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James J. DeDecker, John B. Masiunas, Adam S. Davis, and Courtney G. Flint*

Organic agricultural systems increase the complexity of weed management, leading organic farmers to cite weeds as one of the greatest barriers to organic production. Integrated Weed Management (IWM) systems have been developed to address the ecological implications of weeds and weed management in cropping systems, but adoption is minimal. Organic agriculture offers a favorable context for application of IWM, as both approaches are motivated by concern for environmental quality and agricultural sustainability. However, adoption of IWM on organic farms is poorly understood due to limited data on weed management practices used, absence of an IWM adoption metric, and insufficient consideration given to the unique farming contexts within which weed management decisions are made. Therefore, this study aimed to (1) characterize organic weed management systems; (2) identify motivations for, and barriers to, selection of weed management practices; and (3) generate guiding principles for effective targeting of weed management outreach. We surveyed Midwestern organic growers to determine how specified psychosocial, demographic, and farm structure factors influence selection of weed management practices. Cluster analysis of the data detected three disparate, yet scaled, approaches to organic weed management. Clusters were distinguished by perspective regarding weeds and the number of weed management practices used. Categorization of individual farms within the identified approaches was influenced by primary farm products as well as farmer education, years farming, and information-seeking behavior. The proposed conceptual model allows weed management educators to target outreach for enhanced compatibility of farming contexts and weed management technologies.

Key words: Cluster analysis, decision-making, integrated weed management, logistic regression analysis.

Restriction of synthetic herbicide use in organic agricultural systems increases the complexity of weed management (Bastiaans et al. 2008), leading organic farmers to cite weeds as one of the greatest barriers to organic production (Walz 1999). Research indicates that ecological or integrated approaches to weed management (IWM) have the potential to suppress weed growth with reduced reliance on herbicides (Deytieux et al. 2012). However, application of the IWM concept is impeded by short-term complexity in the level of agroecological knowledge required for integrated management, as well as the fact that benefits of IWM are largely realized in the long-term (Buhler

et al. 2000). Consequently, few growers have adopted IWM (Doohan et al. 2010).

Organic agriculture offers a particularly favorable farming context for the study and application of IWM. Both approaches are motivated by concern for environmental quality and agricultural sustainability, and both seek solutions through the "ecologization of agriculture" (Lamine 2011). The IWM concept has been incorporated into the U.S. organic pest management standard through emphasis on weed prevention, recognition of multiple control tactics, and relegation of herbicide-based control to last resort status (Electronic Code of Federal Regulations 2012). Organic growers are more likely to adopt individual weed management innovations, such as crop rotation and cover crops, than conventional farmers (McCann et al. 1997). Organic agriculture, by definition, also avoids synthetic chemical inputs and the associated barriers to IWM adoption, primarily the ease and apparent low risk of chemical weed management (Liebman et al. 2001).

Research indicates that most U.S. organic farmers manage weeds using a limited suite of mechanical controls supported by cultural management practices such as crop rotation and delayed planting (Walz 1999). According to the available data,

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organic weed management systems may not include many of the information-intensive practices, such as prevention, economic thresholds, and biological control that IWM promotes (Walz 1999). Therefore, it is important to quantify IWM application on working organic farms to determine if and how the IWM concept can translate into viable organic weed management. Recent work by Jabbour et al. (2013) compared weed management mental models of organic growers and scientists to better understand obstacles to adoption of a richer set of weed management practices in organic systems. In this study, we present findings from a survey of Midwest organic farmers, highlighting primary determinants of weed management practice selection along multiple dimensions.

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

Farmers are known to have particular decision-making tendencies that differ from other agriculture stakeholders like scientists and extension agents (Wilson et al. 2009). Many farmers demonstrate particularly risk-averse decision-making. Related to risk aversion is what Gintis (2009) called "time-inconsistency" in decision-making. Farmers tend to discount long-term risks, like environmental impacts of herbicide use, and maximize short-term utility, as in direct weed control (Doohan et al. 2010). Farmers also exhibit a significant preference for accessing information through personal experience, or the experience of other farmers (Jabbour et al. 2013; Walz 1999).

