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Creating a typology of U.S. organic grain farmers using reduced tillage

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Abstract

Despite an increasing number of studies demonstrating the feasibility and value of integrating reduced tillage practices into organic cropping systems, adoption of these practices has been slow, with tillage and cultivation still a primary method of organic weed control. The aim of this study is to provide an insight into the range and scope of implementation of reduced tillage practices implemented by organic corn and soybean farmers in three states in the United States of America (Pennsylvania, Wisconsin, and Iowa). A survey conducted by the University of Madison-Wisconsin to assess the extent to which organic farmers use specific reduced tillage. Additionally, the survey sought to understand the relationship between farm characteristics, production strategies, and socio-demographic factors reduced tillage adoption. The findings of the study indicated that the earliest adopters of reduced-tillage practices had the greatest proportion of land managed using reduced tillage techniques, and shallow cultivation was the most commonly used reduced tillage practice amongst organic farmers. Furthermore, the results suggested that larger organic producers, farmers with a post-secondary education, farmers consulting a variety of sources of information to learn about reduced tillage practices were using reduced tillage practices. Future work could use this typology of U.S organic grain farmers in order to find better ways of promoting the feasibility of using reduced tillage practices in organic cropping system to a broader audience.

Key words: organic agriculture, reduced tillage, no-tillage, conservation agriculture, survey, hierarchical clustering on principal component

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Chapter One: Introduction

1.1 Challenges in designing an alternative agri-food system

With the world population is expected to reach 9 to 10 billion people by 2050, the challenge of ensuring food security for a growing population while protecting our environment is daunting (Reganold et al. 2016). In this context, the global agrarian industry is continuously pressured to meet an unprecedented demand of food and other goods (Foley et al. 2011). The Green Revolution brought forth modern industrial agriculture (or *conventional agriculture*), a production system that would answer this demand, while maximizing profits for the food industry (Foley et al. 2011, Glissman, 2015). Under this highly productive agrarian system, a large proportion of the world's population was able to meet their dietary and nutrition needs (Glissman, 2015). But as the agro-food industry was trading-off the foundation of agriculture (e.g. soil health, ecosystem services and biodiversity) and failing food producers around the world, concerns over the long-terms social and environmental impacts of this production system arose (Frison 2016, Holt-Giménez et al. 2016).

The unsustainability of conventional agriculture has led various actors to demand a systemic change in the current agro-industry, which generated interests in other farming systems such as organic agriculture (Reganold et al. 2016, Alcon et al. 2020). Early organic movements took root in European and Asian farming models, which are based on regenerative soil management (or *humus farming*), and addressed various issues such as soil erosion, the decline of crop variety and rural poverty (Kuepper 2010, Beach et al. 2018). Organic farming aimed to produce food while promoting ecological health by avoiding a variety of inputs (e.g. synthetic crop production aids and genetically modified organisms) and promote practices such as managing crop residues, applying animal manure or green manure, and integrating perennial crops to a rotation (Kuepper 2010, Beach et al. 2018). With the intensification of organic farming, increase in funded research on organic agriculture and the expansion of the market size for organic food and goods, organic farming gained an unprecedent popularity among consumers as the mainstream alternative to conventional agriculture (Reganord et al. 2016, Beach et al. 2018).

In theory, organic farming provides many benefits that could pave the way for sustainable agricultural systems by increasing on-site biodiversity and soil organic matter (Vincent-Caboud et al. 2017). In reality, organic farmers have lower yields (as compared to conventional agriculture) and rely strongly on routine soil disturbance to manage weeds (Reganord et al. 2016, Vincent-Caboud et al. 2017, Wallace et al. 2017, Beach et al. 2018). The decreased yields frequently observed under organic management have a direct impact on farmers' income, and on a national scale, a shortage of organic produce would require higher levels of imported organic food and goods (Wallace et al. 2017). The farmers' dependence on intensive tillage to avoid using synthetic herbicides (Vincent-Caboud et al. 2017, Beach et al. 2018) has many negative impacts on an agroecosystem, such as the deterioration of the physical (e.g. soil erosion), biological (e.g.

microbial activity) and chemical (e.g. carbon sequestration rate) properties of the soil, by breaking down organic matter through mineralization (Johansen et al. 2012, Beach et al. 2018).

Conservation agriculture (CA) has been promoted by institutions and international organizations as an alternative farming model to conventional and organic agriculture, and often as a panacea to agrarian issues related to soil degradation (FAO 2003, Dumanski et al. 2006, Kassam et al. 2009, Jat et al. 2013, Reicosky 2015). CA integrates ecological management, traditional knowledge and modern technologies to intensify agricultural production and achieve economic, social and ecological sustainability (Dumanski et al. 2006, Reicosky 2015). The latter is based on a series of agronomic principles: (1) minimizing soil disturbance (no-tillage or reduced-tillage), (2) maintaining a permanent or semi-permanent soil coverage (e.g. living cover crop, terminated cover crop or mulch) and (3) having a diverse cropping system (least three different species, including one legume) (FAO, 2003; Dumanski et al. 2006, Jat et al. 2013, Reicosky 2015). The first principle aims to support the interactions between the flora and fauna; the second intends to provide a physical protection for the soil and a source of food for the soil life; the last principle aims to manage pests and diseases, while fixing nitrogen and adding organic matter to the soil (Jat et al. 2013). Using conservation tillage practices has many benefits, such as decreasing the energy consumption and CO2 emission, improving water infiltration and water holding-capacity, decreasing soil evaporation, improving on-site biodiversity, maintaining soil life and decreasing soil erosion – just to name a few (Holland 2004, Berner 2008, Jat et al. 2013, Reicosky 2015). However, conservation agriculture principles are primarily applied in conventional cropping systems, as these practices have not been adapted to be successful within the constraints of the organic regulation (Armengot 2015, Peigné 2016).

1.2 Reduced tillage systems in organic farming

Tilling plays different roles in an organic cropping system: it incorporates and distributes organic matter through the topsoil, facilitates the seedbed preparation, and can improve the conditions for root growth and nutrient uptake. Perhaps most critically in organic management, tillage is used as key weed control practice (Peigné et al. 2007, Armengot 2015, Peigné 2016). In addition to mechanically uprooting or cutting emerged weeds, tilling influences weed communities by changing the vertical distribution of the weed seeds and changing the soil conditions which impact weed germination, growth and dormancy (Peigné et al. 2007). However, tilling is not always an efficient and effective weed control method, particularly in the case of perennial weeds with vegetative reproduction that can survive soil disturbances (Colquhoun 2001). Recent studies have demonstrated the feasibility of integrating specific conservation agriculture approaches into organic cropping systems that minimize the need for tillage. Several experiments have shown that using reduced tillage practices in an organic farming system results in enhanced soil organic carbon content, soil structure and microbial activity (Berner et al. 2008, Mäder and Berner 2011). Furthermore, long-term trial studies indicated the viability of reduced tillage systems in organic agriculture, with weed populations remaining within the acceptable levels and yields comparable to a conventional tillage system (Berner et al. 2008, Armengot 2015).

Several conservation tillage practices can successfully be used to provide weed control in an organic farming system. For example, shallow cultivation practices such as harrowing, hoeing, finger weeding, and brush weeding only minimally disturb the soil profile (Peigné et al. 2007). However, these methods may damage the cash crop and can increase soil compaction if not carried out under appropriate soil conditions (Peigné et al. 2007). Intercropping and undersowing may also minimize the need for cultivation, preventing weed seeds from germinating and establishing by restricting access to sunlight, decreasing soil temperature, reducing competition for nutrients, and providing allopathic interactions (Mirsky et al. 2012, Silva et al. 2017, Vincent-Caboud et al. 2017, Beach et al. 2018). Undersown cover crops may compete for nutrients and water with the cash crop, however, limiting the success of this technique to certain environments (Peigné et al. 2007). In an organic production system, in order to limit competition, the cover crop can be terminated through mowing, undercutting, or roller crimping. Most roller crimper implements are designed to not only roll the cover crop, but also crimp the stem tissue of the cover crop without severing it (Bernstein et al. 2011, Beach et al. 2018). This method is often considered the most efficient mechanical method of termination, as it suppresses the regrowth of the cover crop and is more time and energy efficient than a mower, with some implements designed to allow for a one-pass operation of both cover crop termination and cash crop planting (Mirsky et al. 2012, Peigné et al. 2015, Silva et al. 2017, Beach et al. 2018). These preventive weed control approaches are making the use of natural ecological mimicry, which is an agroecological approach that suggests that agricultural system could imitate the functioning and structure of natural ecosystem (Malézieux 2012). In theory, farmers would use preventive measures first and then direct weed control measures (such as mechanical measures) only if necessary – which is not always seen in practice.

1.3 Research objectives

Previous studies have addressed the feasibility of using no-tillage or reduced tillage practices in an organic cropping system and concluded that the system is viable in organic farming. However, a gap exists between the knowledge produced by formal knowledge channels (i.e. academia) and the implementation by farmers. Hence, the aim of the present study was to answer the following research questions:

(i) To which extent are US organic grain farmers using reduced tillage practices?
(ii) What type of reduced tillage practices are farmers using?
(iii) What are the characteristics of the organic grain farms and farmers for which the use of reduced tillage practices is more common?

With this data, strategies for tailoring research and outreach efforts to address farmer challenges and meet farmer needs can be designed, thus contributing to the ultimate goal of more effectively facilitating adoption of reduced-tillage practices on organic grain farms. To answer our research questions, a survey (‘2018 Organic Tillage & Soil Health Management Survey’) conducted by the University of Madison-Wisconsin was administered in 2018 and subsequently analyzed.

Defining tillage terminology

Defining which tillage practices can be characterized as “reduced-till” can vary depending on the system. For example, Baker et al. (1996) identify 14 practices under the term ‘reduced tillage’: zero-tillage, no-till, chemical-plowing, chemical-fallow, state-seedbed, chemical, direct-seeding, disc drilling, drillage, sod-seeding, residue farming, minimum or reduced tillage, strip or zone tillage, and ridge tillage. But according to Mäder and Berner (2011), Europeans have the tendency to refer to this system as ‘reduce tillage’ while Americans would call it ‘no-tillage’. For the purpose of this paper, the term ‘reduced tillage’ will be used to described a system that operates at shallower depths and at lower intensity compared to chisel or moldboard plowing.

Chapter Two: Methods and Materials

2.1 The survey

2.1.1 The constitution of the sample

The survey '2018 Organic Tillage & Soil Health Management Survey' was conceptualized by the University of Madison-Wisconsin and conducted in 2018, before the start of the present master's thesis work. The latter was carried out in three American states: Wisconsin, Pennsylvania and Iowa. The study focused on the aforementioned states, as there were some pre-existing partnerships between researchers in those three states, which were established through active research and outreach programs on organic no-till. The main selection criteria were that farmers needed to have an organic certification by the United States Department of Agriculture (USDA), needed to be located in one of the three selected states, and had to produce either corn or soybean. No pre-existing network of organic farmers was used to select the sample. Instead, farmers were chosen through a public federal database: the USDA's Organic Integrity database. From this set of data, 885 individuals were selected and sent a physical copy of the survey via general mail. The overall response rate was 28.5%, with 251 respondents. Following the exclusion of respondents that did not meet the main selection criteria or that left a significant number of questions unanswered, the sample of the survey consisted of 235 individuals.

2.1.2 The questionnaire

The questionnaire contained a mixture of open-ended and closed-ended questions (binary and multiple choice). The latter was divided in three main sections: (1) demographic information, (2) the land use and (3) management of cropland. The first part of the questionnaire comprised of the socio-demographic characteristics of the respondents, such as the age, gender, highest level of education of the farmer, and the year they started farming as the primary decision maker. In the second part, farmers described their land use and their cropping system (e.g. list of crops, acres that farmers owned and total acres that were certified organic). The last section of the questionnaire focused on the management of the cropland (e.g. fertility inputs and implements) and farmers' level of priority and challenge in adopting reduces tillage practices. The original questionnaire contained 24 main questions with various sub-questions (see Appendix A for full survey).

2.2 Data analysis

The analysis of the survey was structured in three main steps. Descriptive statistics of the results of the survey were provided to summarize the main features of the sample. Then, a hierarchical clustering (HC) on principal component analysis (PCA) and multiple correspondence analysis (MCA) was performed in order to create a typology of the sample. Finally, multiple tests were performed to confirm the trends highlighted by the hierarchical clustering with correlation tests (see Fig. 1). Out of the 24 main questions featured in the original survey, 18 questions were selected to be part of the data analysis based on the level of relevancy and redundancy of the questions.

2.2.1 Typological approach: Hierarchical clustering on a principal component (HCPC)

To understand what kind of organic farmers were using reduced tillage practices, a typological approach was used to create different profiles of farmers based on four categories: (i) farm characteristics, (ii) their agricultural production approaches, (iii) their socio-demographic characteristics and (iv) the factors limiting their abilities to implement practices to reduced tillage. The creation a typology led to the (i) identification of the kind of farmers that were using reduce tillage practices based on the aforementioned categories and (ii) determining the reduced tillage practices that they were using.

For each category, a principal component analysis (PCA) or a multiple correspondent analysis (MCA) was carried out using selected response variables and specific reduced tillage indicators. The choice of PCA or MCA was based on the type of variables selected for each analysis. On one hand, a principal component analysis (PCA) is a multivariate statistical technique that analyzes numerical or continuous data by describing inter-correlated quantitative dependent variables (Abdi and Williams 2010). The aims of using this analysis were to extract the important variables from the dataset, to compress the size of the dataset by excluding the variables that were not statistically significant and to represent the statistically important ones into a new set of variables called 'principal components' (Abdi and Williams 2010). Although there are different theories to determine how many principal components to keep, for the purpose of this study, only the principal components that had an eigenvalue greater than 1 were retained. On the other hand, a multiple correspondence analysis (MCA) is a statistical method that analyses patterns of relationships of categorical or nominal dependent variables (Abdi and Valentin 2007). The latter is used to describe, visualize and summarize information from a dataset (Husson and Josse 2014). The main objectives of using this analysis were to highlight the variables and categories that were the most statistically important and to provide a preliminary typology of individuals (Husson and Josse 2014).

From there, four hierarchical cluster analyses were conducted to provide specific trends and to classify the respondents based on their commonalities. By using a cluster dendrogram, we were able to determine the number of clusters for each category. For every analysis, the clusters were displayed on the Dimension 1 and 2 of the PCA or MCA. To help interpret each grouping of individuals, the significant variables that were contributing to the construction of each group were identified using the V-test (most significant *v*-value or *v*-value greater than 2).

