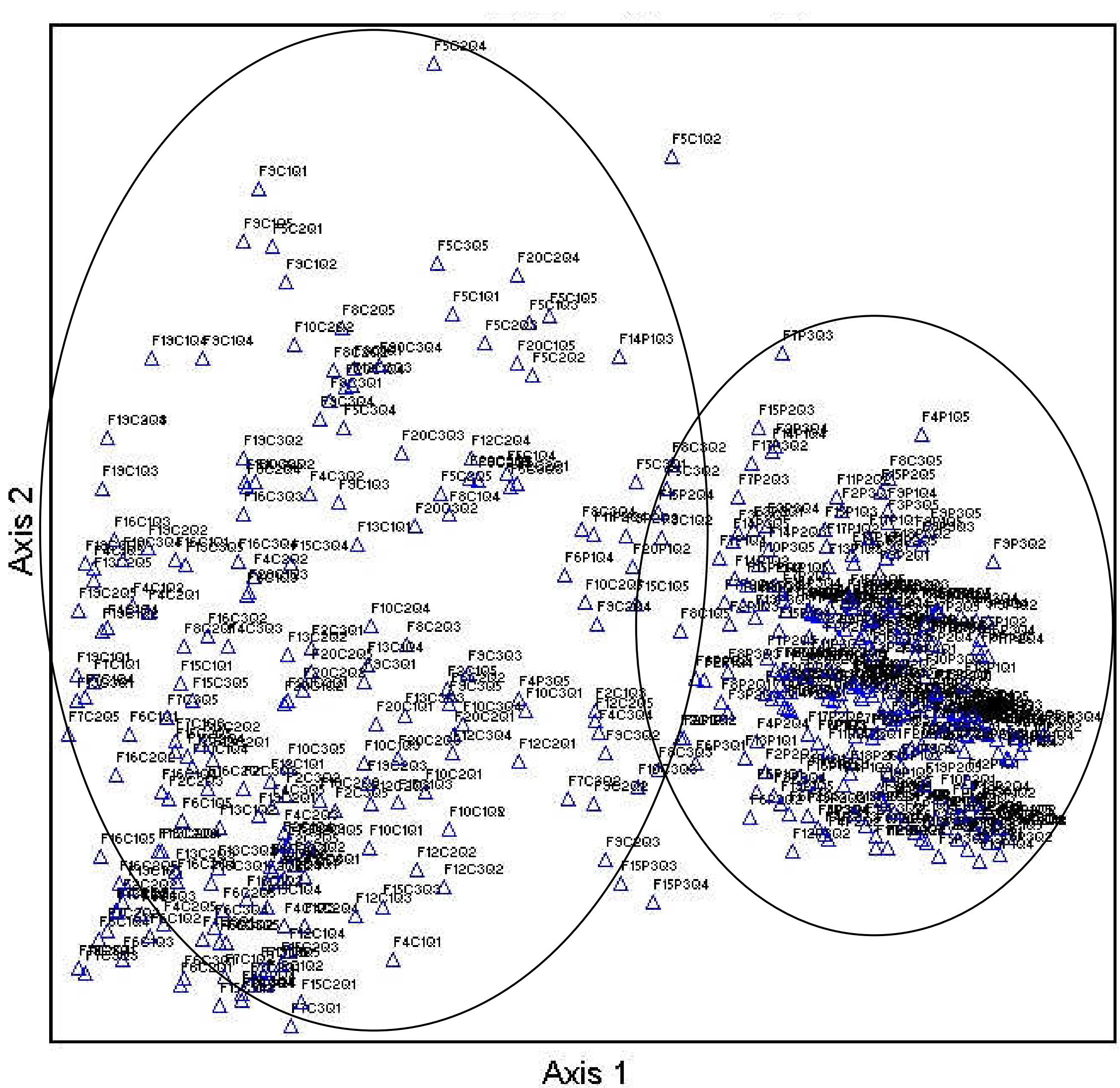


Figure 2.12 Results of Bray-Curtis ordination showing the relatedness of quadrats (n = 494) in cornfields and pastures. Each symbol represents one quadrat.

2.5 Field-Level Analysis

After the initial analyses, transect and quadrat data were aggregated to the level of the individual farm field and then separated by field type. Analyses were then run on cornfield and pasture-level data separately. This was done to see any patterns that might arise from analyzing each set of data by itself, and was validated by the previous analyses that clearly separated cornfields from pastures. Moreover, this design of the analysis enabled comparisons of the environmental and management variables with transect and quadrat data, which were collected by field. These comparisons might also correspond with management variables, which are applied at the field level. To aggregate the data, all like transects (i.e. corn or pasture) were combined into one entry for that farm. Entries remained 0 (absent) or 1 (present), but represented all three transects taken in that particular field. For quadrat data, percent cover became presence-absence (1, 0) data.

2.5.1 Weed Samples Along Transects (Line-Intercept Method) Per Field

In PC-ORD, field-level and field-type spreadsheets of transect data were run through two-way cluster analyses (once for cornfields and again for pastures). Results showed distinct clustering of species in cornfields and pastures. In both cases, the clusters appeared to represent species present on almost all farms, while other less common species were what differentiated farm fields from one another (Figures 2.13 and 2.14). Dissimilarity among farm fields can be seen in the dendrograms (to the left of the grids) of farms in Figures 2.13 and 2.14. Exceptions include cornfields on farms 10, 15, and 19 (Figure 2.13) and pastures on farms 7, 9, and 10 (Figure 2.14). Figures 2.13 and 2.14 show the relatedness of weed species along transects in cornfields and pastures, respectively. In both figures, columns are weed species and rows are a farm's transects. This leads to each square representing the presence (if filled in) or absence (if hollow) of a weed species along a field's transects.

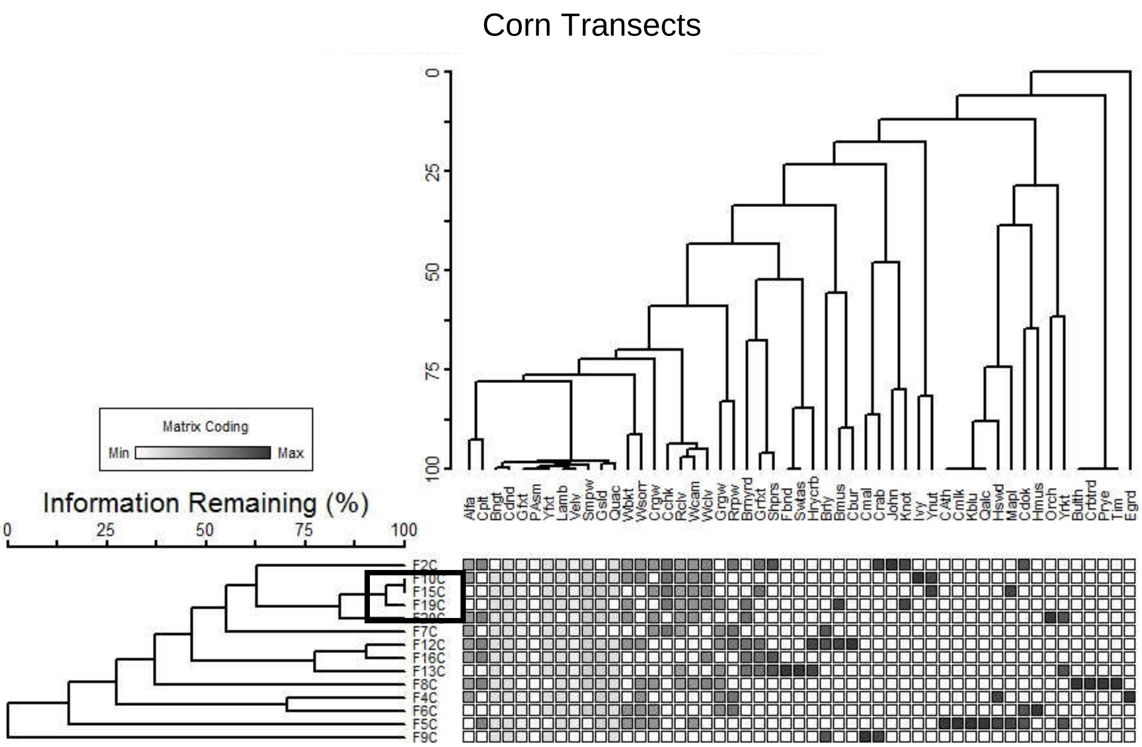


Figure 2.13 Results of two-way cluster analysis showing relatedness of weed species along a farm's transects in cornfields (n = 14). Columns are species and rows are the sum of transects in a single field. The dendrogram of farm fields (to the left of the grid) shows a distinct lack of clustering among farm fields, except for those highlighted.

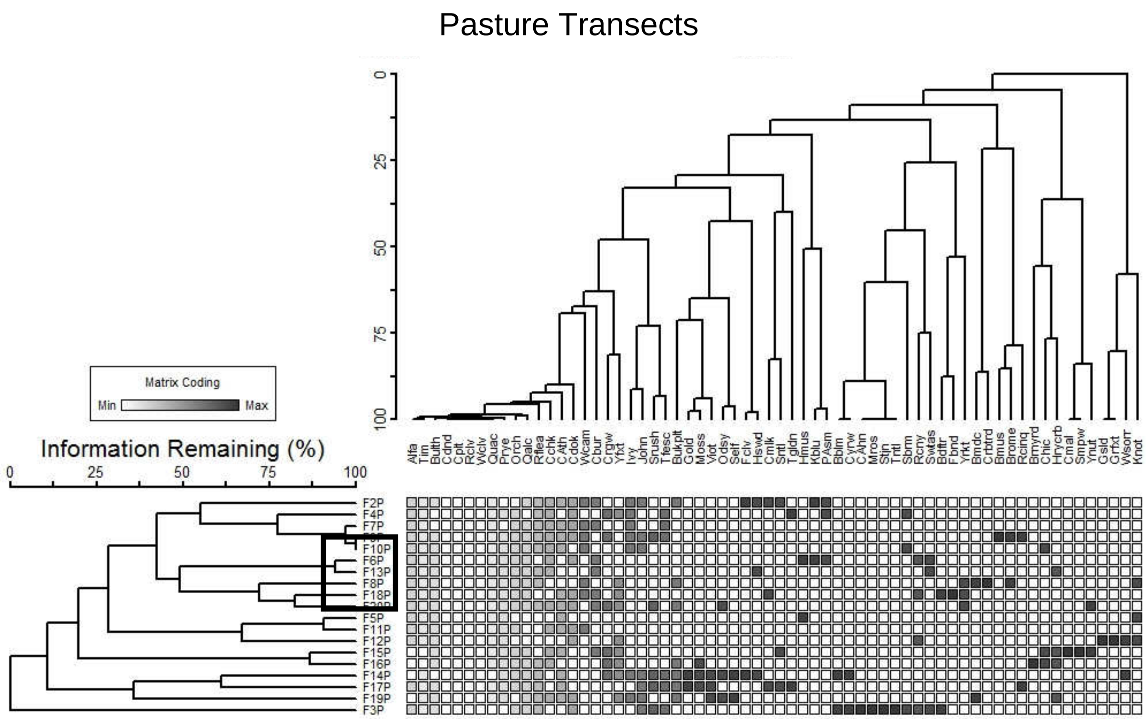


Figure 2.14 Results of two-way cluster analysis showing relatedness of weed species along a farm's transects in pastures (n = 19). Columns are species and rows are the sum of transects within a single field. The dendrogram of farm fields (to the left of the grid) shows a distinct lack of clustering among farm fields, except for those highlighted.

Habitual, in-between, and rare species were determined for both cornfields and pastures (Table 2.7). Species were defined as 'habitual' if they were present on at least two thirds of farm fields for that field type. There were eight habitual species in cornfields only, 10 in pastures only, and two species habitual to both cornfields and pastures. Species were defined as 'in-between' if they were in less than two thirds but more than one quarter of farm fields for that field type. There were eight in-between species in cornfields only, nine in pastures only, and three species in-between to both cornfields and pastures. Species were defined as 'rare' if they were in no more than one quarter of farm fields for that field type. There were 15 rare species in cornfields only, 27 in pastures only, and 13 species rare to both cornfields and pastures. For pastures, there were a greater number of rare species that set each farm apart, resulting in a greater number of species overall in pastures for the study. Corn fields, however, had fewer rare species that set each field apart, resulting in a smaller number of species overall for cornfields in the study. This differentiation in weed species also resulted in few farm fields being alike.

Habitual (In min. of 2/3 of farm fields)		
Common Name	**Scientific Name**	**Field Type**
Black nightshade	*Solanum nigrum*	Corn
Giant foxtail	*Setaria faberi*	Corn
Yellow foxtail	*Setaria lutescens*	Corn
Lambsquarter	*Chenopodium album*	Corn
Velvetleaf	*Abutilon theophrastii*	Corn
Smooth pigweed	*Amaranthus hybridus*	Corn
Gallant soldier	*Galinsoga parviflora*	Corn
Pennsylvania smartweed	*Polygonum pennsylvanicum*	Corn
Alfalfa	*Medicago sativa*	Pasture
Timothy grass	*Phleum pratense*	Pasture
Bull thistle	*Cirsium vulgare*	Pasture
Perennial rye	*Lolium perenne*	Pasture
Orchard grass	*Dactylis glomerata*	Pasture
Queen anne’s lace	*Daucus carota*	Pasture
Common plantain	*Plantago major*	Pasture
Red clover	*Trifolium pratense*	Pasture
White clover	*Trifolium repens*	Pasture
Rough fleabane	*Erigeron strigosus*	Pasture
Quackgrass	*Elytrigia repens*	Both
Common dandelion	*Taraxacum officinale*	Both
In-between (In at least ¼ of farm fields and less than 2/3 of farm fields)		
Wild buckwheat	*Polygonum convolvulus*	Corn
Wood sorrel	*Oxalis stricta*	Corn
Red clover	*Trifolium pratense*	Corn
White clover	*Trifolium repens*	Corn
Giant ragweed	*Ambrosia trifida*	Corn
Redroot pigweed	*Amaranthus retroflexus*	Corn
Barnyard grass	*Echinochloa crus-galli*	Corn
Green foxtail	*Setaria viridis*	Corn
Canada thistle	*Cirsium arvense*	Pasture
Curly dock	*Rumex crispus*	Pasture
Common burdock	*Arctium minus*	Pasture
Yellow foxtail	*Setaria lutescens*	Pasture

Ground ivy	*Glechoma hederacea*	Pasture
Johnson grass	*Sorghum halepense*	Pasture
Slender rush	*Juncus tenius*	Pasture
Tall fescue	*Festuca arundinacea*	Pasture
Buckhorn plantain	*Plantago lanceolata*	Pasture
Common chickweed	*Stellaria media*	Both
White campion	*Silene latifolia*	Both
Common ragweed	*Ambrosia artemisiifolia*	Both
Rare (In less than ¼ of farm fields)		
Shepherd's purse	*Capsella bursa-pastoris*	Corn
Barley	*Hordeum vulgare*	Corn
Common burdock	*Arctium minus*	Corn
Crabgrass	*Digitaria spp*	Corn
Johnson grass	*Sorghum halepense*	Corn
Ground ivy	*Glechoma hederacea*	Corn
Canada thistle	*Cirsium arvense*	Corn
Queen anne's lace	*Daucus carota*	Corn
Maple	*Acer spp*	Corn
Curly dock	*Rumex crispus*	Corn
Orchard grass	*Dactylis glomerata*	Corn
Bull thistle	*Cirsium vulgare*	Corn
Perennial rye	*Lolium perenne*	Corn
Timothy grass	*Phleum pratense*	Corn
Elliot's goldenrod	*Solidago latissimifolia*	Corn
Goldenrod	*Solidago spp*	Pasture
Moss	*Bryophyte spp*	Pasture
Violet	*Viola spp*	Pasture
Oxeye daisy	*Leucanthemum vulgare*	Pasture
Self heal	*Prunella vulgaris*	Pasture
Field clover	*Trifolium campestre*	Pasture
Saint John's wort	*Hypericum perforatum*	Pasture
Tall goldenrod	*Solidago altissima*	Pasture
Pennsylvania smartweed	*Polygonum pennsylvanicum*	Pasture
Bee balm	*Monarda fistulosa*	Pasture
Common yarrow	*Achillea millefolium*	Pasture
Carolina horsenettle	*Solanum carolinense*	Pasture
Multiflora rose	*Rosa multiflora*	Pasture
Stinging nettle	*Urtica dioica*	Pasture
Tall nettle	*Urtica procera*	Pasture
Smooth brome	*Bromus inermis*	Pasture
Reed canary grass	*Phalaris arundinacea*	Pasture
Bird's-foot trefoil	*Lotus corniculatus*	Pasture
Black medic	*Medicago sativa*	Pasture
Bromegrass	*Bromus spp*	Pasture
Rough cinquefoil	*Potentilla norvegica*	Pasture
Barnyard grass	*Echinochloa crus-galli*	Pasture
Chicory	*Cichorium intybus*	Pasture
Smooth pigweed	*Amaranthus hybridus*	Pasture

Gallant soldier	*Galinsoga parviflora*	Pasture
Green foxtail	*Setaria viridis*	Pasture
Wood sorrel	*Oxalis stricta*	Pasture
Field bindweed	*Convolvulus arvensis*	Both
Small white aster	*Aster vimineus*	Both
Hairy crabgrass	*Digitaria sanguinalis*	Both
Black mustard	*Brassica nigra*	Both
Common mallow	*Malva neglecta*	Both
Knotgrass	*Paspalum distichum*	Both
Yellow nutsedge	*Cyperus esculentus*	Both
Common milkweed	*Asclepias syriaca*	Both
Kentucky bluegrass	*Poa pratensis*	Both
Horseweed	*Conyza canadensis*	Both
Hedge mustard	*Sisymbrium officinale*	Both
Yellow rocket	*Barbarea vulgaris*	Both
Creeping bentgrass redtop	*Agrostis stolonifera*	Both

Table 2.7 Biogeographic distribution of habitual, in-between, and rare weed species along farm transects within cornfields and pastures (see definitions in section 2.5.1).

