Implications of adopting soil health practices on the economic performance of Minnesota row crop operations

A Thesis
SUBMITTED TO THE FACULTY OF THE
UNIVERSITY OF MINNESOTA
BY

Katherine Wilts Johnson

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF
MASTER OF SCIENCE

Dr. Joleen Hadrich

February 2021

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1: INTRODUCTION

Agriculture is extremely dependent on the earth's resources. Due to this dependency, farmers work to replenish, preserve, and improve these resources. Within the past decade, environmental sustainability has grown to be an even larger concern (Hamilton et al., 2017). These apprehensions have driven a strong movement toward understanding strategies for agricultural production to coincide with beneficial practices for the environment. Such practices include reduced tillage, cover cropping, and various other techniques. The purpose is to improve water quality and reduce the overall agricultural carbon footprint while maintaining or increasing agricultural productivity.

Many sustainable agricultural practices are beneficial for both the environment and for farmers. However, the main barrier for farmers to implement these environmental practices is the economic cost associated with them (Plastina et al., 2018). For many of these strategies, the initial capital investment is high, with little to no economic benefit in the short-run, and unknown economic gains in the long-run. Despite that most farmers are proactive decision makers, with low economic margins in today's farm economy, many farmers are risk adverse and may opt away from unproven sustainable practices if they do not fit into the farm's budget. Reduced tillage practices are more adopted amongst agriculturalists than cover crops which are a more recent sustainable practice in focus for crop production.

This paper consists of a two-part analysis. First, farm-level financial data from 2009 to 2019 was analyzed to estimate the impacts of reduced tillage methods on

Minnesota row crop yields. Minnesota farm financial data was provided through a partnership between the Minnesota State Colleges, the University Farm Business Management program, Southwest Minnesota Farm Business Management Association, and the Center for Farm Financial Management. This dataset includes over 1,000 different crop farms each year, for the past 20+ years, and is available through an online resource, FINBIN (www.finbin.umn.edu). The FINBIN data was used in the first part of the analysis to determine how tillage methods (no-till, strip-till, chisel-till) impact cash crop yields.

In the second part of this paper, cover crop production and financial data was gathered through voluntary primary and secondary data collection efforts to analyze the economic impact of cover crops on Minnesota row crop farms that will not use livestock grazing as a cover crop termination strategy. Primary data was collected through one-on-one interviews with 28 Minnesota farmers from every region within the state. Secondary data collected by the Sustainable Agriculture Research and Education Program (SARE), the Conservation Technology and Information Center (CTIC), and the American Seed Trade Association (ASTA) included data from a nationwide survey with cover crop financial information from 91 Minnesota farms. The financial data from both of these surveys were used to generate an interactive spreadsheet tool that predicts single-year and multi-year economic impacts of cover crops on Minnesota farms.

Farmers are entrepreneurs. When a change is made on the farm, it is made with the assumption that it will decrease farm expenses or increase farm income, therefore increasing profit. If these changes do not generate profit over the long run the practice may not be implemented (Myers et al., 2019). Therefore, using reduced tillage or planting a cover crop on a farm are much more than an environmental responsibility for farmers. Rather, these decisions rely heavily on economic feasibility as well, and Minnesota's farmers lack economic data to help them make this decision. Understanding the economic risk and return of reduced tillage and cover crops on a farm before the new practice is implemented will allow farmers to make informed and confident decisions.

CHAPTER 2: ESTIMATING YIELD IMPACTS OF REDUCED TILLAGE METHODS ON MINNESOTA ROW CROP OPERATIONS

I. Introduction

Within the past decade, environmental sustainability has grown to be a large discussion topic amid the production agriculture industry (Hamilton et al., 2017). Crop inputs such as fertilizer, chemical, and fuel all cause for environmental concerns. Intensive tillage systems provoke environmental concerns as well due to their impact on increased soil and water erosion, and decreased soil organic matter. Current research shows the use of reduced tillage is a potential solution to combat soil erosion and water pollution concerns associated with production agriculture.

The 2017 Census of Agriculture showed just 6% of Minnesota’s cropland is devoted to no-till methods, up 1.4 percentage points from the no-till reporting in the 2012 Census of Agriculture (USDA and NASS, 2019; USDA and NASS 2014). Reduced tillage methods increased by 10.6 percentage points from 2012 to 2017 to be on 44% of Minnesota’s farmland. Conventional tillage was used on 51% of Minnesota’s farmland in 2017 which contrastingly decreased by 11.4 percentage points from 2012 (USDA and NASS, 2019; USDA and NASS 2014). There are two key tillage takeaways from this census analysis. First, the biggest change from 2012 to 2017 was the large number of acres transitioned from conventional tillage to reduced tillage. Second, the share of no-till acres increased only slightly over the five-year timespan, resulting in analysts questioning if the amount of Minnesota acres devoted to no-till are beginning to plateau (Zulauf and

Brown, 2019). Nonetheless, tillage method usages will continue to shift as research progresses regarding the different methods.

A large motivation for reduced tillage methods is increasing environmental sustainability; however, farm decisions are rarely made without considering both short-term and long-term economic effects. Analyzing the incorporation of reduced tillage on a farming operation as both an environmental and economic decision is crucial to the validity of this analysis. Farmers are business owners, and therefore it is assumed that they are profit maximizers. Business decisions that do not assist in one or both of these goals will likely not be implemented on the farm (Myers et al., 2019). Adoption rates of reduced tillage or no tillage methods will increase when the tillage analysis is considered for both its environmental and economic impacts on a farm.

II. Research Objectives

The objective of this research is to understand how cash crop yields are affected by reduced tillage systems on Minnesota crop farms using crop enterprise data collected through the Minnesota State Colleges and Universities Farm Business Management Association. A range of factors, including farm inputs, that influence crop yield were investigated to discover how tillage methods and other farm management decisions impact this relationship. An ordinary least squares (OLS) regression was used to capture the effects of reduced and conventional tillage methods and to observe varying production levels across each region and across the farms in the sample.

III. Literature Review

Tillage is the foundation of crop production; it prepares the soil for a seed to take root and grow. Suitable tillage breaks up soil compaction, kills weeds, warms and dries the soil, and incorporates fertilizer into the soil (DeJong-Hughes, 2019). However, at times tillage can overwork the soil and cause damage leading to soil erosion and water quality issues. As a result, varying tillage methods are used throughout Minnesota based on each farmers' needs. Chisel-tillage is the most common conventional tillage method on Minnesota farms, and common reduced tillage methods include strip-tillage and no-tillage. Chisel-tillage breaks up the soil at a depth generally between 6-12 inches and usually leaves no crop residue on the field when used following soybeans and leaves 30-60% of crop residue on the field when used after corn (Steinhardt, 2006). This tillage method is beneficial for incorporating fertilizers into the soil, and has seed emergence benefits, but exposes soil to wind and water erosion concerns due to the lack of crop residue cover. Contrastingly, the Conservation Technology Information Center defines conservation tillage as a tillage system that leaves 30% or more of the soil surface covered with crop residue. No-till and strip-till both fall into this category. No-till does not disturb the soil, realizing minimized wind and soil erosion. Strip-tillage disturbs only the row where the following crop will be planted which is generally 6-8 inches wide and six inches deep, leaving the undisturbed portion of the row covered with soil residue (Bertold and Sailus, 2020). This method aims to maximize the seedbed preparation benefits of chisel-tillage with the conservation benefits of no-tillage. Each tillage method has advantages and disadvantages. Maximizing tillage benefits while minimizing tillage harm has been an ongoing mystery to agriculturalists and academics for decades.

Reduced tillage is gaining popularity among soil health experts due to the negative environmental impacts of conventional tillage. One negative impact of conventional tillage is its reduction of crop residue left on the soil. Residue protects the soil from wind and water erosion and increases soil organic matter. A 2007 study by the University of Minnesota analyzed the percent of residue left in the field, comparing conventional and reduced tillage methods across 13 different Minnesota farms in 2004 and 2005 for corn following soybeans (DeJong-Hughes and Vetsch, 2007). Residue coverage percentages varied among the 13 farms, but overall they found coverage was between 55-65% for no-till acres, between 45-50% for strip-till acres, and just over 20% for chisel-till acres (DeJong-Hughes and Vetsch, 2007). With these comparisons, both no-till and strip-till are classified as conservation tillage methods because they meet the federal standard of 30% or more of soil residue left in the field. DeJong-Hughes and Vetsch (2007) used field-level data, but of the 26 total observations, all were located in the southern half of the state, therefore leaving out the varying results of this analysis that may have come from the northern regions of Minnesota.

In addition to the benefits for soil health, recent studies show crop residue also benefits crop yields by increasing moisture in the soil. The same University of Minnesota study compared corn yield on acres that used conventional tillage to those that used reduced tillage. Results showed the highest yields were produced on chisel-till and strip-till acres, with the lowest yields produced on no-till acres. This study proved strip-till could produce similar yields to conventional tillage methods, while still providing many of the soil health benefits of no-till methods. (DeJong-Hughes and Vetsch, 2007)

Research by the University of Nebraska also analyzed corn yield impacts of no-till systems, specifically studying the water content on soil that is covered in residue compared to bare soil. Results showed little difference in actual soil water content, but soil plots with residue coverage yielded 25 bushels per acre higher than the bare plots due to the additional moisture retained in the residue (Van Donk et al., 2010). This yield advantage suggests larger amounts of water are available to crops grown in residue-covered soils.

Water is necessary for plant growth, so capturing moisture in the field is beneficial for crop production. However, Minnesota farmers are reluctant to use reduced tillage methods due to concerns of excess moisture that arise with these tillage practices. One major concern is that crop residue could cause soils to be cool and wet in the spring which may result in delayed planting, late harvest dates, and increased grain moisture levels in the fall. The primary method for farmers to manage soil temperatures and regulate these concerns is through tillage and residue management (Cruse et al., 1980).

Since soil temperature has significant impacts on plant growth and other metabolic functions, it is understandable that farmers are apprehensive of reduced tillage methods. A study conducted by Purdue University (2000) compared soil temperature on no-till acres to soil temperature on plowed acres during spring planting season. This study monitored soil temperatures throughout the day during the month of April, capturing the daily minimum and maximum temperatures from each day. The analysis found both the minimum and maximum temperatures came from the plowed acres. No-tilled acres had less extreme temperatures that were within the range of the temperatures on the plowed acres. The no-till acres had more moisture than the plowed acres. Since dry conditions provide less cushion to temperature changes, the no-till acres fluctuate in temperature less than chisel-tilled acres (Vyn, 2000). Results from this analysis suggest reduced tillage practices benefit soil temperatures more than conventional tillage in cooler years, which contradicts many farmer beliefs.

In addition to excess soil moisture, another concern farmers have with reduced tillage methods is the perceived increase in compaction as a result of reduced tillage. In contrast to this perception, University of Nebraska reports the use of conventional tillage causes soil compaction. Heavy forms of tillage compress aggregates in the soil that are necessary for water and air movement throughout the soil (Wortmann and Jasa, 2009). A 2014 Michigan State report supports this theory, stating that soil compaction caused by tillage is an issue at both the soil surface and the subsurface levels. Conventional tillage removes crop residue from the soil surface, so the uncovered soil particles are pounded together when it rains, creating a crust on the soil surface and increasing potential for water erosion. Even more concerning for crop production is the subsoil compaction, referred to as a plow pan, or compaction below the tillage level that results from heavy tillage equipment putting pressure on the subsoil. (Curell, 2014)

Despite the research results on the negative effects of conventional tillage on soil health and the positive effects of reduced tillage methods on cash crop yields, farmers remain leery to switch from conventional tillage to reduced tillage or no tillage. A likely contributor to this dissonance between farmers and researchers is the lack of farm-level data from actual farms rather than experimental plots or research sites. While each of the studies in this review address issues and benefits on cash crop yields and input costs of both reduced and conventional tillage systems, limited data exists that uses enterprise-level data. This research aims to analyze the economic implications of reduced and conventional tillage methods based on tillage yield impacts, using actual Minnesota farm data to address the gaps in current literature.

IV. Theoretical Model

The methodology in this paper consists of two parts. The theoretical model uses economic assumptions to define farm profit maximization both on the whole-farm and crop enterprise level. However, these economic assumptions do not fully capture the decision-making process on the farm, so the empirical model introduces other factors that impact profit maximization.