All statistical analyses were made using RStudio with several packages (i.e. FactoMineR, factoextra, missMDA, ggplot2 and emmeans). The missing values were handled in two ways: by excluding some respondents or with the package missMDA. When a dataset used the individual reduced tillage practices as response variables, we made the decision to omit all respondents that left more than one question on the usage of reduced tillage practices unanswered, considering that the most missing values were found in those questions. As a result, 62 respondents were excluded from analysis 'Agricultural production approaches and 'Limiting factors', which reduced the sample size to 173 individuals. The dataset 'Farm characteristics' and 'Socio-demographic characteristics' did not include the individual reduced tillage practices as response variables, and therefore used the package missMDA to handle the missing values.

2.2.2 Correlation analysis

Correlation tests were conducted to verify the results of the HCPC. This statistical method evaluates the strength of the relationship between the explanatory variables and the response variables. In the analysis, the independent variables derived from the 18 main questions selected from the survey and the dependent variables corresponded to 5 reduced tillage indicators featured in the questionnaire, i.e. the level of priority given by the respondents to reduce tillage, (2) tillage intensity, which were defined by the degree of soil disturbance resulting from the equipment used for tillage and cultivation, (3) number of reduced tillage practices implemented, (4) the percentage of total acres of cropland under reduced tillage, and (5) using a roller crimper. During this process, the explanatory variables with a greater statistical significance (p-value < 0.05) were retained. Based on the type of variables (i.e. numerical/continuous or categorical/nominal), five different statistical models could be used to calculate the p-value, coefficient and/or odd ratio ; (1) a linear regression test was used when the dependent and independent variables were both numerical; (2) t-test was applied with a numerical dependent variable and a binary independent variable; (3) an ANOVA test was conducted with a numerical dependent variable and a categorical independent variable with more than 2 categories; (4) a logistic regression was used with a binary dependent variable with a significant sample size; (5) Fisher's exact test was employed with a binary dependent variable with a small sample size. In total, 149 individual tests have been conducted with the 5 response variables and 34 explanatory variables.

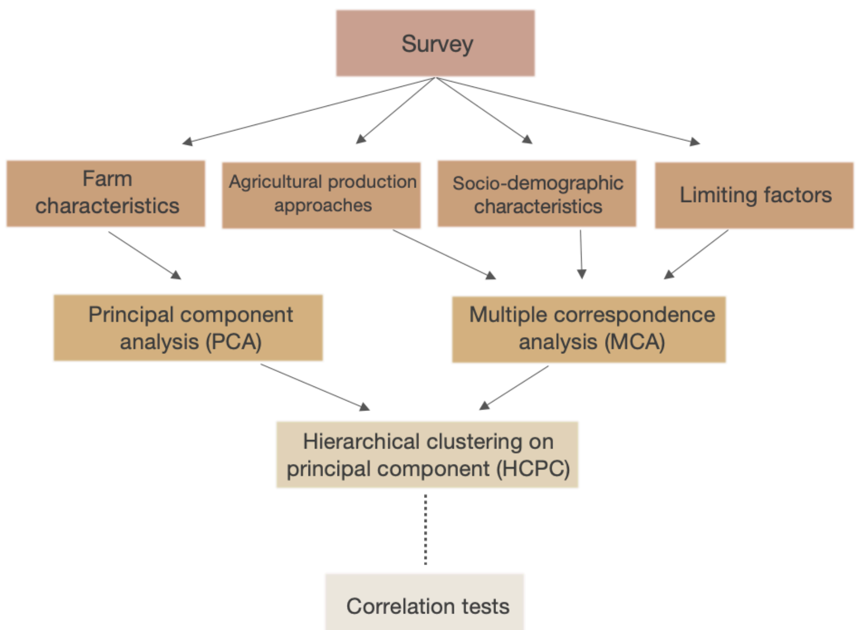

Fig. 1. Visual representation of the general steps of the analysis of the survey

Chapter Three: Results and Analysis of the Survey

3.1 Results of survey

3.1.1 Demographic information

Farm demographic characteristics are summarized in Fig. 2. The sample constituted of 235 individuals, of which 38% of the latter were from Wisconsin, 10% were from Pennsylvania and 52% of the respondents were from Iowa. In the sample, men were overly represented (96% identified as men and 4% identified as women) and most respondents belonged to the 35-49 and 50-65 age class (34% and 33% respectively). Most farmers (38%) had more than 26 years of farming experience, while 16% of the respondent have fewer than 5 years of experience. Most respondents did not have a post-secondary education; 9% of the respondents had 'some high school' education, 18% had a high school diploma or a GED, 26% of the respondents wrote in the box 'Other' that they had an 8th-grade education. At the same time, 8% had some college education, 12% had a 2-year college degree, 15% had a 4-year college degree and 12% had a graduate degree.

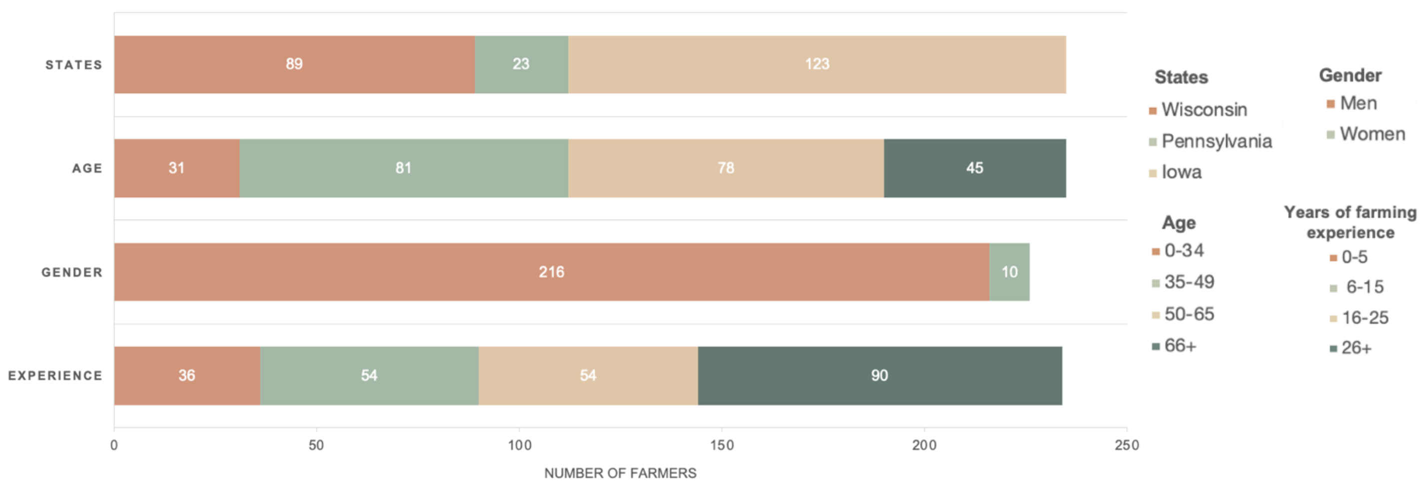

Fig. 2. States, age, gender and years of farming experience level feature in the sample of farmers.

3.1.2 Land use

Most respondents (61%) had a farm spanning from 1 to 249 acres, which is within the range of what is considered to be an average size farm for organic grain production in the United States (MacDonald et al. 2013). In addition, 24% of the respondents farmed 250 to 499 acres, 5% had farmed 500 to 749 acres, and 10% of the sample farmed 750 acres or more.

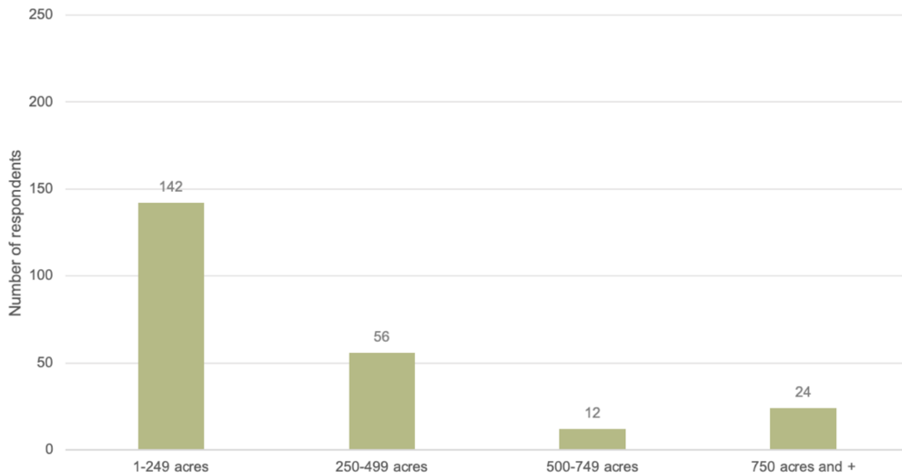

Fig. 3. Farm size of respondents.

Ninety-six percent of respondents were producing corn and 77% were growing soybeans. Additionally, seventy-seven percent of farmers were also producing hay, alfalfa or grass, 66% cereal grains and 24% unspecified crops. Nine percent of the respondent managed pasture for livestock. The majority of the respondent were raising cattle (60%), with fewer respondent were raising hog (10%), poultry (17%), goats (12%) and other types of livestock (16%).

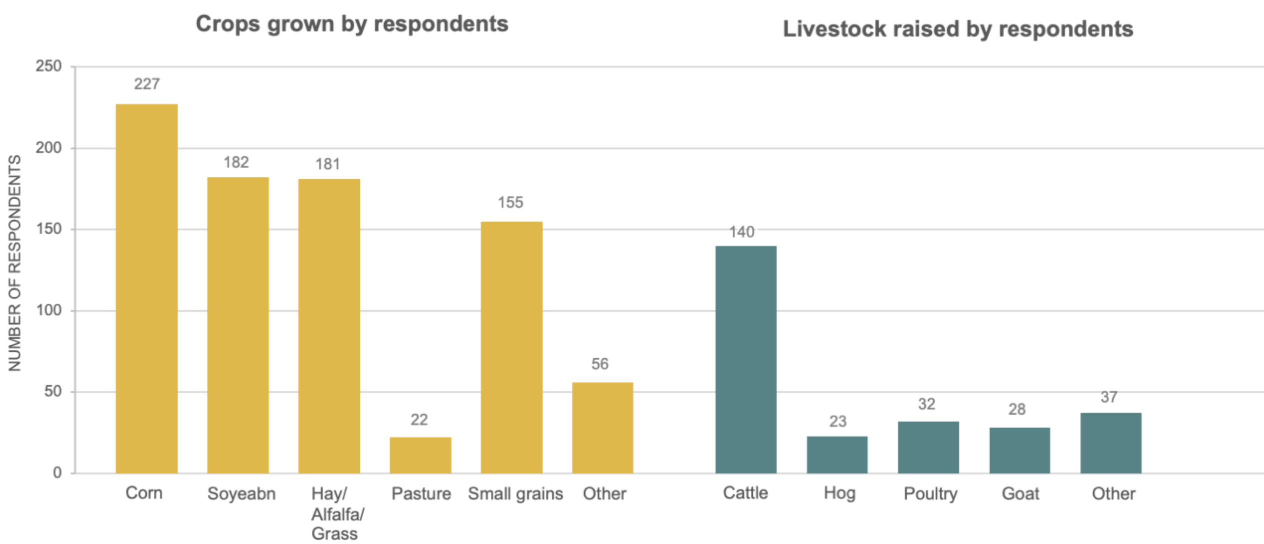

Fig. 4. Left – List of crops grown by the respondents. Right – List of livestock raised by the respondents

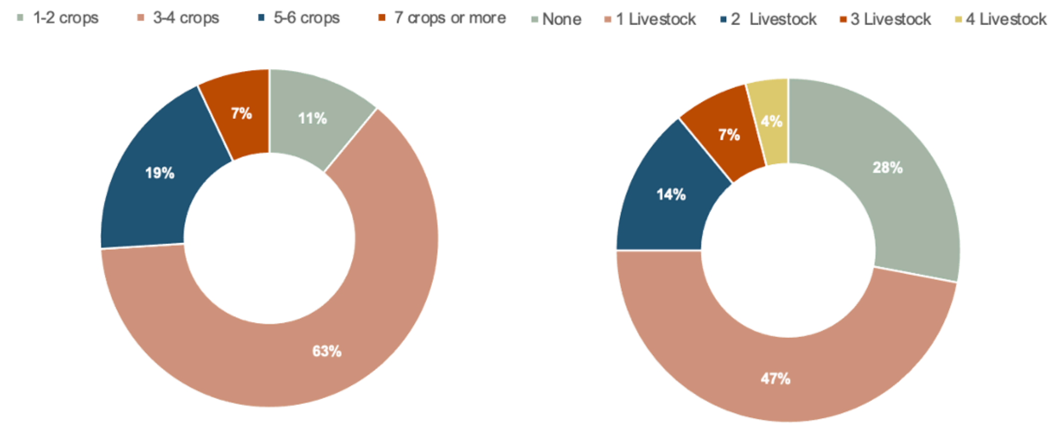

Fig. 5. Right - The number of crops grown by the respondents
Left - The number of different types of livestock raised by the respondents

One measure of agricultural diversification is the number of crops grown by the respondents and the different types of livestock raised by the individuals (Fig. 5). The majority of the sample had a relatively diverse cropping system, with respect to the number of crops grown, with 63% cultivating three to four crops, 19% producing 5 to 6 different crops, and 7% producing more than 7 crops. Farms growing 2 or fewer crops accounted for 11% of respondents. With respect to integrating livestock into the farming system, 28% of the sample were not raising livestock, while 47% were raising one type of livestock, 14% were raising two types of livestock, 7% were raising three types and 4% were raising four different types of livestock.