To verify the findings from the two-way cluster analyses and to better understand the distinctions between habitual and rare weed species, a Bray-Curtis ordination was run (Figures 2.15 and 2.16). These ordinations were run with a Sorensen distance measure and used variance-regression as the endpoint selection method for axes 1 and 2. Results verified the dissimilarity among farm fields of both corn and pasture as well as the small clusters of associated farms. It is important to note that two-way cluster results are not always reflected in Bray-Curtis results.

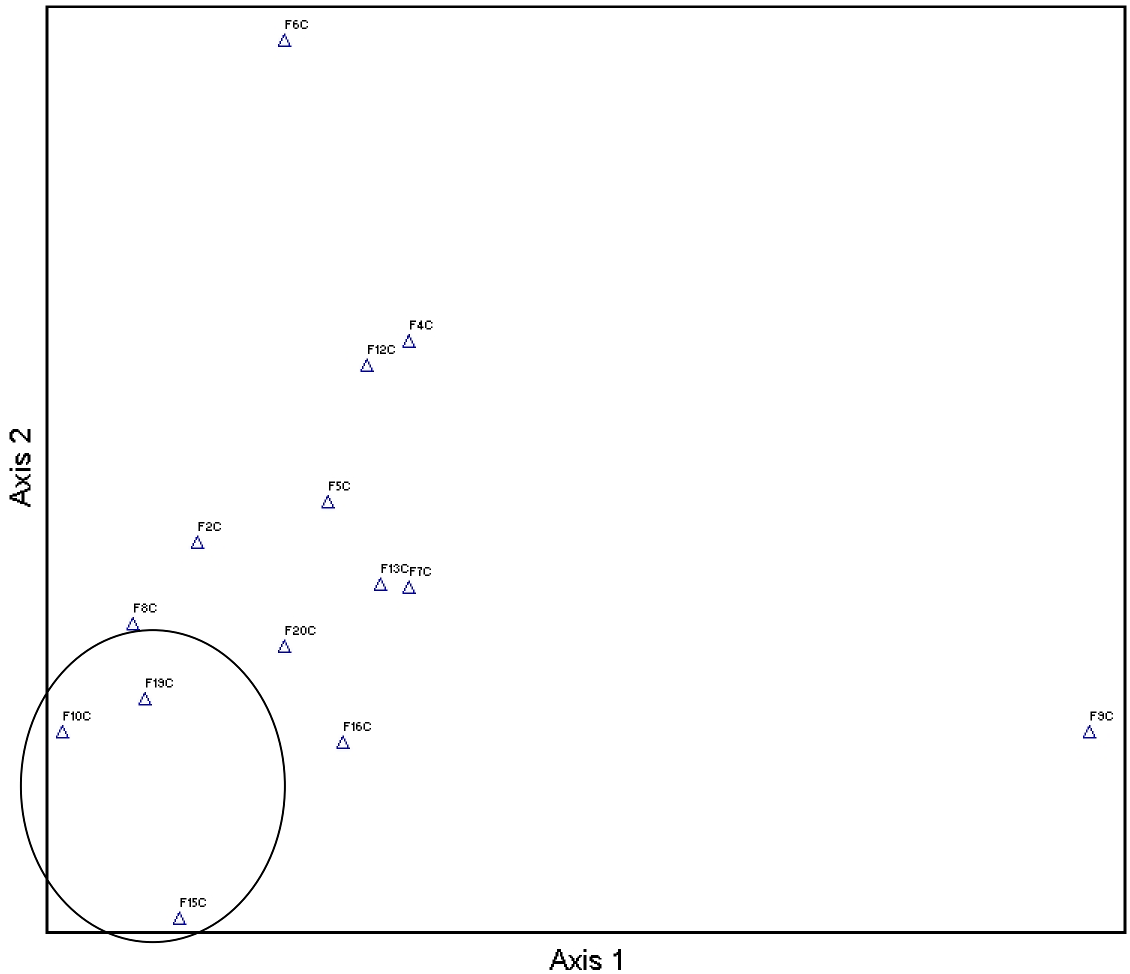


Figure 2.15 Results of Bray-Curtis ordination showing the relatedness of weed species along a farm's transects within cornfields (n = 14). The circle highlights the associated farms from the two-way cluster analysis. Each symbol represents one farm where cornfields were sampled.

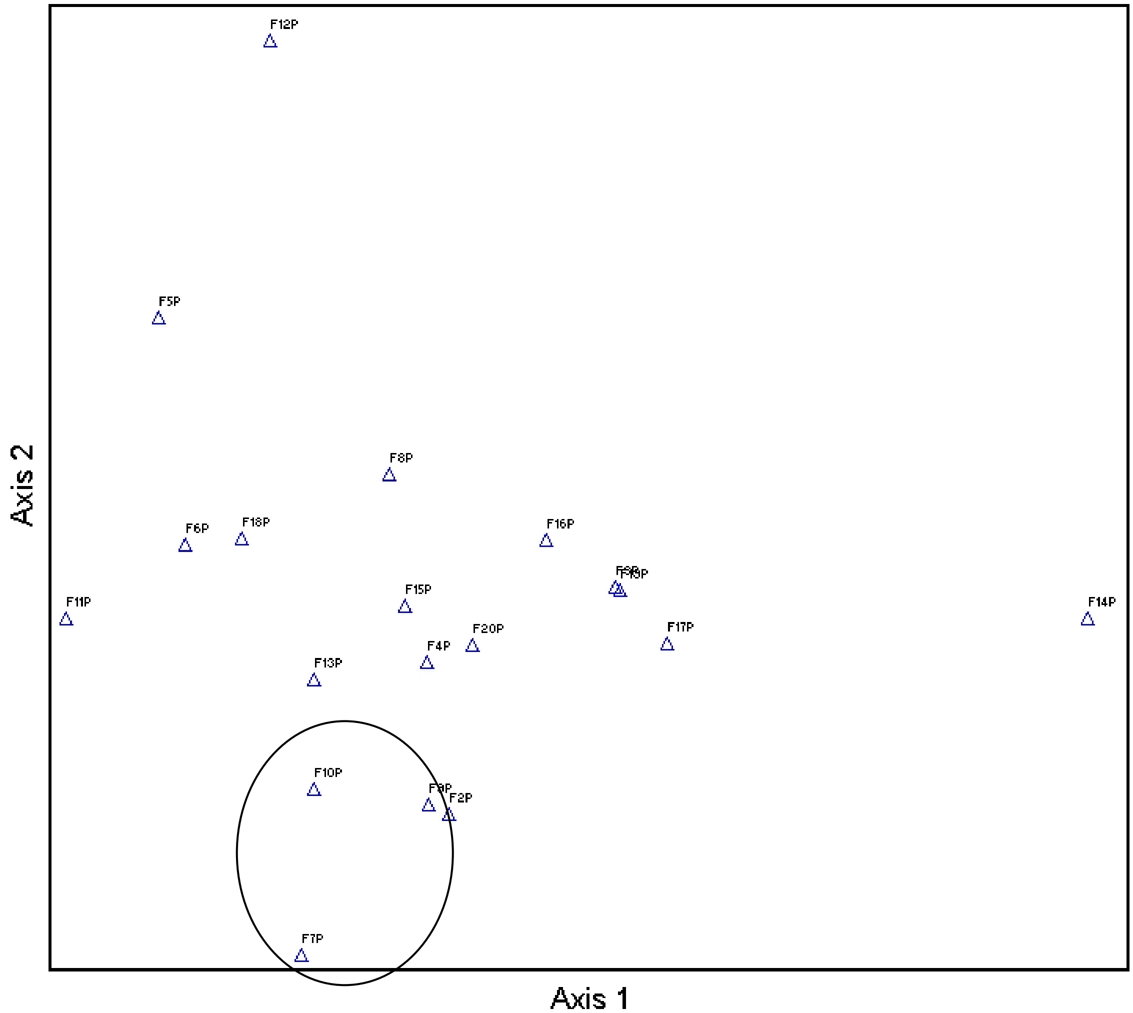


Figure 2.16 Results of Bray-Curtis ordination showing the relatedness of weed species along a farm's transects within pastures (n = 19). The circle highlights the associated farms from the two-way cluster analysis. Each symbol represents one farm where cornfields were sampled.

I then chose to run a joint plot overlay of environmental variables onto the Bray-Curtis ordination results to either verify or disprove previous findings that found environmental variables insignificant in explaining the statistical clustering of weed species along transects and within quadrats. Results showed that elevation was a significant factor in explaining weedy species variation in cornfields (R^2 = 0.33) (Figure 2.17). In Figure 2.17, the variable 'elevation' (DEM) increased along the length of the arrow. For pastures, percent sand (R^2 = 0.29), mean and max slope (R^2 = 0.35), elevation

(R^2 = 0.22), and soil ph (R^2 = 0.20) all proved significant factors in farm field variation (Figure 2.18).

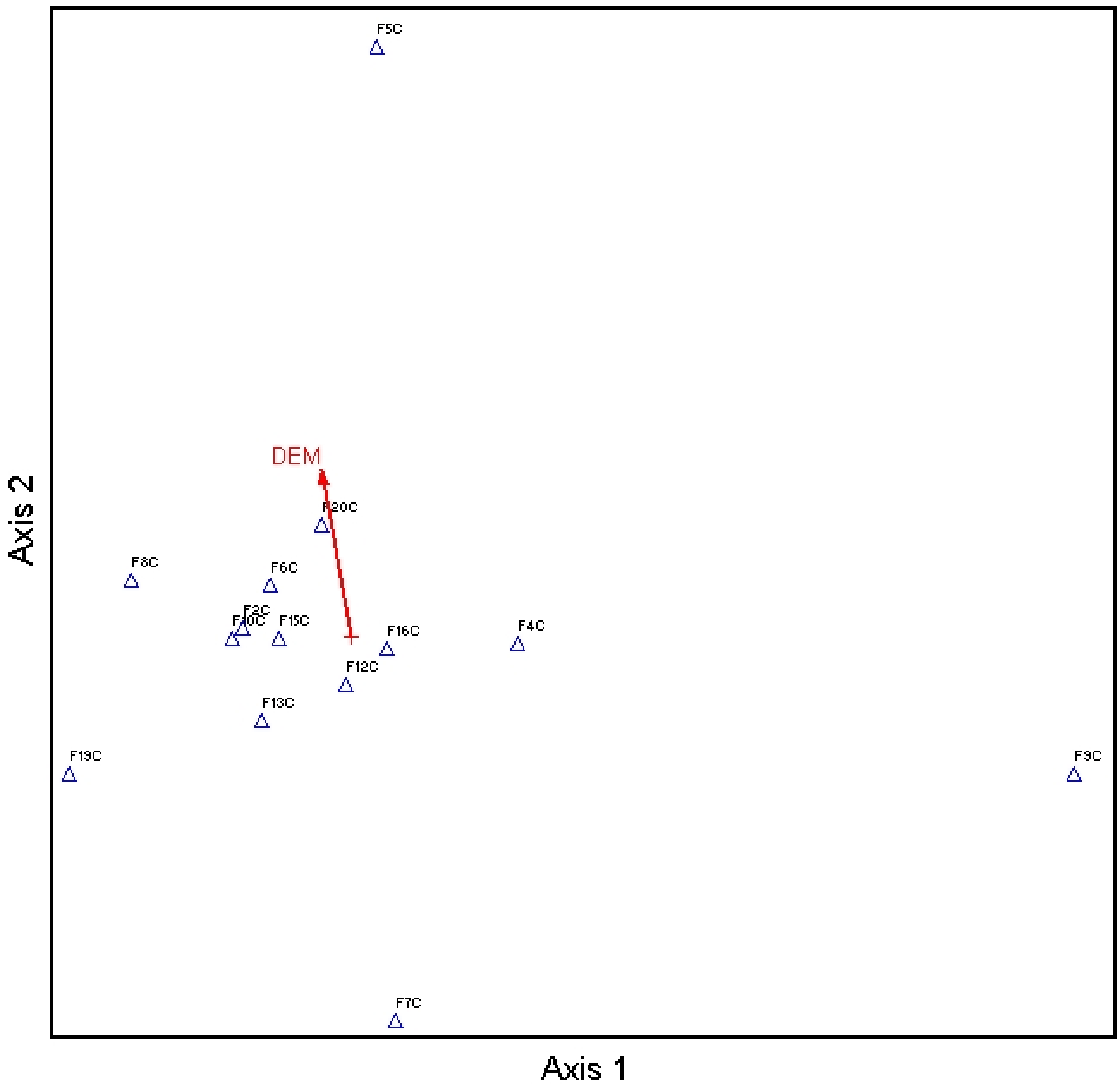


Figure 2.17 Overlay of joint plot analysis on Bray-Curtis ordination results of weed species along farm transects in cornfields (n = 14) showing their relationship to the statistically significant environmental variable ‘elevation.’ Weed samples along farm transects show a statistically significant relation in direction of arrow.