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

In addition, many organic farmers view themselves as part of a counterculture movement (Haydu 2011). Organic agriculture is seen as a righteous alternative to the industrial food system, a system perceived as being developed and promoted by the scientific establishment. Therefore, some organic farmers do not trust university recommendations and exhibit an even greater preference for user generated pest management information than conventional farmers (Park and Lohr 2005). At the same time, organic agriculture proponents have sought empirical verification of their claims. This tenuous relationship between organic agriculture and agricultural science has supported the development of some pseudoscientific concepts within organic circles, such as the base-cation saturation ratio (BCSR) theory of soil fertility and weed management (Jabbour et al. 2013; Padgham 2011).

Why Farmers Manage Weeds As They Do. Farmer decision-making is therefore a complex and difficult to model process. However, technology adoption research has made significant progress in the application of decision theory. Technology adoption is defined as a "dynamic learning process," where potential adopters develop perceptions of an innovation's relative utility in their unique farming context. Adoption diffusion theory suggests that three variable categories influence this learning process, including farm structure, farmer demographics, and perceived characteristics of an innovation (Edwards-Jones 2006; Straub 2009).

The physical, mechanical, and ecological context of a farm system sets clear restrictions on what pest management technologies or practices can be applied. Farm size, crop choice, cropping diversity, and land tenure may all influence IWM adoption (Bastiaans et al. 2008). Characteristics of farm managers, such as age of an operation's principal manager, formal education, and farming experience, also affect decision-making for pest management (Ceylan et al. 2010). Efficacy, initial costs, perceived economic value, as well as ease of use can shape farmers' perceptions of an innovation's utility (Sattler and Nagel 2010). Farmers also differ in

the information they receive regarding pest management, what sources they trust, and how they access information. The more pest management information a grower seeks out, the more likely he or she is to adopt IPM practices (Ceylan et al. 2010; Park and Lohr 2005). However, research indicates inconsistent impacts of extension education and farmer perceptions of extension on IPM adoption (Llewellyn 2007; Samiee et al. 2009).

Research Objectives. Weed management in organic systems is a substantial challenge, and in the absence of synthetic herbicide use, is dominated by cultural and mechanical controls. Understanding of organic weed management behavior is limited by the lack of published surveys and the complexity of quantifying weed management behavior. Therefore, this study aimed to (1) characterize organic weed management systems; (2) identify motivations for, and barriers to, selection of weed management practices; and (3) generate guiding principles for effective targeting of weed management outreach. Given the complexity, and contextual importance, of the farmer decision-making processes, we approached organic weed management as a multidimensional system likely impacted by several independent variables.

Materials and Methods

Study Region: The Midwest United States. The Midwest is the most intensively cropped region of the United States, consisting of 12 states including North Dakota, South Dakota, Nebraska, Kansas, Minnesota, Iowa, Missouri, Wisconsin, Illinois, Indiana, Michigan, and Ohio (U.S. Department of Agriculture [USDA] 2009). The Midwest is uniquely suited to the study of organic weed management behavior for two reasons: Approximately 30% of U.S. organic acreage and operations are located here, placing it second after the Western region, which includes large agricultural states like California (USDA 2010). There is also a diversity of agroecosystems present in the region. Midwest agroecosystems are dominated by grain production; however, forage, vegetable, fruit, and flower farms are also present. Therefore, analysis of organic agriculture in the Midwest United States should provide a picture of applied organic weed management, and significant insight into organic at the national level.

Survey Administration. A survey was developed to determine what weed management practices organic farmers employ and measure factors that may influence adoption of those practices. Section one of the questionnaire included six questions designed to evaluate the structure of respondents' farm operations. In section two of the questionnaire, binary use of 63 different weed management practices was measured using a check-off table organized into nine categories: soil preparation, planting, prevention, thresholds, mechanical controls, biological control, cultural controls, chemical controls, and information management. Our goal was to include as many weed management practices available to organic growers as possible in order to develop a comprehensive picture of organic weed management systems. Section three of the questionnaire included five questions regarding factors that may influence growers' perceptions of weed management innovations. The final section of the questionnaire included eight questions designed to assess the impact of farmer demographics on selection of weed management practices.

The survey instrument was pretested with a small convenience sample of organic growers ($n = 22$) January 6 to 8, 2010 at the Illinois Specialty Crops, Agritourism, & Organic Conference in Springfield, IL, and February 25 to 27, 2010 at the Midwest Organic and Sustainable Education Service Organic Farming Conference in La Crosse, WI. Inclusion/exclusion criteria for the pretest limited participation to organic growers over the age of 18 farming in one of the 12 states of the North Central region (Midwest United States). Pretest participants signed a written consent form, which was collected separately to maintain respondent anonymity. Oral and written feedback from the pretest sample was used to judge and improve the overall quality of the survey instrument.