PROFIT MAXIMIZATION: WHOLE FARM

Following economic theory, it is assumed that farmers are profit maximizers. Using duality we also assume farmers are cost minimizers. In general, farm profit results from subtracting the total costs, which include total direct and indirect expenses, from total revenue. Direct costs are those that can be traced to a specific enterprise, while indirect costs include costs that apply to many enterprises, many production seasons, or are not traceable to a specific enterprise (Hofstrand, 2009).

Farmers rarely produce a single commodity, but rather a combination of commodities. They may have negative profits in one commodity but compensate by having positive profits in other commodities within their farming operation. Ideally, every commodity would make positive profits each year, but this is not the case. Thus, farms maximize whole-farm profitability through risk minimization, such that:

(1) $\pi_w = (TR_{i,t} - TC_{i,t})_{k1} + (TR_{i,t} - TC_{i,t})_{k2} + \cdots \ldots \ldots \ldots + (TR_{i,t} - TC_{i,t})_{ki}$

where whole-farm profit (π_w) is a compilation of individual profit equations for each crop produced on the farm at the enterprise level, as $(TR_{i,t} - TC_{i,t})_{k1}$ is the profit of Enterprise 1, $(TR_{i,t} - TC_{i,t})_{k2}$ is the profit of Enterprise 2, continued until the *i*th enterprise. The profits of each enterprise are calculated by subtracting the total costs (*TC)* from the total revenue (*TR*). Total revenue is calculated by multiplying yield by the price received per unit, and total costs are calculated by adding direct and indirect costs. A comparison of all revenue streams, including grain production, crop insurance, government payments, and conservation program participation, are necessary to analyze total farm revenue. Additionally, knowledge of the price received per unit and marketing strategies are required to determine total revenue.

PROFIT MAXIMIZATION: SINGLE COMMODITY

Farms focus on maximizing whole-farm profits, but they also maximize single-commodity profits. Albouy (2005) calculates a single-year, single-commodity profit equation for a farm as:

(2) $\pi = pq - r_N N - r_K K - r_F F$

where π is profit, *p* is price, q is yield, *N* is inputs, r_N is the rate paid for the inputs, *K* is capital, r_K is the rate paid for capital, *F* is fixed costs and $r_F$is the rate paid for fixed costs (Albouy, 2005). Overall, profit is equal to the yield multiplied by the price, less the input costs, the cost of capital, and fixed costs. Farms maximize their profits by choosing q, *N*, *K*, and *F*, considering the following constraints:

(3) $\max_{q,N,K,FC} pq - r_N N - r_K K - r_F F \quad s.t.\ f(N, K, F) \geq q$

where f is the production function of q. Maximizing profits using these production constraints results in the following profit maximization equation:

$$(4)\ \pi(p, r_N, r_K, r_F) = pq^s(p, r_N, r_K, r_F) - r_N N^D(p, r_N, r_K, r_F) - r_K K^D(p, r_N, r_K, r_F) - r_F F^D(p, r_N, r_K, r_F)$$

where, given the constraints, $q^s(p, r_N, r_K, r_F)$ is yield, $N^D(p, r_N, r_K, r_F)$ is the demanded input, $K^D(p, r_N, r_K, r_F)$ is the capital demanded, and $F^D(p, r_N, r_K, r_F)$ is the demanded fixed cost for a for single-year, single-commodity analysis.

Farmers maximize profits by maximizing crop yields and minimizing crop input costs. Farmers choose inputs that will maximize their total revenue, but they only have control over certain inputs. Yield is an input that can be managed, and it is one of the main drivers behind revenue, which causes it to be chosen as the decision variable to maximize profit. Since there are many factors that impact overall farm profitability yet crop yields are the main driver of farm revenue, yield was selected as the dependent variable of study in this analysis.

V. Empirical Model

Building upon the theoretical model, this analysis used farm-level financial input data in a series of regressions to estimate crop yield, which is a component of revenue in the profit function (Equation 1). This was done by assessing which management decisions and expense categories have a significant impact on crop yield. Many variables exist that are hypothesized to impact yield, but in general these variables fall into five categories: location, farm size, input costs, crop rotation, and weather impacts (measured by a proxy variable). The variables are each discussed below. Each crop analysis separated farm observations by their tillage type, sorting the no-till observations from the strip-till observations, from the chisel-till observations.

Yield is the unknown dependent variable that will be predicted using the known independent variables of geographic location, number of acres planted to the enterprise crop, input costs, the previous crop planted, and the year, as shown in Equation 5:

$$(5)\quad Yield_{i,k} = \beta_0 + \beta_1 Location_{i,k} + \beta_2 Acres_{i,k} + \beta_3 Inputs_{i,k} + \beta_4 Previous\ Crop_{i,k} + \beta_5 Year_{i,k} + \varepsilon_{i,k}$$

where $Yield_{i,k}$ is the yield per acre received for the *i*th observation of the *k*th crop. The *k*th crop includes corn, soybeans, and spring wheat. $Location_{i,k}$ includes six Minnesota regions representing the differences faced by farms based on location such as soil types, crops grown, weather patterns, and various other differences; $Acres_{i,k}$ is the total number of acres planted for crop *k*; $Inputs_{i,k}$ are the monetary dollar amounts of direct inputs for the crop such as seed, fertilizer, chemical, fuel, and machinery costs; $\beta_4 Previous\ Crop_{i,k}$ captures any impact made from the crop that was grown on the field in the prior year; $Year_{i,k}$ is included as a binary variable for the year the yield data was reported to serve as a proxy to measure the impacts of the growing conditions that particular year, and $\varepsilon_{i,k}$ is the error term.

VI. Data

Minnesota farm financial data was provided through a partnership between the Minnesota State Colleges and University Farm Business Management program, Southwest Minnesota Farm Business Management Association, and the Center for Farm Financial Management. This dataset includes over 4,000 unique Minnesota crop farms since 1994 and is available at an aggregate level through an online resource, FINBIN. FINBIN is a farm financial database that provides financial benchmarks to farm producers, educators, and lenders. The database has national representation, with information from producers in thirteen states within the United States.

Every year, farmers who participate in the Minnesota Farm Business Management (FBM) program contribute data to FINBIN. This financial data includes direct and overhead expenses, yields and returns, and various other financial factors such as crop insurance indemnities and government payments. Farmers also provide information about their farming operations which may include their crop rotations, the presence of livestock on their farm, indications of their fertilizer practices, and their farm’s tillage system. All data is captured and summarized through annual averages which are publicly available through FINBIN (www.finbin.umn.edu). For the purpose of this research, access was granted to use individual farm data, rather than using the summary data that FINBIN provides publicly, which allowed for a deeper analysis of the necessary variables in this study.

Data was collected at a crop enterprise level from FINBIN from 2009-2019. This resulted in 85,984 total corn, soybean, and spring wheat observations across 8,176 Minnesota farms. This analysis uses enterprise-level data for corn, soybeans, and wheat to estimate the impact of farm and field-level characteristics on crop yield. The enterprise data is divided between farm-level characteristics, crop expenses, and crop production characteristics.

FARM CHARACTERISTICS

Farm characteristics are explanatory variables that remain the same regardless of the crop grown on the farm. Farm characteristics include the geographic location of the farm and year. Both of these explanatory variables are included in each individual crop-level regression and are defined below.

Geographic Location

Previous studies indicate biological differences, like soil type and climate, play a role in crop yields, rotations, and crop diversity (Dobermann et al., 2003). To account for these biological differences, a regional indicator was generated for each farm based in the county the farm operates in. Using the same regions as FINBIN, Minnesota was divided into six regions: northwest, northeast, central, southwest, south central, and southeast. The regions align with the Farm Service Agency (FSA) regions assigned by the state of Minnesota. Additionally, they correlate with the Farm Business Management colleges throughout the state. Table 1 includes details on the counties included in each region with a visual representation available in Figure 1in the appendix.

Year

The production year was included as a binary variable in this analysis to serve as a proxy to capture crop yield variation over time. The analysis consisted of the timespan between 2009 and 2019, so the binary variables in this study included 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018, and 2019.

CROP CHARACTERISTICS

Crop characteristics vary based on the type of crop grown on the farm. Crop characteristics include the number of acres planted of each crop, the tillage system implemented, and crop rotations. These explanatory variables are included in each individual crop-level regression and are defined below.

Cash Crop

Minnesota's terrain is diverse and provides premier growing conditions for a multitude of crops, depending on the region within the state. According to USDA National Agriculture Statistics Service (NASS, 2019), of Minnesota's 25.5 million farmland acres in 2019, 33% are planted to corn annually, 29% are planted to soybeans, and 6% are planted to spring wheat. The remaining acres are allocated to hay, haylage, alfalfa, potatoes, sweet corn, sunflowers, peas, and various other small grain production. These acreage allocations encouraged the four main cash crops to be included in this analysis: (1) corn, (2) soybeans, and (3) wheat.

Tillage

The three most common tillage methods in Minnesota are chisel-tillage, strip-tillage, and no-tillage, so this analysis considers the differences between farms that use each tillage type to capture the impact of different soil health practices on cash crop yields.

From 2009-2019, there were 3,670 corn farms, with 43,161 unique observations. A unique observation consists of an individual field, where one farm may have multiple field observations or include all of the field observations into one enterprise level entry. Of those, 524 observations reported no-tillage, 779 observations reported strip-tillage, and 24,242 reported chisel-tillage. The remaining corn observations (17,616) either reported the use of ridge-till, moldboard plow, or did not report a tillage method. Most of the no-till farms were located in the southwest (31% of the corn no-till observations) and southeast (22% of the corn no-till observations) regions, with very few no-till farms in the central (6% of the corn no-till observations) and northeast (7% of the corn no-till observations) regions. There were 3,366 total soybean farms that reported 1,150 unique no-till observations, 516 unique strip till observations, and 21,589 unique chisel-till observations with 38,280 total observations. The 945 spring wheat farms reported 3,505 total unique observations, with 57 observations that reported no tillage, no observations that reported strip tillage, and 1,920 observations that reported chisel tillage.

Acres Grown

Economies of scale is characterized by the efficiency increases that result from production increases. A hypothesis could be drawn that as the number of acres planted to corn on a farm increases, that farm becomes more efficient at growing corn. For this reason, the number of acres each farm allocates toward producing each specific crop was added to this analysis. The chisel-till farms in this dataset are larger on average than the no-till farms.

The average no-till corn observation reported 128 corn acres grown; the average strip-till corn farm reported 124 corn acres grown; and the average chisel-till corn farm reported 172 corn acres. For soybeans the average among no-till observations was 145 acres; among strip till was 117 acres; and among chisel-till observations was 175 acres. For spring wheat, an average of 295 acres were reported by the no-till observations and 248 acres were reported by the chisel-till observations.

These acreage reports represent the accuracy of our hypothesis for corn, and soybean operations. Chisel-till corn observations on average report 45 more acres per farm than no-till corn observations and 47 more acres per farm than strip-till observations. Chisel-till soybean observations on average report 30 more acres than no-till soybean observations and 58 more acres than strip-till soybean observations. Conversely, chisel-till spring wheat observations reported approximately 47 less acres than no-till spring wheat observations. A t-test was used to validate that the no-till observations and the chisel-tillage observations were significantly different from one another. The results of this test showed these observations were significantly different, so conclusions may be drawn about the differences between these groups within our analysis.

Crop Rotations by Previous Crop

Plants add and take nutrients from the soil. Each plant has specific nutritional needs and extracts their needs from the soil. Likewise, each plant is susceptible to certain pests and diseases. Crop rotations break up the cycle of diseases and pests that live in the soil, and add greater biomass to the soil, and provide potential yield benefits (Higgs et al., 1990). An explanatory variable capturing the previous crop grown was included in this analysis to determine each commodity's yield impacts. Previous crops that were accounted for include corn, soybeans, wheat, and other small grains. The most common crop rotations in Minnesota include corn and soybeans, covering approximately 73% of Minnesota's cropland (Mold and Rhees, 2020). Northern Minnesota farms tend to grow less corn, typically having soybean/wheat rotations or canola/soybean rotations (Ehlke 2018).