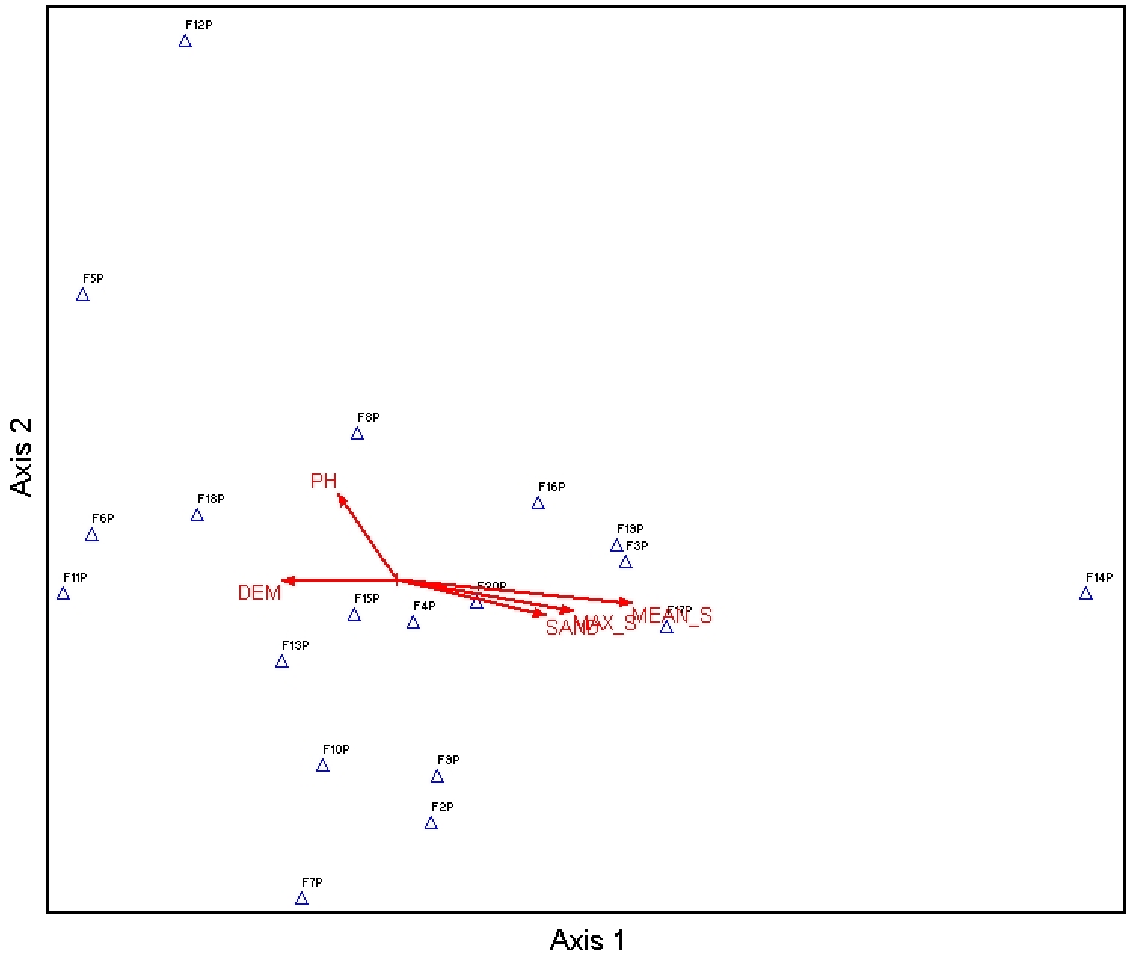


Figure 2.18 Overlay of joint plot analysis on Bray-Curtis ordination results of weed species along farm transects in pastures (n = 19) showing their relationship to the statistically significant environmental variables ‘elevation,’ ‘pH,’ ‘percent sand,’ ‘mean slope’ and ‘maximum slope.’ Weed samples along farm transects show a statistically significant relation in direction of arrows.

A second joint plot overlay of management variables showed that for cornfields, the number of crops on a farm ($R^2 = 0.24$) was a significant factor in explaining farm field variation (Figure 2.19). The minimum number of crops grown on farms where cornfields were sampled was two and the maximum was five. For pastures, organic certifier ($R^2 = 0.22$), number of information sources ($R^2 = 0.21$), length of crop rotation ($R^2 = 0.201$), and number of crops ($R^2 = 0.20$) all showed significant levels of explaining farm field variation (Figure 2.20). There were three organic certifiers used by farmers whose pastures were sampled in this study: MOSA, CROPP, and Oregon Tilth OTCO Farms. The minimum number of information sources identified by farmers whose pastures were sampled in this study was zero and the maximum was three. The minimum crop rotation length used by farmers whose pastures were sampled in this study was zero and the maximum was nine years. Finally, the minimum number of crops grown on a farm where pastures were sampled in this study was zero (not including pasture) and the maximum was five.

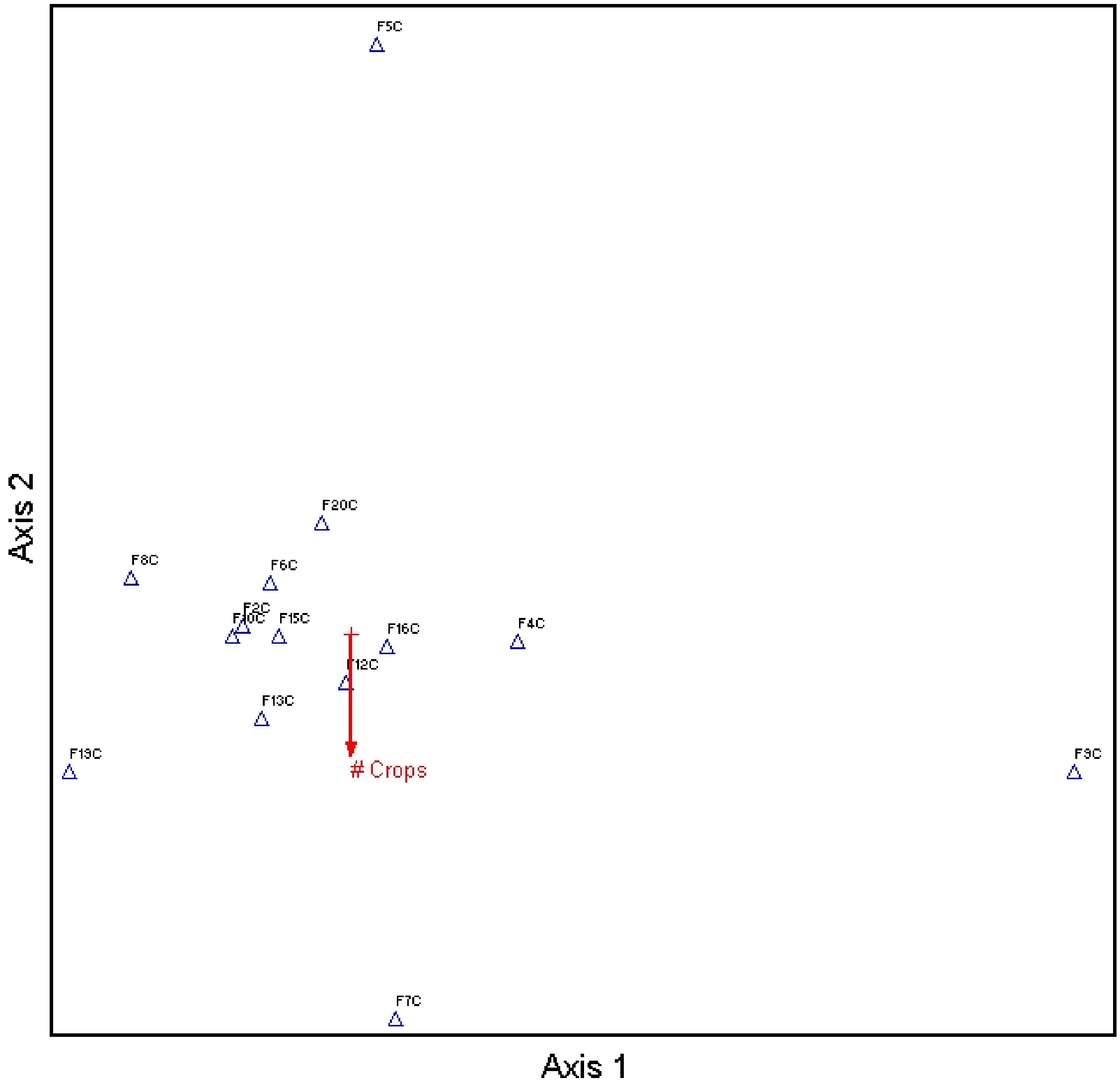


Figure 2.19 Overlay of joint plot analysis on Bray-Curtis ordination results of weed species along farm transects in cornfields (n = 14) showing their relationship to the statistically significant management variable 'number of crops.' Weed samples along farm transects show a statistically significant relation in direction of arrow.

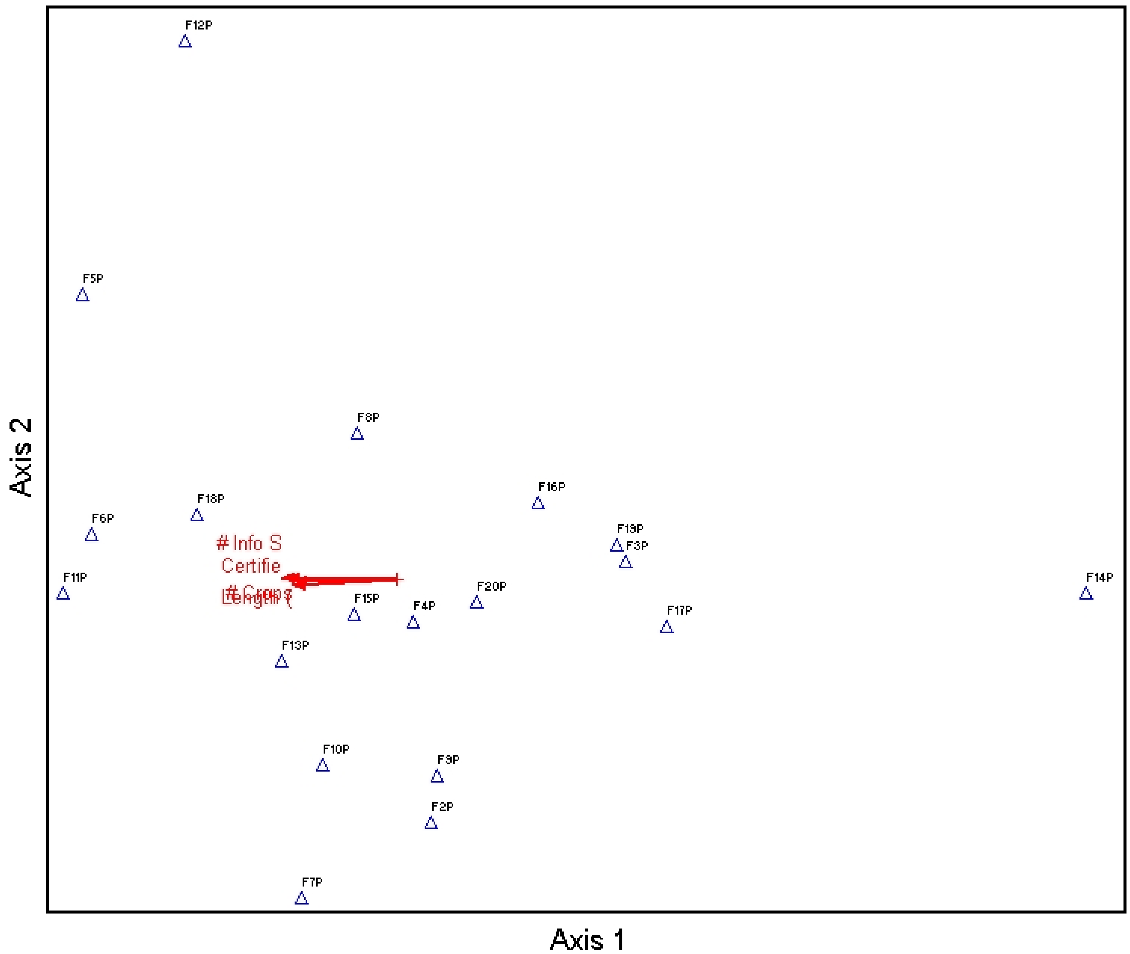


Figure 2.20 Overlay of joint plot analysis on Bray-Curtis ordination results of weed species along farm transects in pastures (n = 19) showing their relationship to the statistically significant management variables 'number of crops,' 'number of information sources,' 'organic certifier,' and 'length of crop rotation.' Weed samples along farm transects show a statistically significant relation in direction of arrows.

2.5.2 Weed Samples in Quadrats Per Field

In PC-ORD, field-level and field-type spreadsheets of quadrat data were run through two-way cluster analyses (once for cornfields and again for pastures). Results again showed distinct clustering of species in cornfields and pastures. In both cases, the clusters appeared to represent species present on almost all farms, and that other less common species were what differentiated farm fields from one another (Figures 2.21 and 2.22). Dissimilarity among farm fields can be seen in the dendrograms (to the left of the grids) of farms in Figures 2.21 and 2.22. Exceptions include cornfields from farms 6 and 19, and pastures in farms 16 and 20. Figures 2.21 and 2.22 show the relatedness of weed species in quadrats in cornfields and pastures, respectively. In both figures, columns are weed species and rows are a farm's quadrats. This leads to each square representing the presence (if filled in) or absence (if hollow) of a weed species in a farm's quadrats.

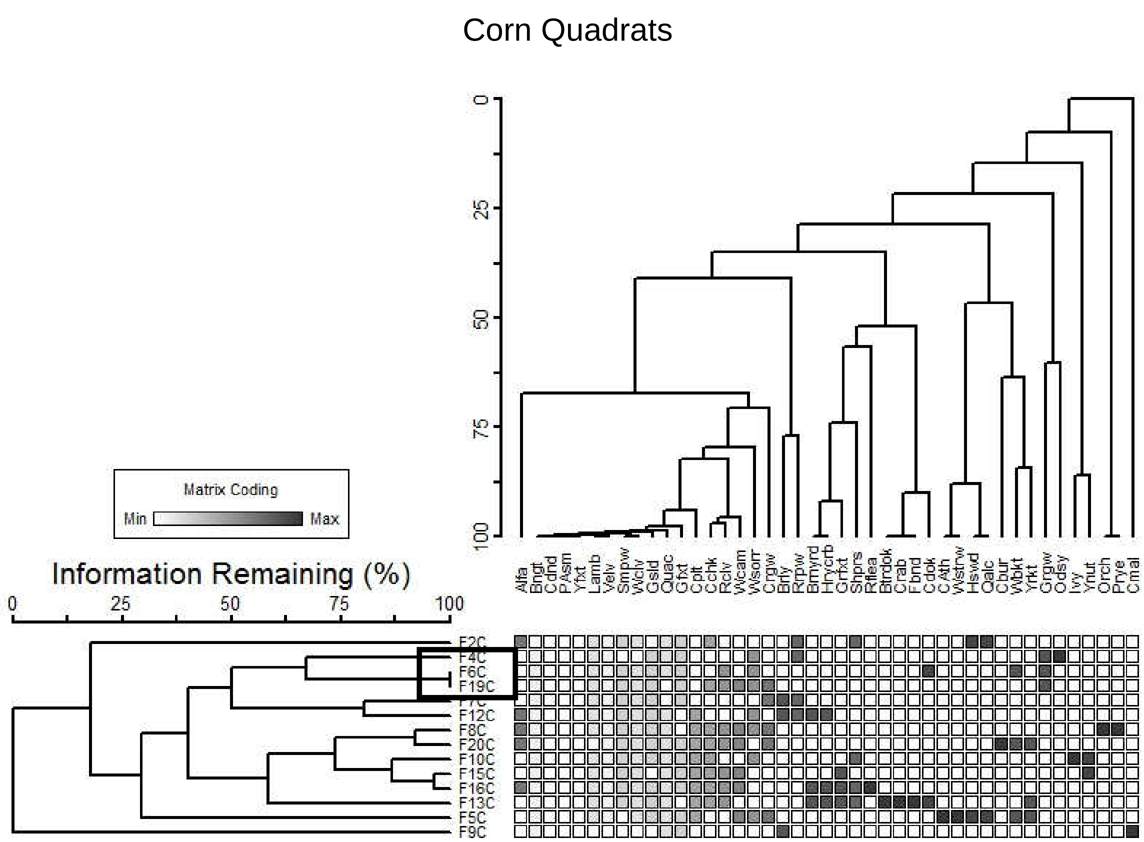


Figure 2.21 Results of two-way cluster analysis showing relatedness of weed species within a farm's quadrats in cornfields (n = 14). Columns are species and rows are the sum of quadrats in a single field. The dendrogram of farm fields (to the left of the grid) shows a distinct lack of clustering among farm fields, except for those highlighted.