3.1.3 Cropland management

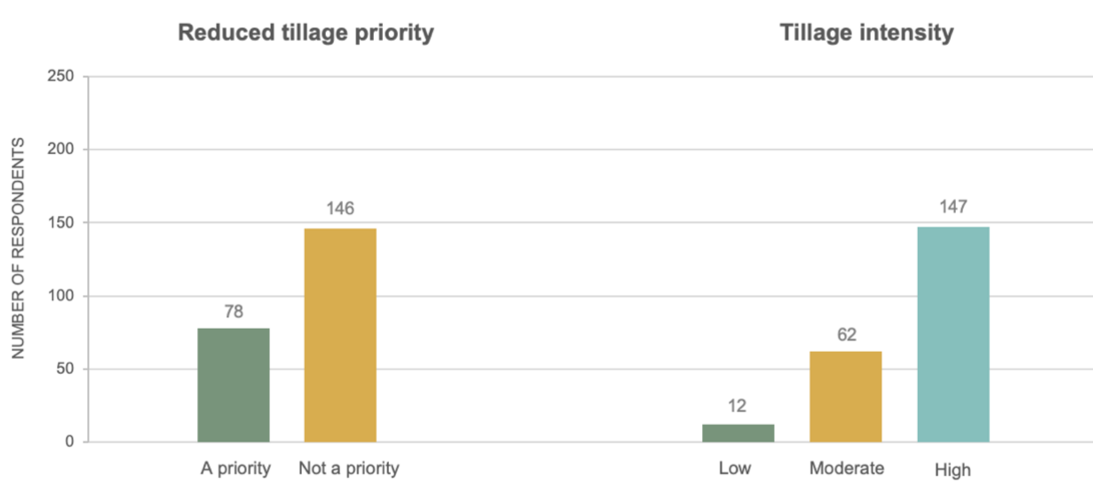

Figure 6: Left – The respondents' priority of using reduced tillage practices
Right – Tillage intensity of respondents

The intensity of tillage used for field management is summarized in Fig. 6 (right). The tillage intensity categories were defined by the degree of soil disturbance (e.g. soil inversion, depth) resulting from the equipment used for tillage and cultivation. Low tillage intensity was characterized by using a field cultivator or finisher, moderate intensity was defined by as using a chisel plow or disk, and high intensity consisted of moldboard plowing. The majority of the respondents (67%) used equipment defined as high tillage intensity on at least some of their fields. Twenty-eight percent used moderate intensity equipment as their most aggressive equipment and 5% solely relied upon low tillage intensity equipment. Most farmers (65%) reported that the implementation of reduced tillage practices was not a priority in their management, whereas 35% of the respondents considered this a priority Fig. 6 (left).

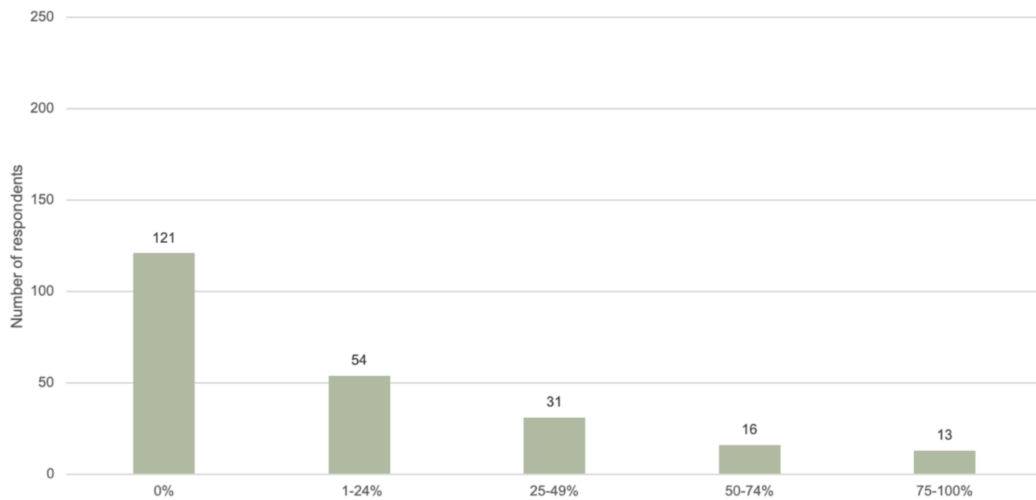

Fig. 7. Percentage of total acres of cropland under reduced tillage

Forty-nine percent of the respondents reported using at least one reduced tillage practice on their cropland. Twenty-three percent were using reduce tillage on a relatively small proportion of cropland (1-24%), whereas 6% of respondents were using practices to reduce tillage on more than 75% of their cropland. With respect to when respondents first used practices to reduced tillage, 6% adopted their first practice between 1960 and 1989, 8% between 1990 and 1999, 11% in the early 2000s, and 32% respondents between 2010 and 2018. Forty-three percent (43%) indicated never using a reduced tillage practice.

The summary of the reduced tillage practices used by the respondents are represented by Fig. 8. According to the results of the survey, most individual practices were not used by the majority of the respondents, except for shallow cultivation which was used by 77% of farmers. In terms of the other reduced tillage practices, 41% of individuals were using interseeding practices, direct planting was used by 35% of individuals, 28% of the sample of farmers were using a roller crimper, 31% used vertical tillage and 19% of farmers were intercropping.

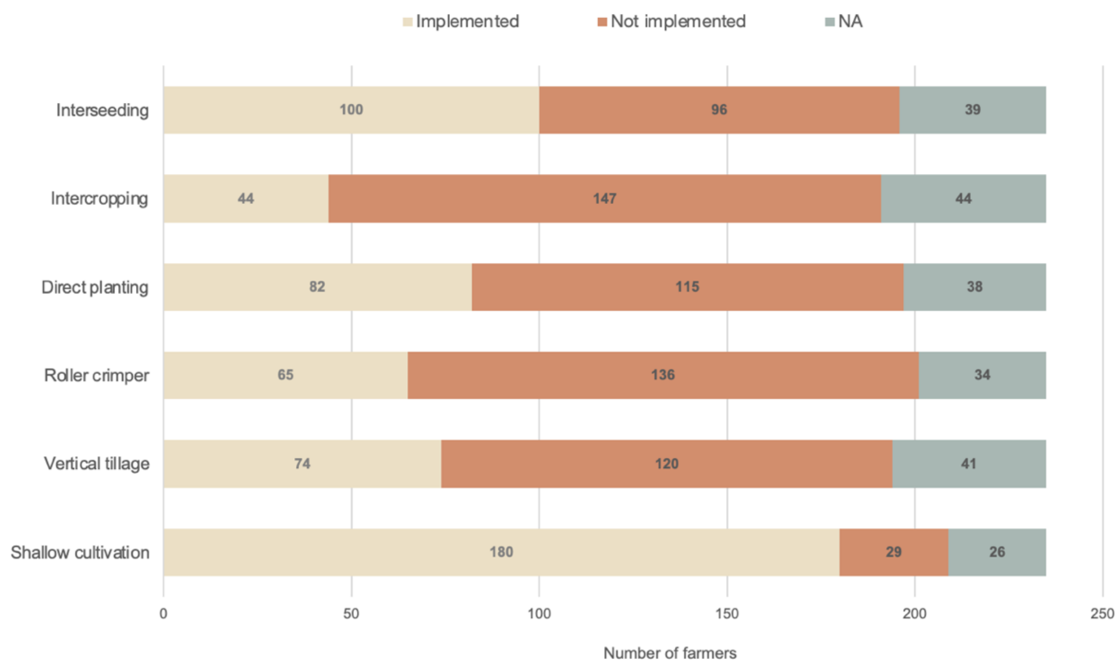

Fig.8.Reduced tillage practices featured in the survey

The respondents reported that the most limiting factors to adopt reduced tillage practices were: having access to appropriate equipment (36%), acceptable weed control (34%), lack of knowledge or information on best practices (32%), and the ability to manage manure (31%). Farmers indicated to a lesser degree that the extra time (25%), the ability to find cover crop varieties adapted to the region or cropping system (14%) and the ability to apply fertilizer (10%) negatively impacted their ability to adopt reduced tillage practices. It is important to note that the respondents had the choice to select more than factors. It, ‘weed control’ was not listed as a stated option on the survey but was frequently specified in the “other” option as farmers’ biggest limiting factor. As a result, it is possible more farmers experienced weed suppression issues than what was reported on the survey.

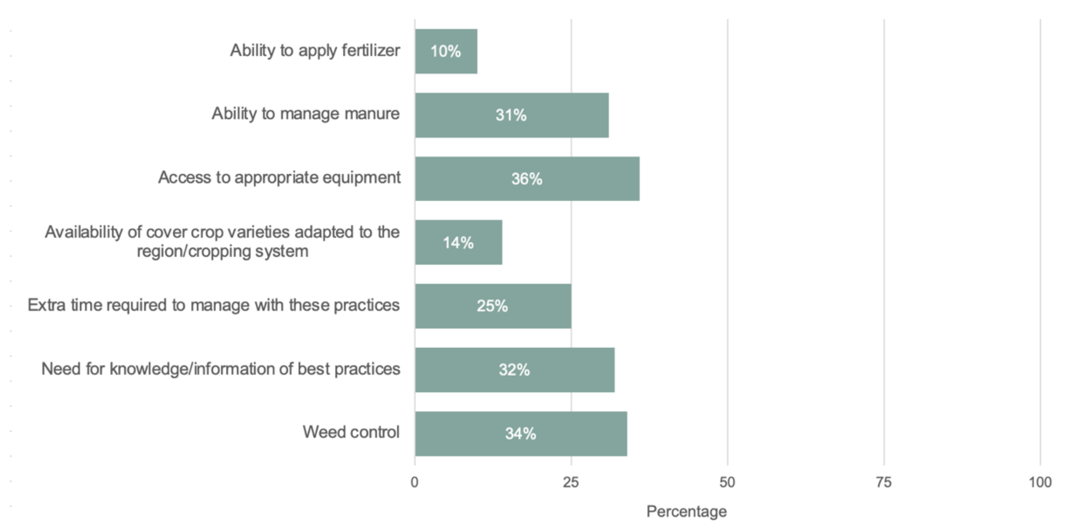

Fig. 9. Most limiting factors to implement reduced tillage practices

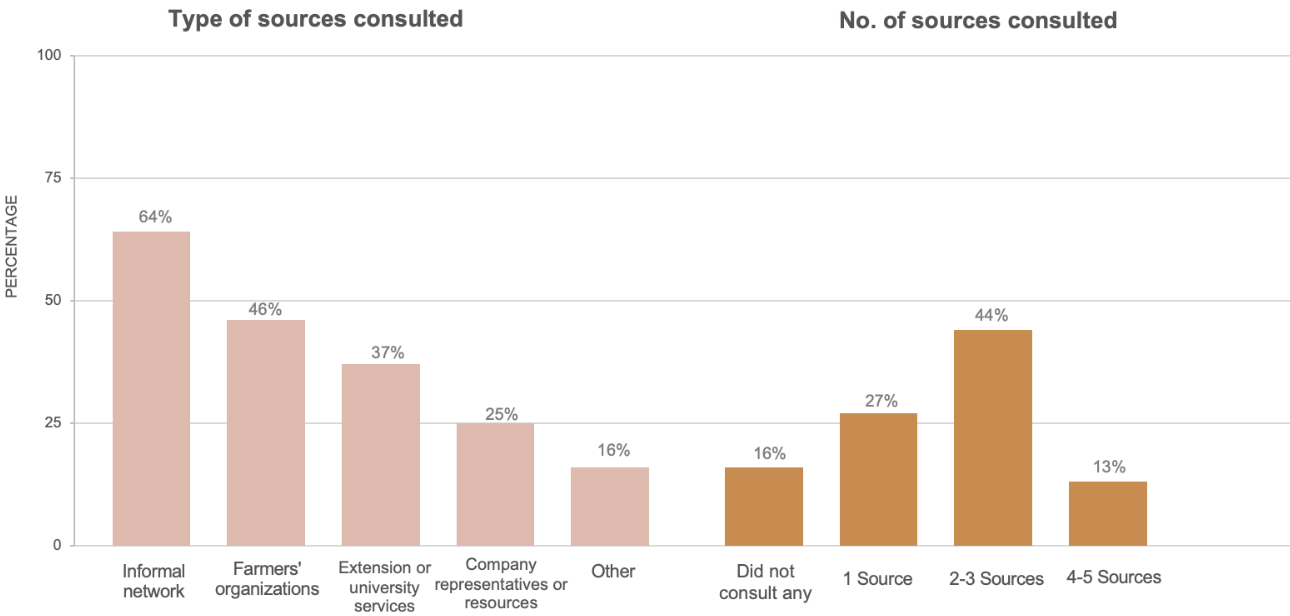

Fig. 10. Left – Sources of information that respondents have consulted to lean about reduced tillage practices. Right – Number of sources that the respondents have consulted to lean about reduced tillage practices

Respondents were asked to rank their ability to find information about reduced tillage practices, with options including "Very Challenging", "Challenging", "Somewhat Challenging", and "Not challenging at all". Forty-four percent of farmers answered this question as 'somewhat challenging' and as "not challenging at all". Seventeen percent found accessing information 'challenging' and 3% found it 'very challenging'. In addition, responses indicated that most respondents (64%) consulted an informal network (e.g. neighbours, family or friends) to learn about practices to reduce tillage. Forty-six percent of farmers sought information from one or multiple farmers' organization(s), 37% consulted Extension or university services, personnel or resources, and 25% sought company representatives or resources to learn about practices, while 16% indicated that they consulted a source of information that was not specified in the survey. Most farmers (44%) consulted two to three different sources of information featured in the survey, while 27% used a single source, 13% sought four to five sources and 16% did not consult any sources of information to learn about those practices.

3.2 Hierarchical clustering on principal component (HCPC)

3.2.1 Impact of Farm Characteristics and Demographics on Reduced Tillage Adoption

The aim of the first analysis was to identify relationships between farm characteristics/demographics and adoption of reduced tillage practices. The explanatory variables selected for the analysis included age of farmer, years of farming experience, farm size, number of different types livestock raised, number of crops grown, and number of sources of information consulted by respondents to learn about reduced tillage. The selected response variables included year of adoption of reduced tillage practices, percent acres of cropland under reduced tillage, and number of reduced tillage practices used.