Of the 524 corn no-till observations, 41% reported a previous crop of soybeans before corn (Table 3). Another 18% reported corn as the previous crop, and 2% had a previous crop of sugar beets, wheat, hay, alfalfa, or other small grains. The remaining 38% of the respondents did not indicate their previous crop, therefore we have categorized them as blank. Of the 24,243 corn chisel-till observations, 50% reported having soybeans as the previous crop, while 18% reported corn as the previous crop, and 30% either had an unreported previous crop or planted to another crop or small grain. Of the 779 strip-till corn observations, 57% reported having soybeans as the previous crop, and 19% reported corn as the previous crop. The remaining 24% either did not report a previous crop or were planted to small grains prior, as shown in Table 3.

In the soybean enterprise analysis, 63% of the 1,150 no-till observations reported a previous crop of corn (Table 4). Another 8% reported soybeans as the previous crop, and the remaining 40% either had an unreported previous crop had a previous crop of other small grains. As shown in Table 4, approximately 56% of the 21,590 soybean chisel-till observations reported having corn as the previous crop, with 10% that reported soybeans as the previous crop, and 34% either had an unreported previous crop or planted to another small grain. Additionally, the soybean strip-till observations reported 53% were previously planted to corn, 18% were previously planted to soybeans, and the remainder were planted to a small grain or did not report a previous crop.

Forty-four percent of the no-till observations for the spring wheat enterprise analysis reported a previous crop of soybeans (Table 5). Another 10% of observations reported corn as the previous crop, and the remaining observations had an unreported previous crop. Of the 3,384 spring wheat chisel-till observations, approximately 49% reported soybeans as the previous crop, 7% reported spring wheat, and 4% reported corn as the previous crop. The remaining farms either had an unreported previous crop or planted to another small grain.

Irrigation

The use of irrigation adds water into the crop production process and can greatly enhance crop yields. It gives the farmer additional management control by specifying both the amount of water and when the water is applied to enhance the growth cycle of the plant. Irrigation was used as a binary variable to differentiate the yield differences between those farms that use irrigators and those that do not. Irrigation is most common in areas with light, sandy soils because the sandy soil does not hold moisture as well as silt or clay. Thus, irrigation was analyzed by region to determine how irrigation impacts yield differently throughout Minnesota's six geographic locations.

Only 3% of the corn no-till observations reported the use of an irrigation system and of that reporting, most observations were in the northeast region. Similarly, 2% of the corn chisel-till observations reported irrigation, with most observations in the central region. Only 2% of no-till soybean enterprises reported using irrigation with most coming from the northeast region, and only 1% of chisel-till observations report irrigation with most from the central region. There were no spring wheat no-till observations that used irrigation, and less than 0.5% chisel-till observations reported irrigation. Due to the small number of respondents that reported the use of irrigation across all crops and all regions, irrigation was not included in this analysis.

DIRECT CROP EXPENSES

Direct expenses or operating expenses are defined as an expense incurred to produce a crop. Operating expenses in this analysis include seed, fertilizer, chemical, fuel, and machinery costs. For the purpose of this analysis, each of these expenses were calculated on the per-acre level. Expenses were recorded in FINBIN based on the year they were incurred. Accounting for the time value of money, each expense in the data was inflated for this analysis to equal its value in 2019, using inflation rates from the Consumer Price Index. A summary of these inflation rates is included in Table A1 of the appendix. Direct expense explanatory variables are included in each individual crop-level regression and are defined below.

Seed Expense

Seed is one of the largest operating expenses incurred on a farming operation. We hypothesize premium seeds have a higher cost and a greater yield, while generic seeds cost and yield less. Or, as seed costs increase yield will also increase, as seen in a 2018 study done by Agricultural Economic Insight (Widmar, 2018). Widmar (2018) showed that the change in corn and soybean seed expenses have accounted for approximately 75% of corn yield increases and 61% of soybean yield increases respectively between 2000 and 2017 (Widmar, 2018). Table 3 shows the average seed cost was $109/acre for no-till corn observations, was $117/acre for strip-till corn observations, and was $118/acre for chisel-till corn observations. Soybean seed cost was $61/acre for both no-till and chisel-till observations and $57/acre for strip till observations, as seen in Table 4. For wheat observations, Table 5 shows no-till had an average of $20/acre and chisel-till averaged $23/acre in seed expense.

Fertilizer Expense

The average fertilizer cost for no-till corn observations was $150/acre, for strip-till corn observations was $143/acre, and for chisel-till corn observations was $146/acre. Soybean fertilizer cost was $41/acre for no-till, $38/acre for strip-till, and $39/acre for chisel-till observations. For spring wheat observations, no-till had an average of $78/acre and chisel-till averaged $87/acre in fertilizer expense.

Chemical Expense

Chemical expenses include herbicide, fungicide, and insecticide expenses. The average chemical expense was $36/acre for no-till corn observations, was $35/acre for strip-till corn observations, and was $34/acre for chisel-till corn observations. Soybean chemical cost was $41/acre for no-till, $43/acre for strip-till, and $38/acre for chisel-till observations. For spring wheat observations, no-till had an average of $27/acre and chisel-till averaged $29/acre in chemical expense.

Fuel Expense

Popular press sources report a large fuel expense savings when comparing no-till to chisel-till due to decreased field passes and lower horsepower needed to pull equipment on fields that are no-tilled (Gullickson, 2017; Helsel, 2007). According to the FINBIN dataset, the average fuel cost was $24/acre for no-till corn observations, was $27/acre for strip-till corn observations, and was $31/acre for chisel-till corn observations. Soybean fuel cost was $16/acre for no-till, $20/acre for strip-till, and $19/acre for chisel-till observations. For spring wheat observations, no-till had an average of $16/acre and chisel-till averaged $17/acre in fuel expense.

Table 1. Minnesota counties distributed across six regions following FSA and FINBIN guidelines

Northwest Region	**Northeast Region**	**Central Region**	**Southwest Region**	**South Central Region**	**Southeast Region**
Becker	Aitkin	Big stone	Cottonwood	Blue Earth	Dakota
Beltrami	Anoka	Chippewa	Jackson	Brown	Dodge
Clay	Benton	Douglas	Lincoln	Carver	Fillmore
Clearwater	Carlton	Grant	Lyon	Faribault	Goodhue
Kittson County	Cass	Hennepin	Martin	Freeborn	Houston
Lake of the Woods	Chisago	Kandiyohi	Murray	Le Sueur	Mower
Mahnomen	Cook	Lac Qui Parle	Nobles	Nicollet	Olmsted
Marshall	Crow Wing	McLeod	Pipestone	Rice	Wabasha
Norman	Hubbard	Meeker	Redwood	Scott	Winona
Ottertail	Isanti	Pope	Rock	Sibley	
Pennington	Itasca	Renville	Yellow Medicine	Steele	
Polk	Kanabec	Stearns		Waseca	
Red Lake	Koochiching	Stevens		Watonwan	
Roseau	Lake	Swift			
Wilkin	Mille Lacs	Traverse			
	Morrison	Wright			
	Pine				
	Ramsey				
	Sherburne				
	St. Louis				
	Todd				
	Wadena				
	Washington				

*Regions were defined using Farm Service Agency (FSA) regions and the corresponding regions used by the farm business program within the Minnesota State Colleges and Universities system.

YIELD REGRESSIONS

Three crops (corn, soybeans, spring wheat) were used to estimate three regressions (no-till, strip-till, chisel-till) for each crop type: corn no-till, corn strip-till, corn chisel-till, soybean no-till, soybean strip-till, soybean chisel-till, spring wheat no-till, and spring wheat chisel-till. A regression for spring wheat strip-till was not included due to the small sample size of spring wheat responses that reported the use of strip-tillage.

Yield regressions for the *k*th crop and the *j*th tillage method (j =1 if the tillage method is no-till, j =2 if the tillage method is strip-till, j =3 if the tillage method is chisel-till) are such that:

$$(6)\ Yield_{k_i,j} = \beta_0 + \beta_1 NWregion_{k_i,j} + \beta_2 NEregion_{k_i,j} + \beta_3 CEregion_{k_i,j} + \beta_4 SCregion_{k_i,j} + \beta_5 SEregion_{k_i,j} + \beta_6 Acres_{k_i,j} + \beta_7 Seed_{k_i,j} + \beta_8 Fertilizer_{k_i,j} + \beta_9 Chemical_{k_i,j} + \beta_{10} Fuel_{k_i,j} + \beta_{11} precropCorn_{k_i,j} + \beta_{12} precropSoybean_{k_i,j} + \beta_{13} precropSprWheat_{k_i,j} + \beta_{15} 2009_{k_i,j} + \beta_{16} 2010_{k_i,j} + \beta_{17} 2011_{k_i,j} + \beta_{18} 2012_{k_i,j} + \beta_{19} 2013_{k_i,j} + \beta_{20} 2014_{k_i,j} + \beta_{21} 2015_{k_i,j} + \beta_{22} 2016_{k_i,j} + \beta_{23} 2017_{k_i,j} + \beta_{24} 2018_{k_i,j} + \varepsilon_{k_i,j}$$

where $Yield_{k_i,j}$ is the yield per acre received for the *k*th crop of the *i*th observation that used *j*th tillage, $NWregion_{k_i,j}$ is a dummy variable for a farm in the northwest region of Minnesota (=1 if the *i*th observation is located in the northwest region and uses *j*th tillage, =0 otherwise), $NEregion_{k_i,j}$ is a dummy variable for a farm in the northeast region of Minnesota (=1 if the *i*th observation is located in the northeast region and uses *j*th tillage , =0 otherwise), $CEregion_{k_i,j}$ is a dummy variable for a farm in the central region of Minnesota (=1 if the *i*th observation is located in the central region and uses *j*th tillage ,

=0 otherwise), $SCregion_{k_i,j}$ is a dummy variable for a chisel-till farm in the south central region of Minnesota (=1 if the *i*th observation is located in the south central region and uses *j*th tillage , =0 otherwise), $SEregion_{k_i,j}$ is a dummy variable for a chisel-till farm in the southeast region of Minnesota (=1 if the *i*th observation is located in the southeast region and uses *j*th tillage , =0 otherwise). $Acres_{k_i,j}$ is the total number of acres planted to the commodity of study for each specific observation that uses *j*th tillage , $Seed_{k_i,j}$ is the per acre cost of seed for the *i*th observation that uses *j*th tillage, $Fertilizer_{k_i,j}$ is the per acre cost of fertilizer for the *i*th observation that uses *j*th tillage, $Chemical_{k_i,j}$ is the per acre cost of chemical for the *i*th observation that uses *j*ih tillage, $Fuel_{k_i,j}$ is the per acre cost of fuel for the *i*th observation that uses *j*th tillage, $precropCorn_{k_i,j}$ is a dummy variable for corn as the previous crop grown on the field (=1 if the *i*th observation grew corn the year before and uses *j*ih tillage, =0 otherwise), $precropSoybean_{k_i,j}$ is a dummy variable for soybeans as the previous crop grown on the field (=1 if the *i*th observation use *j*ith tillage and grew soybeans the year before, =0 otherwise), $precropSprW_{k_i,j}$ is a dummy variable for spring wheat as the previous crop grown on the field (=1 if the *i*th observation uses *j*th tillage and grew spring wheat the year before, =0 otherwise), $2009_{k_i,j}$ is a dummy variable for year (=1 if the *i*th observation uses *j*th tillage and was in 2009, =0 otherwise), $2010_{k_i,j}$ is a dummy variable for year (=1 if the *i*th observation uses *j*th tillage and was in 2010, =0 otherwise), $2011_{k_i,j}$ is a dummy variable for year (=1 if the *i*th observation uses *j*th tillage and was in 2011, =0 otherwise), $2012_{k_i,j}$ is a dummy variable for year (=1 if the *i*th observation uses *j*th tillage and was in 2012, =0 otherwise), $2013_{k_i,j}$ is a dummy variable for year (=1 if the *i*th observation uses *j*th tillage and was in

2013, =0 otherwise), $2014_{k_i,j}$ is a dummy variable for year (=1 if the *i*th observation uses *j*th tillage and was in 2014, =0 otherwise), $2015_{k_i,j}$ is a dummy variable for year (=1 if the *i*th observation uses *j*th tillage and was in 2015, =0 otherwise), $2016_{k_i,j}$ is a dummy variable for year (=1 if the *i*th observation uses *j*th tillage and was in 2016, =0 otherwise), $2017_{k_i,j}$ is a dummy variable for year (=1 if the *i*th observation uses *j*th tillage and was in 2017, =0 otherwise), $2018_{k_i,j}$ is a dummy variable for year (=1 if the *i*th observation uses *j*th tillage and was in 2018, =0 otherwise), and $\varepsilon_{k_i,j}$ is the error term.