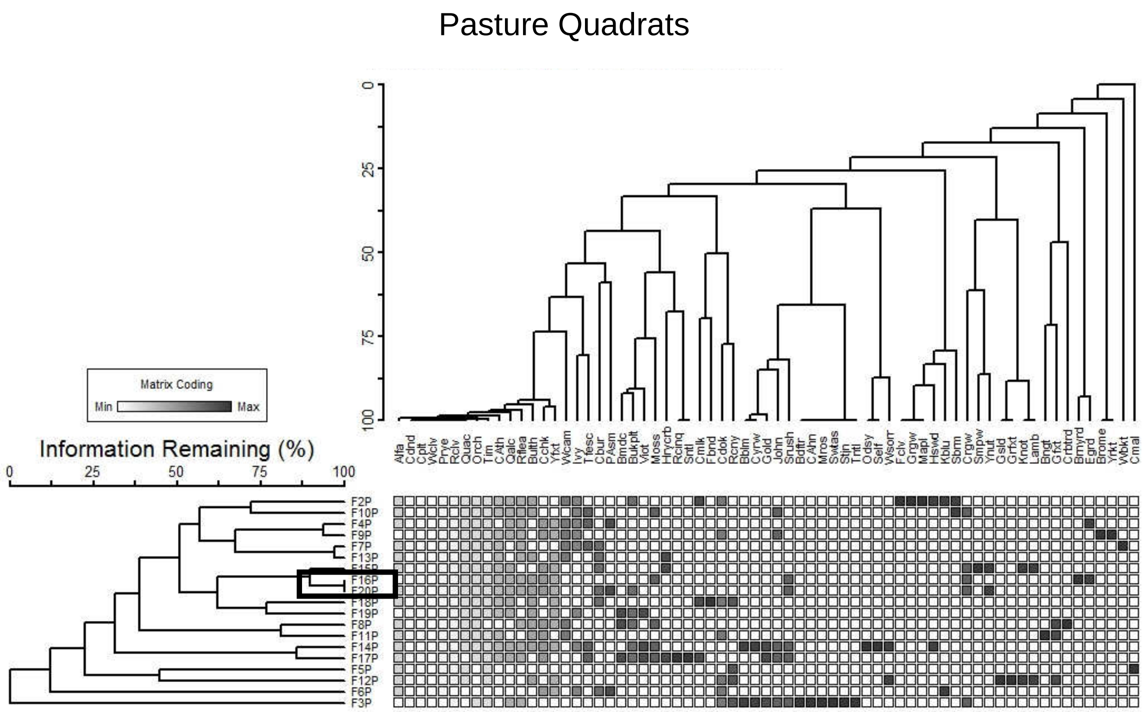


Figure 2.22 Results of two-way cluster analysis showing relatedness of weed species within a farm's quadrats in pastures (n = 19). Columns are species and rows are the sum of quadrats within a single field. The dendrogram of farm fields (to the left of the grid) shows a distinct lack of clustering among farm fields, except for those highlighted.

Habitual and rare species were determined for both corn a pastures (Table 2.8). Species were defined as 'habitual' if they were present on at least two-thirds of farm fields for that field type. There were 9 habitual species in cornfields only, 7 in pastures only, and 2 species habitual to both cornfields and pastures. Species were defined as 'in-between' if they were in less than two-thirds but more than one-quarter of farm fields for that field type. There were 5 'in-between' species in cornfields only, 13 in pastures only, and 3 in both cornfields and pastures. Species were defined as 'rare' if they were in no more than one-quarter of farm fields for that field type. There were 12 rare species in cornfields only, 31 in pastures only, and 11 species rare in both cornfields and pastures. For pastures, there were a greater number of rare species that set each farm apart, resulting in a greater number of species overall in pastures for the study. Corn fields, however, had fewer rare species that set each field apart, resulting in a smaller number of species overall for cornfields in the study. This differentiation in weed species also resulted in few farm fields being alike.

Habitual (In min. of 2/3 of farm fields)		
Common Name	**Scientific Name**	**Field Type**
Black nightshade	*Solanum nigrum*	Corn
Pennsylvania smartweed	*Polygonum pennsylvanicum*	Corn
Yellow foxtail	*Setaria lutescens*	Corn
Lambsquarter	*Chenopodium album*	Corn
Velvetleaf	*Abutilon theophrastii*	Corn
Smooth pigweed	*Amaranthus hybridus*	Corn
Gallant soldier	*Galinsoga parviflora*	Corn
Giant foxtail	*Setaria faberi*	Corn
Alfalfa	*Medicago sativa*	Pasture
Common plantain	*Plantago major*	Pasture
Perennial rye	*Lolium perenne*	Pasture
Red clover	*Trifolium pratense*	Pasture
Orchard grass	*Dactylis glomerata*	Pasture
Timothy grass	*Phleum pratense*	Pasture
Common dandelion	*Taraxacum officinale*	Both
White clover	*Trifolium repens*	Both
Quackgrass	*Elytrigia repens*	Both
In between (In at least ¼ of farm fields and less than 2/3 of farm fields)		
Common plantain	*Plantago major*	Corn
Red clover	*Trifolium pratense*	Corn
Wood sorrel	*Oxalis stricta*	Corn
Red root pigweed	*Amaranthus retroflexus*	Corn
Shepherd's purse	*Capsella bursa-pastoris*	Corn
Canada thistle	*Cirsium arvense*	Pasture
Queen anne's lace	*Daucus carota*	Pasture
Rough fleabane	*Erigeron strigosus*	Pasture
Bull thistle	*Cirsium vulgare*	Pasture
Yellow foxtail	*Setaria lutescens*	Pasture
Ground ivy	*Glechoma hederacea*	Pasture
Tall fescue	*Festuca arundinacea*	Pasture
Common burdock	*Arctium minus*	Pasture
Buckhorn plantain	*Plantago lanceolata*	Pasture
Moss	*Bryophyte spp*	Pasture
Curly dock	*Rumex crispus*	Pasture
Johnson grass	*Sorghum halepense*	Pasture

Slender rush	*Juncus tenius*	Pasture
White campion	*Silene latifolia*	Both
Common chickweed	*Stellaria media*	Both
Common ragweed	*Ambrosia artemisiifolia*	Both
Rare (In less than ¼ of farm fields)		
Barley	*Hordeum vulgare*	Corn
Rough fleabane	*Erigeron strigosus*	Corn
Bitter dock	*Rumex obtusifolius*	Corn
Crabgrass	*Digitaria spp*	Corn
Curly dock	*Rumex crispus*	Corn
Canada thistle	*Cirsium arvense*	Corn
Wild strawberry	*Fragaria virginiana*	Corn
Queen anne's lace	*Daucus carota*	Corn
Common burdock	*Arctium minus*	Corn
Ground ivy	*Glechoma hederacea*	Corn
Orchard grass	*Dactylis glomerata*	Corn
Perennial rye	*Lolium perenne*	Corn
Pennsylvania smartweed	*Polygonum pennsylvanicum*	Pasture
Black medic	*Medicago sativa*	Pasture
Violet	*Viola spp*	Pasture
Rough cinquefoil	*Potentilla norvegica*	Pasture
Stinging nettle	*Urtica dioica*	Pasture
Common milkweed	*Asclepias syriaca*	Pasture
Reed canary grass	*Phalaris arundinacea*	Pasture
Bee balm	*Monarda fistulosa*	Pasture
Common yarrow	*Achillea millefolium*	Pasture
Goldenrod	*Solidago spp*	Pasture
Bird's-foot trefoil	*Lotus corniculatus*	Pasture
Carolina horsenettle	*Solanum carolinense*	Pasture
Multiflora rose	*Rosa multiflora*	Pasture
Small white aster	*Aster vimineus*	Pasture
Saint John's wort	*Hypericum perforatum*	Pasture
Tall nettle	*Urtica procera*	Pasture
Selfheal	*Prunella vulgaris*	Pasture
Wood sorrel	*Oxalis stricta*	Pasture
Field clover	*Trifolium campestre*	Pasture
Maple	*Acer spp*	Pasture
Kentucky bluegrass	*Poa pratensis*	Pasture
Smooth brome	*Bromus inermis*	Pasture
Smooth pigweed	*Amaranthus hybridus*	Pasture
Gallant soldier	*Galinsoga parviflora*	Pasture
Knotgrass	*Paspalum distichum*	Pasture
Lambsquarter	*Chenopodium album*	Pasture
Black nightshade	*Solanum nigrum*	Pasture
Giant foxtail	*Setaria faberi*	Pasture
Creeping bentgrass redtop	*Agrostis stolonifera*	Pasture
Elliot's goldenrod	*Solidago latissimifolia*	Pasture
Bromegrass	*Bromus spp*	Pasture

Barnyard grass	*Echinochloa crus-galli*	Both
Hairy crabgrass	*Digitaria sanguinalis*	Both
Green foxtail	*Setaria viridis*	Both
Field bindweed	*Convolvulus arvensis*	Both
Horseweed	*Conyza canadensis*	Both
Wild buckwheat	*Polygonum convolvulus*	Both
Yellow rocket	*Barbarea vulgaris*	Both
Giant ragweed	*Ambrosia trifida*	Both
Oxeye daisy	*Leucanthemum vulgare*	Both
Yellow nutsedge	*Cyperus esculents*	Both
Common mallow	*Malva neglecta*	Both

Table 2.8 Biogeographic distribution of habitual, in-between, and rare weed species in farm quadrats within cornfields and pastures (See definitions in section 2.5.2).

To verify the findings from the two-way cluster analyses and to better understand the distinctions between habitual and rare weed species, a Bray-Curtis ordination was run (Figures 2.23 and 2.24). These ordinations were run with a Sorensen distance measure and used variance-regression as the endpoint selection method for axes 1 and 2. Results verified the dissimilarity among farm fields of both corn and pasture. Farm clusters from the two-way cluster analyses were not, however, verified.

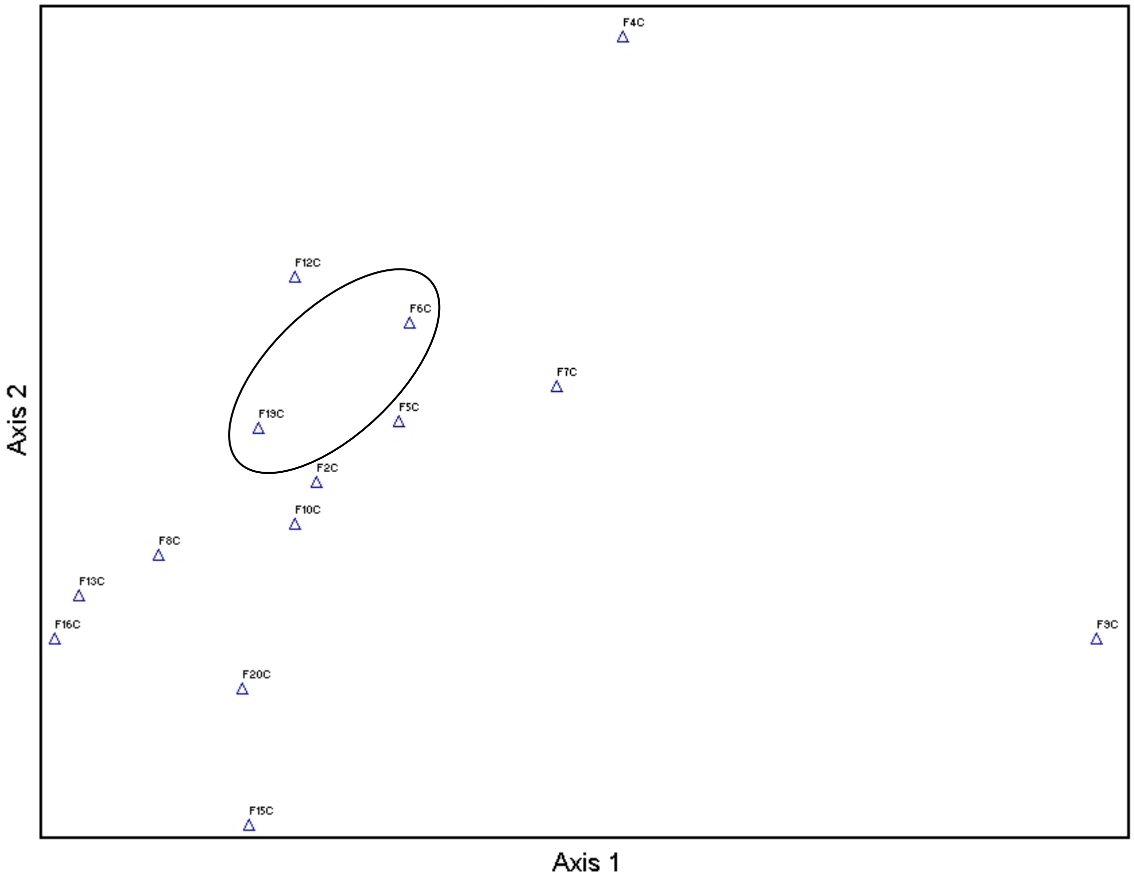


Figure 2.23 Results of Bray-Curtis ordination showing the relatedness of weed species within a farm's quadrats in cornfields (n = 14). The circle highlights the associated farms from the two-way cluster analysis. Each symbol represents one farm where cornfields were sampled.

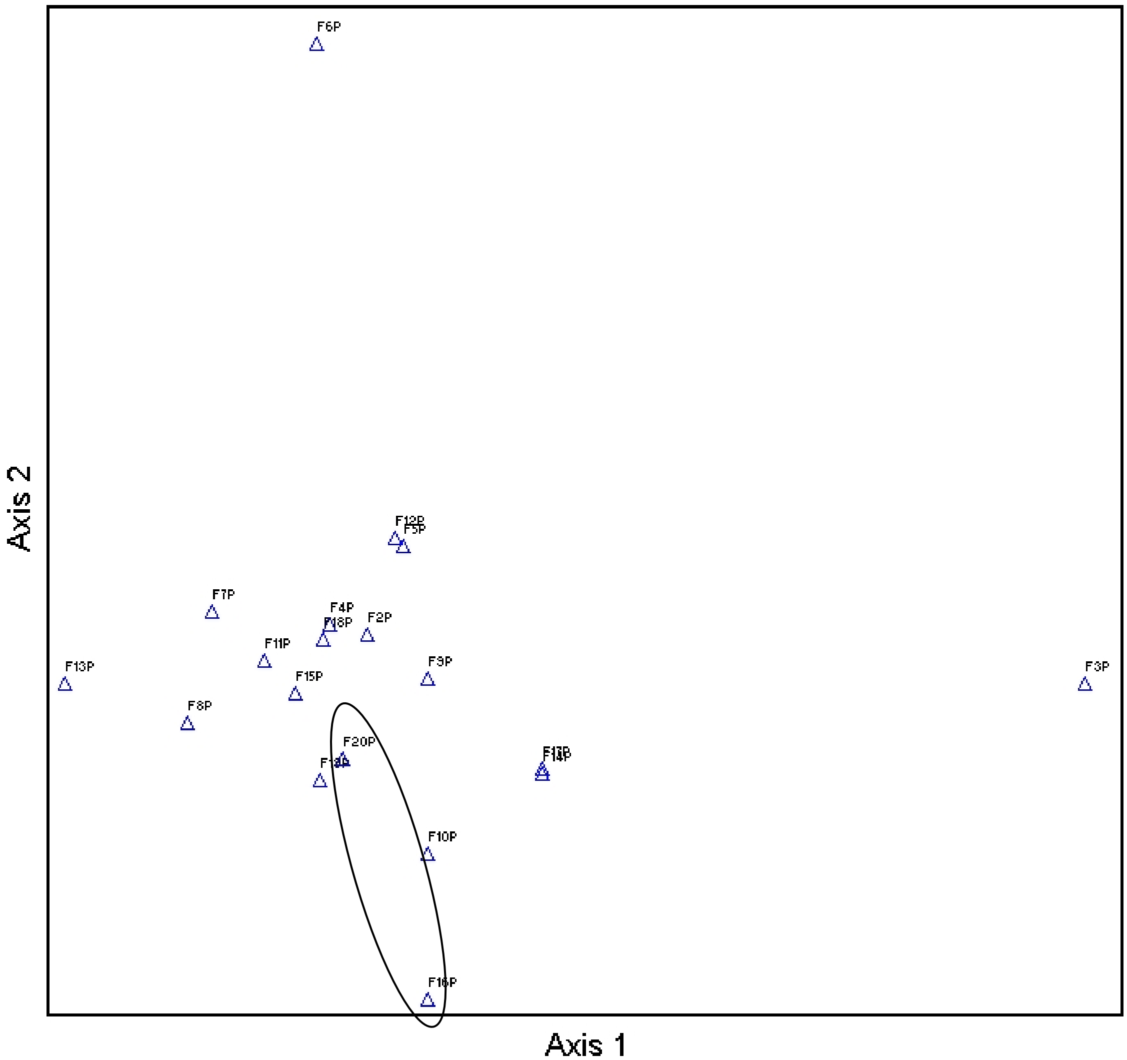


Figure 2.24 Results of Bray-Curtis ordination showing the relatedness of weed species within a farm's quadrats in pastures (n = 19). The circle highlights the associated farms from the two-way cluster analysis. Each symbol represents one farm where pastures were sampled.