Information on the target population of Midwest organic growers was drawn from the 2010 publicly available list of certified organic operations collected by accredited certifying agencies and compiled by the USDA's Agricultural Marketing Service (USDA 2010). Inclusion/exclusion criteria limited the target population to certified organic farm operations located in the Midwest United States whose primary scope was listed as crops. Farm operations meeting the above criteria were classified into mutually exclusive categories based on primary crops produced. Categories included grain, grain & forage, vegetable, forage, fruit, and diversified (operations producing products in three or more categories). Operations producing primarily livestock or wild crop products, such as maple syrup, were eliminated

from the population. A final population of 3,070 farm operations in the North Central Region satisfied all of the criteria.

A stratified random sample of 500 farm operations was drawn from this target population. Stratification occurred by operation class using proportionate allocation due to hypothesized correlation between crops produced and weed management methods (Bastiaans et al. 2008; Riemens et al. 2010). The final sample included 260 (52%) grain & forage farms, 86 (17.2%) grain farms, 56 (11.2%) diversified farms, 46 (9.2%) forage farms, 44 (8.8%) vegetable farms, and 8 (1.6%) fruit farms.

We administered the finalized survey January and February of 2011 following the method of Pennings et al. (2002) for survey research specifically targeting farmers. The survey packet included a cover letter, the survey instrument, a postage-paid return envelope, and a new one-dollar bill as token financial incentive. The survey was mailed to 500 potential respondents on January 21, 2011. A follow-up postcard was mailed to all potential respondents on February 17, 2011, to thank those farmers who had already responded and encourage participation among those who had not.

Data Analysis. Data were analyzed in two steps using complementary statistical methods: hierarchical agglomerative cluster analysis (HACA) and binary logistic regression. In the first step, cluster analysis was used to identify natural groupings within the survey data. Following this, we used logistic regression to identify key predictors of cluster membership. Cluster analysis is useful for increased understanding of complex data through classification, but also aids further analysis through data reduction. It has been applied extensively in ecology and sociology, but has also been used to classify farm operations according to pest management behavior (Burger et al. 2012).

Our goal was to identify distinct weed management approaches based on the qualitative measure of weed management practices used by survey respondents. To this end, use of each weed management practice included in the survey was coded as a dichotomous binary variable with "1" indicating use of the practice and "0" indicating lack of use. Each case included responses to 63 different weed management practices, resulting in a 223 by 63 binary data set.

A number of distance measures are appropriate for binary data. However, a group of distance measures known collectively as matching coefficients consistently and accurately identify known clusters within binary data sets (Finch 2005). Of the matching coefficients, we selected the Dice (1945) coefficient because it gives additional weight to cases of positive agreement (e.g., 1, 1) and discounts cases of negative agreement (e.g., 0, 0). Information regarding what weed management practices farmers are not using may be important to a wider understanding; however, we chose to focus our work primarily on practices selected. IBM Statistical Package for the Social Sciences was used to calculate Dice coefficients and construct a similarity matrix of all possible case pairings (IBM Corp. 2011).

The second step in HACA uses calculated distance measures to form mutually exclusive groups of cases (clusters) in a hierarchical additive process. The appropriate number of clusters can be determined through examination of the clustering dendrogram and analysis of the agglomerative coefficient (Hair et al. 1992). We used Ward's (1963) method because previous research suggests it is the most useful algorithm for clustering of binary data using matching coefficients (Hands and Everitt 1987).

Cluster validation was achieved through internal and external evaluation. Reliability of the cluster solution was determined through calculation of Cronbach's alpha to determine if proposed cluster membership is indeed a reliable measure of weed management practices used. Intraclass correlation (ICC) was calculated for each proposed cluster to measure cluster homogeneity in terms of weed management practices used. Two variables commonly used to classify weed management behavior are operation class (products grown) and number of weed management practices adopted. The categorical measure of operation class was tested against cluster membership using a Monte Carlo simulation (Spall 2005) of the Fisher's Exact Test. A categorical measure of the number of weed management practices adopted was also tested against proposed cluster membership using a chi-square test.

