doi:10.20944/preprints201810.0176.v1

Peer-reviewed version available at *Sustainability* **2018**, *10*, 4096; doi:10.3390/su10114096

Perceptions, experiences, and priorities supporting agro-ecosystem management decisions differ among agricultural producers, consultants, and researchers

Sean McKenzie[1], Hilary Parkinson[1], Jane Mangold[1], Mary Burrows[2], Selena Ahmed[3], and Fabian Menalled[1]

[1] Department of Land Resources and Environmental Sciences, Montana State University, Bozeman, MT, USA 59717-0312

[2] Department of Plant Sciences and Plant Pathology, Montana State University, Bozeman, MT, USA 59717-3150

[3] Department of Health and Human Development, Montana State University, Bozeman, MT, USA 59717-3540

Corresponding author: Fabian Menalled
Email: menalled@montana.edu

Abstract: The sustainability of agriculture depends as much on the natural resources required for production as it does on the stakeholders that manage those resources. It is thus essential to understand the variables that influence the decision-making process of agricultural stakeholders to design educational programs, interventions, and policies geared towards their specific needs, a required step to enhance agricultural sustainability. We examined the perceptions, experiences, and priorities that influence management decisions of five major groups of agricultural stakeholders (conventional small grain producers, organic small grain producers, organic vegetable producers, extension agents and agro-industry crop consultants, and researchers) across the Montana, United States. Results revealed that while stakeholder groups have distinct perceptions, experiences, and priorities, there were similarities across groups. Specifically, organic vegetable and organic small grain producers showed similar responses that were, in turn, divergent of conventional producers, researchers, and crop consultants. Conventional small grain producers and researchers showed overlapping response patterns while crop consultants formed an isolated group. Our results reinforce the need for agricultural education and programs that address unique and shared experiences, priorities, and concerns of multiple stakeholder groups. This study endorses the call for a paradigm shift from the traditional top-down agricultural extension model to one that accounts for participants' socio-ecological contexts to facilitate the adoption of sustainable agricultural systems that support environmental and human wellbeing.

Keywords: agricultural stakeholders, extension, multivariate analysis, socio-ecological systems, mental models, sustainable agriculture

Peer-reviewed version available at Sustainability 2018, 10, 4096; doi:10.3390/su10114096

1. Introduction

Agricultural professionals shape food, fiber, and energy production practices through a series of decision-making processes that ultimately influence the natural and human dimensions of food systems. Decisions regarding what to grow and how to manage it impact the sustainability of the agricultural enterprise, the availability and quality of agricultural products, and the ecosystems services provided by farms and ranches [1]. Agricultural professionals' management decisions are influenced by multiple socio-ecological factors, including interactions with other producers, extension agents, agro-industry personnel, and researchers. For extension efforts to enhance agricultural sustainability, it is critical to understand how the perceptions, experiences, and priorities that support agro-ecosystem management decisions differ among producers, researchers, extension agents, and agro-industry crop consultants. Yet, in the traditional model of top-down agricultural knowledge and technology transfer, researchers, extension agents, and crop consultants design printed materials, conferences, and field days centered around a limited number of challenges they presuppose to be important. This model assumes that those extension efforts inform producers of novel management strategies and technology and it does not account for participants' perceptions, experiences, and priorities [2]. Further, this approach to extension does not monitor emerging commonalities and differences within and across stakeholder groups and fails to consider the many interdependent components that form complex socio-agroecological systems.

Many of the environmental, social, and economic shortcomings associated with agricultural production are largely driven by human decisions and actions, as are solutions to address such problems [3]. Characterizing the variables that determine the decision-making processes of agricultural professionals is thus important for designing best management practices for sustainable and resilient food systems [1, 4]. Decision-making can be characterized as a process based on stakeholder perceptions, experiences, and priorities as well as access to resources such as information and capital. In this context, the personal and socio-ecological variables influencing decision-making should be

Peer-reviewed version available at Sustainability 2018, 10, 4096; doi:10.3390/su10114096

evaluated to better understand how agricultural stakeholders interact among themselves and with the world around them.

The perceptions, experiences, and priorities that influence decisions are context-specific and occur at multiple scales, from individuals, to groups, to societies. When individuals come together and form groups, we can assess the salience of collective perceptions, beliefs, knowledge, and experiences within and across groups of stakeholders to understand joint actions and integration of multiple perspectives [5, 6, 7]. This process is crucial for improving communication within and across groups, overcoming stakeholders' knowledge limitations and misconceptions [8], and enhancing social learning [9, 10]. The perceptions, experiences, and priorities that influence decision making can be organized into mental models that characterize an individual's cognitive representation of the external reality that he/she uses to interact with his/her surroundings [11]. These cognitive representations influence how individuals define problems, assess risks and benefits, and gather and process information [12], including the filtering and storage of new information [3]. An emerging body of socio-ecological systems research focuses on examining the processes that shape mental models of stakeholder groups in food systems [13,14], including determining collective mental models for the design and sustainable management of agroecosystems [15, 16].

Determining agreements and discrepancies within and across agricultural stakeholder groups has the potential to highlight opportunities and constraints for research, outreach, and implementation of sustainable agriculture programs. Yet, the extent to which different agricultural stakeholders share perceptions, experiences, and priorities is largely unknown in numerous regions, including the Northern Great Plains region of the United States. Filling this knowledge gap is imperative for the development of sustainable agricultural extension efforts. Our overall goal was to compare how the perceptions, experiences, and priorities supporting agro-ecosystem management decisions differ among producers, extension agents, agro-industry crop consultants, and researchers in Montana, United States. Montana is a compelling case for conducting research on agricultural stakeholders' perceptions, experiences, and

Peer-reviewed version available at Sustainability 2018, 10, 4096; doi:10.3390/su10114096

priorities as it is home to over 27,000 farms and ranches on >2.38 x 10^7 hectares and its diverse climate supports a range of high-quality food products including beef, small grains, hay, legume crops, potatoes, sugar beets, oilseed crops, and small fruits [17].

To our knowledge, no previous study conducted in the Northern Great Plains region examined the perceptions, experiences, and priorities that influence management decisions of agricultural stakeholders. Specifically, we evaluated perceptions, experiences, and priorities that influence the development of mental models and decision-making processes of five major agricultural stakeholders: conventional small grain producers, organic small grain producers, organic vegetable producers, crop consultants including agro-industry representatives and agricultural extension agents, and researchers. These stakeholders were selected because collectively they represent agricultural research, outreach, and production activities in Montana. To achieve our goal, we administered a survey of multiple-choice and open-ended questions to: 1) characterize the environmental, ecological, and economic contexts of agricultural enterprises, 2) identify perceptions, experiences, and priorities that drive agro-ecosystem management decision making, and 3) highlight opportunities and constraints for improving extension-based activities on agricultural sustainability.

2. Materials and Methods

2.1. Survey Development and Administration

We adapted our survey from one developed by the Montana Organic Advisory and Education Council (OAEC), a non-profit organization composed of certified organic farmers whose mission is to assess and prioritize needs for organic research and education (http://www.oaecmt.org). The survey consisted of 37 questions designed to evaluate experiences, perceptions, and priorities driving agro-ecosystem management decisions, production challenges, and opportunities for sustainable agriculture (Table S1). The Montana State University review board issued the IRB protocol, "Assessing producer's knowledge and attitudes about natural resources" [FM01114-EX] on January 21, 2014; approving this

Peer-reviewed version available at Sustainability 2018, 10, 4096; doi:10.3390/su10114096

study. Prior-informed consent was received from all respondents before administering the survey, and the survey was analyzed anonymously. Twenty-five of the questions were multiple-choice and aimed at identifying the environmental, ecological, and economic contexts of stockholders' farming enterprises. The other twelve questions allowed for open-ended responses and assessed perceptions of agronomic challenges, factors influencing management decisions, priorities for future research, and sources of farming information.

The survey was first distributed by the OAEC to organic small-grain producers and organic vegetable producers throughout Montana in 2012 and 2013. Following the initial dissemination, we administered the survey in 2014 to a broad constituency of stakeholders of conventional and organic producers, crop consultants including agro-industry representatives and agricultural extension agents, and researchers. To do this, the survey was disseminated through Montana State University Extension efforts during nine different field days and meetings across the state as well as by personal communications. To increase participation, the survey was available in both paper and online, depending on respondents' preferences. Although respondents do not represent a truly random sample, it is expected that coverage and non-response error was reduced through the multi-modal nature of the survey and the extensive network reached through stakeholder organizations and the Montana State University's Extension Service [18]. A similar approach was recently used to evaluate agricultural stakeholder perceptions and observations of climate change in the Northern Great Plains [19].