VII. Results

ANALYSIS OF YIELD SUMMARY STATISTICS

The dataset consists of 85,984 observations across 8,182 farms and three cash crops, from 2009 to 2019. Table 2 summarizes the number of observations for each region by tillage type. Table 3 shows the summary statistics for all variables included in the corn enterprise analysis, Table 4 reports soybeans results, and Table 5 presents spring wheat results. There were a similar number of observations across years within each commodity.

There were 43,161 total corn enterprise observations, made up of 524 corn no-till, 779 strip-till, and 24,242 chisel-till observations, and the remaining responses used a moldboard plow, ridge tillage, or did not report a tillage type. Approximately 30.7% of the no-till respondents are in the southwest region, 37.0% of the strip-till respondents are in the southwest region, and 30.4% of the chisel-till respondents are in the southwest region, as shown in Table 3. This region will be the base case scenario for our analysis since it has the largest number of observations reported across all regions in Minnesota.

Closely following, the region with the second largest number of chisel-till observations (29.8% of the corn chisel-till sample) and strip-till observations (29.7% of the corn strip-till sample) is the south central region while the region with the second greatest number of no-till observations (22.1% of the corn no-till sample) is the southeast region. The central region reports the lowest number of corn no-till observations (6.3% of the corn no-till sample), while the northeast region has the fewest corn strip-till observations (1.5%). The northeast region has 4% of the total chisel-till observations, which is the lowest observation level but not abnormal based on the soil types of these regions (Anderson et al., 1999).

A similar pattern follows for soybeans (Table 4). There were 38,280 total soybean observations, consisting of 1,150 no-till, 516 strip-till, and 21,590 chisel-till observations, with the remainder of observations recorded as ridge till, moldboard plow, or no tillage method was reported. The region with the largest number of observations for soybean no-till and chisel-till observations was the southwest region with 37.7% of soybean no-till observations and 30.5% of chisel-till observations reported. The south central region reported the largest number of strip-till observations (39.9%). No-till on soybean acreage was used less frequently in the northwest (8.1% of soybean no-till observations), northeast (8.3% of soybean no-till observations) and central (6.9% of soybean no-till observations) regions. Only 3.0% of the soybean chisel-till observations and 1.0% of soybean strip-till observations came from the northeast region. This is expected since the northeast region has a less productive soil composition and high erosion potential, so this region focuses more on spring wheat, hay, other small grains, and cattle (Anderson et al., 1999; NASS and MDA, 2008).

Contrastingly, over half the observations in the spring wheat analysis are in the northwest region (Table 5). Overall, there are 6,203 total spring wheat observations, consisting of 74 no-till observations, 3,384 chisel-till observations, zero strip-till observations, and the remaining observations reported using a moldboard plow or did not report a tillage type. The northwest region has the majority of the spring wheat acres, with 64.9% of the spring wheat no-till observations in the northwest region and 78.9% of spring wheat chisel-till observations in the northwest region. Due to the soil types, colder weather patterns, and shorter growing season of northern Minnesota compared to other parts of the state, spring wheat grows better than other cash crops, such as corn and soybeans. The fewest spring wheat observations are from the southern regions, with no spring wheat no-till observations coming from the southeast region (Table 5).

Tillage also had a large impact on crop input costs. In the corn enterprise, the highest input cost is fertilizer, with $150/acre on no-till acreage, $143/acre for strip-till acreage, and $146/acre on chisel-till acreage. On average, corn no-till observations reported $3/acre more on fertilizer, $2/acre more on chemical, but spent $9/acre less on seed and $7/acre less on fuel than corn chisel-till farms.

The soybean enterprise analysis shows the highest expense category is seed across all tillage types, with $61/acre for both no-till and chisel-till observations and $57/acre for strip-till observations. Soybean no-till acreage average $2/acre more than soybean chisel-till observations for fertilizer expenses and $3/acre more for chemical costs, but chisel-till reports $4/acre higher fuel costs. Strip-till soybean observations report the lowest seed and fertilizer costs per acre and the highest chemical and fuel costs per acre.

In the spring wheat enterprise analysis, the most expensive input is fertilizer, with an average of $86/acre reported for no-till acres and $94/acre reported for chisel-till acres. Spring wheat no-till observations report an average of $3/acre lower seed costs, $8/acre lower fertilizer costs, $2/acre lower chemical costs, and $1.50/acre lower fuel costs than spring wheat chisel-till observations.

Table 2. Number of observations by tillage type, crop type, and region, 2009-2019

Variable	Corn Observations	Soybean Observations	Spring Wheat Observations
Northwest Region	2,903	5,972	4,384
Northwest Region No-till	37	93	48
Northwest Region Strip-till	14	7	0
Northwest Region Chisel-till	1,790	3,655	2,670
Northeast Region	2,869	1,576	190
Northeast Region No-till	104	95	9
Northeast Region Strip-till	12	5	0
Northeast Region Chisel-till	972	658	62
Central Region	8,599	6,652	1,079
Central Region No-till	33	79	9
Central Region Strip-till	158	129	1
Central Region Chisel-till	3,883	2,931	407
Southwest Region	10,632	9,775	193
Southwest Region No-till	161	433	7
Southwest Region Strip-till	288	130	0
Southwest Region Chisel-till	7,363	6,595	83
South Central region	12,527	10,323	305
South Central Region No-till	73	172	1
South Central Region Strip-till	231	206	1
South Central Region Chisel-till	7,213	5,804	141
Southeast Region	5,631	3,982	52
Southeast Region No-till	116	278	0
Southeast Region Strip-till	76	39	0
Southeast Region Chisel-till	3,022	1,947	21

Source: FINBIN, University of Minnesota (2009-2019).

Table 3. Minnesota Corn Summary Statistics, 2009-2019

	No Tillage			Strip Tillage			Chisel Tillage		
Variable	**Obs**	**Mean**	**Std. Dev.**	**Obs**	**Mean**	**Std. Dev.**	**Obs**	**Mean**	**Std. Dev.**
Corn Yield, Bu/Acre	524	162.970	38.755	779	180.829	26.912	24,242	178.477	34.160
Corn Acres	524	127.717	147.433	779	123.731	140.211	24,243	171.573	267.284
Expenses									
Seed Expense, $/Acre	524	109.068	26.709	779	116.835	22.700	24,241	117.678	26.078
Fertilizer Expense, $/Acre	520	149.783	63.237	779	142.518	51.916	24,033	146.429	62.094
Chemical Expense, $/Acre	523	35.883	18.358	779	34.686	13.857	24,192	34.016	16.165
Fuel Expense, $/Acre	517	24.334	13.271	772	26.967	14.374	23,974	31.085	15.087
Region		Proportion			Proportion			Proportion	
Northwest Region	524	0.071		779	0.018		24,243	0.074	
Northeast Region	524	0.198		779	0.015		24,243	0.040	
Central Region	524	0.063		779	0.203		24,243	0.160	
South Central Region	524	0.139		779	0.297		24,243	0.298	
Southeast Region	524	0.221		779	0.098		24,243	0.125	
Southwest Region	524	0.307		779	0.370		24,243	0.304	
Previous Crop		Proportion			Proportion			Proportion	
Previous Crop Corn	524	0.179		779	0.187		24,243	0.181	
Previous Crop Soybean	524	0.410		779	0.570		24,243	0.500	
Previous Crop Spring Wheat	524	0.002		779	0.000		24,243	0.004	
Previous Crop Other	524	0.405		779	0.243		24,243	0.309	

Table 3 Continued. Minnesota Corn Summary Statistics, 2009-2019

	No Tillage			Strip Tillage			Chisel Tillage		
Variable	**Obs**	**Mean**	**Std. Dev.**	**Obs**	**Mean**	**Std. Dev.**	**Obs**	**Mean**	**Std. Dev.**
Year		Proportion			Proportion			Proportion	
2009	524	0.090		779	0.089		24,243	0.082	
2010	524	0.073		779	0.090		24,243	0.087	
2011	524	0.074		779	0.063		24,243	0.077	
2012	524	0.078		779	0.076		24,243	0.085	
2013	524	0.071		779	0.096		24,243	0.091	
2014	524	0.080		779	0.077		24,243	0.087	
2015	524	0.088		779	0.096		24,243	0.094	
2016	524	0.115		779	0.105		24,243	0.106	
2017	524	0.105		779	0.107		24,243	0.101	
2018	524	0.120		779	0.096		24,243	0.096	
2019	524	0.107		779	0.105		24,243	0.095	

Source: FINBIN, University of Minnesota (2009-2019).

Table 4. Minnesota Soybean Summary Statistics, 2009-2019

	No Till			Strip Till			Chisel Till		
Variable	**Obs**	**Mean**	**Std. Dev.**	**Obs**	**Mean**	**Std. Dev.**	**Obs**	**Mean**	**Std. Dev.**
Soybean Yield, Bu/Acre	1,150	48.267	10.306	516	50.920	10.444	21,589	48.439	11.663
Soybean Acres	1,150	144.643	194.506	516	117.093	134.146	21,590	175.334	246.015
Expenses									
Seed Expense, $/Acre	1,150	60.734	14.781	516	57.133	12.526	21,589	60.670	13.848
Fertilizer Expense, $/Acre	768	40.546	24.039	392	37.742	22.599	12,279	38.812	24.643
Chemical Expense, $/Acre	1,149	40.681	19.289	515	42.905	17.859	21,563	37.884	18.459
Fuel Expense, $/Acre	1,136	15.556	8.036	513	20.143	10.578	21,368	19.452	9.005
Regions		Proportion			Proportion			Proportion	
Northwest Region	1,150	0.081		516	0.014		21,590	0.169	
Northeast Region	1,150	0.083		516	0.010		21,590	0.030	
Central Region	1,150	0.069		516	0.250		21,590	0.136	
South Central Region	1,150	0.150		516	0.399		21,590	0.269	
Southeast Region	1,150	0.242		516	0.076		21,590	0.090	
Southwest Region	1,150	0.377		516	0.252		21,590	0.305	
Previous Crop		Proportion			Proportion			Proportion	
Previous Crop Corn	1,150	0.631		516	0.535		21,590	0.563	
Previous Crop Soybeans	1,150	0.077		516	0.178		21,590	0.102	
Previous Crop Spring Wheat	1,150	0.008		516	0.002		21,590	0.039	
Previous Crop Other	1,150	0.283		516	0.285		21,590	0.285	

Table 4 Continued. Minnesota Soybean Summary Statistics, 2009-2019

	No Till			Strip Till			Chisel Till		
Variable	**Obs**	**Mean**	**Std. Dev.**	**Obs**	**Mean**	**Std. Dev.**	**Obs**	**Mean**	**Std. Dev.**
Year		Proportion			Proportion			Proportion	
2009	1,150	0.140		516	0.068		21,590	0.083	
2010	1,150	0.123		516	0.097		21,590	0.092	
2011	1,150	0.063		516	0.062		21,590	0.081	
2012	1,150	0.060		516	0.097		21,590	0.087	
2013	1,150	0.070		516	0.064		21,590	0.089	
2014	1,150	0.066		516	0.118		21,590	0.087	
2015	1,150	0.089		516	0.083		21,590	0.096	
2016	1,150	0.103		516	0.095		21,590	0.099	
2017	1,150	0.089		516	0.089		21,590	0.101	
2018	1,150	0.080		516	0.132		21,590	0.097	
2019	1,150	0.117		516	0.095		21,590	0.088	

Source: FINBIN, University of Minnesota (2009-2019).