In an effort to identify other less apparent drivers motivating adoption of particular weed management innovations, and thus proposed cluster membership, a stepwise logistic regression procedure was applied to estimate the impact of several probable independent variables, following the method described by Villamil et al. (2012). Independent variables included survey data regarding farm structure, farmer demographics, and psycho-social factors, such as information seeking behavior,

Table 1. Demographic characteristics of the survey sample compared to national trends from a mail survey of organic farmers (Walz 2004).

Farmer population	Area farmed	Total farming experience	Organic farming experience	Gross income	Farmer age	Education level	Gender ratio
	ha	yr	yr	10^3\$ yr^{-1}	yr	degree	% female
Surveyed	109	26.6	12.1	50	51	BA/BS[a]	6
United States	112	20.4	11.5	25	51	BA/BS	22

[a] Abbreviations: BA, Bachelor of Arts; BS, Bachelor of Sciences.

contributing to perceived innovation characteristics. Because each operation class (products grown) occurred in only two of the three proposed clusters, two binary logistic regression models were calculated to describe (1) what drives forage and fruit farmers into Cluster A or Cluster B, and (2) what pushes grain & forage, grain, vegetable, and diversified growers into either Cluster A or Cluster C.

Maximum likelihood estimates of the regression coefficients and their standard errors were computed for each model. Chi-square (χ^2) was employed to test the significance of the regression terms. Using the fitted model, a predicted event (e.g., = *Cluster C [≠ Cluster A]*) odds [*p/1-p*] can be calculated for all cases in a pair of clusters. If the predicted event odds exceed the cutoff value of 0.5, the farm operation is predicted to be a member of the considered cluster (i.e., Cluster C). If not, the farm operation is predicted to be a member of the default cluster (i.e., Cluster A). Odds ratios were also calculated to express the likelihood of cluster membership under one of two possible conditions, holding all other variables constant (Villamil et al. 2012).

Results and Discussion

Survey Response. Anonymous responses to the survey were received by mail in early 2011. Twenty-four survey packets failed to reach potential participants due to address errors or lack of a current forwarding address. This reduced the survey's potential sample size from 500 to 476, and 232 completed survey instruments were received. Of these, 13 respondents indicated that they no longer manage any portion of their farm operation organically. These responses were excluded leaving 219 useable responses for data analysis. As a result, response rate for the survey was 46%. Response rate by stratum was nearly proportional to the fraction of each operation type present in the target population. The 219 useable survey responses included 95 (43%) grain & forage farms, 52 (24%) grain farms, 14 (6%) diversified farms, 24 (11%) forage farms, 30 (14%) vegetable farms, and four (2%) fruit farms. However, due to the large population size (3070) and number of categories (6), statistical analysis indicated a significant difference between the sample and population in terms of distribution among the stratum (χ^2 = 17.32, df = 5, P = 0.004). Distribution of sample cases by state was statistically similar to geographical distribution of all organic farms in the Midwest (χ^2 = 14.8, df = 11, P = 0.192). Therefore, our sample should be sufficiently representative of the target population.

Demographics and Descriptive Statistics. Demographic characteristics of the target population are presented in Table 1. These results largely mirror trends among organic growers at the national level (Walz 2004). However, according to our data, gross farm incomes in the Midwest averaged $50,000 in 2010, well above the 2001 national average of $25,000 (Walz 2004). Some of this difference is likely related to inflation over the intervening 9 yr, but other research indicates that the economic value of U.S. agriculture is concentrated in the Midwest and California (USDA 2009).

When asked to list the most problematic weeds on their farm, respondents most frequently mentioned foxtail [*Setaria faberi* Herrm., SETFA or *Setaria glauca* (L.) Beauv.] (78 times), followed by common lambsquarters (*Chenopodium album* L.) (54 times), giant ragweed (*Ambrosia trifida* L.) (40 times), Canadian thistle [*Cirsium arvense* (L.) Scop.] (36 times), common ragweed (*Ambrosia artemisiifolia* L. var. *elatior*) (35 times), and velvetleaf (*Abutilon theophrasti* Medicus) (34 times). The high incidence of lambsquarter, Canada thistle, ragweed, and velvetleaf supports previously reported shifts toward dicots and less nitrophilous species observed under organic management (Davis et al. 2005; Rydberg and Milberg 2000). However, frequent mention of foxtail does not support a theorized shift away from grasses. Recent compar-

Table 2. Percent of respondents indicating use of each weed management information resource surveyed.