2.2. Open-Ended Response Coding

Following [13], open-ended responses were coded into a series of domains and subdomains to identify recurring themes in the data. We developed domains and subdomains for each question by reading all responses and identifying emerging themes for a particular question prior to coding. Domains consisted of major thematic categories, while subdomains consisted of specific issues within a domain (Table S2). Two researchers (Parkinson and McKenzie) coded responses of seven of the twelve open-ended questions together. Responses of the remaining five open-ended questions were coded by

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 9 October 2018 doi:10.20944/preprints201810.0176.v1

Peer-reviewed version available at Sustainability 2018, 10, 4096; doi:10.3390/su10114096

either Parkinson or McKenzie, independently. For these five independently coded questions, the other researcher re-coded a random subset of 20% of respondents to test for inter-coder reliability, calculated as percent agreement:

$$R = 100\% \times \sum_{(k=1)}^{n} \frac{(D_k - M_k)}{D_k} \tag{1}$$

where R is the percent correspondence between the re-coder and the original coder for a specific question, D_k is the number of respondents whose answers were coded with domain k by either the re-coder or the original coder, and M_k is the number of mismatches between the re-coder and the original coder for domain k [20]. We used the same formula to calculate inter-coder reliability for subdomains. Following [13], if either domain or subdomain inter-coder reliability was below 2/3 (67%) correspondence, the question was re-coded in its entirety jointly by Parkinson and McKenzie. Finally, to validate inter-coder reliability [20], three other researchers (Burrows, Mangold, and Menalled) re-coded a random subset of 20% of respondents to test inter-coder reliability as calculated above. Inter-coder reliability for each open-ended question is reported in Table S2.

2.3. Data Processing and Analysis

We converted all responses in the multiple-choice dataset with categorical nominal answers into a set of binary dummy variables. Responses to questions with categorical ordinal answers in the multiple-choice dataset were given a numeric rank score. For the open-ended data, we converted all domain and subdomain codes for each response into a series of binary dummy variables. We grouped these dummy variables into three distinct subsets: one for multiple-choice questions, one for response domains to open-ended questions, and one for response subdomains to open-ended questions. For each of these subsets, we constructed a dissimilarity matrix using the Bray–Curtis dissimilarity index:

$$BC_{(j,k)} = \frac{\sum_{i=1}^{R} 2\left|a_{(i,j)} - a_{(i,k)}\right|}{\sum_{i=1}^{R} a_{(i,j)} + \sum_{i=1}^{R} a_{(i,k)}} \tag{2}$$

where $BC_{(j,k)}$ is the Bray-Curtis dissimilarity between respondents j and k, $a_{(i,j)}$ is the response value of

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 9 October 2018 doi:10.20944/preprints201810.0176.v1

Peer-reviewed version available at Sustainability 2018, 10, 4096; doi:10.3390/su10114096

respondent j to question i, $a_{(i,k)}$ is the response value of respondent k to question i, and R is the total number of questions in the subset [21].

To investigate differences in the environmental, ecological, and economic contexts of agronomic enterprises among the five agricultural stakeholder groups, we first performed a non-metric multidimensional scaling (NMDS) ordination for the multiple-choice dataset. Initial positions in ordination space were determined by principal coordinates analysis of the dissimilarity matrix. Statistical significance of the separation among agricultural professions was determined using Permutational Multivariate Analysis of Variance (PERMANOVA) with 999 iterations [22]. We then investigated emerging associations among respondents in their answers by performing cluster analyses using a flexible-β hierarchical agglomerative clustering algorithm parameterized with $\alpha_1=\alpha_2=0.625$, $\beta = -0.25$, and $\gamma = 0$, following [23]. For each classification dendrogram, we separated clusters at constant dissimilarity. We tested the correspondence between responses of agricultural stakeholder groups and the clusters derived from each classification using a χ^2 analysis. Due to concerns of low expected values, we obtained p-values using a Monte Carlo simulation with 999 iterations. This Monte Carlo simulation was also used for pairwise comparisons between agricultural professions and the classification clusters. For this analysis, we calculated χ^2 for each pairwise comparison as:

$$\chi^2_{(i,j)} = \frac{\left(O_{(i,j)} - E_{(i,j)}\right)^2}{E_{(i,j)}} \quad (3)$$

where $\chi^2_{(i,j)}$ is the test statistic for the comparison between agricultural stakeholder group i and cluster j, $O_{(i,j)}$ is the observed number of respondents that were simultaneously identified as agricultural stakeholder groups i and classified into cluster j, and $E_{(i,j)}$ is the expected number respondents for that pairing. As explained above, due to concerns of low expected values, we obtained p-values using a Monte Carlo simulation with 999 iterations. P-values for these pairwise comparisons were calculated as:

$$P_{(i,j)} = \frac{\left(R_{(i,j)} + 1\right)}{B + 1} \tag{4}$$

where $P_{(i,j)}$ is the p-value for the comparison between agricultural stakeholder groups i and cluster j, $R_{(i,j)}$ is number of times $\chi^2_{(i,j)}$ obtained from a Monte Carlo iteration exceeded $\chi^2_{(i,j)}$ from the observed data, and B is the number of iterations in the Monte Carlo simulation. Our post-hoc analyses were adapted from [24].

To identify specific concerns of each one of the five agricultural stakeholder groups and the proposed clusters, we found the five most indicative responses for each cluster group by adapting indicator species analysis, a method used in community ecology [25]. In our study, the indicator value of a stakeholder group is the product of the fidelity and exclusivity of that group to a cluster is given by:

$$INDVAL_{(i,j)} = F_{(i,j)} \times E_{(i,j)} \tag{5}$$

where $INDVAL_{(i,j)}$ is the indicator value of stakeholder group i for cluster j, $F_{(i,j)}$ is the fidelity of stakeholder group i to cluster j, and $E_{(i,j)}$ is the exclusivity of stakeholder group i to cluster type j. Fidelity is the propensity for a stakeholder group to occur in a given cluster and is calculated as:

$$F_{(i,j)} = \frac{C_{(i,j)}}{C_{(.,j)}} \tag{6}$$

where $F_{(i,j)}$ is the fidelity of stakeholder group i to cluster type j, $C_{(i,j)}$ is the number of observations in which stakeholder group i occurs in cluster j, and $C_{(.,j)}$ is the total number of observations in cluster j. Exclusivity is the propensity for a stakeholder group to occur only in observations of a specific cluster and is calculated as:

$$E_{(i,j)} = \frac{N_{(i,j)}}{N_{(i,.)}} \tag{7}$$

where $E_{(i,j)}$ is the exclusiveness of stakeholder group i to cluster j, $N_{(i,j)}$ is the mean abundance of stakeholder group i in observations of cluster j, and $N_{(i,.)}$ is the sum of mean abundances of stakeholder group i in each classification cluster. Probabilities for the indicator values were obtained from a Monte Carlo simulation with 999 iterations.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 9 October 2018 doi:10.20944/preprints201810.0176.v1
Peer-reviewed version available at Sustainability 2018, 10, 4096; doi:10.3390/su10114096

All data processing and analyses were conducted in R statistical software version 3.0.2 [26]. Batch data processing and compilation were performed using the labdsv [27], plyr [28], and reshape [29] packages of R. Multivariate analyses and indicator species analysis were performed using the labdsv [27], optpart [30], and cluster [31] packages. Three-dimensional graphics were created in the rgl [32] package.

3. Results

A total of 272 respondents completed the survey, representing the following five distinct agricultural stakeholder groups: 103 (34.9%) conventional producers, 78 (28.7%) consultants, 37 (13.6%) researchers, 33 (12.1%) organic grain producers, and 21 (7.7%) organic vegetable producers. From the multiple-choice response dataset, we identified a strong separation in the responses among agricultural stakeholders (pseudo-F = 22.92; df = 4, 265; r^2 = 0.26; P = 0.001; Fig 1). We observed a distinction between both organic vegetable producers and organic grain producers, located mostly on the negative values of the second NMDS axis, and all other stakeholders, positioned in the positive values of that axis.