Table 5. Minnesota Spring Wheat Summary Statistics, 2009-2019

	No Tillage			Chisel Tillage		
Variable	**Obs**	**Mean**	**Std. Dev.**	**Obs**	**Mean**	**Std. Dev.**
Spring Wheat Yield, Bu/Acre	74	55.925	17.691	3,384	59.882	15.102
Spring Wheat Acres	74	295.374	347.777	3,384	247.980	293.934
Expenses						
Seed Expense, $/Acre	74	22.011	8.480	3,384	24.796	9.153
Fertilizer Expense, $/Acre	71	85.840	27.001	3,320	94.495	30.476
Chemical Expense, $/Acre	72	29.472	11.636	3,298	31.075	13.820
Fuel Expense, $/Acre	73	17.687	7.997	3,368	18.921	7.423
Regions		Proportion			Proportion	
Northwest Region	74	0.649		3,384	0.789	
Northeast Region	74	0.122		3,384	0.018	
Central Region	74	0.122		3,384	0.120	
South Central Region	74	0.014		3,384	0.042	
Southeast Region	74	0.000		3,384	0.006	
Southwest Region	74	0.095		3,384	0.025	
Previous Crop		Proportion			Proportion	
Previous Crop Corn	74	0.108		3,384	0.037	
Previous Crop Soybean	74	0.446		3,384	0.490	
Previous Crop Spring Wheat	74	0.000		3,384	0.071	
Previous Crop Other	74	0.432		3,384	0.387	

Table 5. Minnesota Spring Wheat Summary Statistics, 2009-2019

	No Tillage			Chisel Tillage		
Variable	**Obs**	**Mean**	**Std. Dev.**	**Obs**	**Mean**	**Std. Dev.**
Year		Proportion			Proportion	
2009	74	0.189		3,384	0.087	
2010	74	0.081		3,384	0.100	
2011	74	0.135		3,384	0.078	
2012	74	0.068		3,384	0.100	
2013	74	0.081		3,384	0.085	
2014	74	0.041		3,384	0.098	
2015	74	0.068		3,384	0.100	
2016	74	0.135		3,384	0.087	
2017	74	0.054		3,384	0.083	
2018	74	0.095		3,384	0.103	
2019	74	0.054		3,384	0.079	

Source: FINBIN, University of Minnesota (2009-2019).
There were no responses for strip-till.

ANALYSIS OF YIELD REGRESSIONS

Three regressions (no-till, strip-till, chisel-till) were estimated for three different crops (corn, soybeans, spring wheat) to study the impacts of crop inputs and management decisions on crop yields based on different tillage methods, as shown in Equation 6. The regression results are reported in Table 6.

Corn Yield Regression

For the corn enterprise analysis, each region was statistically significant at the 1% level for no-till, strip-till, and chisel-till observations, excluding the central region and southeast region strip-till variables and the south central region chisel-till variable. The southwest region was used as the comparison group, so each of the coefficients are comparable to the southwest region. The signs of each of the region coefficients in the corn enterprise analysis were as expected, where the southern regions would yield higher than the northern regions. A farm in the southeast region is expected to have the highest corn yield, with 20.47 bushels per acre higher yields than a farm in the southwest region for no-till acres, 5.29 bushels per acre higher yields than a farm in southwest region for chisel-till acres, and 5.97 bushels per acre higher yields than a farm in the southwest region for strip-till acres. Specific yield estimates based on these regression results are shown in Table 7.

The number of acres planted to corn in the corn enterprise analysis was statistically significant at the 5% level for no-till and at the 1% level for chisel-till, but the magnitude of the coefficients was small. For every 100 additional acres planted to corn, the average corn yield on that farm will increase by 1.9 bushels per acre for no-till and 0.6 bushels per acre for chisel-till. One potential reason for this is larger farms operate with efficiencies that smaller farms do not have. They are able to spread costs over more acres than small farms and could therefore be more inclined to invest in technologies or inputs that will positively impact yield compared to smaller farms that cannot spread out these costs over as many acres. The number of strip-till acres planted to corn was not statistically significant.

All the crop inputs except fuel were expected to have positive impacts on yield. For the corn analysis, seed was positive and statistically significant at the 1% level for no-till, strip-till, and chisel till. A $10 increase in seed cost per acre shows an increased yield of 1.81 bushels/acre for no-till, 1.41 bushels/acre for chisel-till, and 1.22 bushels/acre for strip-till. Neither fertilizer expenses nor chemical expenses were statistically significant for no-till or strip-till, likely due to the variability of their usages among farms. The coefficients for fuel expense per acre were statistically significant at the 1% level for no-till and the 10% level for strip-till, and both showed a large positive impact on yield. Contrastingly the chisel-till fuel expense variable showed a statistically significant negative impact on yield.

In the corn chisel-till analysis, previous crop was statistically significant at the 1% level for the previous crop of corn and the previous crop of soybeans. A previous crop of corn only showed 1.62 higher bushels per acre, and a previous crop of soybeans showed 1.78 more bushels per acre for corn chisel-tilled acres. No previous crop variables were statistically significant in the corn no-till or corn strip-till regressions.

In addition to the previous crop planted on the field, year dummy variables were used to estimate how changes in yield occurred from one year to the next. In the corn analysis, the coefficient on the year dummies are negative with statistical significance in 2011, 2012, 2013, and 2014 across all tillage types, with strip-till also having a negative sign in 2010. The coefficient magnitudes are much lower for chisel-till than no-till for each of these years except 2011. Each of the remaining year dummies in the corn analysis were positive and had statistical significance.

Overall when comparing corn yields by tillage type and region, on average, the highest corn yields were produced on chisel-till and strip-till acres (Table 7). The highest yields in the northwest, southeast, and southwest regions were all from chisel-till systems. The highest corn yields in the northeast, central, and south central regions were grown on strip-till acres with 153.55, 182.15, and 184.34 bushels per acre respectively. No-till acres produced the lowest corn yields in all regions except the south central and southeast regions.

Soybean Yield Regression

Yield patterns by region for soybeans are similar to those found for corn. As expected, the highest yield coefficients were from the southeast and south central regions, and the lowest (negative) coefficients were from the northeast and northwest regions for the soybean enterprise analysis. Each of the regions the no-till and chisel-till regressions had statistically significant coefficients except the south central region. Unlike corn, the number of acres planted to soybeans was not statistically significant for the no-till or strip-till regressions but was significant at the 1% level in the chisel-till regression. Again, the coefficient for the number of soybean acres planted has a small magnitude, showing that for every 100 additional acres planted to soybeans on chisel-till acres, the average soybean yield on that farm will increase by 0.10 bushels per acre.

Similar to the corn analysis, the previous crop of corn on chisel-till acres had an estimated yield advantage of 1.09 bushels per acre and a previous crop of soybeans had an estimated yield advantage of 0.68 bushels per acre. The biggest previous-crop yield advantage for no-till soybeans came from the previous crop of spring wheat with 9.45 bushels per acre higher yields.

The year dummies are negative in the soybean analysis for 2009, 2011, 2012, 2013 and 2014. The majority of Minnesota farmland was in a drought for the 2011, 2012, and 2013 growing seasons, so these negative signs are not surprising, as plants need an adequate supply of water to grow. Each of the other years in the analysis have positive coefficients across all tillage types and are statistically significant at the 1% level, excluding the strip-till 2010, and 2017 variables.

Consistent with the corn findings, soybean yields were estimated to be higher using chisel-till or strip-till, but there was a much smaller range in soybean yields than corn yields when comparing tillage methods. Soybean chisel-till acres produced the highest yields in the northwest, southeast, and southwest regions with 37.58, 53.29, and 52.22 bushels per acre respectively. The strip-till acres had the highest yields in the northeast (44.86 bushels per acre), the central (49.94 bushels per acre), and the south central (52.75 bushels per acre) regions. While no-till acres did not produce the highest soybean yields in any region, these acres were within 2 bushels per acre of the highest yields in the northwest, south central, and southeast regions, as shown in Table 7.

Spring Wheat Yield Regression

Contrasting from corn and soybeans, spring wheat yields show the highest coefficients for the northwest region, which is statistically significant at the 1% level for no-till and the 5% level for chisel-till. The positive yield impacts for spring wheat in the northwest region confirms why spring wheat has a much more prevalent presence in northern Minnesota than southern Minnesota, and the smaller presence of corn production in the northern half of the state.

The number of spring wheat chisel-till acres planted was statistically significant at the 1% level and shows that for every 100 additional acres planted of spring wheat, the average spring wheat yield increases by 0.50 bushels per acre. Additionally, the highest spring wheat yields are from no-tilled acres in the northwest region, averaging 64.20 bushels per acre, compared to 61.94 bushels per acre produced by the chisel-till acres in the same region (Table 7). The other five Minnesota regions had the highest spring wheat yields come from the chisel-till acreage.

Table 6: Minnesota Corn, Soybeans, and Spring Wheat Yield Regression Results by Tillage Type, 2009-2019.

	Corn			**Soybeans**			**Spring Wheat**	
	No Till	**Chisel Till**	**Strip Till**	**No Till**	**Chisel Till**	**Strip Till**	**No Till**	**Chisel Till**
Northwest Region	-37.730***	-28.187***	-32.270***	-12.497***	-14.638***	-28.581***	24.793***	3.903**
	(6.316)	(0.758)	(7.070)	(1.253)	(0.268)	(4.206)	(7.809)	(1.555)
Northeast Region	-32.057***	-34.078***	-25.315***	-10.132***	-15.421***	-7.339**	-3.541	-12.588***
	(4.698)	(0.990)	(7.093)	(1.172)	(0.413)	(3.903)	(8.925)	(2.166)
Central Region	-21.810***	-7.987***	3.279	-2.759**	-5.702***	-2.267**	11.129	-2.582
	(5.947)	(0.558)	(2.598)	(1.211)	(0.275)	(1.222)	(9.470)	(1.618)
South Central Region	17.626***	-0.021	5.477***	2.441***	0.320	0.548	-0.342	-4.531**
	(4.271)	(0.448)	(2.120)	(0.831)	(0.216)	(1.156)	(14.735)	(1.898)
Southeast Region	20.473***	5.290***	5.975*	1.837**	1.065***	-1.385	*Omitted*	-9.922***
	(3.982)	(0.596)	(3.060)	(0.745)	(0.294)	(2.112)		(3.174)
Acres	0.019**	0.006***	0.006	-0.001	0.001***	0.005	0.000	0.005***
	(0.009)	(0.001)	(0.006)	(0.002)	(0.000)	(0.003)	(0.005)	(0.001)
Seed Expense/Acre	0.181***	0.122***	0.141***	-0.025	0.020***	-0.016	-0.130	0.110***
	(0.061)	(0.008)	(0.043)	(0.020)	(0.006)	(0.034)	(0.246)	(0.028)
Fertilizer Expense/Acre	0.037	0.060***	0.029	0.023*	0.013***	0.002	0.171**	0.099***
	(0.028)	(0.003)	(0.020)	(0.013)	(0.003)	(0.022)	(0.075)	(0.008)
Chemical Expense/Acre	-0.120	0.092***	0.024	0.062***	0.059***	0.070***	-0.024	0.141***
	(0.079)	(0.011)	(0.065)	(0.016)	(0.005)	(0.025)	(0.147)	(0.016)
Fuel Expense/Acre	0.347***	-0.043***	0.138**	0.065*	0.020**	-0.013	-0.063	0.150***
	(0.130)	(0.013)	(0.072)	(0.034)	(0.010)	(0.050)	(0.234)	(0.033)
Previous Crop Corn	-6.656	1.618***	-3.190	0.425	1.085***	-0.155	6.924	0.750
	(4.290)	(0.522)	(2.539)	(0.682)	(0.201)	(1.082)	(6.627)	(1.260)
Previous Crop Soybeans	-6.297*	1.768***	2.549	0.109	0.681**	-1.260	-10.008***	3.115***
	(3.414)	(0.413)	(2.031)	(1.122)	(0.279)	(1.495)	(3.597)	(0.463)

Table 6 Continued: Minnesota Corn, Soybeans, and Spring Wheat Yield Regression Results by Tillage Type, 2009-2019.