Information resource	Respondent preference
	% using
Other farmers	82.5
Field days, workshops, conferences	55.3
Periodicals and/or newsletters	46.1
Books	45.6
University extension and/or researchers	24.4
Internet sites	18.9
Trade organizations	17.1
Nonuniversity consultants	15.7
Natural Resource Conservation Service	12.0
Equipment or chemical dealers	10.6
Radio or television	1.9

isons of organic farmer and weed scientist mental models found significant differences in fundamental areas of knowledge and perceptions regarding weeds and weed management that could explain this inconsistency (Jabbour et al. 2013). If knowledge of weed biology is indeed relatively limited among organic farmers (Doohan et al. 2010), the open-ended listing of problematic weed species may also reflect popular weed names that farmers are aware of rather than the actual species present on their farm.

Midwest organic farmers used an average of 15 (1 to 34) practices that contribute to weed management. This number is higher than any previously reported value, and may be partially related to the relatively large number of practices included in our survey. However, if adoption of IWM is measured as number of weed management practices used, Midwest organic farmers appear to demonstrate extensive adoption (McDonald and Glynn 1994; Shennan et al. 2001). Percent of respondents using each surveyed weed management practice is presented in Appendix 1. The 10 most commonly adopted practices for the 2010 season were crop rotation (86%) averaging two to four crops in sequence, between-row cultivation (78%), primary tillage (76%), cover cropping (66%), delayed planting (65%), green manure (63%), scouting (57%), hand weeding (57%), mowing (52%), and increased planting density (50%). This supports previous work finding that organic weed management is dominated by cultural and direct mechanical controls (Walz 1999).

Use of various weed management information resources by respondents is presented in Table 2. As hypothesized, organic producers indicated a significant preference for accessing information through personal experience, or the experience of other farmers (Jabbour et al. 2013; Walz 1999). Most growers rated weed control on their organic acres as "fair" on a four-point poor–excellent scale.

Twenty percent of growers surveyed voluntarily mentioned some version of the base-cation saturation ratio (BCSR) theory of soil fertility. The BCSR theory suggests that "ideal" ratios of soil cations exist, which if achieved contribute to "balanced" soil with lower weed pressure and higher crop yields. Soil cations can certainly influence crop yield and the composition of emerged weed communities. However, empirical evidence generated over the last century has continually refuted the BCSR theory, determining that nutrient availability and pH have a much greater impact on crop and weed growth than specific cation ratios (Kelling et al. 1996; Schonbeck 2000). Still, the BCSR theory maintains a large following within the organic agriculture community (Jabbour et al. 2013). A book promoting the application of this theory to weed management, "Weeds and Why They Grow," remains one of the best-selling books available through the Midwest Organic and Sustainable Education Service (Padgham 2011).

The popularity of pseudoscientific concepts, such as the BCSR theory, among the organic community may be partially due to organic's political stance as a counterculture movement and subsequent distrust of the scientific establishment (Haydu 2011). Promotion of the BCSR theory has resulted in significant misappropriation of agricultural resources and limited the development of organic weed management systems (Kopittke and Menzies 2007).

Cluster Analysis of Weed Management Practices. Analysis of the dendrogram and agglomerative coefficient determined that a solution of three clusters maximized distance between clusters while maintaining homogeneity within (Figure 1). Calculation of Cronbach's alpha considering cluster membership and 61 weed management practices ($\alpha = 0.744$) suggests that cluster membership as proposed is a reliable measure of weed management practices used. ICCs for Cluster A (ICC = .589, P < 0.0001) Cluster B (ICC = 0.707, P < 0.0001), and Cluster C (ICC = 0.63, P < 0.0001) all approached or exceeded the threshold of 0.60 and were found to be statistically significant. This suggests satisfactory homogeneity within the proposed clusters in terms of weed management practices used.

The categorical measure of operation class was tested against proposed cluster membership and