I then chose to run a joint plot overlay of environmental variables onto the Bray-Curtis ordination results to either verify or disprove previous findings that found environmental variables significant in explaining the statistical clustering of weed species along field transects (see section 2.5.1), but not in explaining the statistical clustering of weed species along disaggregated transects and quadrats (see sections 2.4.1 and 2.4.2). Results showed that for cornfields, both percent silt (R^2 = 0.25) and elevation (R^2 = 0.41) were significant factors in farm field variation (Figure 2.25). For pastures, percent sand (R^2 = 0.31), mean slope (R^2 = 0.318), and climatic zone (R^2 = 0.23) all proved significant factors in farm field variation (Figure 2.26).

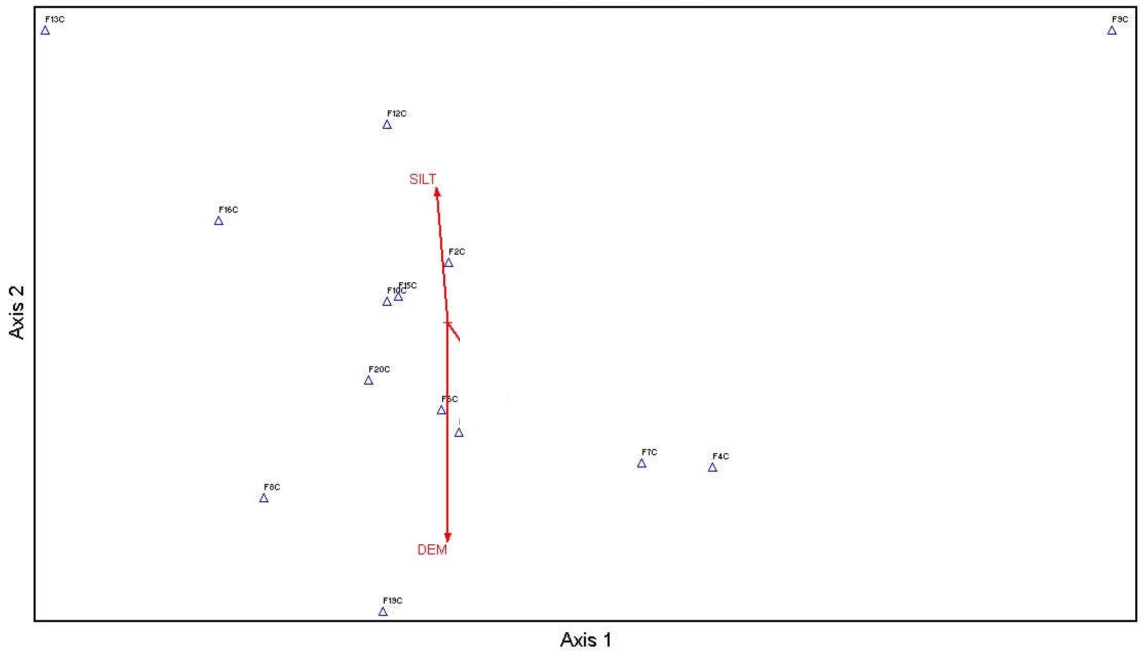


Figure 2.25 Overlay of joint plot analysis on Bray-Curtis ordination results of weed species within farm quadrats in cornfields (n = 14) showing their relationship to the statistically significant environmental variables ‘percent silt’ and ‘elevation.’ Weed samples within farm quadrats show a statistically significant relation in direction of arrows.

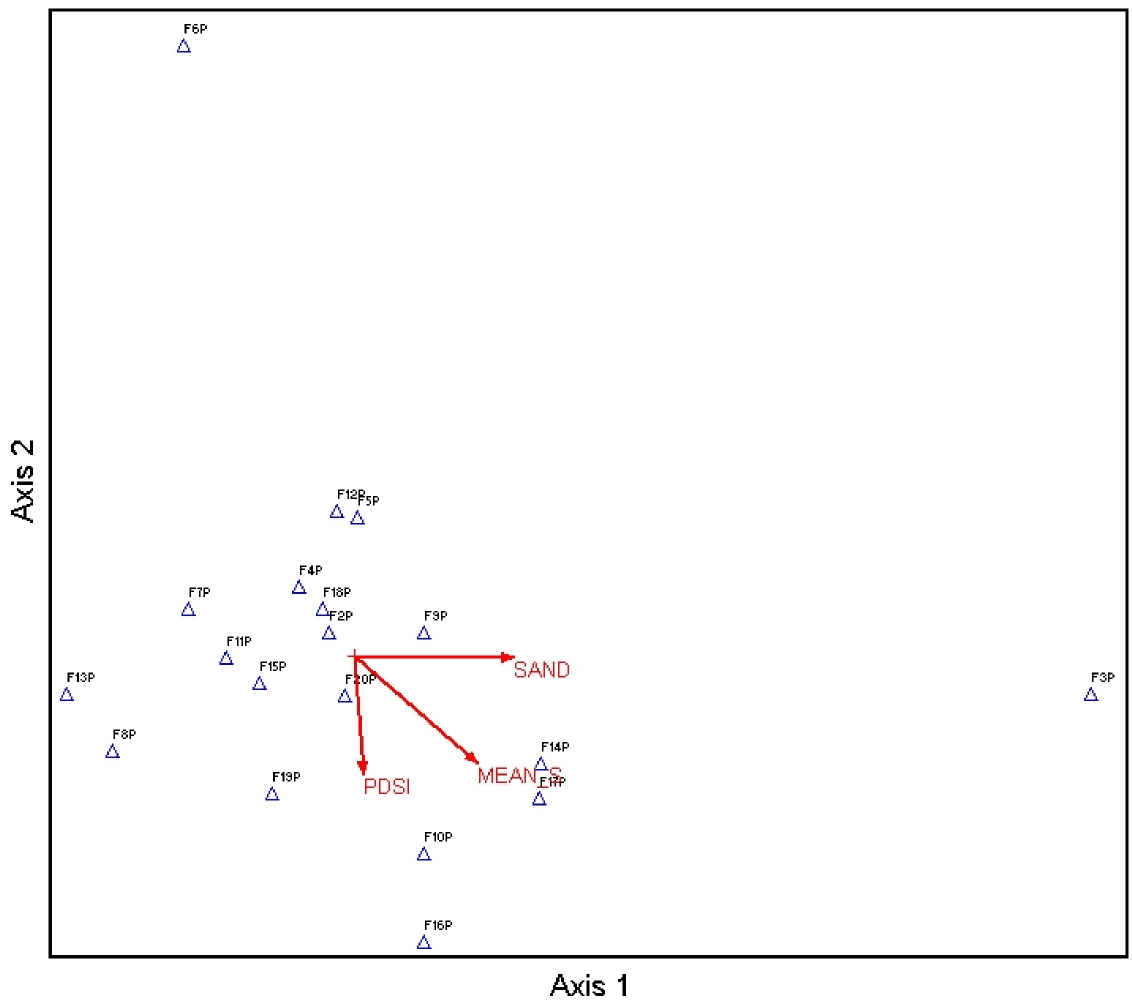


Figure 2.26 Overlay of joint plot analysis on Bray-Curtis ordination results of weed species within farm quadrats in pastures (n = 19) showing their relationship to the statistically significant environmental variables ‘percent sand,’ ‘mean slope’ and ‘climatic zone.’ Weed samples within farm quadrats show a statistically significant relation in direction of arrows.

A second joint plot overlay of management variables showed that for cornfields, both the number of years a farmer has been organic (R^2 = 0.202) and the number of common weed species on a farm (as indicated by the farmer) (R^2 = 0.21) were significant factors in explaining farm field variation (Figure 2.27). The minimum number of years a farmer (whose cornfields were sampled in this study) has been organic was zero, and the maximum number of years someone has been organic was 57. There were two farms included in this study that were not USDA certified organic, so those two farms have been organic for zero years. The minimum number of common weed species identified by a farmer for his/her farm (whose cornfields were sampled in this study) was zero, and the maximum was nine. For pastures, organic certifier (R^2 = 0.52), number of information sources (R^2 = 0.33), length of crop rotation (R^2 = 0.42), and number of crops (R^2 = 0.41) all showed significant levels of explaining farm field variation (Figure 2.28). There were three organic certifiers used by the farmers whose pastures were sampled in this study; MOSA, CROPP and Oregon Tilth OTCO Farms. The minimum number of information sources used by farmers whose pastures were sampled in this study was zero and the maximum was three.

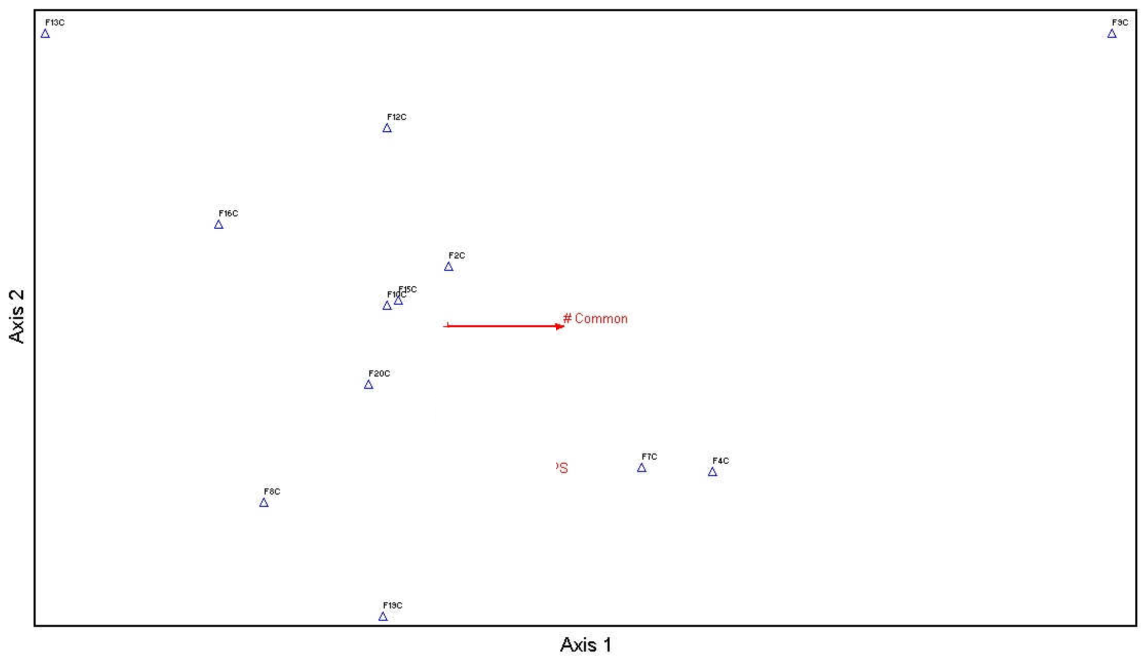


Figure 2.27 Overlay of joint plot analysis on Bray-Curtis ordination results of weed species within farm quadrats in cornfields (n = 14) showing their relationship to the statistically significant management variable ‘number of common weeds.’ Weed samples within farm quadrats show a statistically significant relation in direction of arrows.

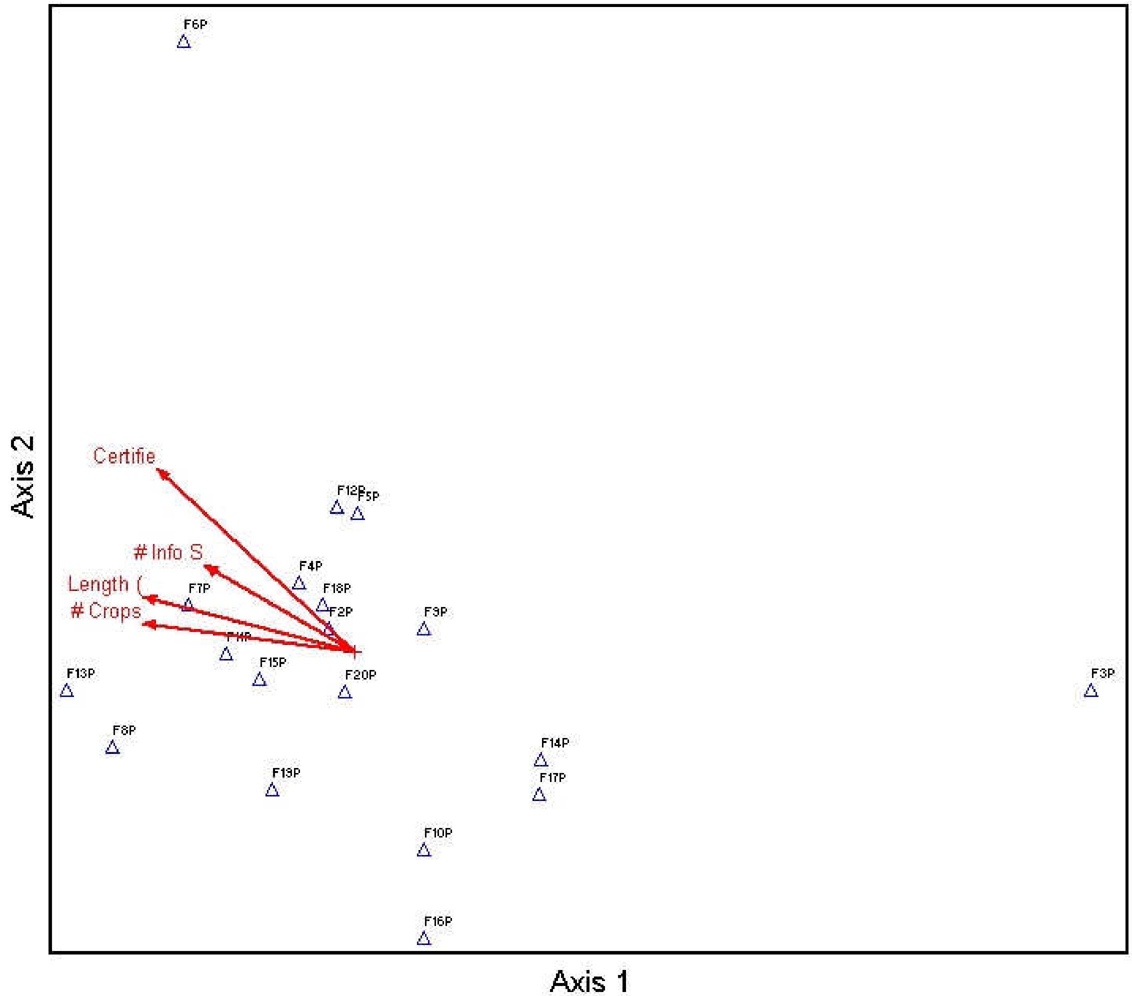


Figure 2.28 Overlay of joint plot analysis on Bray-Curtis ordination results of weed species within farm quadrats in pastures (n = 19) showing their relationship to the statistically significant management variables ‘number of crops,’ ‘length of crop rotation,’ ‘number of information sources’ and ‘organic certifier.’ Weed samples within farm quadrats show a statistically significant relation in direction of arrows.

Chapter 3

RESULTS & DISCUSSION

3.1 Introduction

This chapter reviews the findings from Chapter 2 and interprets those findings in agroecological and cultural-social contexts. Section 3.2 explores the environmental interpretation findings and section 3.3 explores the cultural-environmental interpretation findings. Section 3.2 is subdivided into three more sections that cover the following topics: the environmental impacts of the unusually wet growing season, weed flora of cornfields and pastures, and farm clusters based on field-level data. Section 3.3 is further subdivided into four sections covering the impacts of the wet growing season on cultural management, determination of what is a weed, cultural management of cornfields and pastures, and farm clusters based on field-level data. Section 3.4 explores the significance of the cultural management variable ‘number of crops.’

3.2 Environmental Interpretation

This section explores the agroecological findings in four parts. Section 3.2.1 discusses the unique growing season of 2010 and how that may have affected the data and analyses. Section 3.2.2 compares the weed flora of cornfields and pastures. Section 3.2.3 explores the environmental characteristics of the cornfield and pasture clusters (based on their weed flora) found in the two-way cluster analyses in Chapter 2.