3.2.1.a Principal component analysis (PCA)

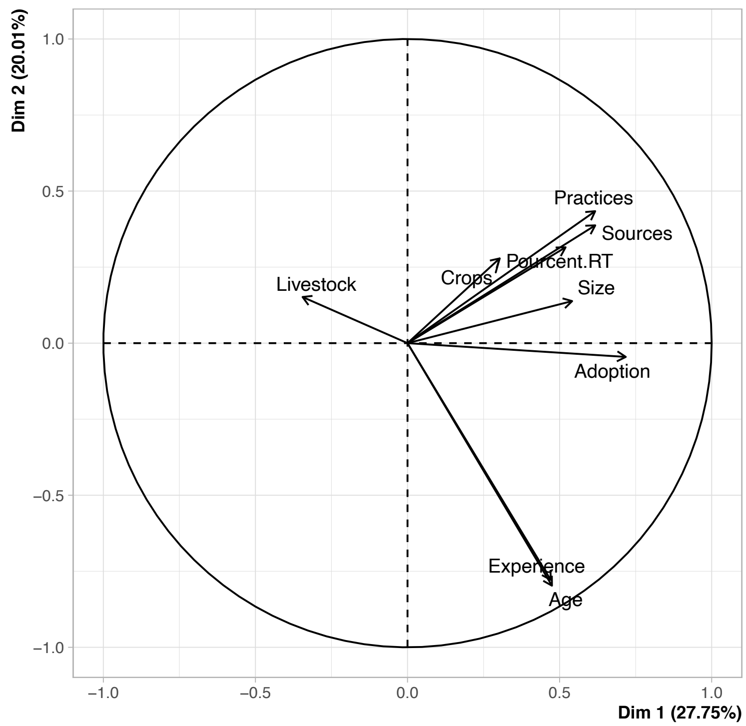

Fig. 11. Graph of variables represented in the PCA on farm structure. (Adoption = the year of adoption of reduced tillage practices; Percent = % of acres of cropland under reduced tillage; Practices = the number of reduced tillage practices used per respondent).

The components 1 and 2 of the PCA explained 47.76% of the variance (27.75% and 20.01% respectively). The first component was defined by the first year that farmers have adopted a reduced tillage practice (r = 0.717), the number of sources farmers consulted to learn about reduced tillage (r = 0.619), the number of implemented reduced tillage practices (r = 0.607), the size of the respondents' farm (r = 0.547), the percentage of total acres of cropland under reduced tillage (r = 0.520), the age of the respondent (r = 0.470), their years of farming experience (r = 0.467) and the number of crops grown per respondent (r = 0.297). The second component was mainly characterized by the number of implemented reduced tillage practices (r = 0.448), the number of sources farmers consulted to learn about reduced tillage (r = 0.385), the percentage of total acres of cropland under reduced tillage (r = 0.309), and the number of crops grown per respondent (r = 0.267), the number of different types of livestock raised by the respondents (r = 0.145) and the farm size of the sample (r = 0.141). The results of the PCA (Fig. 11) indicate two strong statistical relationship between (1) the age and years of farming experience of the respondents, and (2) the number of sources consulted to learn about reduced tillage practices and the number of reduced tillage practice adopted by farmers.

3.2.1.b Hierarchical cluster analysis on PCA

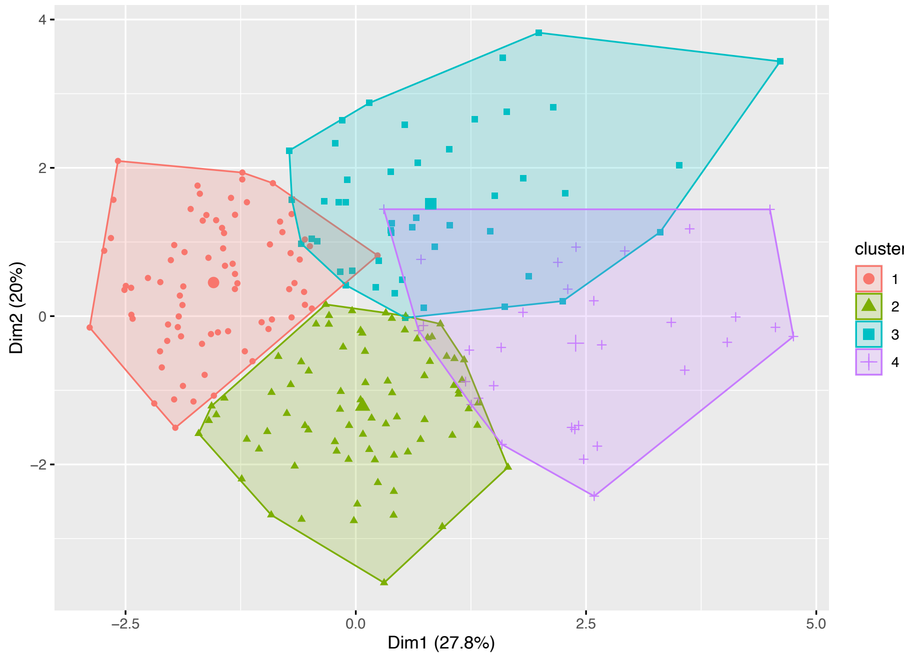

Fig. 12. Factor map of distribution and grouping of respondents based on farm structure and reduced-tillage practices. At first glance, the clusters appear to be overlapping because they are displayed on 2 dimensions (Dimensions 1 and 2 of the PCA). In reality, they are clearly separated from one another (see the dendrogram in Fig. 13).

Based on the results of a cluster dendrogram (see Fig. 13), we cut the latter at a height of 0.35, which provided us with 4 clusters. To interpret each group, the significant variables were identified using the V-test (greatest *v*-value). The clusters are colour-coded and the individual are represented by a coloured shape.

The clusters can be characterized as follows:

- Cluster 1: farmers raising on average two type of livestock (v = 6.062).
- Cluster 2: farmers approximately 62 years old (v =8.749) with 33 years of farming experience (v = 8.219)
- Cluster 3: farmers managing an average of 645 acres of crop land (v = 3.743,), using four different reduced tillage practices (v = 7.807), and consulting three different type of sources of information (v = 6.676) to learn about those practices.
- Cluster 4: farmers approximately 63 years old (v = 5.397) and had 35 years of farming experience (v = 5.585). This group of individuals had adopted their first reduced tillage practice at the 27 years ago (v = 11.044) were using reduced tillage practices on 49% of total acres of cropland (v = 7.431).

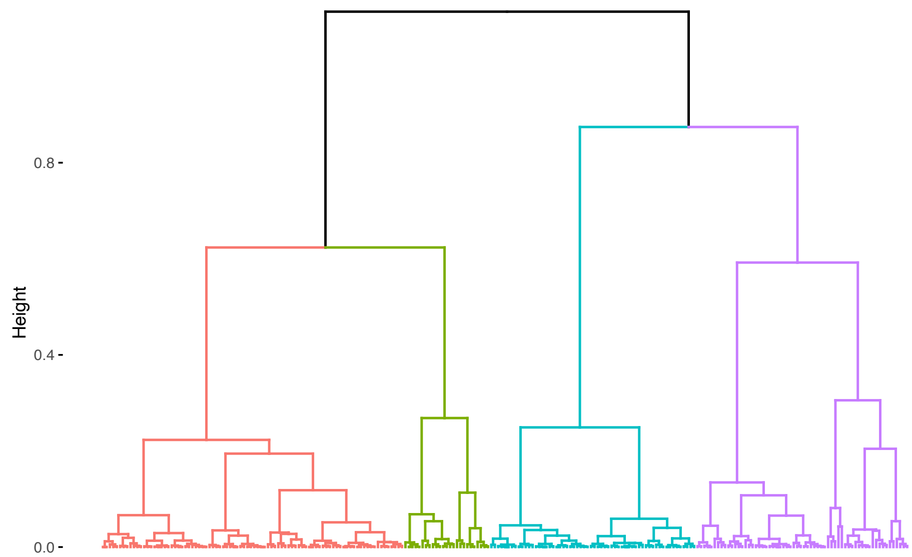

Fig. 13. Cluster dendrogram of PCA on structural variables

Based on the different profiles of the farmers, the hierarchical clustering on a principal component analysis (HCPC) indicated several trends. Farmers managing more acres tended to implement multiple reduced tillage practices. However, an integrated farming system with livestock and a diversified crop rotation were not linked to the implementation of reduced tillage practices. Farmers who sought out information from a variety of sources of information tended to employ several practices to reduce tillage, while farmers that began implementing reduced tillage practices in the 1990s tended to use them on a relatively greater proportion of cropland acres.

3.2.2 Impact of Agricultural Production Approaches on Reduced Tillage Adoption

The second analysis sought to determine the association of agricultural production approaches on the adoption of reduced tillage practices. As illustrated in Fig. 14, the explanatory variables were the following: the number of crops grown by the respondents, the number of different species of livestock raised, the application of manure, and the use of cover crops. The response variables included year of adoption of reduced tillage practices, percentage of total acres of cropland under reduced tillage, prioritization of adoption of reduced tillage practices, and the implementation of specific reduced tillage practices, i.e. shallow cultivation, direct planting, roller crimping, interseeding, intercropping and vertical tillage.

3.2.2.a Multiple correspondence analysis (MCA)

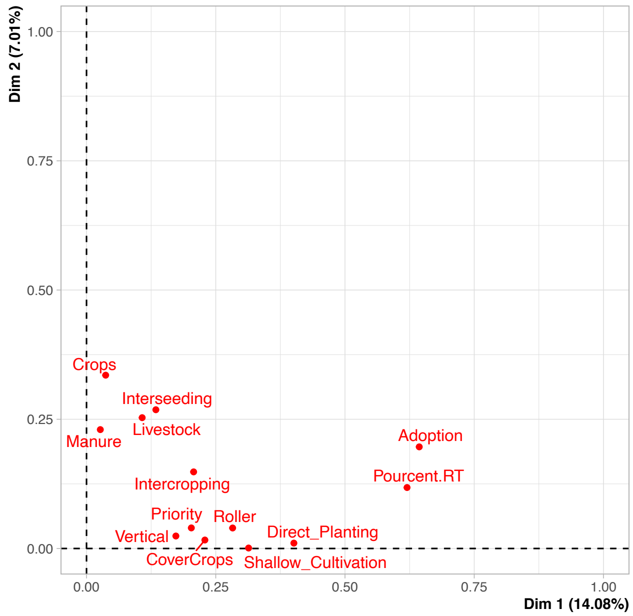

Fig. 14. Representation of the variables in the MCA on agricultural practices. (Adoption = the year of adoption of reduced tillage practices; Percent.RT = percentage of total acres of cropland under reduced tillage; Priority = the level of priority to adopt those practices, Roller = roller crimper; Vertical = vertical tillage)

The Dimensions 1 and 2 of the MCA explained 21.09% of the variance (14.08% and 7.01% respectively). The first dimension was represented by the following variables: the year that the respondent first adopted a practice to reduce tillage (R^2=0.644), the percent of total acres of cropland under reduced tillage (R^2=0.620), direct planting (R^2=0.401), shallow cultivation (R^2=0.314), using a roller crimper (R^2=0.283), using cover crops (R^2=0.229), intercropping (R^2=0.207) and the respondents' prioritization of reduced tillage practices (R^2=0.204), The second dimension corresponded to the following variables: the number of crops grown on the farm (R^2=0.335), interseeding (R^2=0.268), applying manure (R^2=0.241), the different types of livestock raised by the respondents (R^2=0.253), intercropping (R^2=0.148), the year that the respondent first adopted a practice to reduce tillage (R^2=196) and the percentage of total acres of cropland under reduced tillage (R^2=0.118).

Fig. 15 represents the results of the MCA, in which the 15 categories that contributed the most to the construction of the Dimensions 1 and 2. Looking at the distribution of the categories on axes will provide a first level of interpretation of the dataset by underscoring some general trends.

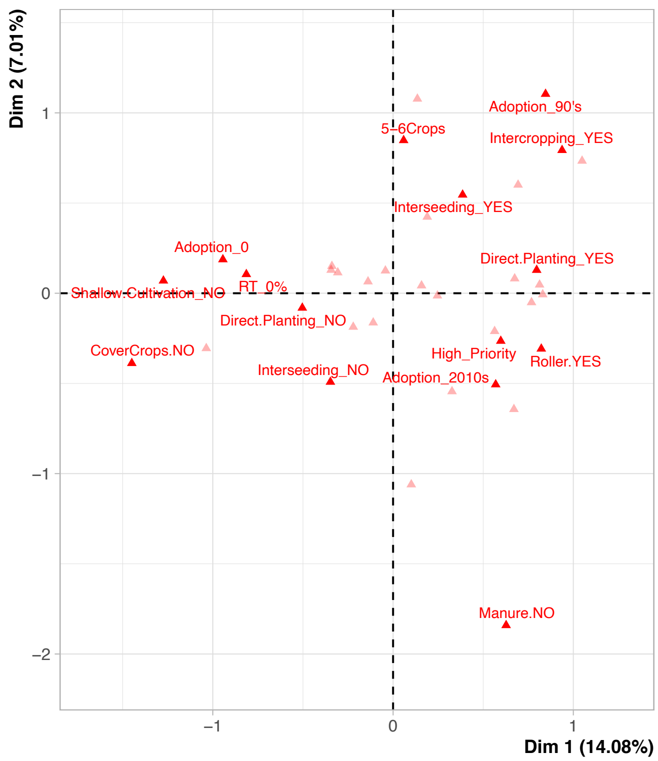

Fig. 15. Factor map of the 15 categories that contributed the most to the construction of Dimensions 1 and 2 of the MCA on agricultural practices. In the figure, 'YES' indicates the usage of a reduced tillage practice, whereas 'NO' indicate that the practice was not used. The number before the variable 'Crops' represent the number of crops grown.

Fig. 15 indicates three different groupings of farmers based on the use of specific agricultural practices. On left-hand side (below 0 on Dimension 1), we can find farmers who have never adopted a reduced tillage practice and were not using cover crops. The upper right-hand side (above 0 on Dimension 1 and above 0 on Dimension 2) represented farmers integrating a relatively diversified cropping system; adopting their first reduced tillage practice in the 1990s; and implementing intercropping, interseeding and direct planting. Lastly, the lower right-hand side of the figure (above 0 on Dimension 1 and below 0 on Dimension 2) was characterized by farmers who did not apply manure to their fields, placed a high priority on the implementation of reduced tillage practices, first adopted one of those practices in the early 2010s, and used a roller crimper.

3.2.2.b. Hierarchical clustering analysis on MCA

Based on the results of a cluster dendrogram (see Fig 17), we cut the dendrogram at a height of 0.04, which provided 4 clusters. To interpret each group, we used the V-test (*v*-value greater than 2), which identified the significant variables represented in each cluster. The groups were represented by a different colour and the individuals are represented by different shapes.