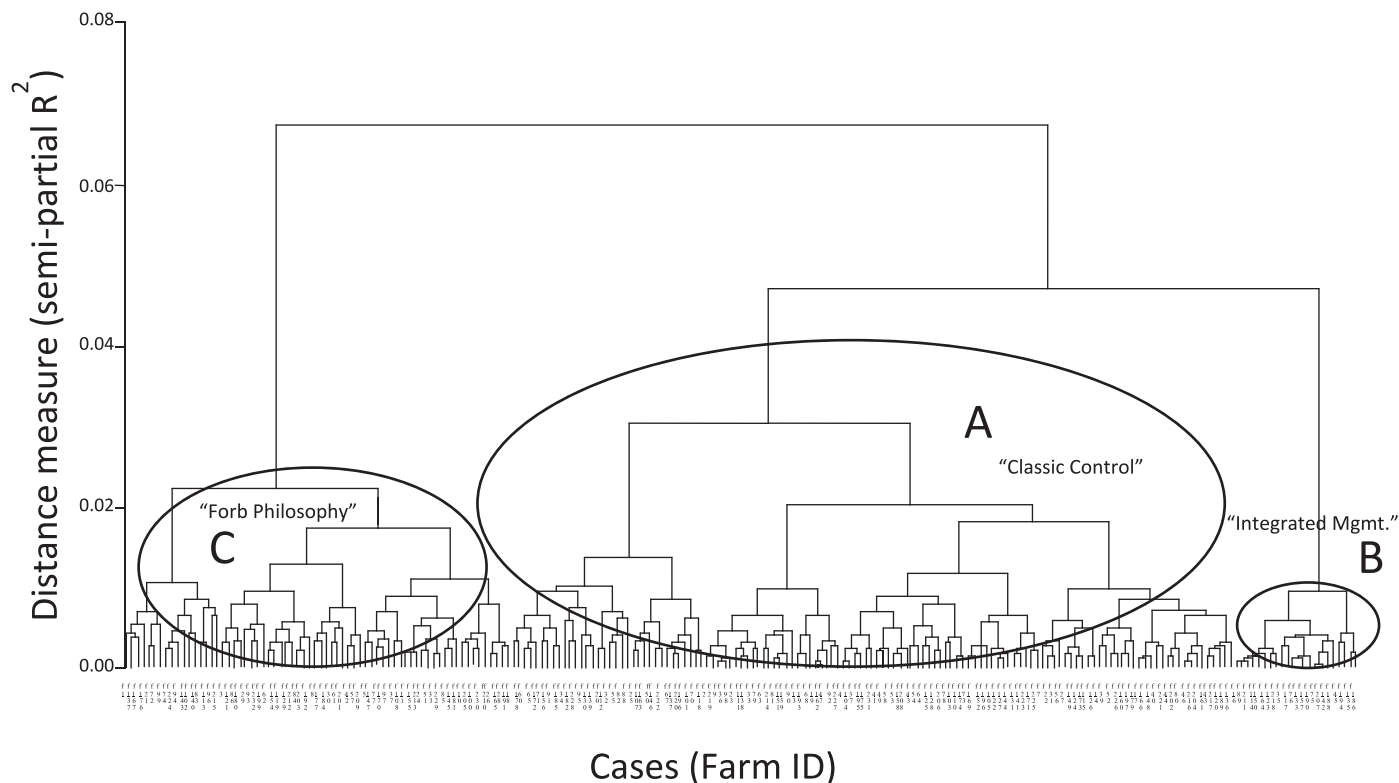DeDecker et al.: Organic grower weed management • 525

Figure 1. Dendrogram of the cluster analysis solution showing individual cases grouped hierarchically into three clusters.

found to be significantly different from the expected distribution among clusters A, B, and C ($\chi^2 = 150.02$, df = 10, $P < 0.0001$). Cluster A contains farms from each operation class surveyed. On the contrary, Clusters B and C split the classes. Cluster B includes only forage and fruit operations; Cluster C contains only grain & forage, vegetable, grain, and diversified farms. A categorical measure of the number of weed management practices adopted was also tested against cluster membership and found to be significantly different from the expected distribution among clusters ($\chi^2 = 94.11$, df = 4, $P < 0.0001$). Farm operations in Cluster B used the lowest average number of weed management practices (7), led by Cluster A (13), and ultimately C (21). External evaluation validated our typology, suggesting that operation class ($P < 0.0001$) (Riemens et al. 2010) and practice count classifications ($P < 0.0001$) (Jasinski et al. 2001) correctly reflect natural variation in organic weed management behavior, and can thus be considered valid measures that aid understanding of IWM adoption. A description of the three identified clusters follows.

The Classic Control Cluster. Cluster A is the largest group comprising 59% ($n = 129$) of the sample, and contains farms in each of the six identified operation classes including grain & forage

(68), grain (34), vegetable (12), forage (6), diversified (5), and fruit (1) (operation class not reported [3]). Farms in Cluster A use an average of 13 practices to manage weeds on their farms and are referred to as the "Classic Control" cluster (CCC) due to a strong emphasis among its members on control of existent weeds, or future weed growth viewed as inevitable, through cultural and mechanical controls.