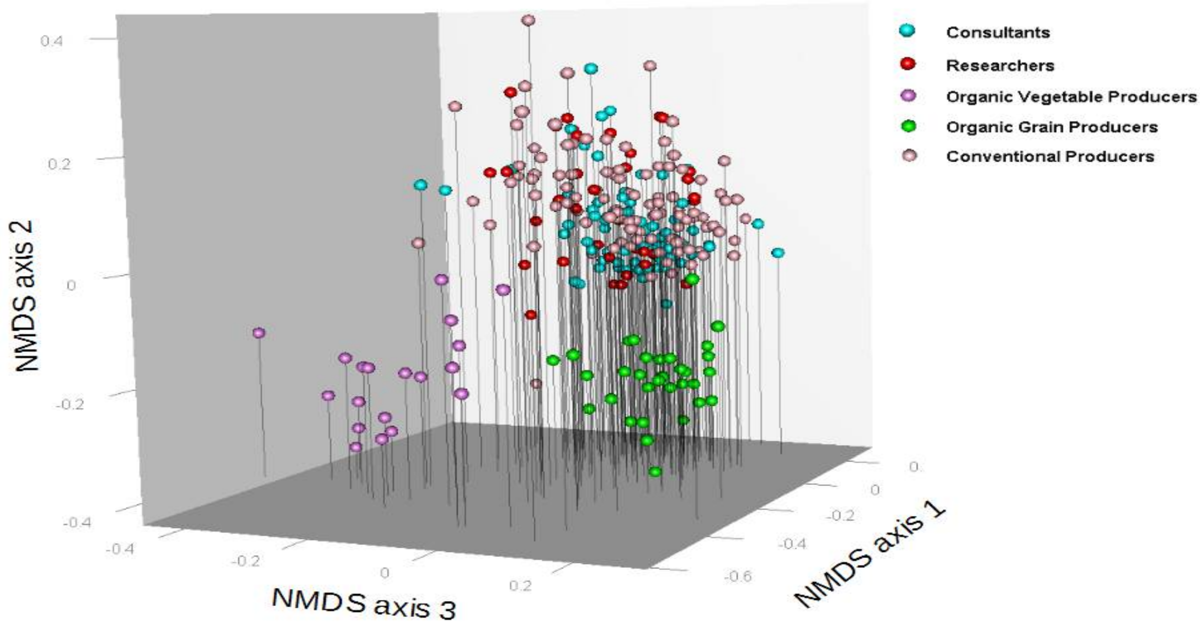
---Insert Figure 1 Here ---

The six clusters resulting from the classification of the multiple-choice response dataset associated with specific agricultural professions (χ^2 = 549.72; df =20; P = 0.001; Fig 2). Specifically, while both conventional producers and researchers positively associated with the first cluster (P1); consultants, organic grain growers, and organic vegetable producers negatively associated with this cluster. Conventional producers associated positively with cluster P2, but no other agricultural profession associated with this cluster. Organic vegetable producers associated positively with cluster P3, while conventional producers, researchers and consultants were negatively associated with this cluster. Organic grain producers positively associated with cluster P4, whereas all other agricultural professions negatively associated with this cluster. Consultants positively associated with cluster P5, but both

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 9 October 2018 doi:10.20944/preprints201810.0176.v1

Peer-reviewed version available at *Sustainability* **2018**, *10*, 4096; doi:10.3390/su10114096

Fig 1: Non-metric multidimensional scaling (NMDS) ordination of responses provided by agricultural stakeholders to multiple choice questions aimed at identifying contextual information about agricultural production conditions. Agricultural stakeholders' professions are color coded and respondents closer in ordination space had answers that more closely resembled each other whereas those farther apart had more dissimilar answers.



Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 9 October 2018 doi:10.20944/preprints201810.0176.v1

Peer-reviewed version available at *Sustainability* **2018**, *10*, 4096; doi:10.3390/su10114096

conventional producers and organic producers negatively associated with this cluster. Finally, cluster P6 did not associate with any specific agronomic profession.

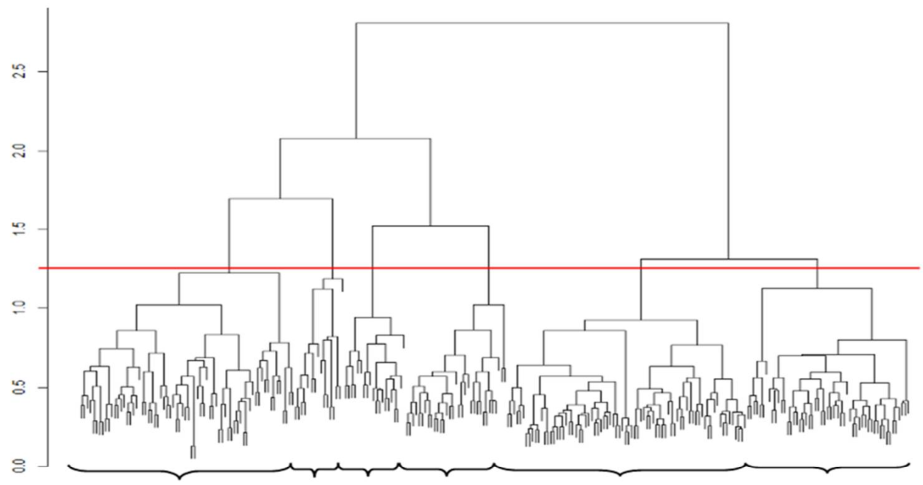
--Insert Figure 2 Here --

Results of the indicator response analysis showed specific associations between clusters and the twenty-five multiple-choice responses we utilized to identify information about the environmental, ecological, and economic contexts of farming operations (Table 1). We found no indicator responses associated with cluster P1, suggesting heterogeneous contextual conditions associated with the researchers and conventional producers presented in this cluster. Specifically, researchers cited soil fertility, phytophagous insect pests, precipitation, and crop varieties as the strongest influences on crop yields. In addition, this group operated primarily in Gallatin County, MT. By contrast, conventional producers were characterized by extensive career length and operating primarily in Broadwater and Valley Counties, MT. The strongest indicators for stakeholders in P2, a cluster dominated by conventional producers, included the location of their farming enterprise; difficulty managing houndstongue (*Cynoglossum officinale* L.), musk thistle (*Carduus nutans* L.), and American licorice (*Glycyrrhiza lepidota* (Nutt.) Pursh); and producing on rangeland. The indicator responses associated with P3, a cluster dominated by organic vegetable producers, included success growing lettuce (*Lactuca sativa* L.), tomato (*Solanum lycopersicum* L.), alliums (Amaryllidaceae:Allioidae), and brassicas (Brassicaceae). Additionally, respondents in P3 noted that phytophagous insects had a major impact on brassicas. Top indicator responses for cluster P4, a cluster dominated by organic grain producers, included success growing spring wheat (*Triticum aestivum* L.), impacts of weeds on flax (*Linum usitatissimum* L.) and forage crops, difficulty marketing flax, and difficulty managing kochia (*Bassia scoparia* (L.) A.J. Scott). Specific indicators of cluster P5, a group positively associated with consultants, included diseases impacting chickpea (*Cicer arietinum* L.), lentil (*Lens culinaris* Medik.), and oilseed production; as well as weeds and insect pests impacting chickpea production. Finally, the

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 9 October 2018 doi:10.20944/preprints201810.0176.v1

Peer-reviewed version available at *Sustainability* **2018**, *10*, 4096; doi:10.3390/su10114096

Fig 2: (Top) Dendrogram based on twenty-five multiple-choice questions aimed at identifying contextual information about agricultural production conditions. The horizontal red line delineates proposed clusters. (Bottom) Contingency table of cluster membership (columns) by agricultural stakeholder profession (rows), where n denotes the number of respondents with joint membership in a cluster and an agricultural stakeholder group, and ln(o/e) denotes the log likelihood ratio. Significance levels: $0.05 \geq P \geq 0.01$ *; $0.01 > P \geq 0.001$**; $0.001 > P$***.



		P1	P2	P3	P4	P5	P6
Convectional producers	n	36^{**}	9^{**}	1^{**}	0^{***}	19^{*}	31
	ln(o/e)	0.394	0.879	-2.011	-∞	-0.402	0.448
Researchers	n	18^{***}	0	0^{*}	0^{**}	14	5
	ln(o/e)	0.654	-∞	-∞	-∞	0.246	-0.423
Consultants	n	11^{*}	1	0^{**}	0^{***}	43^{***}	17
	ln(o/e)	-0.504	-1.030	-∞	-∞	0.703	0.135
Organic grain producers	n	0^{***}	0	0	33^{***}	0^{*}	0
	ln(o/e)	-∞	-∞	-∞	2.053	-∞	-∞
Organic vegetable producers	n	0^{*}	0	19^{***}	0	0^{**}	0
	ln(o/e)	-∞	-∞	2.553	-∞	-∞	-∞

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 9 October 2018 doi:10.20944/preprints201810.0176.v1

Peer-reviewed version available at *Sustainability* **2018**, *10*, 4096; doi:10.3390/su10114096

indicative responses for cluster P6 included difficulty marketing winter wheat and barley (*Hordeum vulgare* L.), success growing barley, and difficulty managing downy brome (*Bromus tectorum* L.) and wheat stem sawflies (Hymenoptera:Symphyta), but no stakeholder group associated with this cluster.