3.2.1 Wet Growing Season – Environmental Impacts

The growing season of 2010 had an exceptional amount of rainfall, particularly early in the season. Southwestern Wisconsin in particular received approximately 5 inches of above-average rainfall in June (Figure 3.1) (MWCW 2011). In July, southwestern Wisconsin had anywhere from 2 to 5 inches of above-average rainfall (MWCW 2011). Temperatures in July and August were also above average with mean minimum temperatures 3˚ to 4˚ F higher than normal (MWCW 2011). The 30-year (1971-2000) mean precipitations for June and July are ~ 4 and ~ 5 inches, respectively (MRCC 2011a). July and August 30-year (1971-2000) mean temperatures are 69˚ and 67˚ F, respectively (MRCC 2011b).

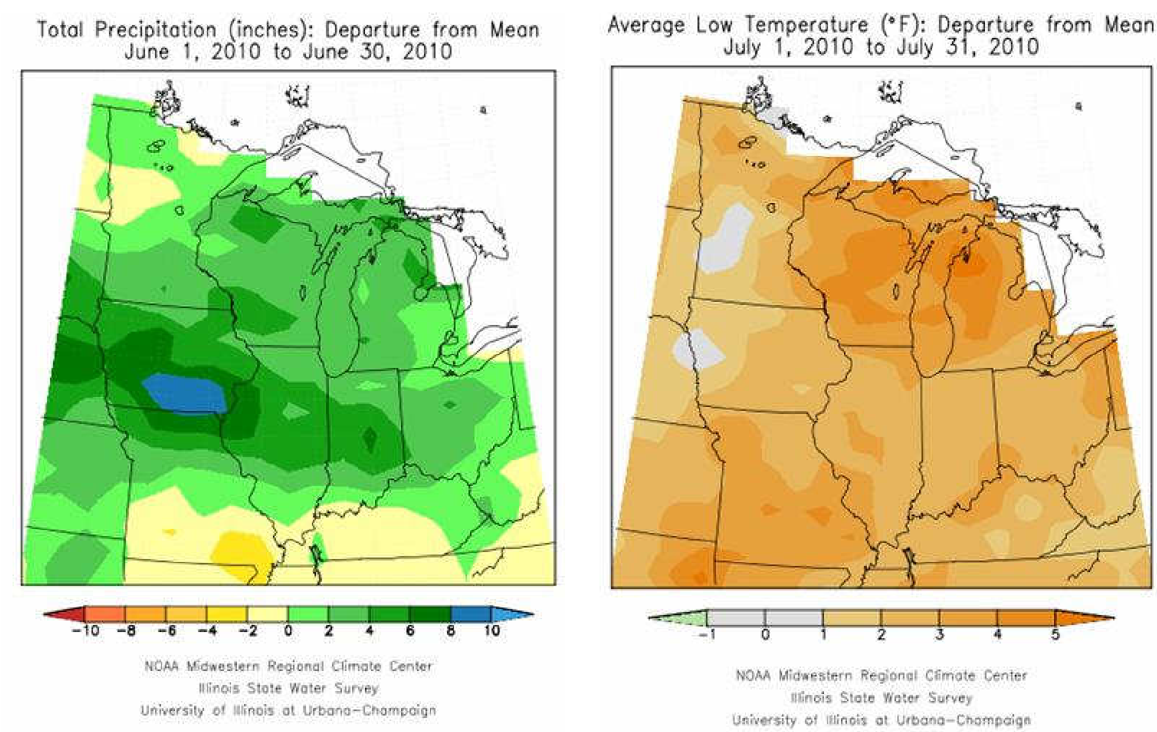


Figure 3.1 Precipitation and temperature departures from mean (June and July, respectively)

The timing of precipitation early in the growing season, directly followed by higher than average temperatures, greatly affected plant growth of both crops and weeds. When asked if the farm had a lot of weeds, farmer 3 responded, "This year it's a lot worse than other years – 'cause of the rain. But other years we do pretty good. This is the worst year in the 22 years that we've done (been farming)" (Interview 3). Another farmer noted that, "The ones (weeds) that are there just get worse when you get a rainy year" (Interview 3). The abundance of weeds in the 2010 growing season was partially due to favorable weather conditions, but also delayed and decreased weed management. This will be further discussed in section 3.3.3. Generally speaking, overall plant growth benefited from increased amounts of available water and increased temperatures.

3.2.2 Weed Flora of Corn and Pasture Fields

The weed flora of cornfields and pastures varied in composition with broadleaves dominating the cornfields and a more even mix of broadleaves, grasses and the addition of legumes in pastures. In the data analyses, six species were found to be common to cornfield transects. Of those six species, five were broadleaves and one was a grass. Twelve species were found to be associated with cornfield transects. Of those species, seven were broadleaved, two were cultivated species (buckwheat and barley), and 3 were grasses. Meanwhile, one species was common to cornfield quadrats (yellow foxtail) and seven were associated with cornfield quadrats (six broadleaved and one grass). These results show a clear dominance of broadleaved weedy species in annual crop fields.

In interviews, farmers were typically concerned about fast growing broadleaved species which can out-compete (leaf-out earlier than) corn in its early stages when it is most vulnerable (Interviews 1, 6, 12, 15). Farmers also identified species as problematic if they were 'hard to control' (Interview 2) or 'spread quickly' (Interview 3). For example, one farmer mentioned that while mustard was a predominant weed species in his cornfields, he did not consider it to be as problematic as ragweed, which he indicated as his most problematic weed species in cornfields because it could out-compete corn (Interview 12). Giant ragweed was mentioned the most (8 out of 20) as a problematic species on farms participating in this study. Several farmers also mentioned velvetleaf as a problematic species. Both giant ragweed and velvetleaf are fast growing broadleaved annuals.

Similar numbers of common and associate weed species were found in pastures; however, many of those species were not considered weeds by farmers, particularly the legumes and grasses. What is and what is not considered a weed is further discussed in section 3.3.2. Six species were common to pasture transects and, of those, one was broadleaved, two were legumes, and three were grasses. Twelve species were found to be associated with pasture transects. Of those species, nine were broadleaved and three were grasses. Four species were common to pasture quadrats: one was broadleaved, two were grasses, and one was a legume. Seven species were associated with pasture quadrats: three were broadleaved, two were legumes, and two were grasses. These results show a distinctly greater mix of broadleaves, legumes and grasses in pastures, as well as a greater mix of annuals, perennials, and biennials in pastures. This gives pastures a more 'natural' appearance, and while some species occurred naturally in pastures, others were intentionally sown in. The amount of management for pastures also varied greatly. Differences between cornfield and pasture weed management is further discussed in section 3.3.3.

Four species were neutral to both cornfield and pasture transects. These species were alfalfa, quackgrass, common dandelion and common ragweed. Quackgrass was the only neutral species in both cornfields and pasture quadrats. While the term ‘neutral’ is my own and describes these species’ lack of preference for a particular field type, it might be more appropriate to say that these are the most aggressive weeds. This explanation better accounts for the widespread presence of these weeds in most fields and both field types sampled in this study.

Differences between the number of common, associate and rare species could also be artifacts of small sample size. Had more samples been taken within each field, more species might have shown up as common or associate, and fewer species as rare. The sampling technique utilized in this study was aimed to identify common weed species, and the limited number of samples does well at identifying those species most common to fields. This method works well because weeds are opportunists and so one would expect these species to be in many fields or habitats. The results clarified differences in weed species assemblages within annual (corn) and perennial (pasture) farm fields, while also identifying highly aggressive weedy species that showed no preferences for field type.

3.2.3 Farm Clusters (Field-Level Data)

The two-way cluster analyses in Chapter 2 showed four field clusters. Clusters indicated similar weed flora in fields. This section explores environmental variables and spatial distribution of farms to see if they helped explain farm correlations.

For corn transects, farms 10, 15, and 19 appeared as a cluster, indicating similar weed flora. The three farms were approximately 5 to 12 miles apart, appearing somewhat close to one another; however, additional farms were located within the cluster. Similar spatial patterns occurred for the other three clusters. For pasture transects, farms 7, 9, and 10 were approximately 4 to 11 miles apart, but also had other farms within their cluster. For corn quadrats, farms 6 and 19 were approximately 15 miles apart. For pasture quadrats, farms 16 and 20 were approximately 35 miles apart. The indistinct spatial distribution of similar farm fields, combined with the increased distance between similar farm fields where quadrats were sampled suggests that spatial proximity does not explain the similar weed flora among clustered farms.

Environmental variables for the four clusters showed similar indistinct correlations. While some variables such as climatic zone (PDSI), percent clay (CLAY), percent organic matter (OM), and pH (PH) have similar values for farms, these values had small ranges for all farms, so the likelihood of any farms having similar values for them was high. The greatest variation among farms was their minimum, maximum, and mean slope. Tables 3.1 – 3.4 show the environmental variable values for the four farm field clusters.

	PDSI	SAND	SILT	CLAY	OM	PH	DEM	MIN_S	MAX_S	MEAN_S
F10C	7	9	67	24	2	6.00	361.04	0.20	20.79	7.73
F15C	7	11	67	22	3	6.00	356.02	0.07	33.09	8.93
F19C	7	9	41	24	2	6.00	373.56	0.16	128.06	18.27

Table 3.1 Environmental variables for farms 10, 15, and 19.

	PDSI	SAND	SILT	CLAY	OM	PH	DEM	MIN_S	MAX_S	MEAN_S
F7P	7	11	67	21	3	6.00	370.08	0.12	57.82	11.17
F9P	7	9	67	24	2	6.00	351.81	0.09	88.75	12.88
F10P	7	9	67	24	2	6.00	357.96	0.36	39.81	10.75

Table 3.2 Environmental variables for farms 7, 9, and 10.

	PDSI	SAND	SILT	CLAY	OM	PH	DEM	MIN_S	MAX_S	MEAN_S
F6C	4	12	70	18	3	6.20	387.28	0.06	52.90	10.08
F19C	7	9	41	24	2	6.00	373.56	0.16	128.06	18.27

Table 3.3 Environmental variables for farms 6 and 19.

	PDSI	SAND	SILT	CLAY	OM	PH	DEM	MIN_S	MAX_S	MEAN_S
F16P	7	11	67	21	3	6.00	349.94	0.10	72.65	19.86
F20P	4	14	55	15	2	6.20	411.07	0.07	64.31	17.20

Table 3.4 Environmental variables for farms 16 and 20.

It has also been noted that separating and testing the significance of various environmental variables is extremely difficult, and further complicated by agricultural practice (Pysek & Leps 1991). Thus, it was not surprising that few environmental variables showed significance in determining field weed species relatedness. In another study, Andersson and Milberg (1998) found sites to differ substantially in regards to their weed flora. However, while there was little climatic difference between study sites there were soil (edaphic) differences. My environmental variables showed similar results. The authors, however, also note the difficulty of comparing sites with different land-use histories and management, which determine the available species pool in any particular area.

3.3 Cultural-Environment Interpretation

This section explores the cultural-environmental findings in four parts. Section 3.3.1 discusses the impacts of the wet growing season on cultural management. Section 3.3.2 discusses the definition of a weed and what farmers considered to be a weed on their farms. Section 3.3.3 explores the differences in cultural management of cornfields and pastures. Section 3.3.4 explores the farm field clusters identified in Chapter 2 by two-way cluster analyses of cornfield and pasture data.

3.3.1 Wet Growing Season – Cultural Management Impacts

As stated earlier, overall plant growth of both crops and weeds benefited from increased amounts of available water and increased temperatures. The abundance of weeds in the 2010 growing season, in particular, was partially due to favorable weather conditions, but perhaps more so due to the timing and general decrease in weed management. Heavy rain early in the growing season greatly limited weed management after initial planting of corn. In fact, many farmers only got into their fields once or twice for cultivation, when they would normally cultivate anywhere from 4-5 times (Figure 3.2). Although a significant portion of the farmers were able to cultivate as many as three times, this still seemed to have a large impact on the abundance of weeds on farms.

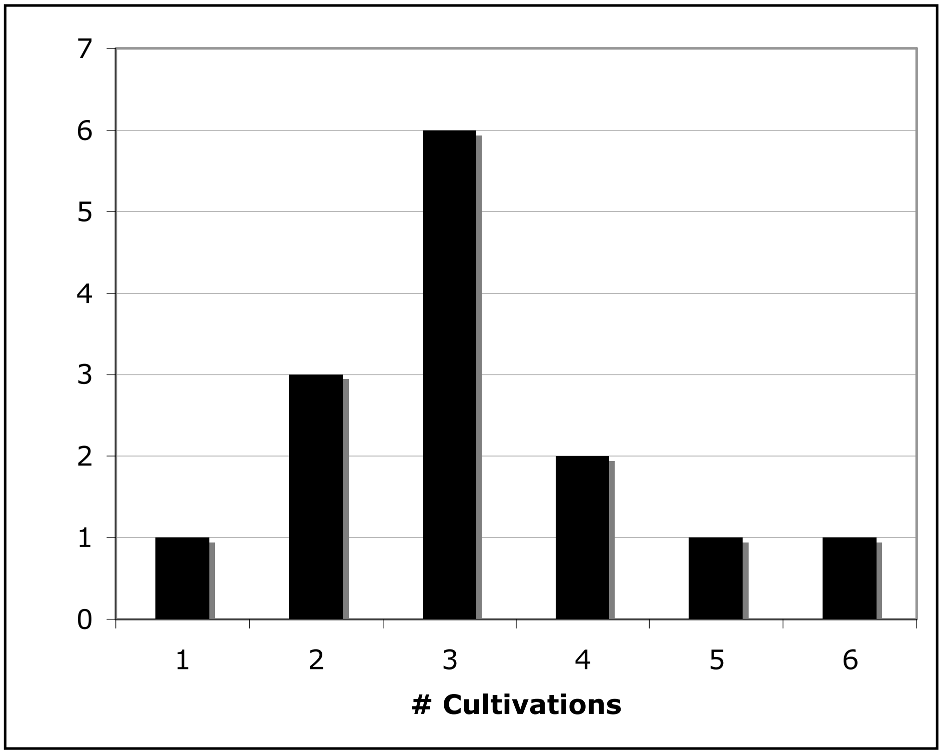


Figure 3.2 The number of times farmers were able to cultivate in the 2010 growing season.

As one farmer put it, “We’ve learned to control weeds – to manage and control weeds….and most years we have essentially no weeds in our corn by following a specific practice. Now if you don’t follow the practices there are weeds all over the place” (Interview 1). Other farmers expressed similar sentiments, noting that the constant rain throughout the month of June kept them out of their fields precisely when they should have been conducting repeated cultivations. The notable exception to the decrease in cultivation was a farm that was able to carry out its full series of 5 cultivations – this farm was the southernmost farm visited and likely experienced significantly different rainfall.

3.3.2 What Is A Weed?

As was discussed in section 3.2.3 weed flora between cornfields and pastures varied in their composition of plants based on physiological (i.e. broadleaf vs. grass vs. legume) and life-cycle type (i.e. annual vs. perennial vs. biennial). What further differentiated cornfields and pastures was farmer perception of what was considered a weed. As was discussed in section 1.1.3, the definition of a weed is highly subjective and depends not only on the person using the term, but also the environment being considered. In cornfields, the definition of a weed was more certain – any unwanted plant was considered a weed (i.e. anything other than corn in a cornfield). In pastures, what was considered a weed was often more fluid. As one farmer put it, “We’re doing more pasturing and in the…rotational grazing process…new species of plants are introduced but in rotational grazing in particular you just don’t talk very much about weeds, you talk about forage and what’s edible” (Interview 1).

Species often identified as weeds in pastures were not palatable to cows – thistles (Canada and Bull) were mentioned by 9 out of 20 farmers interviewed for this study. Queen anne’s lace and multiflora rose were also mentioned several times as pasture weeds, while other naturally occurring species such as common dandelion were not considered a weed or did not bother farmers with their presence (Interview 17). These species were not considered a weed because they were palatable or nutritious for cows (Interview 13, 17). On a farm visit, farmer 12 saw another farmer who ground his weed seeds into flour – “There are amino acid proteins in weed seeds that you can’t get in other crops. They are not our enemy, they are our friends” (Interview 12). In a similar vein, when another farmer was asked if his farm had a lot of weeds, he replied “It’s all weeds, corn is a weed! It's all a weed! Yeah, there's a fair amount, but I don't care" (Interview 10). He went on to explain that during a drought several years ago, some farmers had the roadside weeds tested and found that they had 18% protein (the same as alfalfa) (Interview 10). He also noted that the cows eat most weeds anyway (Interview 10).