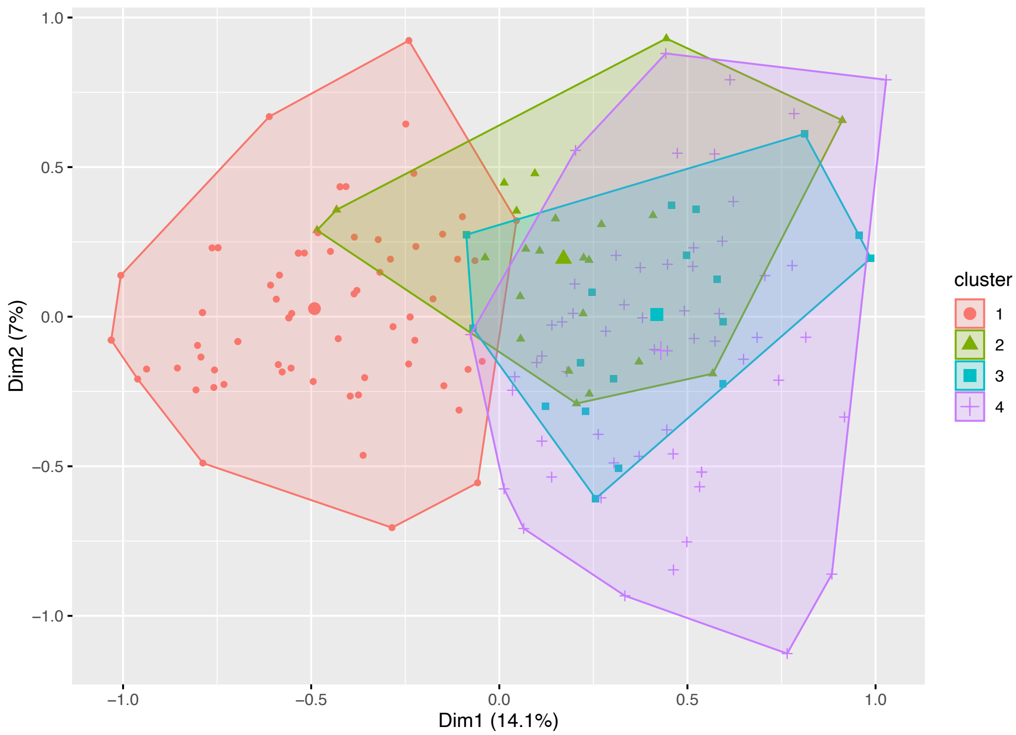

Fig 16. MCA factor map of distribution and grouping of respondents based agricultural and reduced tillage indicators. At first glance, the clusters appear to be overlapping because they are displayed on 2 dimensions (Dimensions 1 and 2 of the MCA). In reality, they are clearly separated from one another (see Fig. 17 for cluster dendrogram).

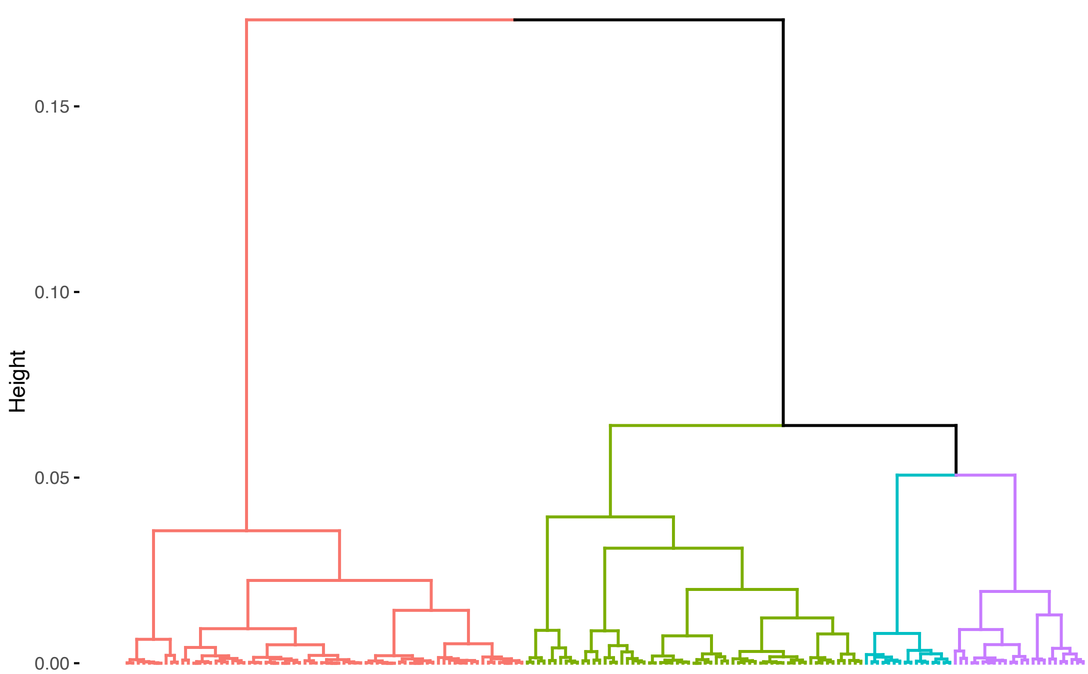

Fig. 17: Cluster dendrogram of MCA on agricultural practices

A group of individuals emerged that was not implementing any conservation agriculture practices (represented by the first cluster.) According to the results of the V-test, these farmers were not using cover crops (v = 5.235) and had never adopted a reduced tillage practice (v = 10.851), and therefore were using those practices on 0% of acres of cropland at the time of the survey (v = 10.1486). Additionally, they placed a low priority on the implementation of reduced tillage practices (v = 3.961). This cluster was also characterized by farmers that were raising three different types of livestock (v = 3.031).

Cluster two was characterized by farmers implementing diversified integrated farming system approaches. These farmers were producing more than seven crops (v = 5.576) and raising four different types of livestock (v = 5.123).

The third cluster represented the earliest adopters of reduced tillage practices (between 1960 and 1989) (v = 6.828). These individuals reported using those practices on 75 to 100% of total acres of cropland and considered the use of these practices to be a high priority for their farm management (v = 3.236).

The last cluster represented farmers who were using a variety of reduced tillage practices, such as direct planting (v = 7.103), roller crimping (v = 5.470), shallow cultivation (v = 4.006), and vertical tillage (v = 3.481). They also used cover crops (v = 3.419) and did not apply manure on their cropland (v = 3.265). Moreover, the respondents represented in this group had adopted their first reduced tillage practices in the past two decades (2000-2009 v = 5.177 and 2010-2018 v = 3.770) and were using those practices on less than 49% of total acres of cropland (1-24% v = 3.060 and 25-49% v = 5.076). In addition, they highly prioritized implementing practices to reduce tillage (v = 3.032).

Based on the different profiles of the farmers, the hierarchical clustering on a multiple correspondence analysis (HCPC) indicated various trends. There was no link between applying manure and using reduced tillage practices. Farmers that used roller crimping as a management strategy tended to also use other reduced tillage practices. Conversely, the number of different crops grown and number of different types of livestock raised were not linked to the implementation of reduced tillage practices. Further, farmers who were earlier adopters of reduced tillage practices tended to use those practices of a large proportion of cropland (more than 75%), whereas the later adopters tended to use them on smaller proportion of cropland (less than 49%).

3.2.3 Socio-demographic characteristics

The third analysis aimed to identify the relationship between the socio-demographic characteristics of the respondents the adoption of reduced tillage practices. The explanatory variables included: age; gender; years of farming experience; farm location (state); highest level of education; and consultation with resources. The response variables or reduced tillage indicators were: year of adoption of reduced tillage practices; percent of total acres of cropland under reduced tillage; level of priority to adopt practices; number of reduced tillage practices used; and perceived challenge in finding information.

3.2.3.a. Multiple correspondence analysis (MCA)

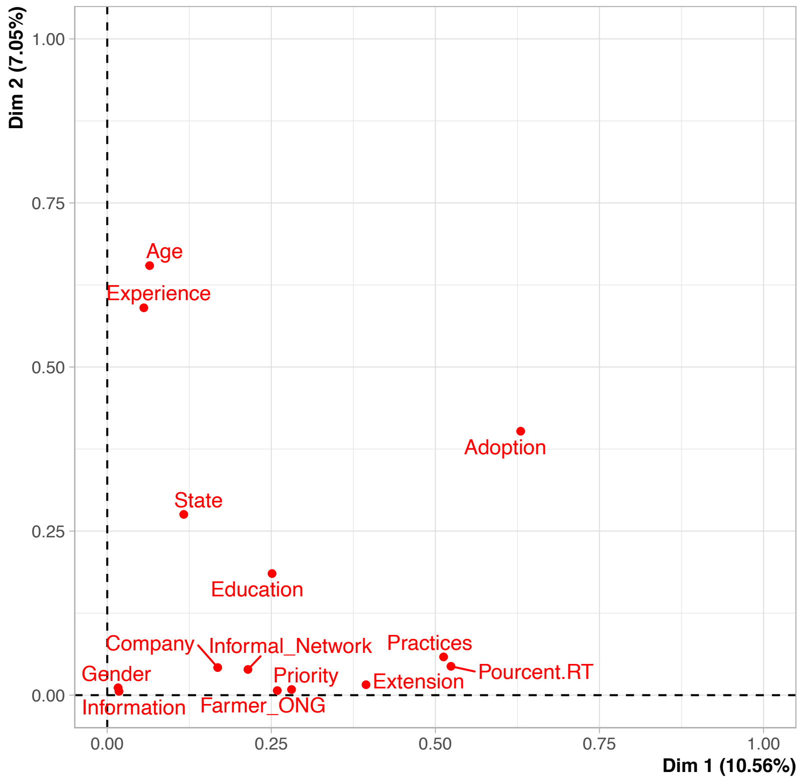

Fig. 18: Representation of the variables in the MCA of socio-demographic characteristics. (extension = extension/university personnel or resources; Farmer_ONG = farmers' organization, Company = company representative or resources; Adoption = year of adoption of reduced tillage practices; Percent.RT = % of acres under reduced tillage in 2018; Priority = the level of priority to adopt those practices; Practices = the number of reduced tillage practices used per respondent; Information = how challenging is finding information on reduced tillage)

The Dimensions 1 and 2 of the MCA explained 17.61% of the variance (10.56% and 7.05% respectively). The first dimension was represented by the following variables: year which farmers first implement reduce tillage practices (R^2=0.630); percent total acres of cropland under reduced tillage (R^2=0.524); number of reduced tillage practices implemented (R^2=0.512); level of priority to implement those practices (R^2=0.303); highest level of education of the farmer (R^2=0.278); state in which the farm was located (R^2=0.117); and consultation of educational resources (extension/university personnel or resources (R^2=0.394), farmers' organizations (R^2=0.259), informal networks (R^2=0.214), and company representative or resources (R^2=0.168)). The second dimension corresponded to the farmer's age (R^2=0.654); years of farming experience (R^2=0.593); year of implementation of first reduced tillage practice (R^2=0.402); the state in which the farm was located (R^2 = 0.275); and highest level of education of farmers (R^2=0.189).

The Fig. 19 represents the results of the MCA, in which the 15 categories most contributed to the construction of the Dimensions 1 and 2. Looking at the distribution of the categories on axes provided a first level of interpretation of the dataset by underscoring some general trends.

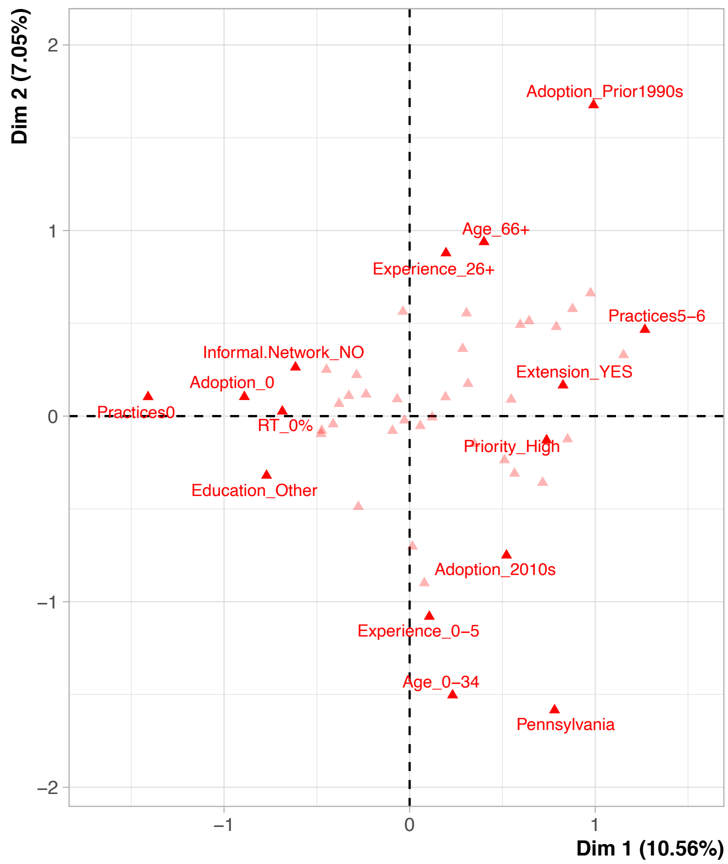

Fig 19: Factor map of the 15 categories that contributed the most to the construction of Dimensions 1 and 2 of the MCA on socio-demographic characteristics. In this figure, 'Yes' indicates that the respondents consulted a certain source of information to learn about reduce tillage, whereas 'NO' means that the source was not consulted. The numbers following the variables 'Practices', 'Experience' and 'Age' represent the number of reduced tillage practices implemented, the years of farming experience and the age of a farmer – respectively.

Fig. 19 indicated three different grouping of farmers based on the individuals' socio-demographic characteristics. On the left-hand side of the figure (below 0 on Dimension 1), we found the individuals with no greater than an eighth-grade education and who were not implementing any reduced tillage practices. The upper right-hand side of (above 0 on Dimension 1 and above 0 on Dimension 2) represented the oldest and most experienced farmers, having first implemented practices to reduce tillage between 1960 and 1989. On lower right-hand side of the figure (above 0 on Dimension 1 and below 0 on Dimension 2), we can find the youngest and least experienced farmers from Pennsylvania.

3.2.3.b. Hierarchical clustering analysis on MCA

Based on the results of a cluster dendrogram (see Fig. 21), we cut the dendrogram at a height of 0.03, which provided us with six clusters. To interpret each group, we used the V-test (v-value greater than 2), which identified the significant variables represented in each cluster. The clusters were colour-coded and the individuals are represented by different coloured-shapes.