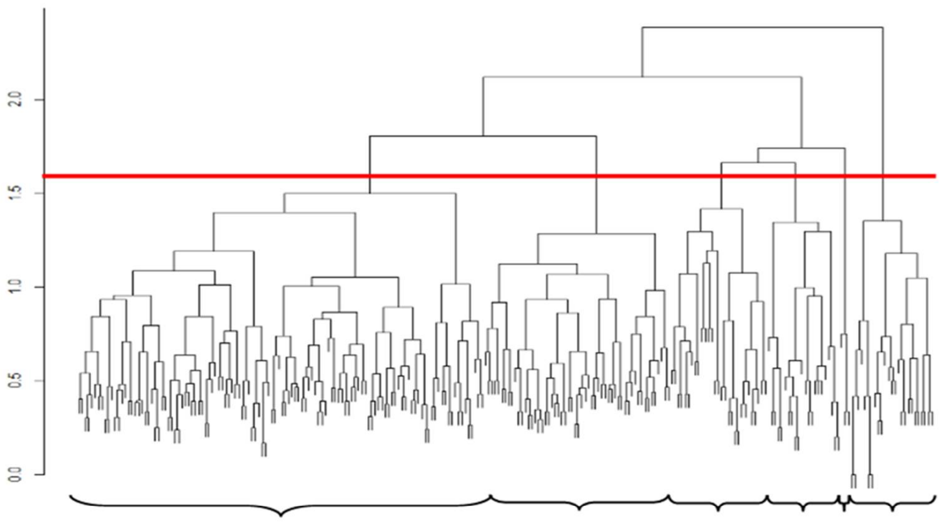
--Insert Table 1 Here---

The classification of open-ended domains used to assess agronomic challenges and research needs resulted in six distinctive clusters (Fig 3), with specific associations between clusters and agricultural stakeholder groups ($\chi^2 = 164.41$; df = 20; P = 0.001). Consultants associated positively with cluster D1, while researchers, organic grain producers, and organic vegetable producers were negatively associated with this cluster. Organic grain producers and organic vegetable producers associated positively with cluster D2, while consultants and conventional producers associated negatively with that cluster. Cluster D3 had a marginally positive association with researchers and a marginally negative association with organic vegetable producers. Conventional producers were positively associated with cluster D4, while consultants and organic grain growers were negatively associated with that cluster. Finally, we found no associations between any stakeholder groups and cluster D5, and researchers were the only stakeholder group that associated positively with cluster D6.

--Insert Figure 3 Here---

Indicator response analysis for the open-ended response domains (Table 2) showed that the strongest indicators for cluster D1, a cluster positively associated with consultants, were obtaining information from extension/university outlets and personal communication, fertilizer use, and conducting on-farm research on specific agricultural inputs. The strongest indicator domains of D2, a cluster dominated by organic grain and organic vegetable producers, were the need to conduct research on specific agronomic and insect pest and weed management issues. We found that the strongest indicator domains for organic grain producers included the length of no-till practices, the need of conducting research on specific weed species, agroecological factors challenging production, indicating

Fig 3: (Top) Dendrogram of domains with recurrent themes from open-ended questions aimed at assessing agricultural stakeholder perceptions of agronomic challenges. The horizontal red line delineates proposed clusters. (Bottom) Contingency table of cluster membership (columns) by agricultural stakeholder profession (rows), where n denotes the number of respondents with joint membership in a cluster and an agricultural profession, and ln(o/e) denotes the log likelihood ratio of each joint membership. Statistical significance levels: 0.05 ≥ P ≥ 0.01 *; 0.01 > P ≥ 0.001**; 0.001 > P***.



		D1	D2	D3	D4	D5	D6
Convectional producers	n	47	4***	15	19***	0	11
	ln(o/e)	0.031	-1.654	0.325	0.838	-∞	0.164
Researchers	n	16	5	7*	1	1	7*
	ln(o/e)	-0.093	-0.478	0.517	-1.153	0.840	0.665
Consultants	n	53***	6**	5	2*	2	4
	ln(o/e)	0.439	-0.961	-0.485	-1.125	0.867	-0.560
Organic grain producers	n	2***	27***	2	0*	0	2
	ln(o/e)	-2.058	1.323	-0.622	-∞	-∞	-0.473
Organic vegetable producers	n	4*	14***	0*	0	0	1
	ln(o/e)	-0.813	1.218	-∞	-∞	-∞	-0.614

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 9 October 2018 doi:10.20944/preprints201810.0176.v1

Peer-reviewed version available at Sustainability 2018, 10, 4096; doi:10.3390/su10114096

that research on environmental factors would be of the greatest benefit to their operations, and choosing their crop rotations based on economic factors, The strongest indicator domains for organic vegetable producers were fertilizer use, choosing crop rotations based on their specific agronomic management practices, citing social factors as the most needed marketing research, indicating that research on agronomic factors would be of greatest benefit to their enterprises, and mentioning environmental factors as their greatest production challenge. We found no significant indicator domains for D3, a cluster that showed a marginal positive association with researchers suggesting divergent interests within this stakeholder group. Among the varied interest researchers cited were conducting on-farm research, managing pests and beneficial insects, including ecological factors in weed research, and conducting marketing research. The only indicator domain for cluster D4, a group positively associated with conventional producers, was gaining experience with no-till practices. We found that the only indicator domains of respondents in cluster D5, a cluster not associated with any specific stakeholder group were citing environmental factors and agronomic management as the greatest agronomic challenge. Finally, the only indicator domain for cluster D6, a cluster positively associated with researchers, was citing agroecological factors as the greatest agronomic challenge.

--Insert Table 2 Here---

From the classification of the open-ended subdomain data, we obtained six distinct clusters, suggesting differences in the concerns of the five studied agricultural stakeholder groups (χ^2 = 144.83; df = 20; P = 0.001; Fig 4). While consultants associated positively with cluster S1, organic grain producers and organic vegetable producers were negatively associated with this cluster. Organic vegetable producers associated positively with cluster S2, but consultants negatively associated with this cluster. Consultants positively associated with cluster S3, while both organic grain and organic vegetable producers were negatively associated with S3. Organic grain producers associated positively with cluster S4, while conventional producers, researchers, and consultants were negatively associated with this cluster. Organic grain producers were also positively associated with cluster S5 while no other

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 9 October 2018 doi:10.20944/preprints201810.0176.v1

Peer-reviewed version available at Sustainability 2018, 10, 4096; doi:10.3390/su10114096

stakeholder group associated with this cluster. Finally, no associations were found between any stakeholder group and cluster S6.

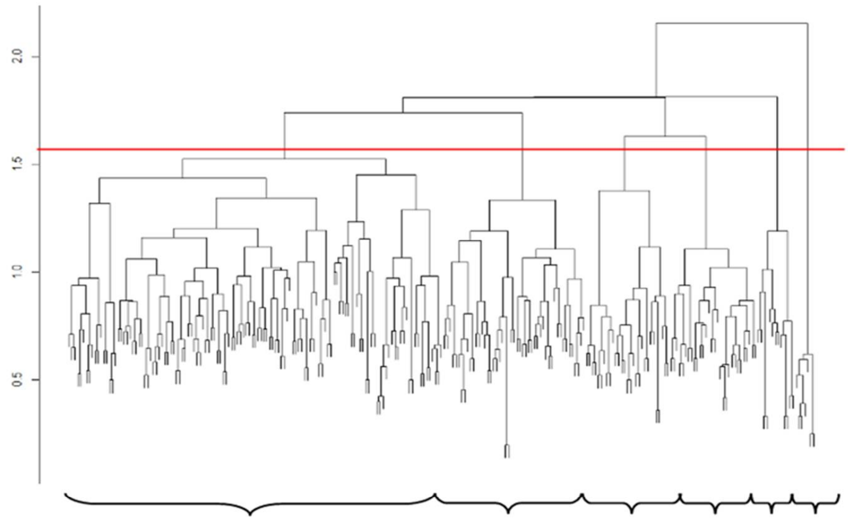
--Insert Figure 4 Here---

Indicator subdomains for consultants, the only stakeholder group positively associated with S1, included having experience with no-till practices; adding fertilizer based on soil test results; and obtaining farming information from field demonstrations, internet resources, and conducting training workshops (Table 3). The strongest indicator subdomains for organic vegetable producers, the only stakeholder group to associate positively with S2, fertilizer use; improving crop rotation based on nutrient biogeochemistry; citing education as the most needed marketing research; and conducting research on perennial weed management. The most indicative subdomains for cluster S3 included conducting research of new revenue streams and markets, as well as integrated weed management. Indicator subdomains for organic grain producers, the only stakeholder group positively associated with either cluster S4 or cluster S5, included lacking experience with no-till practices; and citing management of perennial and dicotyledonous weeds as the most needed weed research. The strongest indicator subdomains for respondents in cluster S6 were obtaining farming information from university faculty; assessing plant community responses to management as the most needed weed research; using GPS mapping technology and foliar-applied fungicides, and investigations into crop nutritive value as the most needed marketing research. While we found no significant associations between any stakeholder groups and cluster S6, conventional producers comprised the majority of this cluster. While researchers did not associate positively with any cluster from the subdomain classification, indicator subdomains for this group included obtaining farming information from peer-reviewed journals, neighbors, and colleagues; citing nitrogen cycling and biogeochemistry as the most needed soil fertility research; conducting on-farm research on specialized crop varieties; and adding fertilizer based on leaching and volatilization potential.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 9 October 2018 doi:10.20944/preprints201810.0176.v1