Some species were borderline as far as being considered a weed – while some farmers considered burdock a weed (Interviews 7, 18) others noted that their cows ate it, so they did not consider it a weed (Interview 11). Others took a more holistic view towards weeds in general. When asked about weeds on his farm, farmer 1 said, "Probably the most problematic weed is velvetleaf – it's difficult to control. But none of them are a problem, I mean, they're all there" (Interview 1). A handful of farmers also mentioned the use of weeds as indicators of soil quality, nutrients and conditions (Interviews 2, 12, 13).

3.3.3 Cultural Management of Corn and Pasture Fields

While weed flora of cornfields and pastures differed, their cultural management also differed. Regarding land use, farmers typically put their least productive land into pasture and broadcast-seeded a forage mix while putting their most productive land into crop production. Exceptions to this included one farmer who put his best land into pasture. He said that people thought he was crazy, but his stance was that his cows lived off the pasture and putting his best land into pasture enabled him to put his cows out early and take them off late (Interview 8). A handful of farmers in this study had pasture only; one farmer, with only 33 acres stated that he could not afford to have weeds in his pasture, so he managed it like a crop (Interview 10).

Aside from the locations of pastures, similar to identical management techniques were used for pasture weed management. At least 11 of the 20 farmers mowed their pastures once a season, while three farmers mowed their pasture at least twice a season, and one farmer mowed his pastures after each grazing. Meanwhile, management of corn pastures was also strikingly similar among the studied farms. After initial plowing of the ground, seven farmers cultivated their fields once before planting. Planting on average took place in mid to late May. After planting, most farms then continued a pattern of letting their fields sit and cultivating them anywhere from one to five times. Before cultivating, two farms utilized flaming, with one of those farms just experimenting with it.

The important thing to note is the lack of variation of management among farms in their pastures and cornfields. Many alternative weed management techniques have been and continue to be developed by researchers, extension agents and innovative farmers; however, this study clearly showed a dominant weed management system across all farms in the study area.

3.3.4 Farm Clusters (Field-Level Data)

Section 3.2.4 explored the environmental variables of farm fields to determine if they explained weed flora similarity among farm clusters as indicated by two-way cluster analyses. Indistinct patterns suggested environmental variables did not help explain farm clusters. If environmental variables do not help explain weed flora similarity on farms, then it is likely that cultural management may help to explain similarities among farms.

The first farm cluster based on weed species sampled along corn transects included farms 10, 15, and 19. All three farms were certified by MOSA around the same time (2002 – 2003) and grew similar numbers of crops on them (although the actual crops grown varied). Both farm 10 and 19 grew three different crops – both included corn and hay, but while farm 10 grew barley, farm 19 grew oats. Farm 15 grew four different crops: corn, hay, oats, and sudan sorghum. Farmers also reported similar common weed species on their farms – ragweed, velvetleaf and various grasses. All the farms cultivated/rotary hoed three-four times after planting corn. The time between cultivation was similar among the farms (one week to 10 days). The farms had similar lengths of crop rotation (five-six years).

The second farm cluster based on weed species sampled along pasture transects included farms 7, 9, and 10. In this cluster, certifiers varied greatly with one farm using MOSA, another using CROPP and the third farm not being certified organic. Farmers managing farms 7 and 9 had been farming for similar amounts of time (since 1991 and 1990, respectively). The number of crops grown was more varied, with farm 7 growing five different crops, and farms 9 and 10 both growing three crops. Like the corn transects cluster, farmers again identified similar common weed species on their farms – ragweed, velvetleaf, lambsquarter, and thistles. For pasture management, both certified organic farms clipped their fields. Crop rotation varied among the three farms from three to six years.

The third farm cluster based on weed species sampled in corn quadrats, included farms 6 and 19. Both farms used different organic certifiers (Oregon Tilth and MOSA, respectively). The farms were, however, certified around the same time (2002 and 2003, respectively). Both farms grew three crops, with corn and hay being on both farms. Where farm 6 grew barley for its third crop, farm 19 grew oats. Both farmers reported ragweed and foxtails as common weeds on their farms. Both farmers also reported that overall or specific weed pressure had decreased since going organic or within the past few years. Both farms have similar length of crop rotations (five to six years).

The fourth farm cluster based on weed species sampled in pasture quadrats, included farms 16 and 20. Both farms were certified by MOSA in 2002 and 2001, respectively. Unfortunately, the manager of farm 20 was not available for an interview during this study so any other similarities between the farms are unknown.

Across the four clusters, the year a farm was certified organic appears to be significant. Interestingly, this variable did not prove to be significant when all the farms were run through Bray-Curtis ordinations. Also constant for the four farm clusters was the variation in farm size (in total acres).

3.4. Number of Crops – A Proxy for Agroecosystem Complexity?

Data analyses showed that the number of crops grown on a farm was significant in terms of farm field and sampling unit relatedness (based on weed species sampled). At the surface, this appears to be a disincentive for agroecosystem complexity, especially in results such as those seen in the corn transects analysis where corn transects appeared to increase in weed species relatedness as the number of crops on a farm decreased (Figure 2.19). Other results, from all transects (Figure 2.10), pasture transects (Figure 2.20), and pasture quadrats at the field-level (Figure 2.28), appear more indistinct as to the directions of their relationships.

The number of crops grown on a farm as a disincentive for agroecosystem complexity in regards to weed species makes perfect sense. Ecologically speaking, the fewer crops grown on a farm, the fewer microhabitats – where each field not only has a different dominant plant species directing the functioning of that field, but also different management for each of those fields. Together, the dominant crop species and farm management create a limited number of niches for weedy species to inhabit. The fewer crops, the fewer niches and therefore the more related each field becomes.

The counter-argument to this, however, is that if weed species are managed categorically, as in plant functional groups, as opposed to on an individual basis, then minor variations in weed species diversity do not necessarily matter. As was discussed in section 3.2.3, farmers do in fact appear to be managing weeds categorically, as opposed to individually. Again, farmers were typically concerned about fast-growing broadleaved species which can out-compete (i.e. leaf-out earlier than) corn in its early stages when it is most vulnerable (Interviews 1, 6, 12, 15).

While farmer 6 considered giant ragweed and foxtails to be his most common weeds, he clarified that “mostly the giant ragweed (was problematic), the foxtail, that stays pretty short so once the corn gets to canopy – they don’t bother as much” (Interview 6). Farmer 1 also commented on the difference between broadleaves and grasses, saying giant ragweed and velvetleaf were his most problematic weed species because they out-compete corn and seed-out well, as compared to quackgrass, which he felt did not compete with corn as much (Interview 1). Farmers 3 and 14 both said “The one that gives us the most trouble is…giant ragweed…’cause they’ll get bigger than the corn” (Interview 3, 14). Farmer 3 clarified that “When a slow growing weed – when you get into a cornfield, you can cultivate them out easy. But when you get something that comes up even with the corn, that's when it gets to be tough" (Interview 3).

Plant functional groups are "…a set of species that have similar effects on a specific ecosystem process or similar responses to environmental conditions" (Hooper et al. 2005, pg 6). Hooper et al. (2005) note the difficulty in determining plant functional groups and opt for the slightly more neutral term 'functional type' so as to downplay the idea that plants naturally group together as opposed to lying on a gradient of functionality. They also note that the "Traits that determine how a species responds to a disturbance…may differ from those that determine how that species affects ecosystem properties" (Hooper et al. 2005, pg 6). In this case, farmers appear to be managing weed functional groups in terms of their inherent phenology (specifically, when they emerge and leaf-out) and their overall plant structure (e.g. broadleaved vs. grass). Those species who physically have the ability to compete for light (broadleaves) are potentially problematic, while those that are broadleaved and have a similar phenology to corn are most likely to be considered problematic. More generally speaking, this phenomenon can be thought of in terms of a plant's life-cycle type – annual, biennial or perennial, where fast growing, broadleaved annuals are the most problematic in similar-type crops (i.e. corn, also an annual).

Anderson and Milberg (1998) found crop species to have significant association with the weed flora, with the main differences among species being sowing time and competitiveness. The authors did note that each crop had many indirect associations with weed flora, mostly stemming from different management regimes. Their study found that perennial weeds characterized second-year rotational grassland, while spring-germinating weeds characterized spring-sown crops, and that the most abundant weed species were generalists in regards to their time of germination. This is similar to the farmers' grouping of weed species in terms of their phenology and life-cycle type.

Likewise, in their study of the effect of nitrogen fertilization on weed species, Pysek and Leps (1991) found that prostrate, low-lying weed species were out-competed for light by the dense cover of the crop and therefore were not able to take advantage of the increased nitrogen supply. Erect species similar in height to the crop, however, were not out-competed for light and able to respond to the increased nitrogen supply. This correlates with the farmers' grouping of weed species by their overall structure.

Dekker (1997) notes that while there is diversity among individual weed species, higher level species-groups at the genus level are important as it is the aggregate behavior of the individual weeds that is the emergent property defining the diversity and adaptation at the higher levels of organization. That farmers manage weed species as functional groups is significant not only from a cultural management standpoint, but also for a much-debated topic on the role of biodiversity in organic production. Here, biodiversity refers to the diversity of plant life cycles and structures.

That weeds are managed categorically means that minor weed species variation may not matter. In fact, when combined with other studies regarding biodiversity, this finding further supports the argument for biodiversity and agroecosystem complexity. Hooper et al. (2005), in a census of current literature, determined that the "susceptibility of invasion…is strongly influenced by species composition and…generally decreases with increasing species richness." As discussed earlier, the terms 'weed' and 'invasive' species are value-laden terms dependant on the person using the term. Here, if we think of weeds as invasive species, then Hooper et al. make the argument for ecosystem complexity, where the chance of one particular weed species being dominant decreases as the number of different weed species increases. So, in terms of a farm and the number of crops grown on it, the greater the number of crops grown, the less likely one weed species will dominate the farm and pose a problem individually. This view is supported by Dekker (1997), who notes that crops are selected for their uniformity and due to their lack of diversity leave unused resources in fields, which allows diverse communities of weeds to exploit and take advantage of the leftovers. Farmer 12 alludes to this, referring to weeds as ‘soil balancers’ that take up excess nutrients form the soil (Interview 12). Again, this study supports increased agroecosystem complexity, but indicates that complexity refers to a diversity of plant species types – specifically a diversity of life cycles and plant structures.

From a cultural management standpoint, farmers appear to be lumping – as opposed to splitting – their weed management. While lumping and splitting is often talked about in regards to plant families, we can take this concept into the realm of cultural management as well. In a conventional setting, weed management is more split from the rest of the farm management, but in an organic setting, lumping weed management with the rest of the farm and crop management makes sense. Moldboard plowing and finishing, for example, not only prepare the soil for planting, but also initiate weed seed germination.

Determining how a single management technique is affecting weed species field relatedness is difficult, as Pysek & Leps (1991) note. In their study of nitrogen fertilization, it was hard to determine the direct and indirect affect of fertilization because of the high correlation between the amount of nitrogen applied and the cover of the barley crop. They found some weed species to be more affected by the increased nitrogen supply, while others were affected by competition.

Chapter 4

DISCUSSION

4.1 Introduction

This chapter is meant to take a more comprehensive look at this study and its findings. Drawing from the results section, findings are tied back to issues brought up in the introduction. The Chapter focuses on weed management and the temporal scale within which they are applied.

4.2 Discussion

With the continued growth of organic farms, issues concerning organic systems are extremely important. Weeds have been singled out as a major impediment to the adoption of organic farms as well as one of the major problems for farmers operating organically (Cavigelli et al. 2008, Barberi 2002, Padel 2001, Bond & Grundy 2001, Turner et al. 2007, Pimentel et al. 2005). The first challenge to addressing weeds and weed management in organic farms is the highly varied outlook on weeds and what farmers consider to be a weed. Farmers were most in agreement over what was considered a weed in cornfields – anything other than corn. What was considered a weed in pastures, however, was more varied. As noted earlier, organic producers in some European countries have taken the initiative to redefine weeds by referring to them as ‘accompanying herbs’ (Beikraut) (Rist 2009). As shown earlier, a few farmers in this study appear to have already taken this mindset, noting that weeds contain nutrients not available in other forage plants. The majority of farmers, however, continue not only to separate weeds from crops or forage plants, but also to think of them as at odds with crops and/or forage.

This mindset is concurrent with dominant weed management in U.S. agriculture – chemical control. Chemical control not only "…allows farmers to envisage the weed problem in such a short-term perspective", but also to do so "…in relative isolation from other crop management" (Bastiaans et al. 2008, 481). Another way to put it is that chemical control allows for the splitting of weed management from whole farm management, where organic systems aim to bring the two together. The similarity between conventional and organic mindsets also carries over into the current weed management system utilized by the majority of farmers in this study. The lack of variation in management between farms, between fields, and within fields, was significantly noticeable. The current dominant weed management system in the study area consists of a series of waiting and cultivating. This echoes conventional weed management application of herbicides, which is also a series of waiting and application. The similarity in management systems suggests the continuation of a mental model of weed management that has continued into the organic system.

In the structure-agency debate within which this project resides, agency can be seen in the farmers who took a more holistic view of weeds on their farms. This enables these farmers to fully transition to an organic system of production that manages the whole farm, as opposed to different aspects of the farm. While some weeds will always pose a threat to crops, a more holistic view not only sees the benefits of some weeds, but also has the potential to cut down on time spent on weed management. A major question then becomes “How do we get other farmers to envisage their weeds as beneficial or complimentary to their farm production”?

Knowledge networks are likely ways for farmers to spread their views and management techniques for weeds. Knowledge networks can be described as the creation and transfer of knowledge through personal networks (Isaac et al. 2007). These networks bring together one’s social ties and their subsequent access to knowledge and information (Isaac et al. 2007). When asked about where they get their information from regarding farm management, six farmers explicitly noted other farmers, while several others brought up field days and pasture walks as well as newsletters. Farmer-to-farmer interactions strongly appeared as the dominant form of information exchange. There are many benefits to this – farmers are typically more comfortable talking with one another than someone from an academic institution, for example. As one farmer put it “Farmers will be straight with you if you talk to them one on one” (Interview 13). The farmer-to-farmer interactions are the likely source of similar to identical weed management techniques throughout the study area. In fact, a sub-group of the farmers I interviewed not only knew one another, but also were friends.

A subsequent question is then “How do we get farmers with more holistic weed management to share their knowledge with other farmers?” The ‘core-periphery’ model is just one example of how a knowledge network may be structured. Isaac et al. (2007) describe ‘core-periphery’ structures as “…those in which a small group of individuals has a high number or density of ties, for instance, advice-seeking connections,” leading to “…a two-class partitioning of individuals: one class for highly sought farmers and the other class for minimally sought farmers” (33). What are the characteristics of a ‘core’ individual and can we mold a network such that farmers with ‘the right information’ are at core positions?

The downside to farmer-to-farmer interactions is that it can lead to the spread of mis- or even bad information. This was exemplified in this study by the spread of a static management system throughout the study area. While the organic farmers in this study have developed an effective system for managing weeds, it is inflexible as shown by 2010’s unusually high rainfall and temperatures. In the face of climate change, greater interannual variability of climate conditions is likely. If this should happen, the organic producers in this study area are not prepared to manage their weeds effectively. As discussed earlier, the abundant rainfall greatly hindered their current management system leading to an overabundance of weeds, particularly in the cornfields. The spread of alternate management systems for these ‘off’ years would greatly benefit the farmers in this area. For this to happen, however, farmers with alternate management systems must first be identified and then moved into ‘core’ positions within the network of farmers. While farmers are likely to take notice of successful farms and how they are being managed, the spread of that management system may take years or even decades. The adoption of new techniques relies on not only ‘off’ years of a similar kind (e.g. too much rain, higher than normal temperatures), but also a willingness by the new farmer to experiment in those ‘off’ years. This is a potentially high hurdle to overcome as many farmers may feel more comfortable continuing with a management system they are already comfortable with and knowledgeable about, especially in the face of a growing season that they already know will be challenging.

Accumulation of knowledge over time may help address this issue. Discussing mechanisms for cultural internalization of traditional ecological knowledge, Berkes et al. (2000) exemplify the milpa shifting cultivation system in Mexico. The milpa is described as "…an internalized plan consisting of a series of routine steps with alternative subroutines, decision nodes, and room for experimentation" (Berkes et al. 2000, 1258). I envision this plan as a sort of decision tree, with the main trunk as the typical management routine and the branches as alternative routines based on various climatic and environmental factors (Figure 4.1). This can be contrasted with the current system of management that is more linear, with any changes simply pushing back the timing of management actions (Figures 4.2 & 4.3).