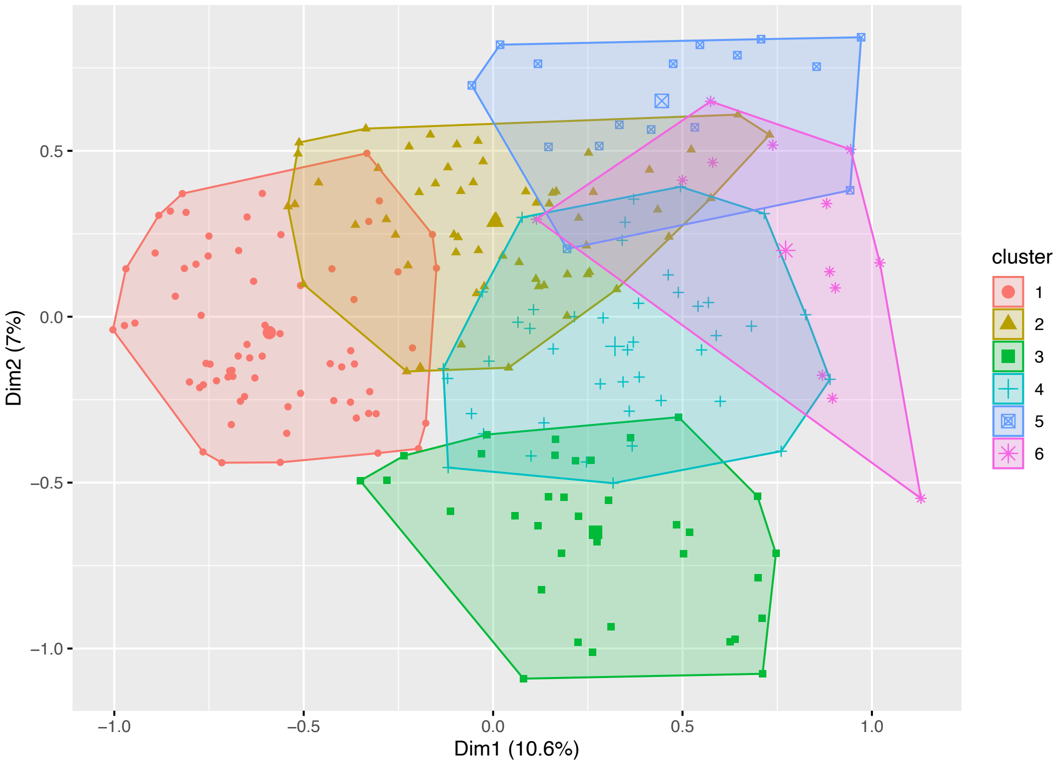

Fig. 20. Factor map of distribution and grouping of respondents based on socio-demographic characteristics and reduced tillage indicators. At first glance, the clusters appear to be overlapping because they are displayed on 2 dimensions (Dimensions 1 and 2 of the MCA). In reality, they are clearly separated from one another (see Figure for the cluster dendrogram).

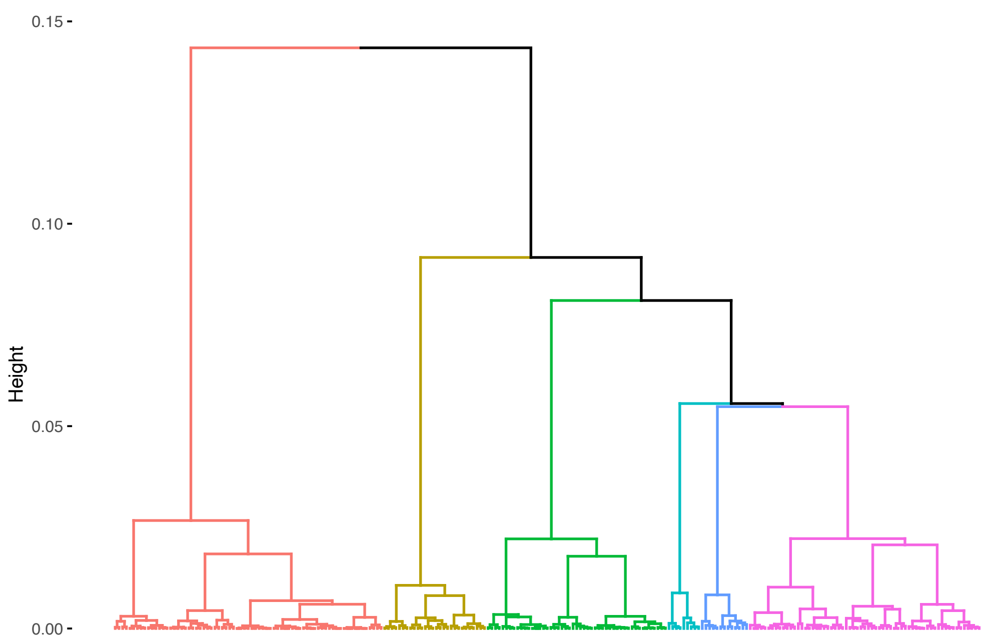

Fig. 21. Cluster dendrogram of MCA socio-demographic characteristics

As previously indicated in Fig. 19, a group of farmers emerged from the sample who were not implementing any conservation agriculture practices, represented by the first cluster. The V-test indicated that those individuals had never implemented reduced-tillage practices (v = 10.969) and therefore were using zero reduced tillage practices (v = 6.409) on 0% of acres of cropland (v = 9.750). This group of individuals fell between the ages of 35 and 49 years old (v = 5.070), had 16 to 25 years of farming experience (v = 3.644), had an 8th grade education (v = 6.096), and were from Iowa (v = 3.701). In addition, the respondents had a low priority to implement reduced tillage practices (v = 3.955) and did not consult any of sources of information to learn about those practices (extension/university personnel or resources v = 7.207, farmers' organization v = 5.566, informal network v = 5.273, company representative or resources v = 3.846). In addition, this cluster was also characterized for having left the question "How challenging is it to find information on reduced tillage" unanswered (v = 4.903).

The second cluster represented the farmers that had implemented their first reduced tillage practice in the early 2000s (v = 4.315) and were using 1 to 2 reduced tillage practices (v = 3.711). This group of individuals were older than 50 years old (50-65 years of age v = 5.393 and older than 66 years of age v = 3.149), had more than 26 years of farming experience (v = 7.824), had a high school diploma or a GED (v = 4.347) and were from Wisconsin (v = 3.842). In addition, the cluster was characterized for not using company representative or resources to learn about reduced tillage (v = 3.110).

The third cluster was characterized by the youngest class of farmers (v = 8.207) with fewer than 5 years of farming experience (v = 5.556), some high school education (v = 4.369), and located in Pennsylvania (v = 7.305). In addition, this group of respondents had first implemented reduced tillage practices in the 2010s (v = 6.651).

Farmers using between 3 to 4 reduced tillage practices (v = 5.690) on 1 to 24% of acres of cropland (v = 4.500) were represented in the fourth cluster. Those respondents were between 35 to 49 years old (v = 3.827), had between 6 to 15 years of farming experience (v = 3.059), and obtained a 4-year college degree (v = 4.713). This group of individuals highly prioritized using reduced tillage practices (v = 3.015) and sought information to learn about those practices from a variety of sources, including farmers' organizations (v = 4.775), extension/university personnel or resources (v = 3.827) and company representative or resources (v = 3.059).

The fifth cluster represented the earliest adopters of practices to reduce tillage (between 1960 to 1989 (v = 8.105)), implementing those practices on 75 to 100% of acres of cropland (v = 3.369). This group of respondents were older than 66 years of age (v = 3.901), had more than 26 years of farming experience (v = 5.351), and had obtained a 2-year college degree (v = 3.416).

The last cluster was characterized by farmers who were using between 5 and 6 reduced tillage practices (v = 6.151) on 50-74% of acres of cropland (v = 5.390), but had employed their first practice in the 1990s. These respondents highly prioritized using reduced tillage practices, seeking information from farmers' organizations (v = 3.441) and company representative or resources (v = 3.395). In addition, this group of individuals had a graduate degree (v = 3.876).

Based on the different profiles of the farmers, the hierarchical clustering on a multiple correspondence analysis (HCPC) indicated multiple trends: (i) the earliest adopters of reduced tillage practices have a tendency to implement those practices on the largest proportion of cropland (75-100%), (ii) respondents with a 4-year college degree or graduate degree have a tendency to consult a variety of sources of information to learn about reduced tillage practices, while the other consult fewer sources or none, (iii) individuals with a 4-year college degree or graduate degree tend to employ the highest number reduced tillage practices (three to six), whereas those with an 8th-grade education were not using any practices and (iv) consulting sources of information outside of the informal network to learn about reduced tillage is linked to the adoption of those practices.

3.2.4 Limiting factors to implement reduced tillage practices

3.2.4. Multiple correspondence analysis (MCA)

The aim of the fourth data set was to determine if certain factors (see Fig. 9) were limiting the adoption of specific reduced tillage practices. For the analysis, the explanatory variables included: ability to apply fertilizer; ability to manage manure; access to appropriate equipment; availability of cover crop varieties adapted to my region/cropping system; extra time required to manage with these practices; and need for knowledge/information of best practices. The selected response variables or reduced tillage indicators included: the percentage of total acres under reduced tillage in 2018; the level of priority to adopt those practice; and the specific reduced tillage practices used per respondent (shallow cultivation, vertical tillage, roller crimper, intercropping, interseeding and direct planting).

The Dimensions 1 and 2 of the MCA explained 23.68% of the variance (14.47% and 9.28% respectively). The first dimension was represented by the percentage of total acres of cropland under reduced tillage in 2018 (R^2=0.528), direct planting (R^2=0.434), intercropping (R^2=0.313), shallow cultivation (R^2=0.292), roller crimper (R^2=0.289), vertical tillage (R^2=0.238), the level of priority to reduce tillage (R^2=0.242), and interseeding (R^2=0.174). The second dimension corresponded to the need for knowledge or information of best practices (R^2=0.429), weed control (R^2=0.396), extra time required to manage with reduced tillage practices (R^2=0.310) and having access to appropriate equipment (R^2=0.288). Reduced-tillage practices are aligned on Dimension 1, whereas the challenges or limiting factors construct the Dimension 2.

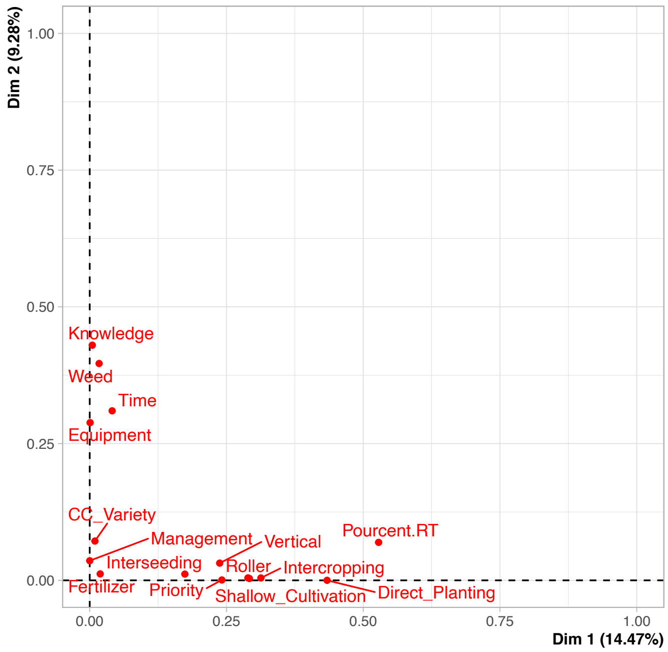

Fig. 22. Representation of the variables in the MCA of limiting factors to implement reduced tillage practices.

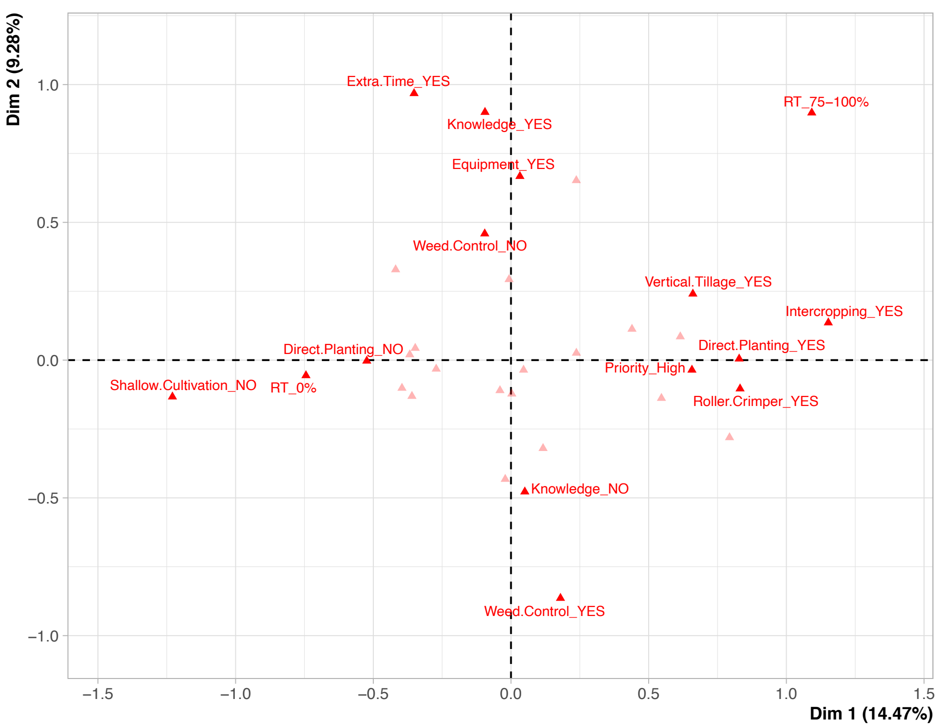

Fig. 23. Factor map of the 15 categories that contributed the most to the construction of Dimensions 1 and 2 of the MCA on limiting factors to implement reduced tillage practices. In this figure, limiting factors followed by 'Yes' indicates that respondents were restrained by a factor to implement practices to reduce tillage or whereas 'No' indicates that this was not a limiting factor. Reduced tillage practices followed by 'Yes' indicate if the practice is applied and 'No' indicate that the practice was not used by the respondents. 'RT' stands for the percentage of total acres of cropland under reduced tillage. The level of priority to adopt those practices ('Priority') is indicated as being 'Low' or 'High'.