Peer-reviewed version available at Sustainability 2018, 10, 4096; doi:10.3390/su10114096

Fig 4: (Top) Dendrogram of open-ended response subdomains aimed at assessing agricultural stakeholder perceptions of agronomic challenges. The horizontal red line delineates proposed clusters. (Bottom) Contingency table of cluster membership (columns) by agricultural stakeholder profession (row), where n denotes the number of respondents with joint membership in a cluster and an agricultural profession, and ln(o/e) denotes the log likelihood ratio of each joint membership. Statistical significance levels: 0.05 ≥ P ≥ 0.01 *; 0.01 > P ≥ 0.001**; 0.001 > P***.



		S1	S2	S3	S4	S5	S6
Convectional producers	n	54	13	13	4**	6	6*
	ln(o/e)	0.114	-0.342	0.182	-1.030	0.212	0.831
Researchers	n	24	9	2	1*	1	0
	ln(o/e)	0.256	0.244	-0.736	-1.463	-0.627	-∞
Consultants	n	47*	6*	14*	3*	1*	1
	ln(o/e)	0.263	-0.828	0.544	-1.030	-1.293	-0.674
Organic grain producers	n	1***	9	0*	18***	5**	0
	ln(o/e)	-2.807	0.358	-∞	1.542	1.097	-∞
Organic vegetable producers	n	3*	12***	0*	4	0	0
	ln(o/e)	-1.157	1.198	-∞	0.590	-∞	-∞

Peer-reviewed version available at Sustainability 2018, 10, 4096; doi:10.3390/su10114096

--Insert Table 3 Here--

4. Discussion and Conclusions

The design and management of sustainable agroecosystems requires shifting from an industrial agriculture paradigm focused on yield, returns, and efficiency maximization to one that aims at jointly enhancing the environmental, social, and economic dimensions of the food system [33]. For example, this includes a focus on sustainable agricultural practices for the cultivation of high-quality crops that support consumer demand for flavorful food and human nutrition while supporting farmer livelihoods [34]. In this process, assessing the perceptions, experiences, and priorities underpinning agricultural professionals' decisions is critical to develop alternative extension programs that will facilitate the adoption of sustainable agricultural practices [35]. Nevertheless, Land Grant Universities and the industrial sector traditionally use a top-down extension approach to disseminate technological information developed in laboratories and research stations in a process that treats research results as universally applicable information [36]. This approach does not account for the unique environmental, ecological, and economic context of individual agricultural enterprises, making it inadequate for solving complex socio-ecological issues of sustainable food, fiber, and bioenergy production [37].

The development of alternative extension programs requires an interdisciplinary perspective that combines bio-physical science and social science, recognizes that there is as much diversity in the human dimension of management as in the biological and natural resources being managed [38], and finds a common ground of understanding between agricultural producers, educators, agro-ecologists, and social scientists [39, 40]. Prior experiences, values, beliefs, and perceptions that underpin the mental models of agricultural stakeholders guide their actions, decisions, and use of information [41]. Researchers and agricultural educators can, in turn, draw from this information to better tailor their efforts with producers' environmental, ecological, and economic contexts, goals, and available technology [35]. Such approach would enable effective extension efforts that link knowledge and action, a central tenet in sustainability [42].

Peer-reviewed version available at Sustainability 2018, 10, 4096; doi:10.3390/su10114096

Previous research has demonstrated variation in the mental models and decision-making processes within specific groups of agricultural stakeholders including agroforestry practitioners [15], vineyard growers [16], and organic farmers [13, 14]. Yet, the extent to which mental models vary across stakeholder groups is largely unknown, but see [43] for “experts” versus farmers comparison. Our results indicate similarities and differences across agricultural stakeholder groups, suggesting that sustainable agricultural education programs should address the context specificity of management systems including the crops being produced, cropping systems utilized, environmental conditions, and the socio-economic constraints of the agricultural operations. In this study, organic vegetable and organic grain producers showed particularly divergent perceptions, experiences, and priorities when compared with those of conventional producers, researchers, and crop consultants. Thus, extension programs tailored to the needs of organic producers should specifically consider these divergent needs, issues that are not usually addressed in traditional education programs [2]. At the same time, conventional producers and researchers showed similarities, as indicated by their joint association in the ordination and cluster analysis; suggesting agreement between these groups. However, researchers did not show strong agreement with each other in their open-ended responses, highlighting the varied perspectives and priorities of this group of stakeholders. Finally, crop consultants formed an isolated group with divergent priorities and perspectives with all other agricultural stakeholders. The divergence of priorities, needs, and perspectives of crop consultants with other agricultural stakeholders is concerning because this group includes Cooperative Extension agents from Land Grant Universities who have the task of supporting producers' interests [44].

Our findings highlight the importance of addressing methods of information dissemination for specific agricultural stakeholders in order to design more effective outreach programs that support sustainability objectives. For example, while researchers obtained information from scientific literature, consultants took advantage of colleagues, neighbors, field demonstrations, internet resources, and workshops. By contrast, conventional producers obtained information primarily from periodicals.

Previous studies have also suggested that producers do not place as much importance on information gathering from scientific research compared with their own experiences [42, 43, 45]. Future research and outreach efforts aimed at promoting sustainable agro-ecosystem management decisions should incorporate producers' experiences and priorities and consider the alternative approaches to disseminate information. This can be accomplished by including producers on research and extension teams, incorporating citizen science in research efforts, and developing Producer Community Advisory Boards to guide research and outreach [36].

This study was not designed to formally test for communication gaps across stakeholder groups; therefore we cannot pinpoint the reason for the observed discrepancies in perceptions, experience, and priorities. Nonetheless, our results underscore the importance of improved communication to avoid conflicting efforts between producers and the researchers, educators, and consultants that support their work. Indeed, the lack of a system in which agricultural professionals exchange information and experiences with researchers and consultants has been cited as a barrier hindering the adoption of ecologically-based farming practices [2, 5, 46]. Furthermore, evaluations of social networks indicate that information exchange helps generate shared understanding of challenges, constraints, and opportunities; a required step for conversing about complex information [37], an approach not commonly used in current models of agricultural outreach and education [47]. Bringing this approach to fruition may require agricultural stakeholders to challenge their assumptions [47] and engage in a collaborative dialogue to share contrasting perceptions, experiences, and priorities. This process can highlight areas of disagreement or conflict that extension efforts can target, such as non-target effects of pesticide applications on organic farms or increased propagule pressure on conventionally managed farms adjacent to organically managed fields.

Our study highlights the need for developing agricultural innovation systems, an approach that embraces the importance of the totality and interaction among all actors involved when addressing the complex agricultural challenges and transforming old extension paradigms [48]. Core elements of

Peer-reviewed version available at *Sustainability* **2018**, *10*, 4096; doi:10.3390/su10114096

agricultural innovation systems include understanding the roles, attitudes, and practices of key stakeholders in the food system, characterizing patterns of stakeholder interactions, and assessing how enabling the environment is for innovation [49]. Neglecting to involve the network of agricultural stakeholders in designing and implementing sustainable production systems may impede the adoption of sustainable agricultural practices, particularly in a rapidly changing world. As a result, many countries are shifting their agricultural innovation models from one focused on agricultural research to a network approach that includes researchers, farmers, entrepreneurs, and other organizations in the creation, dissemination, adaptation, and use of knowledge and resources for agricultural innovation [50]. Individuals' internal cognitive representations that support agro-ecosystem management decisions are not static and vary based on numerous and changing experiences, including their participation in sustainable education programs [51]. For example, Cranton [52] demonstrated how agricultural producers changed their mental models as a result of transformative events that called to question their own values, beliefs, knowledge, and skills. Future studies should thus examine how different agricultural stakeholder groups modify their agricultural perceptions, experiences, and priorities as a result of specific educational and extension programming.