Relative engagement (average number of practices used within a particular category) in the nine surveyed categories of weed management practices among the proposed clusters is presented in Table 3. Adoption of weed management practices among the proposed clusters is also shown in Appendix 1. Ninety-two percent of growers in the CCC adopted crop rotation, followed by extensive adoption of between-row cultivation (87%), primary tillage (79%), and cover cropping (66%). Weed management systems in this group are not the most diverse and work from the limited perspective of the cropping cycle, lacking a focus on prevention or long-term management. However, members of the CCC achieve a perceived level of weed control very similar to the other clusters, without investing in information-intensive and risky ecological management.

The Forb Philosophy Cluster. Cluster B is the smallest group comprising 10% ($n = 21$) of the

Table 3. Relative engagement in weed management practice categories among management clusters.

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

[a] Management clusters were determined via hierarchical cluster analysis.
[b] Relative engagement is measured as average percent of practices used within a given category.

sample, and contains farms in two operation classes, including forage (16) and fruit (3) (operation class not reported [2]) farms. Farms in Cluster B use the lowest average of seven practices to manage weeds on their farms. Cluster B will be discussed as the "Forb Philosophy" cluster (FPC) due to an alternative weed management philosophy that highlights the value of weeds in perennial farm systems. "Forb" use has been extended by managers of perennial systems to describe any uncultivated plant with beneficial characteristics, such as forage value, nitrogen fixation, or pollinator attraction (Smith and Collins 2003).

Members of the FPC use relatively few weed management practices from only three categories. The category with the highest level of engagement among the FPC is information management (29%) followed closely only by biological controls (17%). The one mechanical control with significant adoption among the FPC was mowing (83%). Other mechanical controls rely on soil disturbance, which is less desirable in perennial systems.

Eighty-three percent of growers in the FPC adopted mowing, supported by grazing (70%), and weed scouting (48%). Growers in the FPC manage weeds for long-term control at acceptable levels through information management and the application of one specialized method of direct mechanical control (mowing) and one flexible biological control (grazing), which are also traditional elements of forage and perennial fruit production systems. In building farm systems that value rather than battle weeds, members of the FPC achieve a level of management integration not observed in the other

two groups. Through integration into the production system at a fundamental level, weed management is transformed. Effort is focused on maximization of production through longevity, and weed management treated as almost incidental. Design of cropping systems that truly integrate weed management has long been a goal of IWM science (Cardina et al. 1999). However, this goal is not being achieved as the capstone of a progression through ever-increasing diversity in weed management, as some have theorized (Lamine 2011). It instead appears to be occurring extensively only in the specific context of perennial systems, which demonstrate the least diversity in weed management, driven by an alternative view of what a weed is.

The Integrated Management Cluster. Cluster C comprises 32% ($n = 69$) of the sample, and contains farms in four operation classes, including grain & forage (26), vegetable (18), grain (17), and diversified (7) (operation class not reported [1]). The only farm types not included in Cluster C are forage and fruit farms found in the FPC. Farms in Cluster C use the highest average of 21 practices to manage weeds on their farms. Cluster C will be discussed as the "Integrated Management" cluster (IMC) due to the diverse and information-intensive nature of the management strategies adopted by cluster members, building on direct control efforts with additional emphasis on prevention, information management, and the application of control thresholds.

The category with the highest level of engagement among the IMC is information management (51%) followed closely by several other categories including planting management (49%), cultural controls (42%), prevention (39%), mechanical controls (36%), and control thresholds (33%). Growers in the IMC have adopted diverse systems composed of a suite of management innovations. Their systems build on cultural and mechanical controls with preventative practices not used by either other cluster, and information management practices not extensively adopted among the CCC.

The diversity of weed management among the IMC suggests adoption of the IWM philosophy, but, as is noted in previous literature, biological controls have not been incorporated into the most diverse organic weed management systems (Lamine 2011). This may be evidence that biological weed controls fit better in perennial farm systems with long-term management outlooks.

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Table 4. Parameter estimates for most parsimonious logistic regression model discriminating between membership within the classic control (CC) cluster and the integrated management (IM) cluster.