Fig. 23 indicated four different grouping of farmers based on the limiting factors to implement reduced tillage practices and the practices employed. On the left-hand side of the figure (below 0 on Dimension 1 and on 0 on Dimension 2), we can find the individuals who did not use shallow cultivation and direct planting on any of their crop acres. The right-hand side of the figure (above 0 on Dimension 1 and on 0 on Dimension 2) regrouped various reduced tillage practices (i.e. roller crimper, vertical tillage, direct planting and intercropping), as well as farmers that highly prioritized those practices. At the top of the figure (on 0 on Dimension 1 and above 0 on Dimension 2), we can find the various challenges that restrain respondents from employing reduced tillage practices, such as the extra time required to manage with these practices, having access to appropriate equipment and the need for knowledge/information of best practices. At the bottom of figure (on 0 on Dimension 1 and below 0 on Dimension 2), we find individuals limited by poor weed control, but were not restrained by the need for knowledge or information to learn about those practices.

Based on the construction of the Dimensions 1 and 2 (the reduced tillage practices were aligned on Dimension 1 and the limiting factors were aligned on Dimension 2) and the distribution of the categories on the dimensions on Fig. 23 (the practices are clustered on Dimension 1 and the limiting factors are clustered on Dimension 2), the MCA indicates no statistical link between the factors limiting farmers to implement practices to reduce tillage and individual practices. In other words, the analysis suggests that the limitations listed in the survey would not necessarily increase nor will they decrease the implementation of a specific reduced tillage practice. In light of those conclusive results, there was no need to perform a hierarchical clustering analysis on this MCA.

3.3 Correlation tests

3.3.1 Priority to reduce tillage

Table 1: Variables correlated to respondents' **priority** to reduced tillage.

Variables	*P*-value (<0.05)	Coef. or odd ratio	Type of test
Education			Logistic regression
Some high school	0.0131	-1.3863	
2-year college degree	0.0452	1.3863	
4-year college degree	0.0224	1.5115	
Size of farm			Logistic regression
1-249 acres	2.55e-05	-0.7841	
750 acres or more	0.0136	1.1206	
Cover crops			Logistic regression
Not used	0.0113	-1.2809	
Shallow cultivation			Logistic regression
Not used	0.00338	-1.3437	
Used	0.05623	0.9239	
Vertical tillage			Logistic regression
Not used	3.83e-05	-0.8232	
Used	0.00423	0.8773	
Direct planting			Logistic regression
Not used	3.96e-06	-0.9727	
Used	0.00035	1.0963	
Intercropping			Logistic regression
Not used	2.6e-05	-0.7450	
Used	0.0477	0.6985	
Interseeding			Logistic regression
Not used	0.00123	-0.7091	
Availability of suitable cover crop variety			Logistic regression
Not a challenge	1.22e-06	-0.7481	
A challenge	0.0377	0.8126	
Challenge of finding information			Logistic regression
Not a challenge	0.0265	-0.57808	
Company representative or resources	0.000222	1.1665	Logistic regression
Extension services or university personal	6.08e-06	1.3375	Logistic regression
Farmer organizations	0.0389	0.5859	Logistic regression
Informal network	0.0174	0.7447	Logistic regression
Tillage intensity	0.0284	-0.6549	Logistic regression
No. of reduced tillage practices	2.37e-06	0.4759	Logistic regression

A logistic regression test confirmed the results of the HCPC on socio-demographic characteristics, illustrating that the completion of a 2- or 4-year college degree is correlated with farmers having a higher priority to implement reduced tillage practices.

In terms of trends that were not found in the HCPC but were established by the individual tests, the correlation tests indicated that: (i) farmers indicating a low priority to reduce tillage also lacked in their of cover crops and reduced tillage practices; (ii) farmers managing more acres tended to prioritize the use of practices to reduce tillage, while farmers managing less acres had a tendency to not prioritize those practices; and (iii) farmers' consultation with a variety of sources to learn about reduced tillage was correlated with a higher priority to implement those practices.

3.3.2 Tillage intensity

Table 2: Variables correlated to the **tillage intensity** of field activity

Variables	*P*-value (<0.05)	Coef. or odd ratio	Type of test
Age			Logistic regression
0-34 years of age	0.0239	0.8938	
Education			Logistic regression
Some high school	0.0481	1.0296	
Size of farm			Logistic regression
1-249 acres	5.28e-09	1.2139	
250-499 acres	0.001899	-1.0655	
750 acres or more	0.000493	-1.6558	
Livestock			Logistic regression
Not raising livestock	0.035937	-0.6709	
Raising livestock	0.000386	1.5570	
Cover crops			Logistic regression
Not used	0.00162	1.9459	
Used	0.03063	-1.3723	
Shallow cultivation			Logistic regression
Not used	0.00279	1.4816	
Vertical tillage			
Not used	4.52e-05	0.8267	
Roller crimper			Logistic regression
Not used	1.14e-06	0.9430	
Used	0.0241	-0.7198	
Direct planting			Logistic regression
Not used	1.5e-06	1.0394	
Used	0.0273	-0.6985	
Intercropping			Logistic regression
Not used	3.84e-07	0.9458	
Interseeding			Logistic regression
Not used	8.34e-06	1.0561	
Used	0.0397	-0.6506	
Access to appropriate equipment			Logistic regression
Not a challenge	0.0139	0.4299	
A challenge	0.0181	0.7333	
Challenge of finding information			Logistic regression
Not a challenge	0.0168	0.6444	
Farmer organizations	0.0331	-0.6149	Logistic regression
1st years of adopting reduced tillage			Logistic regression
2010-2018	0.02648	1.4422	

Considering that the degree of tillage intensity employed by a farmer was not present in any HCPC, the individual tests were able to establish the following correlations: (i) younger farmers tended to employ field activities characterizing a higher tillage intensity; (ii) farmers with an 8th-grade education tended to employ field activities characterizing a higher tillage intensity; (iii) farmers managing between 250 to 499 acres and larger than 750 acres tended to perform field operations characterizing a lower tillage intensity; (iv) farmers managing less than 249 acres tended to perform field operations characterizing a lower tillage intensity; (v) farmers raising livestock tended to perform field operations characterizing a higher tillage intensity; (vi) farmers using cover crops tended to perform field operations characterizing a lower or moderate tillage intensity; (vii) farmers not employing the reduced tillage practices featured in the survey tended to perform field operations characterizing a higher tillage intensity; and (viii) farmers implementing a reduced tillage practices for the first time after 2010 tended to perform field operations characterizing a higher tillage intensity.

3.3.3 Number of reduced tillage practices implemented

Table 3: Variables correlated to the **numbers** of reduced tillage practices implemented

Variables	*P*-value (<0.05)	Coef. or odd ratio	Type of test
Education	0.0003513		ANOVA
Size of farm	1.165e-06		ANOVA
Crops	0.005983		ANOVA
Cover crops	4.198e-06		T-test
Company representative or resources	0.00384		T-test
Extension services or university personal	2.777e-09		T-test
Farmer organizations	2.945e-07		T-test
Informal network	6.53e-05		T-test
Reduced tillage priority	1.266e-06		T-test

The HCPC of socio-demographic characteristics suggested a statistical relationship between the highest level of education of the respondents and the implementation of multiple reduced tillage practices. This link was confirmed by an ANOVA test, which indicates that on average, farmers with a 4-year college degree or a graduate degree would employ 2.97 and 3.04 reduced tillage practices, respectively, whereas farmers with an 8th-grade education would implement 1.64 practice. In addition, a separate ANOVA test supported the statistical relationships established by the HCPC on farm structure, where farmers managing more acres tended to implement multiple reduced tillage practices. According to this test, farms between 1 and 249 acres will employ on average 1.99 practices, while farms that are 500 to 749 acres or larger than 750 acres will implement 3.17 and 3.67 reduced tillage practices respectively. Furthermore, the link established by the HCPC on farm structure and socio-demographic characteristics between the various sources of information consulted to learn about reduced tillage practices and the implementation those practices were confirmed by multiple t-tests.

In terms of trends that were not found in the HCPC but were established by the individual tests, the correlation tests indicated that: (i) farmers implementing a more diversified cropping system had a tendency to employ more reduced tillage practices than those that are producing fewer crops and (ii) using cover crops is correlated to using more reduced tillage practices.

3.3.4 Percentage of total acres of cropland under reduced tillage

Table 4: Variables correlated to the **percentage of total acres** of cropland under reduced tillage

Variables	*P*-value (<0.05)	Coef. or odd ratio	Type of tests
Cover crops	2.762e-06		T-test
Shallow cultivation	7.977e-14		T-test
Roller crimper	0.04355		T-test
Direct planting	0.004059		T-test
Interseeding	0.004388		T-test
Company representative or resources	0.004143		T-test
Extension services or university personal	0.002645		T-test
Farmer organizations	0.002173		T-test
Informal network	0.00229		T-test
1st year of adopting reduced tillage	0.03465		ANOVA
Priority to reduce tillage	9.162e-06		T-test
No. of reduced tillage practices	2.41e-06	0.05257	Linear regression

The ANOVA test confirmed that the earliest adopters of reduced-till (between 1960-1989) used these practices on the larger proportion of acres of cropland (46%), while the respondents that had first adopted those practices between 2000 and 2009 implemented them on the smallest portion of cropland (23% of total acres of cropland). In addition, the analysis indicated that seeking information from any of the sources featured in the survey is correlated with a higher proportion of total acres of cropland under reduced tillage. Those trends appeared in the HCPC on farm structure, agricultural practices and socio-demographic characteristics.

In terms of trends that were not found in the HCPC but were established by the individual tests, the correlation tests indicated that the individuals not using cover crops will implement reduced tillage practices on 40% of acres of cropland, while those that using cover crops will employ those practices on a smaller proportion of cropland (18% of total acres).

3.3.5 Using a roller crimper

Table 5: Variables correlated to using a **roller crimper**

Variables	*P*-value (<0.05)	Coef. or odd ratio	Type of tests
Size of farm			Logistic regression
1-249 acres	1.31e-07	-1.1451	
500-749 acres	0.03904	1.3275	
750 acres or more	0.00181	1.5129	
Cover crops			Logistic regression
Not used	0.0049	-2.890	
Used	0.0289	2.270	
Shallow cultivation			Logistic regression
Not used	0.000666	-1.8326	
Used	0.039886	1.1578	
Vertical tillage			Logistic regression
Not used	2.87e-09	-1.3350	
Used	0.000475	1.1581	
Direct planting			Logistic regression
Not used	1.75e-10	-1.5686	
Used	1.96e-06	1.5946	
Intercropping			Logistic regression
Not used	3.14e-09	-1.1350	
Used	0.00148	1.1863	
Interseeding			Logistic regression
Not used	8.97e-05	-0.86681	
Challenge of finding information			Logistic regression
Not a challenge	0.00428	-0.83035	
Company representative or resources	0.00387	0.9537	Logistic regression
Extension services or university personal	0.000212	1.1580	Logistic regression
Farmer organizations	0.000227	1.1800	Logistic regression
Informal network	0.00839	0.9629	Logistic regression
Tillage intensity	0.0241	-0.7198	Logistic regression
No. of reduced tillage practices	6.83e-11	0.9044	Logistic regression

The logistic regression tests confirmed the statistical relationship established by the HCPC of agricultural practices, where farmers using a roller crimper had a tendency to use other reduced tillage practices.

In terms of trends that were not found in the HCPC but were established by the individual tests, the correlation tests indicated that: (i) farmers managing greater than 500 acres were more likely to use a roller crimper, while farmers managing less than 500 acres were less likely, and (ii) farmers were more likely to consult a variety of sources of information to learn about this reduced tillage practice (i.e. Extension, informal networks, company representatives, or farmers' organizations).

Chapter Four: Discussion

4.1 To which extent are US organic grain farmers using reduced tillage practices?

4.1.1 Earliest versus later adopters

The analysis indicated that the extent of which farmers will implement reduced tillage practice is linked to the time farmers first adopted a reduced tillage practice; farmers that first implemented those practices between 1960 and 1989 will implement them on 75-100% of total acres of cropland, farmers that first adopted those practices in the 1990s will use them on 50-74% of their total cropland and farmers that first used reduced tillage between 2000 and 2018 will implement them on less than 49% of total acres of cropland. Hence, the earliest adopters have a tendency to use reduced tillage practices on the largest proportion of cropland, while the latest adopters would use them on the smallest proportion. Although the type and number of reduced tillage practices implemented by the earliest adopters remains indeterminate, the analysis was able to determine that the later adopters were using a high number of reduced tillage practices on their cropland, such as direct planting, vertical tillage, shallow cultivation and using a roller crimper. Considering that the clustering analysis indicated limited information regarding the agricultural production approaches and reduced tillage practices used by the earliest adopters, a possible avenue of research could be to investigate this trend more in-depth. For example: what type of practices are the earliest adopters using? For which purpose? Do early adopters of reduced tillage practices have a tendency to have larger farms? Are the latest implementers of practices to reduced tillage facing some specific challenges and limitations to implement those practices on a larger proportion of cropland? Do the latest adopters of those practices have a more diversified farming and cropping system than the earliest adopters?

4.2 What type of reduced tillage practices are organic farmers using?

4.2.1 Shallow cultivation

From the results of the survey, shallow cultivation was the most widely used reduce tillage practice. Nonetheless, it is important to note that 51% of the respondents indicated that they were not using any reduce tillage practice at the time of the survey, but 77% of the sample reported using shallow cultivation. This mean that 26% the respondents do not consider shallow cultivation as a practice to reduce tillage. In this sense, it would be interesting for future research to understand how organic farmers are implementing shallow cultivation practices and what type of practices do organic producers consider as reduced tillage practice.

4.2.2 Roller crimper

The research indicated that 28% of our sample of farmers were using a roller crimper. As previously mentioned, roller crimping can be an effective method to terminate a cover crop without herbicides and create a surface mulch to suppress weeds. Although the findings were not able to link the usage of this machinery with specific challenges (such as having access to appropriate equipment or suitable weed control) we were able to find a positive correlation between using a roller crimper and the size of a farm (Table 5). According to Wozniak (1993), farm size could be a proxy for an individual's income, as larger producers have more collateral and easier access to credit with lower interest rates than smaller producers. In this regard, acquiring a roller crimper might be a more significant expenditure for smaller producers that are financially constrained, in comparison to larger producers that have greater financial means to afford this equipment. Additionally, it is possible that smaller producers do not consider a roller crimper to be the best investment for their farms, given the relatively limited use of this piece of equipment as compared to other purchases. A possible solution to this issue could be to put in place a cooperative for the use of agricultural equipment ("Coopérative d'utilisation de matériel agricole" or CUMA). In France, those types of agricultural cooperatives are quite popular amongst smaller producers, as they enable farmers to pool their resources in order to acquire agricultural equipment that would otherwise be too costly. Establishing a similar network of cooperatives in the United States could help alleviate the cost of using a roller crimper and facilitates its adoption amongst organic grain farmers.