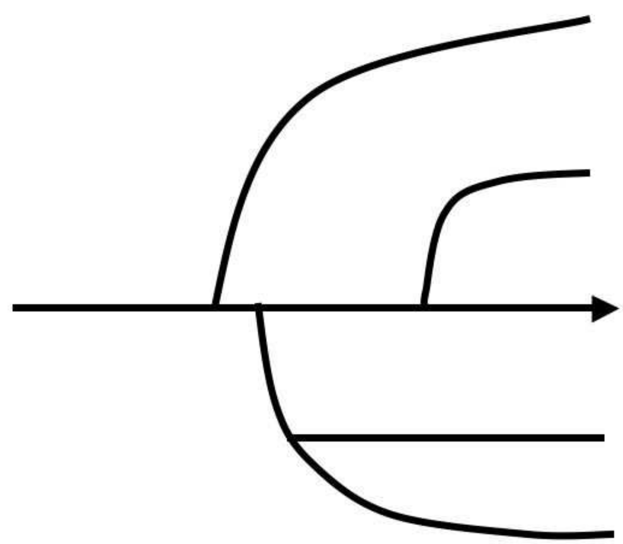


Figure 4.1 Decision tree of main and alternate management strategies.

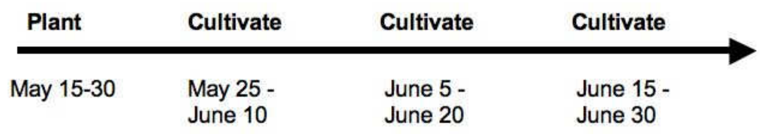


Figure 4.2 Current management system with approximate dates of actions.

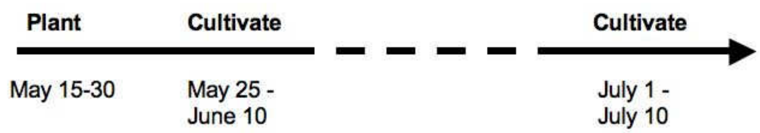


Figure 4.3 Example alterations to current management system, due to weather, with approximate dates of actions.

Berkes et al. (2000) go on to note that, "Ecological knowledge is encoded in the local variation of the milpa script, derived from experiences and experiments of farmers over generations" (1259). The accumulation of knowledge over time is what not only created but also shaped the decision tree or milpa shifting cultivation system. This also helps explain the lack of alternative management routines seen in this study. While 'organic' and sustainable production systems have been in place for centuries, the USDA's National Organic Program with its sometimes very specific set of rules and regulations has only been in existence for nine years. Over time (decades) I would expect the farmers in this study area to exhibit a more flexible management routine that was dependant on climatic and environmental factors. As the farmers experience more atypical growing seasons, the more likely they will be to alter their traditional routines of management and, as they find successful alternatives, pass the information on. In this way, farmers in the area accumulate knowledge and cultivate their own decision tree.

The question then becomes, at what point do farmers search for alternative management routines for atypical growing seasons? This is particularly interesting when we consider the fact that this years growing season was not the only recent 'off' year. In 2008, heavy rains caused the Kickapoo River to flood, not only disrupting agricultural activities in the area, but also causing the evacuation of residents in low-lying areas (Brown 2008). With two major rainy seasons only two years apart, it was surprising to see some farmers' strong disinterest in changing their management techniques to better adapt to the varying climatic conditions.

The fourth IPCC report states that in addition to increased temperatures across the United States, precipitation is also expected to increase over the majority of the continent (IPCC 2007). Increases in extreme precipitation events are also projected, increasing probability of flooding and drought from increased temporal variability of precipitation (IPCC 2007). Forecasted changes in precipitation extremes are greater than forecasted changes in mean precipitation (IPCC 2007). While the increased temperatures are likely to lengthen the growing season, the increased variability of precipitation makes the future of agriculture in Wisconsin indeterminate. While we are not entirely sure of the nature of the changes, we are sure that the climate will be changing over the future.

In light of overwhelming evidence that the temperatures and precipitation in Wisconsin will change in the near future, the ability of farmers to adapt to new conditions is extremely important. While the transition to organic gets farmers 'up and running' so to speak, they must also be prepared to change their management system under changing environmental conditions. In a way, these farmers are still transitioning to the organic system. While they have developed a highly successful system for managing weeds under typical weather conditions, any significant change in either temperature or precipitation seems to throw them off track. In this way, true success for these farmers can be envisioned as their ability to continually produce high yields under an organic system despite variations in climate.

These findings suggest that certifiers, researchers, and extension agents have to help farmers not only in their immediate transition to organic, but also in a longer term capacity as ‘surprises’ throw farmers off track. As farmers are transitioning to organic, it might also help if the transition process were described as a two-phase process, with both a short-term and a long-term transition. This might help make farmers more receptive to continue experimenting and to continue to seek new information on managing their weeds when new conditions arise. Farmers in this study mostly appeared to choose certain management techniques based on information from other farmers. Many farmers also noted experimentation with management methods, particularly while they were transitioning to organic. This indicates not only the method through which most farmers receive information, but also the period in which farmers are most receptive to trying new techniques.

Chapter 5

CONCLUSIONS

5.1 Introduction

This chapter summarizes the findings of this study and comes to some conclusions regarding the relationship between weed management and weed species diversity. This chapter also notes the limitations of this study and directions for future research.

5.2 Conclusions

My research question was "What is the relationship between variations in weed management and biodiversity of weeds?" I had hypothesized that weedy species would be spatially distributed according to environmental characteristics (e.g. soil type and moisture), as well as land uses (e.g. pasture vs. crop fields). I found weed species distribution to be independent of environmental variables, but significantly correlated with field type (pasture vs. cornfield). Cornfields were largely dominated by broadleaved weedy species, while pastures contained a more even mix of broadleaves, grasses and the addition of legumes.

Minor variation in weed species diversity, however, does not seem to matter much because weed species appear to be managed categorically, as in plant functional groups. Farmers were typically concerned about fast growing broadleaved species that could out-compete (leaf-out earlier than) corn in its early stages when it was most vulnerable (Interviews 1, 6, 12, 15). Categorical weed management is significant because it supports agroecosystem complexity, where an increase in crop variety may lead to increased weedy species diversity, but will not necessarily complicate or increase weed management. The functional groups in this study appeared to refer to plant life cycles (annual, biennial, and perennial) as well as overall plant structure (e.g. broadleaves and grasses).

Weed species differences in fields may be inherent to the ecology of each field, but more significantly indicates the importance of field management, as management differs greatly from cornfields to pastures. This finding is significant for two reasons. The first is that under recently updated USDA rules, organic produces must provide at least 30% of feed from forage (NOS 2010). This means an increase in pasture for many farms. While most farmers have a clear and regimented plan for weed management in cornfields, weed management in pastures is more of an afterthought. With this increase, however, farmers may want to consider more consistent weed management in their pastures. The second reason this finding is important is because it verifies the importance of weed management for weed species present in certain field types. There has been and continues to be a large amount of research focused on weed management techniques. This finding supports the continued efforts for helping organic producers manage their weeds. Whether or not farmers choose to employ those researched methods of management is another concern.

I had stated earlier that clarifying the relationship between weeds and weed management would enable a better understanding of (1) why farmers chose certain management methods, (2) why what they are doing is or is not successful both in terms of managing their weeds and supporting other aspects of environmental sustainability, and

(3) how their actions enable researchers, extension agents, certifiers, and others to facilitate transitions into organic agriculture.

Farmers in this study showed a significant preference for getting information regarding weeds and weed management from other farmers. This may explain the widespread usage of an inflexible yet highly successful weed management system – in a typical year – throughout the study area. The current weed management system also has parallels to conventional weed management, not only in the separation of weed management from overall farm management, but also in the timing and application of techniques.

Envisioning the transition process from conventional to organic as a two-phase process (one short-term and one long-term phase) may enable farmers to remain open to trying new management techniques and to continue experimenting after being certified. Many farmers had noted that while they experimented frequently during the transition process, they did significantly less so afterwards. Researchers, extension agents and certifiers might find it more effectual to reach farmers via farmer-to-farmer interactions such as field days and pasture walks.

5.3 Limitations of Research

While the findings of this study are significant, there are some limitations, and further research would help support these findings. The first and foremost limitation is sample size. Due to time constraints and the method in which farmers were identified and contacted, only 20 farms were visited. Some farmers simply did not wish to take part in the study, while others thought that they could not afford the time needed for the interview. Two of the farms visited were not USDA certified organic, but this was not known until the interview was underway.

A second limitation of this study is the abnormal growing season within which this study took place. Not only were there significantly more weeds in fields but management had also been altered due to the atypical weather conditions. Conducting this study during a normal year might have resulted in different findings. The atypical year did, however, bring to light issues regarding adaptation of weed management to varying climatic conditions.

5.4 Future Work

Future research that repeats this study will benefit from increasing the sample size. A larger set of participants would help verify the finding of this study and perhaps bring to light some more nuanced details of farmers weed management systems. For example, both the small sample size and wet year could be the causes of a homogenized weed management system. In recruiting farmers, researchers might also be interested in comparing organic farmers in the area to Amish farmers. This would be particularly interesting when focusing on knowledge networks and how information is spread from one farmer to another. Given the results of this study, I would hypothesize that weed management among a group of Amish organic producers would be even less varied than what was found in this study. Another route would be to compare organic producers who are in the transition process versus those who are well past it, shedding light on weed management adaptability in atypical years.

Because the most significant differences in weed species were found to be between cornfields and pastures, including different types of crop fields (e.g. hay) might clarify whether the differences are based on field ecology or field management. Here, special attention should be paid to the life cycle and plant structure of each crop. As corn is typically the only broadleaved row crop grown on a dairy farm, its weed species should remain distinct from those of other crops. Hay fields in particular, could be described as more analogous to pastures, but with slightly more management. Similar weed species in hay and pastures might support the argument that field ecology is the driving force behind weed species presence or absence within a field, while different weed species in hay and pastures might support the argument that field management is the driving force behind weed species presence or absence. A multiyear study would also be able to follow field rotations and distinguish the effect of previous crops on the current field crop and the weed species among them.

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APPENDIX A.

Background info

How long have you been farming?

How long have you had this farm/been farming here?

How long have you been organic?

Other than pasture, what do you grow in your fields?

Weeds

Would you say you have a lot of weeds on your farm?

What are your most common weeds?

So X, Y, and Z are your most common weeds, but what weeds are the worst/give you the most trouble?

What makes them such a problem/hard to deal with?

Can you make any generalizations about where different weed types are found on your farm?

Have the kinds of weeds (types) on your farm changed over the years?

How did they change when you first converted to organic?

Has the amount of weeds on your farm changed over the years?

How did they change when you first converted to organic?

Weed Management

Corn fields

What method(s) do you use to control your weeds before you plant in the spring?

How about after planting, but before your crop emerges?

What about during the rest of the growing season?

What about during the rest of the growing season?

Do you rotate your crops?

Pasture

How do you control weeds in your pastures?

Do you control weeds in your margins or access roads?

After you work in a field with a high amount of weeds – do you clean your machines?

Do you find that the same weed management methods are more effective in some fields than in others?

Learning Weed Mgt. Methods

Do you change your weed management methods at all?

Do you experiment with them first, before applying it to your fields?

How do find out about those methods?

When your first transitioned to organic, were your weed control methods any different than they are now?

Are there other weed management methods you've thought of trying but haven't yet?

Are there other weed management methods that you think are more effective than what you are doing right now?

Time Management

How much time (on average) would you say you put into weed management – per day/per week/per month/per growing season?

APPENDIX B.

Abbreviation	**Common Name**	**Scientific Name**
Alfa	Alfalfa	*Medicago sativa*
Brly	Barley	*Hordeum vulgare*
Brnyrd	Barnyard grass	*Echinochloa crus-galli*
Bblm	Bee balm	*Monarda fistulosa*
Bdftr	Birds foot trefoil	*Lotus corniculatus*
Bmdc	Black medic	*Medicago sativa*
Bmus	Black mustard	*Brassica nigra*
Bngt	Black nightshade	*Solanum americanum*
Brome	Bromegrass	*Bromus spp*
Bukplt	Buckhorn plantain	*Plantago lanceolata*
Bulth	Bull thistle	*Cirsium vulgare*
CAth	Canada thistle	*Cirsium arvense*
CAhn	Carolina horsenettle	*Solanum carolinense*
Chic	Chicory	*Cichorium intybus*
Cbur	Common burdock	*Arctium minus*
Cchk	Common chickweed	*Stellaria media*
Cdnd	Common dandelion	*Taraxacum officinale*
Cmal	Common mallow	*Malva neglecta*
Cmlk	Common milkweed	*Asclepias syriaca*
Cplt	Common plantain	*Plantago major*
Crgw	Common ragweed	*Ambrosia artemisiifolia*
Cyrw	Common Yarrow	*Achillea millefolium*
Crab	Crabgrass	*Digitaria spp*
Crbtrd	Creeping bentgrass redtop	*Agrostis stolonifera*
Cdok	Curly dock (Sour dock)	*Rumex crispus*
Egrd	Elliott's goldenrod	*Solidago latissimifolia*
Fbnd	Field bindweed	*Convolvulus arvensis*
Fclv	Field clover	*Trifolium campestre*
Gsld	Gallant soldier	*Galinsoga parviflora*
Gfxt	Giant foxtail	*Sateria faberi*
Grgw	Giant ragweed	*Ambrosia trifida*
Gold	Goldenrod	*Solidago spp*
Grfxt	Green foxtail	*Setaria viridis*
Ivy	Ground ivy	*Glechoma hederacea*
Hrycrb	Hairy crabgrass	*Digitaria sanguinalis*
Hmus	Hedge mustard	*Sisymbrium officinale*
Hswd	Horseweed	*Conyza canadensis*
John	Johnsongrass	*Sorghum halepense*
Kblu	Kentucky bluegrass	*Poa pratensis*
Knot	Knotgrass	*Paspalum distichum*
Lamb	Lambsquarter	*Chenopodium album*
Mapl	Maple seedling	*Acer spp*
Moss	Moss	*Bryophyte spp*

Mros	Multiflora rose	*Rosa multiflora*
Orch	Orchard grass	*Dactylis glomerata*
Odsy	Oxeye daisy	*Leucanthemum vulgare*
PAsm	PA smartweed	*Polygonum pennsylvanicum*
Prye	Perennial ryegrass	*Lolium perenne*
Quac	Quackgrass	*Elytrigia repens*
Qalc	Queen Annes Lace	*Daucus carota*
Rclv	Red clover	*Trifolium pratense*
Rrpw	Redroot pigweed	*Amaranthus retroflexus*
Rcny	Reed Canary grass	*Phalaris arundinacea*
Rcinq	Rough cinquefoil	*Potentilla norvegica*
Rflea	Rough fleabane	*Erigeron glabellus*
Self	Selfheal	*Prunella vulgaris*
Shprs	Shepherd's purse	*Capsella bursa-pastoris*
Srush	Slender rush	*Juncus tenius*
Swtas	Small white aster	*Aster vimineus*
Sbrm	Smooth Brome	*Bromus inermis*
Smpw	Smooth pigweed	*Amaranthus hybridus*
Stjn	St. Johnswort	*Hypericum perforatum*
Sntl	Stinging nettle	*Urtica dioica*
Tfesc	Tall fescue	*Festuca arundinacea*
Tntl	Tall nettle	*Urtica procera*
Tgldn	Tall goldenrod	*Solidago altissima*
Tim	Timothy grass	*Phleum pratense*
Velv	Velvetleaf	*Abutilon theophrastii*
Viot	Violet	*Viola spp*
Wcam	White campion	*Silene latifolia*
Wclv	White clover	*Trifolium repens*
Wbkt	Wild buckwheat	*Polygonum convolvulus*
Wstrw	Wild strawberry	*Fragaria virginiana*
Wsorr	Wood sorrel	*Oxalis stricta*
Yfxt	Yellow foxtail	*Setaria lutescens*
Ynut	Yellow nutsedge	*Cyperus esculentus*
Yrkt	Yellow rocket	*Barbarea vulgaris*