Author Contributions: Conception and design of the project: FM, JM, MB, SA. Collection of data: HP, SM, FM. Analysis and interpretation of data: SM, HP, FM, SA, JM, MB. Drafting the article: SM, SA, FM, HP. Critical revision for important intellectual content: FM, SA, SM, JM, MB. Approval of the final draft: FM, SA, SM, JM, MB, HP.

Funding: Support for this research was provided by the Montana Western Sustainable Agriculture Research and Education Professional Development Program and the NIFA – Organic Research and Education Initiative grant number 2012-51300-20004 and NIFA – ORG grant number 2015-51106-23970.

Acknowledgements: We thank the agricultural producers, consultants, and researchers that participated

Peer-reviewed version available at *Sustainability* **2018**, *10*, 4096; doi:10.3390/su10114096

in this project. Dr. R. Jabbour helped us develop the domain and subdomain categories used in this study. Drs. Perry Miller, Zachariah Miller, and Dr. Colter Ellis provided valuable insights on the agricultural and social analysis and implications of our research. Special thanks to the Montana OEAC for sharing with us the results of the initial survey they conducted. We are grateful to Alicia Leitch for her support inputting survey data for this study.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Ahmed, S.; Stepp, J.R.; Orians, C.; Griffin, T.; Matyas, C.; Robbat, A. et al. Effects of extreme climate events on tea (*Camellia sinensis*) functional quality validate indigenous farmer knowledge and sensory preferences in tropical China. PLoS One **2014**, *9(10)*: e109126.

2. Menalled, F.D.; Landis, D.A.; Dyer L. Research and extension supporting ecologically based IPM systems. J. Crop. Improv. **2004**, *11*, 153- 174.

3. Jones, N.; Ross, H.; Lynam, T.; Perez, P.; Leitch, A. Mental models: An interdisciplinary synthesis of theory and methods. Ecol. Soc. **2011**, *16*, 46.

4. McKey, D.; Cavagnaro, T.R.; Cliff, J.; Gleadow, R. Chemical ecology in coupled human and natural systems: people, manioc, multitrophic interactions and global change. Chemoecology **2010**, *20*, 109-133.

5. Langan-Fox, J.; Wirth, A.; Code, S.; Langfield-Smith K.; Wirth, A. Analyzing shared and team mental models. Int. J. Ind. Ergon. **2001**, *28*, 99-112.

6. Abel, N.; Ross, H.; Walker P. Mental models in rangeland research, communication and management. Rangeland J. **1998**, *20*, 77-91.

7. Ozesmi, U.; Ozesmi, S.L. Ecological models based on people's knowledge: a multi-step fuzzy cognition mapping approach. Ecol. Model. **2004**, *176*, 43-64.

Peer-reviewed version available at Sustainability 2018, 10, 4096; doi:10.3390/su10114096

8. Morgan, M.G.; Fischhoff, B.; Bostrom, A.; Atman, C. Risk Communication: a Mental Models Approach. Cambridge: Cambridge University Press, New York, 2002.

9. Pilewort. C.; Hare, M. Processes of social learning in integrated water management. J Community Appl. Soc. Psychol. **2004**, *14*, 193-206.

10. Kolkman, M.J.; Kok, M.; van der Veen, A. Mental model mapping as a new tool to analyse the use of information in decision-making in integrated water management. Phys. Chem. Earth. **2005**, *30*, 317-332.

11. Johnson-Laird P.N. Mental models: Towards a cognitive science of language, inference, and consciousness. Cambridge: Cambridge University Press, **1983**.

12. Wilson, J.R.; Rutherford, A. Mental models: theory and application in human factors. Hum. Factors. **1989**, *31*, 617-634.

13. Jabbour, R.; Gallandt, E.R..; Zwickle, S.; Wilson, R.S.; Doohan, D. Organic farmer knowledge and perceptions are associated with on-farm weed seedbank densities in northern New England. Weed Sci. **2014**, *62*, 338-349.

14. Dedecker, J.J.; Masiunas, J.B.; Davis, A.S.; Courtney, G. Weed management practice selection among Midest U.S. organic growers. Weed Sci. **2014**, *62*, 520-531.

15. Banes, J.; Herbohn, J.; Russel, I. The influence of farmers' mental models on an agroforestry extension program in the Philippines. Small-scale For. **2010**, *10*, 377-387.

16. Hoffman, M.; Lubell, M.; Hillis, V. Linking knowledge and action through mental models of sustainable agriculture. Proc. Nat. Acad. Sci. **2014**, *111*, 13016–13021.

17. National Agriculture Statistic Service. Montana Office of USDA's NASS. 2015. Available online: http://www.nass.usda.gov/Statistics_by_State/Montana (accessed on September 28, 2018).

18. Roberts, C. Mixing modes of data collection in surveys: A methodological review. ESRC National Centre for Research Methods NCRM Methods Review Papers NCRM/008, 2007. Available

online: http://eprints.ncrm.ac.uk/418/1/MethodsReviewPaperNCRM-008.pdf (accessed on September 28, 2018).

19. Grimberg, B.I.; Ahmed, S.; Elis, C., Miller, Z; Menalled, F. Climate Change Perceptions and Observations of Agricultural Stakeholders in the Northern Great Plains. Sustainability **2018**, *10*, 1687; doi:10.3390/su10051687.

20. Neuendorf, K. *The content analysis guidebook*. Sage Publication: California, USA, 2002.

21. Bray, R.J.; Curtis, J.T. An ordination of the upland forest communities of southern Wisconsin. Ecol. Monogr. **1957**, *27*, 325-349.

22. Anderson, M. J. PERMANOVA. Permutational multivariate analysis of variance. A computer program. Department of Statistics, University of Aukland, 2005. Available online: http://img2.timg.co.il/forums/1_124959686.pdf (accessed on September 28, 2018).

23. Lance, G.N.; Williams, W.T. A general theory of classificatory sorting strategies. Comput. J. **1967**, *9*, 3737-380.

24. Jin M, Wang B. Implementing multiple comparisons on Pearson Chi-square Test for an R×C contingency table in SAS®. SAS Global Forum. Statistical Analysis Software, Washington, DC, 2014. Available online: http://support.sas.com/resources/papers/proceedings14/1544-2014.pdf (accessed on September 28, 2018).

25. Dufrene, M.; Legendre, P. Species assemblages and indicator species: the need for a flexible asymmetrical approach. Ecol. Monogr. **1997**, *67*, 345–366.

26. R Development Core Team. R: A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing, 2013. Available: http://www.R-project.org (accessed on September 28, 2018).

27. Roberts DW. Labdsv. Ordination and multivariate analysis for ecology. R package version 1 (1), 2007. Available online: http://cran.r-project.org/web/packages/labdsv/labdsv.pdf. (accessed on September 28, 2018).

28. Wickham, H. The split-apply-combine strategy for data analysis. J. Stat. Softw. **2011**, *40*, 1–29.

29. Wickham, H. Reshaping data with the reshape package. J Stat. Softw. 2007; 21:1–20.

30. Roberts, D.W. optpart: Optimal partitioning of similarity relations. R package version: 2.0–1, 2010. Available online: http://cran.r-project.org/web/packages/optpart/optpart.pdf (accessed on September 28, 2018).

31. Maechler, M.; Rousseeuw, P.; Struyf, A.; Hubert, M.; Hornik, K. cluster: Cluster analysis basics and extensions. R package version 2.0.1, 2012. Available online: http://cran.r-project.org/web/packages/cluster/ (accessed on September 28, 2018).

32. Adler, D.; Murdoch, D. rgl: 3D Visualization Device System (OpenGL). R package version 0.75. 2007; Available: http://CRAN.R-project.org/package=rgl (accessed on September 28, 2018).

33. Prost, L.; Berthet, E.T.; Cerf, M., Jeuffroy, M.-H.; Labatut, J.; Meynard, J.M.. Innovative design for agriculture in the move towards sustainability: scientific challenges. Res. Eng. Des. **2017**, *28*, 119–129.

34. Ahmed, S.; Stepp, J.R. Beyond yields: Climate effects on specialty crop quality and agroecological management. Elem. Sci. Anth. **2016**, *4*, 92.