4.3 What kind of organic producers are using reduced tillage practices?

4.3.1 Larger producers

This study indicated that managing a farm greater than 500 acres was correlated with a higher prioritization of reduced tillage (Table 1), greater use of lower tillage-intensity equipment (Table 2), higher number of reduced tillage practices implemented (Table 4), and greater use of thee roller crimper (Table 5). Previous studies also indicated a positive correlation between the size of a farm and the probability of adoption of soil conservation practices, agri-environmental schemes and agricultural technology (Wozniak 1993, Hounsome et al. 2006, Micheels and Nolan 2016; Fantappiè et al. 2020). Following Wozniak (1993) reasoning once more, in which the size of a farm would be a proxy for a farmer's income, his empirical study showed that wage income will impact the speed of adoption and the active means to obtain knowledge. At the same time, Fantappiè et al. (2020) found that smallholder farmers had a lower adoption rate of soil conservation practices, due to their financial vulnerability, poor economic resilience and need for technical assistance to make those practices more profitable. To better understand the relationship between the size of a farm and the implementation of reduced tillage practices, future research could investigate if a farmer's income is correlated to the size of a farm, and see if the income of a producer affects the agricultural practices that they will adopt.

4.3.2 Farmers with a post-secondary education

The finding of our study indicated that farmers with a post-secondary education had higher prioritization of reduced-tillage practices, used equipment characterizing lower tillage intensity, and adopted multiple reduced tillage practices in comparison to farmers with an 8th-grade education. The results showed that individuals with a higher level of education tended to consult a variety of sources of information to learn about reduced tillage practices, while individuals with a primary education would consult fewer sources or none. Those results aligned with Wozniak's (1993) empirical study, in which he suggested that more educated farmers would be better suited to assimilate first-hand information, find information on agricultural practices, and assess the value of information found in comparison to less educated producers. However, Fantappiè et al. (2020) and Rochecouste et al. (2015) found that the main motivation for farmers with a higher level of education to implementing conservation practices was the potential increase of profitability of the practices – not for the potential environmental and soil health benefits. Hence, it would be beneficial to understanding farmers' motivation to implement reduced tillage practices in future research and if they share the same concerns as researchers.

4.3.3 Farmers that seek information

The study showed that organic farmers who use multiple sources of information to learn about reduced tillage most relied upon informal networks. However, the clustering analysis also indicated that farmers who were using reduced tillage sought out information outside of an informal network. Hence, while the farmers responding to the survey shared advice and information with their neighbours, families and friends, these networks do not play a more significant role than formal knowledge channels, unlike what previous studies suggested. Research on conservation practices in conventional cropping systems indicated that farmers would be more willing to adopt or invest in conservation agriculture if they had seen other food producers using them and if their peers claimed that those practices were profitable (Prager and Posthumus 2011; Ramireza 2013; Beach et al. 2018; Šūmane et al. 2018). As trust amongst food producers plays an important role in adoption behaviour, farmers view their peers as a reliable source of information considering their years of experience, accumulated intimate knowledge of local resources, and their ability to select solutions that best fits their unique conditions (Šūmane et al. 2018).

It can be hypothesized that the significant role that the Rodale Institute, the non-profit research organization who designed a commonly-used roller crimper, and its subsequent partnerships with land-grant Universities regarding research on best practices, may have influenced farmers' confidence in the information being disseminated by more formal institutions. Additionally, with the numbers of organic farms remaining relatively low in certain areas of the United States, some farmers may be more likely to adopt reduced tillage practices after consulting sources outside of the informal network, as their local farming communities may not yet have adopted reduced tillage practices suitable for organic production (Gruber and Claupein 2009, Armengot 2015).

Furthermore, it is important to note that the clustering analysis and correlation tests only established a link between consulting sources of information and implementing reduced tillage practices – not a cause and effect relationship. As a result, this raises the question: do farmers use reduce tillage practices because they sought information on those practices or did they seek information because they wanted to reduce tillage?

4.4 Reliability of research

As previously mentioned, farmers were chosen through a public data base and sent a physical copy of the survey via mail. Considering that the individuals provided the information on a voluntary basis, our sample of farmers was not proportionate to the actual numbers of organic grain farmers in the state of Wisconsin, Pennsylvania and Iowa. According to the United States Department of Agriculture National Agricultural Statistics Service (2017a,b), Wisconsin had the most certified organic farmers (1 267 farms) in 2016 and represented 38% of the study's sample, while Iowa had the lowest number of certified organic farmers (732 farms) but represented 52% of the sample. Moreover, as the survey was only administered in those three states, conducting a similar study in other states located in different area (e.g. California, Washington and Nebraska) might produce different results. In this regard, the findings of this study are limited to its geographical location and might not reflect the situation for all 50 American states.

Furthermore, the category 'weed control' was not originally listed as one of the limiting factors to implement reduced tillage practices in the version of the survey sent to the respondent. As mentioned in the statistic description of the data, we created this new category after seeing that 80 individuals indicated in the box 'Other' that weed suppression was their biggest limiting factor. This means that it is possible that farmers experiencing weed suppression issues were underrepresented in our survey.

4.3.1 How could the survey be improved?

In this study, we tested independently four different set of hypotheses. As a result, individuals were portrayed in four different ways, based on their farm structure, agricultural practices, socio-demographic characteristics and challenges. In future research, it could be beneficial to (i) have all the explanatory and response variables in a single dataset and (ii) not have a fluctuating sample of individuals between categories. By doing so, we would be able to (i) create a single portray of the sample (ii) identify interactions between the different clusters and (iii) select individuals to conduct interviews in the future based on a single profile.

Moreover, the survey could be improved by having a more consistent format. Due to the fact that the survey contained both (i) open-ended and closed questions and (ii) numerical/continuous and categorical/nominal variables (binary or multi-levelled), we had to perform different analytical tests (PCA and MCA) as we were not able to put all the variables in a single dataset to perform the analysis. A possible solution would be to have a uniform questionnaire format, in which all questions would be close ended and would be formulated based on the type variable needed to perform an analysis. In other words, all the questions featured in the survey could be close ended and formulated to have either numerical/continuous answers or categorical/nominal.

4.4 Implication for future research

According to Wozniak (1993), to enhance the return on information and to better serve our organic producers, it is important that information providers reflects the attributes of the potential adopters. The author suggests that extension services or university personnel should target larger organic producers and farmers with a post-secondary education, as they would have a greater capacity of processing information independently, while company representatives should focus on providing partially processed technical information. Although I do not completely disagree with Wozniak's (1993) reasoning, it seems that by focusing on larger and more educated farmers, extension services or universities would be neglecting the needs and concerns of smaller producers with less education. For this reason, I argue that research organizations and institutions should adapt their strategies for diffusion of information to the needs and attributes of their target audience. In this sense, future research could utilize this typology of U.S organic grain farmers to find better ways of transmitting information regarding the feasibility of using reduced tillage practices in organic cropping system to a broader audience. For example, this study has indicated that organic producers with more limited adoption of reduced tillage practices tended to have an 8th-grade education and would not consult any sources of information to learn about those practices. As a result, extension services, company representatives and farmers' organizations should take the initiative to seek out those farmers to try to understand the reasons for the lack of adoption and to find ways to motivate them to implement those practices, such as creating a training program based on their specific concerns or with financial incentives.

Chapter Five: Conclusion

The study indicated that the earliest adopters of reduced tillage would use those practices on the largest proportion of cropland, while the latest adopters would use them on the smallest proportion. In addition, shallow cultivation was the most commonly used reduced tillage practice among organic farmers. Furthermore, the results suggested that larger organic producers, farmers with a post-secondary education and farmers that had consulted a variety of sources of information to learn about reduced tillage practices tended to use those practices. Future research could utilize this typology of U.S organic grain farmers in order to find better ways of promoting the feasibility of using reduced tillage practices in organic cropping system to a broader audience.

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Appendices

Appendix A: “2018 Organic Tillage & Soil Health Management Survey”

WISCONSIN
UNIVERSITY OF WISCONSIN–MADISON

2018 Organic Tillage & Soil Health Management Survey

1. Do you have any **Certified Organic land** on your farm? □ Yes □ No

   If no, you can stop here – we thank you for your time.

2. In what **county** and **state** is your farmland located? County: ____________________ State: ______

Demographic Information:

3. **How many people** are involved in the day-to-day decisions for this farm? # of decision-makers: ______
   - How many of these decision-makers are **women**? # of women: ______
   - If there is more than one decision-maker, what is the **relationship** between the decision-makers? *Please describe the relationships, e.g. spouse, child, business partner.* ________________________
     ____
     ____

4. What is your **age** and **gender**? Age: _____ Gender: _____

5. What is the highest **level of education** you have achieved?
   - □ Some high school
   - □ High school diploma/GED
   - □ Some college
   - □ 2-year college degree
   - □ 4-year college degree
   - □ Graduate degree

6. In what year did you **start farming** as the primary decision maker? Year: __________
   - In what year did you begin **managing this farm**? Year: __________
   - In what year did your farm first receive **organic certification**? Year: __________

Land Use:

7. **Total Acres operated** in 2018. *Please fill in the boxes below, which should add up to the total acres you operated in 2018.*

   Acres OWNED + Acres RENTED **FROM** others - Acres RENTED **TO** others = **TOTAL ACRES OPERATED**

   [ ] + [ ] - [ ] = [ ]

8. **Land use** in 2018. *Please fill in the boxes below, which should add up to the total acres you operated in 2018 (the same total as in Question #7).*

CROP acres	+	PASTURE acres	+	WOODLAND acres (not pastured)	+	OTHER uses	=	**TOTAL ACRES OPERATED**
	+		+		+		=	

9. **Organic Certification of CROPLAND** in 2018. *Please fill in the boxes below, which should add up to the total acres in CROPLAND (first box in Question #8).*

ORGANIC crop acres	+	Crop acres IN TRANSITION to certified organic	+	NON-ORGANIC crop acres	=	**TOTAL CROP ACRES**
	+		+		=	

10. Did you raise **livestock** on your farm in 2018? □ Yes □ No

If yes, what type(s) of livestock did you raise? ____

11. In 2018, what crops did you grow, and on how many acres?

Crops	**Acres**	**Crops (continued)**	**Acres (continued)**

Management of Cropland:

12. Do you apply manure on your farm? □ Yes □ No

If yes, what type(s) of manure do you apply? *Check all that apply.*

□ Poultry □ Cow □ Other: ____________________________

If yes, in what form do you apply the manure? *Check all that apply.*

□ Liquid □ Solid □ Other: ____________________________

If yes, please briefly describe how you apply manure: ____
____

If yes, how does manure application influence your tillage practices?

□ Manure application *increases* my need for tillage.
□ Manure application *decreases* my need for tillage.
□ Manure application *does not influence* my need for tillage.
□ Other *(please describe)*: ____

13. Please describe any other fertility inputs you use on your farm: ____________________________________
____
____
____

14. Do you plant cover crops on your farm? □ Yes □ No

If yes, please briefly describe your cover cropping practices (e.g. species, timing): _________________
____
____
____

If yes, how do cover crops influence your tillage practices?

□ Cover crops *increase* my need for tillage.
□ Cover crops *decrease* my need for tillage.
□ Cover crops *do not influence* my need for tillage.
□ Other *(please describe)*: ____

If yes, do you use tillage to incorporate cover crops into the soil? □ Yes □ No

15. Do you save cover crop seed on your farm? □ Yes □ No

16. Please describe the implements you used for tillage, planting, cultivation, and other field operations.

Tillage Implement(s)	**Planter(s)**	**Planter Attachment(s)**	**Cultivation Implement(s)**	**Other Implements**

17. Have you modified or fabricated any planting or tillage implements for use on your farm? □ Yes □ No

If yes, please briefly describe the modification(s)/fabrication(s): ________________________________
____
____

18. To what extent is reducing tillage a priority on your farm?

□ Not at all a priority □ Somewhat a priority □ A priority □ A very high priority

19. Which of the following reduced tillage/reduced cultivation practices do you use on your organic land? *See definitions in the attached informational sheet if you are unsure whether you have used the practice.*

	Used in 2018	**Used in the past (but not 2018)**	**Never Used**
Shallow cultivation	□	□	□
Vertical tillage	□	□	□
Roller crimping cover crops	□	□	□
Planting directly into a previously harvested crop	□	□	□
Intercropping (e.g. simultaneously growing soybeans and wheat)	□	□	□
Interseeding cover crops into a cash crop	□	□	□
Other (please describe):	□	□	□

20. In what year did you first implement practices to reduce tillage/cultivation on your farm? *Or, indicate that you have never used reduced tillage/cultivation practices.*

Year: ____________ □ I have never used reduced tillage/cultivation practices.

21. On how many acres of cropland did you implement reduced tillage/cultivation practices in 2018? *Or, indicate that you have never used reduced tillage/cultivation practices.*

# of Acres: ______ □ I have never used reduced tillage/cultivation practices.

22. Which factor(s) are the **most limiting** for your ability to reduce tillage/cultivation on your farm? *Please select **up to 3 factors** that are the most critical challenges.*

□ Ability to apply fertilizer
□ Ability to manage manure
□ Access to appropriate equipment
□ Availability of cover crop varieties adapted to my region/cropping system
□ Extra time required to manage with these practices
□ Need for knowledge/information of best practices
□ Other: ____

23. How challenging is it to find information on reduced tillage practices in organic production systems?

□ Not at all challenging □ Somewhat challenging □ Challenging □ Very challenging

24. Which of the following sources of information have you consulted to learn about practices to reduce tillage? *Check all that apply.*

□ Company representatives/resources
□ Extension/University personnel/resources
□ Farmer organizations
□ Informal network (e.g. neighbors, family, friends)
□ Other: ____

Thank you for participating in this survey! We value your knowledge, experience, and opinions. In the coming months, we will be conducting **in-depth interviews** about reduced tillage practices in organic production systems. If you are willing to tell us more about your experiences with reduced tillage, please leave your contact information (e.g. phone number/email address) below and we will arrange a follow-up interview with you.

Preferred Contact Information: ____
____
____

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