	Corn			**Soybeans**			**Spring Wheat**	
	No Till	**Chisel Till**	**Strip Till**	**No Till**	**Chisel Till**	**Strip Till**	**No Till**	**Chisel Till**
Previous Crop Spring Wheat	-10.438	-0.477	*Omitted*	6.569**	0.945**	-26.023***	*Omitted*	2.235***
	(30.354)	(2.728)		(3.001)	(0.384)	(7.546)		(0.858)
2009	7.625	4.021***	0.874	-3.000**	-3.359***	-6.320***	-3.151	0.503
	(6.174)	(0.841)	(3.698)	(1.197)	(0.436)	(2.206)	(8.182)	(1.035)
2010	12.663***	4.356***	-3.873	1.900*	1.431***	-0.726	9.425	-0.544
	(6.425)	(0.821)	(3.607)	(1.130)	(0.406)	(1.945)	(9.689)	(1.011)
2011	-19.798***	-18.018***	-22.815***	-5.066***	-6.072***	-9.298***	-16.361*	-16.338***
	(6.822)	(0.868)	(4.212)	(1.299)	(0.407)	(2.264)	(8.556)	(1.091)
2012	-7.689	-14.659***	-5.092	-2.114	-0.197	4.782**	4.263	-3.937***
	(6.991)	(0.878)	(4.211)	(1.296)	(0.387)	(1.937)	(10.127)	(1.070)
2013	-17.378**	-22.293***	-24.409***	-3.690***	-3.804***	-5.643**	2.965	-0.514
	(7.510)	(0.869)	(3.933)	(1.251)	(0.378)	(2.304)	(9.244)	(1.083)
2014	-17.888***	-25.107***	-28.378***	-5.079***	-3.318***	-7.717***	0.332	-1.537
	(6.701)	(0.860)	(4.096)	(1.311)	(0.381)	(1.907)	(11.414)	(1.030)
2015	18.805***	16.533***	15.535***	9.117***	5.944***	8.725***	15.389	5.771***
	(6.302)	(0.810)	(3.705)	(1.137)	(0.340)	(1.813)	(9.649)	(0.997)
2016	29.141***	21.193***	20.280***	11.532***	9.621***	11.200***	10.620	7.385***
	(5.773)	(0.784)	(3.690)	(1.089)	(0.332)	(1.834)	(8.508)	(1.032)
2017	38.996***	26.085***	20.478***	5.336***	2.586***	2.730	19.204**	12.523***
	(5.791)	(0.787)	(3.494)	(1.088)	(0.329)	(1.768)	(9.365)	(1.033)
2018	14.694***	2.233***	4.586	2.732**	3.089***	3.420**	-7.888	1.926*
	(5.603)	(0.795)	(3.634)	(1.200)	(0.329)	(1.617)	(8.603)	(0.991)

Table 6 Continued: Minnesota Corn, Soybeans, and Spring Wheat Yield Regression Results by Tillage Type, 2009-2019.

	Corn			**Soybeans**			**Spring Wheat**	
	No Till	**Chisel Till**	**Strip Till**	**No Till**	**Chisel Till**	**Strip Till**	**No Till**	**Chisel Till**
Constant	130.865***	155.039***	152.407***	44.916***	46.199***	49.548***	31.940**	35.120***
	(9.074)	(1.210)	(5.439)	(1.540)	(0.518)	(2.862)	(13.268)	(2.069)

Note: The quantities below the estimates are the standard errors.
*=Significant at the 5% level, **=Significant at the 1% level
Source: FINBIN, University of Minnesota (2009-2019). There were no responses for spring wheat strip-till

Table 7: Minnesota Corn, Soybeans, and Spring Wheat Average Yield Estimates by Region and Tillage Type from Regression Results, 2009-2019.

	Corn			**Soybeans**			**Spring Wheat**	
Regions	**No Till**	**Chisel Till**	**Strip Till**	**No Till**	**Chisel Till**	**Strip Till**	**No Till**	**Chisel Till**
Northwest Region	128.80	154.55	146.6	37.08	37.58	23.62	64.20	61.94
Northeast Region	134.47	148.66	153.55	39.44	36.8	44.86	35.86	45.45
Central Region	144.72	174.75	182.15	46.81	46.52	49.94	50.53	55.45
South Central Region	184.15	182.72	184.34	52.01	52.54	52.75	39.06	53.50
Southeast Region	187.00	188.03	184.84	51.41	53.29	50.82	-	48.11
Southwest Region	166.53	182.74	178.87	49.57	52.22	52.20	39.41	58.03

Source: FINBIN, University of Minnesota (2009-2019).
These yield estimates were estimated using the regression coefficients from Table 6.
There were no responses for spring wheat strip-till.

VIII. Discussion

The research objective of this study was to understand how cash crop yields and input costs are impacted by reduced tillage methods on Minnesota crop farms. Investigating a range of factors that influence crop yields showed that tillage methods impact both crop inputs and crop yields. This study demonstrates a relationship between cash crop yields, cash crop costs, and tillage methods. This correlation is useful for producers to consider when choosing a tillage method for their farm. The results indicate that chisel-till and strip-till acres produce higher yielding cash crops than no-till acres, contradicting the results of the University of Nebraska work that suggested a no-till yield advantage over conventionally tilled acres due to moisture retention in crop residue (Van Donk et al., 2010). However, Nebraska has a different precipitation regime than most of Minnesota. Our yield results align with the University of Minnesota's 2007 tillage study on yield (DeJong-Hughes and Vetsch, 2007).

Although no-till acres produce the lowest yielding crops across all crop types and all regions, no-till acres overall have lower costs per acre than the previously mentioned tillage methods, confirming our expectations that no-till operations have fewer input costs than conventional tillage operations.

An additional finding of this study is the impact of geographic location on yield. In line with the hypothesis, geographic location plays a significant role in yield. Excluding the northwest region in the spring wheat analysis, the highest yields across all regions, tillage methods, and crops came from the southern regions of Minnesota. While geographic location and tillage method are impactful of crop yields, due to the lack of data for Minnesota spring wheat strip-till farms, conclusions cannot fully be drawn for tillage and regional impacts on spring wheat.

An important aspect of this study in comparison to previous literature is the use of on-farm data rather than experimental studies. The use of actual farm-level data resulted in large sample sizes that provided statistically significant implications. The corn enterprise analysis had 524 no-till observations, 779 strip-till observations, and 24,242 chisel-till observations from 2009-2019. Similarly, the soybean analysis included 1,150 observations, 516 observations, and 21,590 observations for no-till, strip-till, and chisel-till methods respectively over the 11-year timespan. The large sample of farm data validates the findings in the regression results of this study. Additionally, it represents many different farm types by including farms throughout Minnesota.

Certain data-entry boundaries limited the scope of the research. FINBIN data is entered by a Farm Business Management instructor, or it is entered directly by the producer. Since data entry was not streamlined, some of the FINBIN observations did not contain all the information studied in this analysis such as tillage method used or other tillage-specific cost information. For example, of the 43,161 total corn enterprise observations in FINBIN between 2009 and 2019, 15,544 observations did not report a tillage method. Therefore, only 25,545 of the 43,161 observations were used in this analysis. Additionally, not all participating farms entered their farm data into FINBIN for the entire time period. This dissonance caused issues in studying the data as a time-series model. So, rather than a time-series analysis, year dummy variables and price inflations were utilized to incorporate changes between each year for the 11-year time period. Data with more detailed management decision information and time series capabilities could improve the tillage yield regressions.

IX. Conclusion

Environmental sustainability in agriculture has caused growing concern among crop producers, farm stakeholders, and soil health experts over the past decade. Soil and water conservationists are encouraging the use of reduced tillage methods to decrease the negative environmental impacts of crop production. With greater promotion of reduced tillage, farmers are pursuing answers to how reducing tillage on their operations will impact farm profitability, specifically cash crop input costs and yields. This research underlines the impact of tillage methods on crop input costs and crop yields.

It is important to jointly analyze both the environmental and economic implications of reduced tillage on the farm. The majority of farmers will not adopt a positive environmental practice if it has negative impacts on the farm's bottom line.

An environmental-focused analysis suggests the use of no-till as the proven tillage method due to its benefits on soil health in maximizing crop residue, and minimizing soil compaction and erosion. Contrastingly, an economic-focused analysis would suggest the use of chisel-till due to its yield benefits over its tillage counterparts. Analyzing the economic and environmental impacts of tillage together suggests strip tillage is a successful compromise between minimized negative environmental impacts and maximized yields in crop production. The results of this analysis could help farmers determine which tillage method is the most beneficial for their farm's specific needs and goals. As more research is performed regarding tillage methods, comparing both environmental and economic implications will be critical to increase the adoption rate of environmentally sustainable practices on agriculture production operations.

CHAPTER 3: PROJECTING THE ECONOMIC IMPACTS OF COVER CROPS ON MINNESOTA ROW CROP OPERATIONS WITHOUT GRAZING

I. Introduction

A common agricultural topic of discussion in the United States is the growing concern of environmental sustainability in production agriculture. Many recent agricultural policies are based on environmental sustainability and decreasing the negative environmental impacts of farming (Angelo, 2009; Claassen et al., 2004). New research shows the use of cover crops is a potential solution to the negative environmental impacts that are tied to crop production.

The 2017 Census of Agriculture showed an overall increase in cover cropped acres from 2012 to 2017, but they continue to be used minimally on U.S. cropland. The 2017 census reported only 1.8% of Minnesota's farmland as cover cropped acres, which is an increase of 0.8 percentage points from the cover crop reporting in the 2012 Census of Agriculture (USDA and NASS, 2019; USDA and NASS, 2014). Similar patterns of land allocation to cover crops are observed throughout most Midwestern and Western states (Zulauf and Brown, 2019). The results of this census analysis concludes that Minnesota has large potential to increase its cover crop acreage; however, it is critical to consider why cover crops have such low adoption rates in Minnesota and throughout the country.

The excitement for cover crops amid soil and water conservationists regards the positive influence that cover cropping has on soil health and the overall reduction of a farm's carbon footprint. Biological benefits of cover crops include increasing organic matter in soil, improving soil drainage capabilities, decreasing soil compaction and erosion, assisting in weed management, and reintroducing nutrients back into soil (Chatterjee, 2013). Each of these benefits have the potential to decrease farm fertilizer or chemical inputs over time. While cover crops seem promising among soil conservationists, farmers are hesitant to adopt them.

Uncertain impacts on farm profitability are amongst leading causes for farmer hesitancy in adopting cover crops (Gonzalez-Ramirez, 2017). A financial decision tool would be helpful to assist farmers with this uncertainty. Agricultural financial decision tools are useful to farmers when analyzing production and management decisions on their farm. However, farm decisions are rarely made without considering short-term and long-term economic effects. Theoretically there are many potential cost reduction and yield increasing benefits connected to using cover crops, but there is limited research on the specific long-term economic impacts of the practice. Even more limitations arise when considering long-term economic impacts of cover crops. Providing farmers with a decision tool focused on the multi-year economic impacts of cover crops would be beneficial to farmers who are interested but unsure about adopting cover crops on their farms.

The information available to farmers regarding cover crop economics is limited to a single-year analysis and does not consider the longevity of cover crops' implications on a farm's bottom line (Plastina, 2018). Analyzing cover crops as both an environmental and economic decision, and as a short-term and long-term decision is critical to the reception of the results in this study. By studying the input costs, yields, and other returns and expenses associated with cover crops over multiple years, the short-term and long-term effects of cover cropping on farm profitability can be measured using a net present value (NPV) analysis. An NPV analysis calculates cash flows of an investment and accommodates for the timing of those cash flows. The concept of time value of money indicates that the timing of an investment's cash flows impacts the investment's present value. Thus, NPV is a valuable tool for this analysis to account for the short and long-term economic impacts of the decision to implement cover crops in a crop rotation.

II. Research Objectives

There are three objectives of this research. The first objective is to understand how farm profitability is impacted by the establishment of cover crops on Minnesota crop farms that do not use livestock to graze their cover crop. A range of factors that influence cover crop establishment was investigated to discover the economic impact of cover crops. The second objective is to use the yield estimates from the farm financial analysis in Chapter 2 to proxy the impact of cover crops on farm revenue. The third objective of this research is to develop an interactive Excel spreadsheet to create a simple and easy-to-use decision tool, using NPV and the Chapter 2 regression results as the underlying foundation of the spreadsheet. The role of cover crops as a factor of farm profitability has not been widely reported on a multi-year level, and has especially not been reported on a regional-level throughout Minnesota. Thus, the purpose of this tool is to assist farmers in understanding the financial feasibility of cover crops on their unique farm operations over multiple years.