35. Menalled, F.D.; Grimberg, B.; Jones, C. Evaluation of agricultural professionals' perceptions and knowledge on sustainable agriculture: A useful step in the development of an on-line extension program. J. Ag. Educ. **2009**, *50*, 86-97.

36. Warner, K.D. *Agroecology in Action: Extending Alternative Agriculture through Social Networks (Food, Health, and the Environment).* The MIT Press: Massachusetts Institute of Technology, Cambridge, 2007; 291 p. ISBN 0262731800, paperback.

37. Wood, B.; Blair, H.; Gray, D.; Kemp, P.; Kenyon, P.R et al. Agricultural science in the wild: A social network analysis of farmer knowledge exchange. PLoS One **2014,** *9(8),* e105203.

38. Nowak, P.J.; Cabot, P.E. Human dimension of resource management programs. J. Soil Water

Peer-reviewed version available at *Sustainability* **2018**, *10*, 4096; doi:10.3390/su10114096

Conser. **2004**, *59*, 128A-135A.

39. Viseu, A. Integration of social science into research is crucial. Nature **2015,** *525*: 291.

40. Brown, R.R.; Deletic, A.; Wong T.H.F. Interdisciplinarity: How to catalyze collaboration. Nature **2015**, *525*, 315-317.

41. Eckert, E.; Bell, A.A. Invisible force: Farmers' mental models and how they influence learning and actions. J. Ext. **2005**; *43*, Article 3FEA2. Available online: http://extension.unh.edu/adultlearning/invisibleforce.pdf (accessed on September 28, 2018).

42. Turner, R.J.; Davies, G.; Moore, H.; Grundy, A.C.; Mead, A. Organic weed management: A review of the current UK farmer perspective. Crop Prot. **2007**, *26*, 377–382.

43. Jabbour, R.; Zwickle, S.; Gallandt, E.; McPhee, K.; Wilson, R.; Doohan, D. Mental models of organic weed management: Comparison of New England US farmer and expert models. Renew. Agr. Food Sys. **2013**, *29*, 319-333.

44. Gornish, E. S.; Roche, L. M. Cooperative Extension is key to unlocking public engagement with science. Front. Ecolog. Env. **2017**,*15*, 487-488

45. Macé, K.; Morlon, P.; Munier-Jolain, N.; Quéré L. Time scales as a factor in decision-making by French farmers on weed management in annual crops. Agric Syst. **2007**, *93,* 115–142.

46. National Research Council. *Alternative agriculture*. The National Academies Press, Washington, DC, USA, **1989**.

47. Eckert, E.; Bell, A.A. Continuity and change: themes of mental model development among small-scale farmers. J. Ext. **2006**, *44*, Article 1FEA2. Available online: http://extension.unh.edu/adultlearning/continuityandchange-eckert-bell.pdf (accessed on September 28, 2018)

48. Hickey, G.M.; Klerkx, L.; Pigford, A.E.; Hickey, G. M. Beyond agricultural innovation systems? Exploring an agricultural innovation ecosystems approach for niche design and development in

sustainability transitions. Ag. Sys. **2018**, *164,* 116-121.

49. World Bank. Enhancing agricultural innovation: How to go beyond the strengthening of research systems. The International Bank for Reconstruction and Development / The World Bank World Bank. 2006. Available online: http://siteresources.worldbank.org/INTARD/Resources/Enhancing_Ag_Innovation.pdf (accessed on September 28, 2018)

50. Klerkx, L.; Hall, A.; Leeuwis, C. Strengthening Agricultural Innovation Capacity: Are innovation brokers the answer? Int. J. Ag. Res., Governance and Ecology, **2009,** *8*, 409-438.

51. Arnes, E.; Diaz-Ambrona, C.G.H.; Marin-Gonzalez, O.; M. Astier. Farmer Field Schools (FFSs): A tool empowering sustainability and food security in peasant farming systems in the Nicaraguan H. Sustainability **2018**, *10*(9), 3020; doi.org/10.3390/su10093020

52. Cranton, P. Teaching for transformation. In: *Contemporary viewpoints on teaching adults effectively: No. 93. New directions for adult and continuing education.* Imel, S., Ross-Gordon, J.M., Eds.; Jossey-Bass, San Francisco, USA 2002, pp. 63-72.

Table 1: Indicative responses for (top) clusters and (bottom) agricultural stakeholders for twenty-fivepredetermined responses aimed at identifying contextual information about farming condition. P1 to P6 refers to the cluster group of Figure 2. CG: conventional grower. OGG: organic grain growers. OVG: organic vegetable grower. CON: crop consultant. RES: researcher.

Cluster	Question	Indicator	INDVAL	P
P1		No significant indicators found		
P2	What county do you primarily operate in?	Broadwater County	0.403	0.001
P2	What are your ten most problematic weed species and how difficult are they to manage?	Houndstongue (*Cynoglossum officinale* L.)	0.111	0.021
P2	What are your ten most problematic weed species and how difficult are they to manage?	Musk thistle (*Carduus nutans* L.)	0.109	0.006
P2	Describe your primary crop rotation.	Rangeland	0.102	0.011
P2	What are your ten most problematic weed species and how difficult are they to manage?	American Licorice (*Glycyrrhiza lepidota* (Nutt.) Pursh)	0.094	0.012
P3	Rank the crops you've observed are the easiest to produce.	Lettuce (*Lactuca sativa* L.)	0.700	0.001
P3	Rank the crops you've observed are the easiest to produce.	Tomatoes (*Solanum lycopersicum* L.)	0.700	0.001
P3	Rank the crops you've observed are the easiest to produce.	Alliums (Amaryllidaceae:Allioidae)	0.650	0.001
P3	Rank the crops you've observed are the easiest to produce.	Brassicas (Brassicaceae)	0.600	0.001
P3	What crops are most influenced by insects?	Brassicas (Brassicaceae)	0.600	0.001
P4	Rank the crops you've observed are the easiest to produce.	Spring Wheat (*Triticum aestivum* L.)	0.967	0.001
P4	What crops are most influenced by weeds?	Flax (*Linum usitatissium* L.)	0.576	0.001
P4	What crops are most influenced by weeds?	Hay and forage	0.515	0.001
P4	Which crops do you think face the biggest challenge to market?	Flax (*Linum usitatissium* L.)	0.485	0.001
P4	What are your ten most problematic weed species and how difficult are they to manage?	Kochia (Bassia scoparia (L.) A.J. Scott)	0.424	0.001
P5	What crops are most influenced by disease?	Chickpeas (*Cicer arietinum* L.)	0.607	0.001
P5	What crops are most influenced by disease?	Lentils (*Lens culnaris* Medik.)	0.604	0.001
P5	What crops are most influenced by weeds?	Chickpeas (*Cicer arietinum* L.)	0.590	0.001
P5	What crops are most influenced by disease?	Oilseed crops	0.577	0.001
P6	Which crops do you think face the biggest challenge to market?	Winter Wheat (*Triticum aestivum* L.)	0.284	0.001
P6	What are your ten most problematic weed species and how difficult are they to manage?	Cheatgrass (*Bromus tectorum*)	0.261	0.001

Peer-reviewed version available at *Sustainability* **2018**, *10*, 4096; doi:10.3390/su10114096

P6	Rank the crops you've observed are the easiest to produce.	Barley (*Hordeum vulgare* L.)	0.240	0.002
P6	Which crops do you think face the biggest challenge to market?	Barley (*Hordeum vulgare* L.)	0.232	0.004
P6	What are your ten most problematic insect pests and how difficult are they to manage?	Sawflies (Hymenoptera:Symphyta)	0.213	0.001
Stakeholder				
CG	How long have you been in your agricultural profession?	Increasing duration	0.257	0.001
CG	What county do you primarily operate in?	Broadwater County	0.174	0.001
CG	What county do you primarily operate in?	Valley County	0.101	0.001
RES	What factors most influence yield?	Soil fertility	0.380	0.001
RES	What factors most influence yield?	Phytophagous insect pests	0.369	0.001
RES	What factors most influence yield?	Precipitation	0.365	0.001
RES	What factors most influence yield?	Crop Varieties	0.334	0.001
RES	What county do you primarily operate in?	Gallatin	0.324	0.001
CON	What crops are influenced the most by disease?	Winter Wheat (*Triticum aestivum* L.)	0.377	0.001
CON	What factors most influence yield?	Disease	0.372	0.001
CON	Rank the crops you've observed are the easiest to produce.	Spring Wheat (*Triticum aestivum* L.)	0.367	0.001
CON	What crops are influenced the most by insects?	Barley (*Hordeum vulgare* L.)	0.361	0.001
CON	What crops are influenced the most by disease?	Barley (*Hordeum vulgare* L.)	0.359	0.001
OGG	Rank the crops you've observed are the easiest to produce.	Spring Wheat (*Triticum aestivum* L.)	0.970	0.001
OGG	What crops are influenced the most by weeds?	Flax (*Linum usitatissium* L.)	0.576	0.001
OGG	What crops are influenced the most by weeds?	Hay and forage	0.515	0.001
OGG	Which crops do you think face the biggest challenge to market?	Flax (*Linum usitatissium* L.)	0.485	0.001
OGG	What are your ten most problematic weed species and how difficult are they to manage?	Kochia (*Bassia scoparia* (L.) A.J. Scott)	0.424	0.001
OVG	Rank the crops you've observed are the easiest to produce.	Lettuce (*Lactuca sativa* L.)	0.667	0.001
OVG	Rank the crops you've observed are the easiest to produce.	Tomatoes (*Solanum lycopersicum* L.)	0.667	0.001
OVG	Rank the crops you've observed are the easiest to produce.	Alliums (Amaryllidaceae:Allioidae)	0.619	0.001
OVG	Rank the crops you've observed are the easiest to produce.	Brassicas (Brassicaceae)	0.571	0.001
OVG	What crops are most influenced by insects?	Brassicas (Brassicaceae)	0.571	0.001