Parameter	df	Estimate	SE[a]	Wald χ^2	Odds ratio	95% confidence interval	
						Lower	Upper
Intercept	1	−3.42	0.63	28.96***[b]			
Education	1	0.53	0.14	14.56***	1.70	1.29	2.23
Years farming	1	0.03	0.01	4.63*	1.03	1.00	1.05
Information seeking	1	0.19	0.09	4.39*	1.21	1.01	1.44

[a] Abbreviation: SE, standard error.
[b] The symbols * and *** represent $P > F$ at $\alpha = 0.05$ and 0.0001, respectively.

Logistic Regression Analysis. To identify other less apparent drivers motivating adoption of particular weed management innovations, and thus proposed cluster membership, a stepwise logistic regression procedure was applied. Independent variables included data regarding farm structure, farmer demographics, and perceived innovation characteristics, which the literature suggests influence weed management behavior. Because each operation class (products grown) occurred in only two of the three proposed clusters, two binary logistic regression models were calculated to describe (1) what drives forage and fruit farmers into the FPC over the CCC, and (2) what pushes grain & forage, grain, vegetable, and diversified growers into the IMC rather than the CCC.

Results of stepwise logistic regression for the CC and IM Clusters are presented in Table 4. The selected model achieved 73% of correct classification, and the Hosmer-Lemeshow lack-of-fit test indicated a reasonable model fit ($\chi^2 = 5.86$, df = 8, P = 0.663). The resulting equation indicates that years of formal education, years farming, and information seeking (measured as number of resources used) are the most important variables determining whether an organic grain & forage, grain, vegetable, or diversified grower will manage weeds in the pattern of the CCC or the IWC. The odds ratio of being a IMC member indicates that each step along our categorical measure of formal education, (1) middle school, (2) high school diploma or equivalent, (3) some college, (4) college degree, and (5) graduate or professional degree, increases the odds of being in the IMC by 70%, with a confidence interval (CI) for this term ranging from 1.29 to 2.23. This supports other findings suggesting that formal education is correlated with adoption of diverse pest management strategies (Ceylan et al. 2010; Park and Lohr 2005). Since the 1970s, formal agricultural education has exposed farmers to ecology-based pest management and the

increasing variety of technologies available. Formal education, regardless of the field, also trains students to critically assess information under uncertainty and may indoctrinate a farmer to trust information-intensive scientific concepts generated by university research (Park and Lohr 2005).

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

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

Results of logistic regression for the CC and FP Clusters are presented in Table 5. The selected

Table 5. Parameter estimates for most parsimonious logistic regression model discriminating between membership within the classic control (CC) cluster and the forb philosophy (FP) cluster.

Parameter	df	Estimate	SE[a]	Wald χ^2	Odds ratio	95% confidence interval	
						Lower	Upper
Intercept	1	−1.87	1.19	2.46	0.12		
Education	1	0.97	0.43	5.17[*b]	2.65	1.14	6.12

[a] Abbreviation: SE, standard error.
[b] The symbol * represents P > F at α = 0.05.

model achieved 66% of correct classification, and the Hosmer-Lemeshow lack-of-fit test indicated a reasonable model fit ($\chi^2 = 5.34$, df = 3, P = 0.148). The resulting equation indicates that years of formal education is the most important variable determining whether an organic forage or fruit grower will manage weeds in the pattern of the CCC, or instead shift their approach to accommodate perennial systems ecology as in the FPC. The odds ratio of being a FPC member indicates that each step along our categorical measure of formal education increases the odds of being in the FPC by 1.65%, with a CI ranging from 1.14 to 6.12. This indicates that formal education not only promotes diversification of weed management in line with the IWM concept, but in the context of perennial systems also fosters an alternative philosophy of weed management based on a few integrated mechanical, biological, and information management practices.

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

have diversified their weed management systems. This diversification is facilitated by formal education, experience in farming, and additional information sourcing behavior. We agree with Jabbour et al. (2013) that new types of educational materials are needed to train growers in specific weed management practices, but also see the need to tailor these materials to specific subgroups within the spectrum of organic weed management philosophies.

Discussion

If increased adoption of diverse IWM systems is the goal, our findings suggest that (1) organic weed management systems are on average quite diverse, (2) what a grower chooses to produce imposes restrictions on weed management behavior, (3) information availability and sourcing are central to successful diffusion of ecological weed management, and (4) information-intensive weed management innovations (particularly prevention and economic action thresholds) should be targeted at formally educated and experienced growers.

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

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Acknowledgments

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