Cover crop decisions were analyzed to identify common inputs utilized to incorporate cover crops on a farming operation. Crop establishment and termination decisions have the largest impacts on cover crop costs, therefore cover crop inputs that are affected by these decisions were identified and studied on the farm enterprise level. In addition to the yield regressions estimated in Chapter 2, two Minnesota-specific surveys were utilized to capture the financial effects of using cover crops and observing the financial implications that resulted from varying cover crop management decisions across farms in the sample. These long-term financial effects are difficult to capture and there are limited resources that have procured them. Thus, primary data was critical for this analysis.

III. Literature Review

Sustainability is a broad topic that has been one of the driving forces of U.S. businesses. The United Nations' Bruntland Commission of 1987 defined sustainability as, "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (United Nations General Assembly, 1987). However, sustainability is also defined as a triple-bottom-line concept, meaning there are three aspects of sustainability within the one word. The triple-bottom-line refers to economic, social, and environmental sustainability (Slaper and Hall, 2011). For this research, the United Nations' definition of sustainability will be assumed in conjunction of the triple-bottom-line concept.

Cover crops have proven to be an environmentally sustainable farming practice (Chatterjee, 2013; Tillman et al., 2002). Cover crops impact a farm's profitability by altering cash inflows and outflows. The Sustainable Farming Association suggests the main variables that affect cover crop profitability include fuel costs, herbicide costs, and changes in cash crop yields (Dooley, 2018). Additionally, Myers et al. (2019) points out many management decisions exist that coordinate with the decision to grow cover crops, and that cover cropping may reap the most economic gains when paired with other environmentally sustainable practices, such as reduced tillage or decreased herbicide applications (Myers et al., 2019).

Cover crops have gained a reputation for increasing soil health on farming operations. In addition to increasing soil health, many farmers have an underlying goal for adopting cover crops. The three purposes often considered when making this decision are: (1) increased soil health such as additional organic matter in the soil and less compaction, (2) weed management or suppression to decrease chemical use, and (3) erosion management to minimize water and soil loss.

A survey conducted by the Sustainable Agriculture and Research and Education Program (SARE) concluded that corn fields following cover crops yield 2.3 bushels per acre higher than when not following cover crops, and soybean fields following cover crops have increased yields of 2.1 bushels per acre (Myers et al., 2019). These yield increases are the result of increased organic matter, added soil nutrients, improved drainage, weed and erosion management, and compaction benefits that are tied to cover crops. The economic analysis in the SARE study showed positive returns per acre for land that was cover cropped. However, the majority of the economic gains came from grazing benefits (CTIC, 2017). Only 4.2% of Minnesota’s farmland is grazed, therefore the economic gains in this SARE report can be misleading for a Minnesota farmer considering cover crops without a grazing purpose (Mold and Rhees, 2020).

Plastina et al. (2008) used partial budgets to analyze the adoption of cover crops on Iowa farms that do not graze livestock. Consistently they found that farms showed negative returns when they incorporated cover crops into their operations without the purpose of grazing or using the cover for forage (Plastina et al., 2018). The foundation of the partial budget used assumptions to define farm conditions. Plastina's decision tool calculates the economic implication of adopting cover crops as an independent one-year decision rather than incorporating the long-term financial impacts of cover crops. Additionally, the economic data is from 2015, which has not been updated to-date. Other work has emphasized the importance of this being a multi-year decision to realize the full impacts of cover crop adoption (Myers, et al. 2019). Plastina's strategy does not capture the potential long-term benefits of adopting cover crops which may take more than one year to observe. Many academic papers acknowledge the importance of cover crops generating profit, however limited resources are available that completed an in-depth economic analysis (Hughes and Langemeier, 2020; Mahama, et al., 2016; Myers, et al., 2019; Roberts, et al., 1998). In addition to academic papers, articles from popular press materials were analyzed due to their popularity amongst farmers. Similar to academic papers, a popular press analysis confirmed the limited data available to farmers that shows the economic impacts of cover crops (Dooley, 2018; Looker, 2018).

Cover crops are relatively unutilized throughout the United States. A 2012 study conducted by the USDA Census of Agriculture showed the states with the most cover crop adoptions in the United States were in the northeastern, mid-Atlantic, and southeastern states; however, this adoption was less than 30% of the U.S. farmland (USDA and NASS, 2014). These numbers were confirmed in the 2017 Census of

Agriculture, five years later. The cover crop adoption rate was the lowest in Midwestern and Western states, which suggests a large potential for future cover cropping goals in the Midwest (Hamilton et al. 2017; USDA and NASS, 2017). While there is potential for growth in this region, Midwest farmers are hesitant to adopt the practice due to the uncertainty of economic impacts to the farm as well as the short growing season common in this region (Myers et al., 2019).

Since the economic impacts of cover crops are uncertain but their environmental impacts are substantially beneficial, government agencies have instituted cost-share programs to assist and incentivize farmers in cover crop establishment. The Natural Resources Conservation Service (NRCS) within the United States Department of Agriculture (USDA) has two cost-share programs available to producers. First, the Environmental Quality Incentives Program (EQIP), offers technical and financial support to farmers to incorporate farming practices that address environmental concerns or provide environmental benefits (Coppess and Gramig, 2018). Most EQIP contracts are three years. Second, the Conservation Stewardship Program (CSP) offers financial incentive to farmers who meet environmental thresholds on their operations. CSP is a five-year commitment that may be renewed at the end of the contract. Farmers receiving CSP payments must maintain or improve conservation practices on their farm throughout the duration of their CSP contract (Coppess and Gramig, 2018). Both EQIP and CSP are federal programs. Soil and Water Conservation Districts (SWCD) also offer cost-share programs throughout Minnesota, using funding designated from Minnesota legislation since 2016 (Minnesota BWSR, 2019). This funding is distributed to each county's SWCD who then allocates the funds to qualifying farmers. Since SWCD cost-share is determined at the county-level, cost-share payments and benefits are unique to each county. Even with the availability of cost-share programs, farmers remain leery of cover crops due to the limited research available about their economic impacts.

The cover crop economic research that has been conducted limits the decision of incorporating cover crops on a farm to a single-year decision and does not consider the multi-year longevity of the decision to. The analysis in this paper aims to analyze the long-term economic implications of adopting cover crops and create a multi-year analysis tool for farmers to address gaps in current literature.

IV. Methodology

On an annual basis, it is assumed that farmers maximize profit subject to production and financial constraints. Management decisions also consider multi-year impacts that affect farm profit over many production seasons (Debertin, 2012). Farmers treat profit maximization differently when they consider profit over a 20-year period compared to maximizing profits for a single-year production period, or even 20 separate production seasons. For example, consider the decision for a dairy farm to invest in a manure pit. Manure pits collect the manure produced by cows on the farm and store the manure for 2-6 months at a time so the farm can use the manure as fertilizer on their fields. Manure pits are expensive, non-revenue stream investments, but they provide the farm with many efficiencies. They allow farms to (1) apply manure to a field in large quantities that have been collected over weeks or months rather than the small quantities of manure the cows produce each day, (2) spread manure only a couple days each year, rather than spreading manure every day as the cows produce it, and (3) capture the nutrients in the manure for fertilizer on their fields, rather than purchasing fertilizer. Each of these examples are positive, long-term, indirect financial impacts of the manure pit. A farmer looking to maximize single-year profits would not invest in the manure pit due to the large capital demand of the investment. However, a multi-year focus makes the non-revenue stream investment of the manure pit more attractive, as it captures many of the long-term benefits.

Similar to the manure pit on a dairy farm, non-revenue stream investments on a crop farm could include purchases such as equipment or buildings; these require a large capital investment and little or no financial return up-front but provide long-term economic gains. This is also how environmental conservation practices can be viewed on a farm – as non-revenue stream investments. Investing in conservation practices, such as reduced tillage systems or cover crops, trades off single-year profits in early years for maximized profits in later years. There is little economic data available showing the payback period of cover crops, making this decision difficult for farmers to consider.

NET PRESENT VALUE

Cover crops are often a multi-year decision. Rarely do farmers plant a cover crop for only one year except in rare prevent plant situations. More often, cover crops are used year after year. Therefore, the decision to plant cover crops needs to be evaluated on a single-year level, along with a multi-year level. Since many indirect benefits of cover crops are not realized in the first year of the practice, estimates from a multi-year model are difficult to capture relative to the single-year model. The single-year model accounts for the revenue increases, cost increases, and cost decreases that will be experienced in one growing season, while the multi-year model accounts for each of these changes over several years and generates their net present value (NPV) over a specific timeframe.

Assuming the principles of time value of money that states a dollar is worth more today than in the future, NPV is defined as the present value of an investment's projected cash outflows subtracted from the present value of the investment's projected cash inflows (Debertin, 2012). NPV is calculated as the following:

$$(7)\ NPV_k = CF_{0_k} + \frac{CF_{1_k}}{{(1+r)^1}_k} + \frac{CF_{2_k}}{{(1+r)^2}_k} + \frac{CF_{3_k}}{{(1+r)^3}_k} + \frac{CF_{4_k}}{{(1+r)^4}_k} \ldots\ldots + \frac{CF_{i_k}}{{(1+r)^i}_k}$$

where *NPV* is the net present value, *CF* is the cash flow, and *r* is the discount rate. The subscripts *0, 1, 2, 3, 4,* are the years of the analysis, which continues until the *i*th year for the *k*th crop (Debertin, 2012). Each year's cash flow in equation (7) is the profit of the *k*th crop for that year, as shown in Albouy's (2005) single-year, single-commodity profit equation for a farm, similar to the equation in Chapter 2:

$$(8)\ \pi = p\hat{q} - r_N N - r_K K - r_F F$$

where π is profit, *p* is price, $\hat{q}$ is the estimated yield from the regressions in Chapter 2, *N* is inputs, r_N is the rate paid for the inputs, *K* is capital, r_K is the rate paid for capital, *F* is fixed costs and $r_F$is the rate paid for fixed costs (Albouy, 2005).

INTERACTIVE TOOL

The Excel spreadsheet-based decision tool calculates the total cost increase or decrease from cover crops based on the user's input information in five categories: (1) producer or farm characteristics, (2) information about the cash crop on the field, (3) costs for establishing the cover crop, (4) costs for terminating the cover crop, and (5) other income or costs.

In conjunction with producer or farm characteristics, the spreadsheet tool estimates cover crop cost as a function of the farm's geographic location. Total acres operated and acres devoted to cover crops also impact the model, which assumes a corn/soybean rotation. Information about the cash crop include the tillage type, the cash crop prior to and following the cover crop. Cover crop establishment information in the spreadsheet includes the cover crop planting method and seeding rate. Finally, termination-specific information includes the termination method and the party administering the termination. The final cost analysis is a product of revenue increases, cost increases, and cost savings that are reaped from the use of cover crops. Revenue increases were derived from yield benefits, and cost-share programs; cost increases included cover crop seed, seeding rate, planting, and termination; and cost savings come from fuel, fertilizer, or herbicide savings. The total cost analysis was a function of these three cost points.

The single-year model generates this calculation for the first year, or the establishment year, of the cover crop, while the multi-year model evaluates this calculation over time, with a five-year and ten-year net present value (NPV) analysis. The multi-year model accounts for crop rotations, tillage rotations, and cost-share payments from year to year.

V. Data

Two surveys were utilized as the basis of cover crop-specific costs and yield benefits for this analysis. Results from each of these surveys were verified by farmer-reported financial data submitted to SWCD cost-share programs. Survey results about cover crop cost and management information that is specifically tied to establishment and termination were of special interest to this analysis.

PRIMARY DATA: WILTS JOHNSON SURVEY

Informal conversations via email, phone, and in-person took place to collect primary data from farmers to supplement the FINBIN dataset. This resulted in a dataset consisting of 23 farms across Minnesota that provided both financial and informational data on their experiences with reduced tillage and cover crops on their farms. We reached many of these farmers through their local SWCD or watershed district. This survey was used specifically to report cover crop seed costs and termination costs. Additionally, the costs and benefits gathered in this study were verified by farmer financial data reported through the SWCD cover crop cost-share programs. For ease of reporting, this survey will be referred to as the Wilts Johnson Survey for the rest of this paper. Results of this survey are reported in Table 9.