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 9 October 2018 doi:10.20944/preprints201810.0176.v1

Peer-reviewed version available at *Sustainability* **2018**, *10*, 4096; doi:10.3390/su10114096

Table 2: Indicator responses for (top) clusters and (bottom) agricultural stakeholders for open-ended response domain data from the 2014 Montana State University Agricultural Professional Survey. D1 to D6 refers to the cluster group of Figure 3. CG: conventional grower. OGG: organic grain grower. OVG: organic vegetable grower. CON: crop consultant. RES: researcher.

Cluster	Question	Indicator Domain	INDVAL	P
D1	How do you get your farming information?	Extension and University Outlets	0.422	0.001
D1	What factors determine whether you add fertilizer or not?	Agronomic Factors	0.33	0.001
D1	How do you get your farming information?	Personal Communication	0.245	0.023
D1	Please explain any “on farm” research you are currently conducting.	Specific Inputs	0.16	0.048
D2	What specific research would have the most impact on your production system?	Managing specific pests	0.313	0.009
D2	What specific research would have the most impact on your production system?	Agronomic Factors	0.264	0.014
D2	What weed research do you feel is most needed?	Specific Weeds	0.242	0.023
D3		No significant indicator domains found		
D4	What are your experiences with no-till?	Experiential Perceptions	0.244	0.002
D5	What is the most challenging agronomic issue you deal with? Please explain.	Environmental Factors	0.302	0.006
D5	What is the most challenging agronomic issue you deal with? Please explain.	Agronomic Management	0.29	0.033
D6	What is the most challenging agronomic issue you deal with? Please explain.	Agroecological Factors	0.382	0.001
Stakeholder				
CON	How do you get your farming information?	Extension and University Outlets	0.276	0.001
CON	How do you get your farming information?	Media	0.169	0.036
OGG	What are your experiences with no-till?	Duration of Practice	0.288	0.001
OGG	What weed research do you feel is most needed?	Specific Weeds	0.269	0.001
OGG	What is the most challenging agronomic issue you deal with? Please explain.	Agroecological Factors	0.223	0.002
OGG	What specific research would have the most impact on your production system?	Environmental Factors	0.223	0.001
OGG	What factors influence your crop rotations?	Economic Factors	0.221	0.003
OVG	What factors determine whether you add fertilizer or not?	Social Factors	0.223	0.001
OVG	What factors influence your crop rotations?	Agronomic Management	0.223	0.008
OVG	What marketing research do you feel is most needed?	Social Factors	0.181	0.002

Peer-reviewed version available at Sustainability 2018, 10, 4096; doi:10.3390/su10114096

OVG	What specific research would have the most impact on your production system?	Agronomic Factors	0.179	0.037
OVG	What is the most challenging agronomic issue you deal with? Please explain.	Environmental Factors	0.137	0.024
CG		No significant indicator domains found		
RES	Please explain any "on farm" research you are currently conducting.	Agronomic Factors	0.146	0.005
RES	Please explain any "on farm" research you are currently conducting.	Managing specific pests	0.123	0.004
RES	What specific research would have the most impact on your production system?	Marketing research	0.095	0.038
RES	What insect research do you feel is most needed?	Ecological Factors	0.077	0.027
RES	Please explain any "on farm" research you are currently conducting.	Beneficial Insects	0.072	0.028

1

Peer-reviewed version available at Sustainability 2018, 10, 4096; doi:10.3390/su10114096

Table 3: Indicator responses for (top) clusters and (bottom) agricultural stakeholders for open-ended response subdomain data from the 2014 Montana State University Agricultural Professional Survey. S1 to S6 refers to the cluster group of Figure 4. CG: conventional grower. OGG: organic grain grower. OVG: organic vegetable grower. CON: crop consultant. RES: researcher.

Custer	Question	Indicator Subdomain	INDVAL	P
S1		No significant indicators found		
S2		No significant indicators found		
S3	What specific research would have the most impact on your production system?	Revenue streams and specific markets	0.105	0.031
S3	What weed research do you feel is most needed?	Unspecified integrated pest management	0.094	0.050
S4		No significant indicators found		
S5	What marketing research do you feel is most needed?	Prediction and forecasting	0.106	0.037
S5	What disease research do you feel is most needed?	Soil borne diseases	0.097	0.042
S6	How do you get your farming information?	University faculty	0.170	0.017
S6	What soil fertility research do you feel is most need?	Effects on plant community structure	0.143	0.025
S6	What specific research would have the most impact on your production system?	GPS and mapping	0.143	0.036
S6	What marketing research do you feel is most needed?	Nutritive value	0.136	0.035
S6	What specific research would have the most impact on your production system?	Foliar-applied fungicides	0.136	0.026
Stakeholder				
CON	What are your experiences with no-till?	Had experience with no-till	0.261	0.001
CON	What factors determine whether you add fertilizer or not?	Soil test results	0.179	0.023
CON	How do you get your farming information?	Field demonstrations	0.128	0.011
CON	How do you get your farming information?	Internet resources	0.128	0.031
CON	How do you get your farming information?	Workshops	0.102	0.023
OGG	What are your experiences with no-till?	No experience with no-till	0.466	0.001
OGG	What weed research do you feel is most needed?	Field bindweed (*Convolvulus arvensis* L.)	0.354	0.001
OGG	What weed research do you feel is most needed?	Perennial weeds	0.336	0.001
OGG	What weed research do you feel is most needed?	Dicotyledonous weeds	0.296	0.001
OGG	What are your experiences with no-till?	Not feasible	0.249	0.001
OVG	What factors determine whether you add fertilizer or not?	Personal knowledge	0.270	0.001
OVG	What factors influence your selection of crop rotations?	Point in a predetermined crop rotation	0.264	0.001
OVG	What factors influence your selection of crop rotations?	Nutrient biogeochemistry	0.173	0.001
OVG	What marketing research do you feel is most needed?	Education	0.155	0.003
OVG	What specific research would have the most impact on your production system?	Perennial weed management	0.146	0.001
CG	How do you get your farming information?	Periodicals	0.106	0.038
RES	How do you get your farming information?	Peer-reviewed journals	0.219	0.001

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 9 October 2018 doi:10.20944/preprints201810.0176.v1

Peer-reviewed version available at *Sustainability* **2018**, *10*, 4096; doi:10.3390/su10114096

RES	What soil fertility research do you feel is most needed?	Nitrogen cycling and biogeochemistry	0.219	0.005
RES	How do you get your farming information?	Neighbors and colleagues	0.145	0.017
RES	Please explain any "on farm" research you are currently conducting.	Specialized crop varieties	0.115	0.008
RES	What factors determine whether you add fertilizer or not?	Leaching and volatilization potential	0.081	0.012

Peer-reviewed version available at *Sustainability* **2018**, *10*, 4096; doi:10.3390/su10114096

Supplementary Materials.

Table S1. Appendix A. Survey utilized to assess context, knowledge, experiences, and perceptions regarding environmental conditions, management practices, production challenges, and research needs of agricultural stakeholders in Montana, USA.

Table S2. Domains (underlined) and subdomains used to identify recurring themes in open-ended questions of the survey utilized to assess context, knowledge, experiences, and perceptions regarding environmental conditions, management practices, production challenges, and research needs of agricultural stakeholders in Montana, USA.