Most of the farms that participated in this survey were from the northwest and central regions. There were twelve farm participants form the northwest region, nine farms from the central region, three farms from the south central region, and two farms from the southwest region. The surveys were conducted via informal phone conversations. Farm participants in this survey ranged from having 6 acres to 2,400 acres of cover cropped land. The three most common cover crop seed varieties were cereal rye, a cereal rye mix, and a multi-species cover crop mix. The most common seed variety and rate reported was cereal rye planted between 60-90 pounds/acre. The survey results showed this combination ranging from \$9-\$18/acre, but most farms spent between \$11-\$13/acre.

The two most common reported planting methods were (1) a farm planting their own cover crops and (2) paying an aerial applicator to establish the cover. Aerial application was most prevalent in the northwest region. The cost to hire an airplane ranged between \$8-\$10/acre. The cost for a farmer to plant their own cover crop varied significantly from \$0-\$33/acre, likely depending on the value each farm placed on operator labor.

Approximately 58% used herbicide to terminate their cover crops, with an average cost of \$4-\$5/acre. Most of these farms would apply a pre-emergent herbicide with or without cover crops on the field, so the \$4-\$5/acre cost associated with herbicide termination is for the additional glyphosate required in the existing herbicide pass to kill the cover crop. The remainder of farms reported termination methods of tillage, winter kill, and grazing or harvesting for forage.

All farm participants except four had received a cost-share payment. The list of participants for the survey was obtained from local SWCD, so it was not surprising that a high percentage participated in cost-share programs. The median reported cost-share payment was \$34/acre.

In addition to costs and benefits directly tied to the establishment and termination of cover crops, farms were also asked about how cover crops impacted their fertilizer and herbicide programs. Many farms indicated a decrease in fuel cost; however, this decrease was associated with a change in tillage method, going from conventional tillage to reduced tillage, rather than being associated with the adoption of cover crops. Approximately 36% reported decreased fertilizer costs associated with cover crops through decreased rates of nitrogen application to cover cropped acres. The remainder of farms (64% of participants) reported that the adoption of cover crops did not change their fertilizer programs.

Only 27% of respondents reported a change to their herbicide program due to cover crops use. Two of these farms reported their ability to decrease herbicide costs on the cover crop acreage, and the third farm reported a slight herbicide cost increase due the additional glyphosate needed for cover crop termination. The other 72% of respondents did not change their herbicide programs after cover crop adoption.

When asked about yield changes, most respondents answered positively but did not provide a specific yield increase. Three farms reported noticeable yield advantages of 10-50 bushels/acre on cover cropped acres compared to their yields before cover cropping those acres. The remainder of farmers believed their yields were better than before the cover crop, but the yield increase was not large enough to report. None of the participating farmers mentioned a yield decrease.

PRIMARY DATA: FINBIN

The FINBIN dataset used in Chapter 2 of this analysis has 8,182 total farms with 85,984 total unique observations across corn, soybean, and spring wheat enterprises from 2009-2019. However, only 13 observations reported the use of cover crops. The small sample size is likely the result of two reasons. First, the “Cover Crop” option was added in the database in 2018, so this FINBIN dataset only had one year’s worth of data regarding cover crops. Second, since the “Cover Crop” option was new in 2018, it is likely a number of farmers and Farm Management Instructors were not aware of the option or did not know how to use it. The small sample size of cover crop users was insufficient, so gathering additional data was necessary for this study.

SECONDARY DATA: SARE/CTIC SURVEY

Sustainable Agriculture Research and Education (SARE), the Conservation Technology and Information Center (CTIC), and the American Seed Trade Association (ASTA) also conducted a survey of farmers throughout the United States. These organizations conducted a similar study each year since 2012. The data for this research came from the 2019-2020 survey. The survey had 1,172 respondents, with 91 reporting that most of their acreage was in Minnesota. The Minnesota respondents had a range of zero to 30+ years of experience with cover crops on their farms.

DATA ASSUMPTIONS

A combination of the primary data collected in the Wilts Johnson survey and the Minnesota responses from the 2019-2020 SARE/CTIC cover crop survey were used to supplement the unavailable FINBIN cover crop economic variables. The Excel spreadsheet has five evaluation categories, all of which are based on user input. These categories are (1) information about the producer or farm, (2) information about the cash crop on the field, (3) costs for establishing the cover crop, (4) costs for terminating the cover crop, and (5) other income or costs. The financial implication in the model of each of these options is associated with the survey responses and is detailed below. This information is also summarized in Table 9.

Producer or Farm Information

Information about the producer included the state and county of the operation, the total acres in the field, and the total field acres planted to cover crops. These items are input by the producer into the spreadsheet. The producer's county of operation is used to determine the cash crop yield on the farm using the yield estimates calculated in Chapter 2 from the FINBIN data.

Cash Crop Information

Information about the cash crop on the field included the cash crop species, the tillage method that will follow corn, and the tillage method that will follow soybeans. This spreadsheet only considers farms with a corn and soybean rotation which is a product of the main crops and rotations reported from all three data sources. The tillage method options come from the FINBIN data used in Chapter 2. The costs for establishing and terminating cover crops are detailed below.

Cover Crop Establishment Information

One of the largest costs of growing cover crops is the cost of seed (Myers et al., 2019). The seed cost/acre varies based on the seed variety and the seeding rate. Survey results show the most common cover crop seed varieties planted on Minnesota farms are

(1) cereal rye, (2) a cereal rye mixture that contains 1-3 other cover crop varieties, or (3) a cover crop mixture that contains 4-5+ cover crop varieties. Seed costs collected from the Wilts Johnson survey were used to predict the seed costs in the spreadsheet tool. On average, farmers who planted cereal rye incurred the lowest seed costs, and farmers who planted cover crop mixtures incurred the highest cover crop seed costs.

The cover crop seeding rate is often influenced by the seed selection. Seeding rates were included in 30 pounds per acre increments, starting at 30 pounds per acre up to 120 pounds per acre. The seeding rate options in the interactive spreadsheet and the model's financial implications were derived from the SARE/CTIC survey (Table 9). Farmers who planted cover crops with lower seeding rates experienced lower per acre seed costs compared to farmers who planted higher seeding rates of cover crops. Seed costs varied significantly based on these establishment decisions. For example, a farm that planted cereal rye at 30-60 pounds per acre had a seed expense of $7.50/acre, while a farm that planted a cover crop mix at 60-90 pounds per acre had a seed expense of $35/acre.

Given that cover crop seeding usually occurs when there is already a cash crop growing in the field or shortly after the cash crop is harvested, planting a cover crop without harming the cash crop requires strategic planning. The main methods for planting cover crops are aerial application with an airplane, highboy application, drilling with a planter, and broadcasting with soil incorporation. Aerial application is often more expensive than using a drill or highboy, but it is the easiest method when seeding the cover crop before harvesting the cash crop. Drilling is the most common planting method post-harvest. To capture the planting methods in the model, the interactive tool incorporates the following planting options: (1) I will plant my own cover crops, (2) I will pay an aerial applicator to plant my cover crops, (3) I will pay an agricultural retailer or cooperative to plant my cover crops, or (4) I will pay a neighbor or friend to plant my cover crops. These options coincide with the 2019-2020 SARE/CTIC survey.

According to the SARE/CTIC survey results, farms that plant their own cover crop reported no seeding cost. Farms that pay an agricultural retailer or cooperative to establish the cover crop costs reported $8/acre in seeding cost, those who pay an aerial applicator reported $12/acre, and farms that pay a neighbor or friend to plant the cover crop reported $15/acre in cover crop seeding expense. These results were similar in the Wilts Johnson survey.

Cover Crop Termination Methods

Similarly to seeding methods, termination methods vary across farms. Three termination methods were considered for this analysis: (1) winter termination, (2) herbicide termination, and (3) tillage termination. Termination costs were also impacted by the party performing the termination: (1) operator, or (2) custom hired. These options and their financial impacts come from the Wilts Johnson survey and are shown in Table 9. The cheapest termination method was winter kill, which had $0/acre reported for termination expense. Tillage termination, done by either the operator or custom hired, that did not require a new pass over the field also had a reported termination expense of $0/acre. Termination costs for herbicide applied as an additional pass by the operator or custom hired, and additional pass custom hired tillage termination methods were $10/acre, $12/acre, and $12/acre respectively. The most common termination method in the Wilts Johnson study was herbicide applied by the operator with no additional pass, which had a reported cost of $4.50/acre. Farmers reported the $4.50/acre termination cost in this scenario is the price of the Roundup that is added to the existing pre-emergent herbicide pass on the field.

Other Cover Crop Costs and Revenue

As determined in Chapter 2, yield is impacted by geographic location and by tillage method. The regression results from Chapter 2 were used to estimate the cash crop yield in the interactive spreadsheet based on the farm's tillage method and the county in which the majority of the farm is located. A summary of these yield estimates are in Table 7 and represent the region-specific yield of the cash crop before any yield impacts from cover crop are incorporated, based on the selected tillage method.

Cash crop yield impacts from the use of cover crops were studied in the SARE/CTIC survey. Yield impacts varied between corn and soybeans, with the largest yield increases reported for cover cropped soybean acres. For both cash crops, no yield impacts were observed in the first year of cover crop establishment, but a long-term analysis showed yield increases. In soybeans, reported yields increased by 1.6% after one year of cover cropping, 3.6% after three years of cover cropping, and 5.9% after five years of cover cropping. Corn yields decreased in the first year after cover cropping, but increased after that. One year following the cover crop showed a reported corn yield decrease of 0.5%, three years following reported and increased yield of 0.9%, and five years following showed a 1.0% reported corn yield increase. The survey included yield analyses from five Midwestern states including Minnesota, North Dakota, South Dakota, Iowa, and Wisconsin. Additional details of the yield impacts from cover crops can be found in Table 8.

NPV ASSUMPTIONS

Two NPV analyses were used in this decision tool to evaluate the economic impact of cover crops. The first NPV was projected over a five-year time period; the second used a 10-year time period. Since the inflation rate is between 2%-3%, both of these analyses used a conservative discount rate of 2.5% to reflect the currently low interest rates.

Table 8. Corn and soybean yield increases based on the number of consecutive years a field has had cover crops

Crop	Years Consecutively Cover Cropped	Observations	Yield Increase (%)
Soybeans	1	29	1.6
Soybeans	2	20	3.5
Soybeans	3	22	5.9
Corn	1	31	-0.5
Corn	2	23	0.9
Corn	3	21	1.0

*Data is from the 2019-2020 SARE survey using Minnesota, North Dakota, South Dakota, Iowa, and Wisconsin

VI. Results

The data collected from this research was used to develop an interactive Excel spreadsheet to be used by farmers when considering the adoption of cover crops. This spreadsheet is designed to calculate cover crop cost increases and decreases associated with each user input as a function of the 2019-2020 SARE/CTIC survey and the Wilts Johnson survey. Cash crop yield estimates associated with each user input were calculated as a function of the farm financial data in FINBIN based on tillage type and geographic location. Once a user enters their farm information into the spreadsheet tool, the total cost increase or decrease that can be associated with cover crops is calculated, given the specific user-entered scenario. An NPV analysis is the underlying economic tool incorporated in the spreadsheet to analyze the financial impacts of cover crops as a single-year decision and as a multi-year decision.

BASE COMPARISON SCENARIO

The base comparison farm in the sensitivity analysis was a no-till farm in south central Minnesota that plans to plant cereal rye following soybeans and following corn, where the first fall of growing a cover crop is following corn. This farm will plant and establish their own cover crops at a seeding rate of 50 lbs/acre. They will terminate the cereal rye in the spring with an already existing pre-emergent herbicide pass over the field. The farm reports operator labor at 0.25 hours/acre for seeding and 0.25 hours/acre for termination, with a reported value of operator labor at $15/hour. They are not receiving a cost-share payment. These farm assumptions are summarized in Table 11.

With the given scenario, the farm shows a loss of $19.50/acre in the establishment year. The five-year NPV analysis shows the farm losing $47.68/acre on cover cropped acres, and the 10-year NPV analysis shows the farm losing $49.46/acre on cover cropped acreage. The cover crop establishment year costs are broken down to be $7.50/acre for seed cost, $11.25/acre in seeding, and $8.25/acre for termination costs. The expected soybean yield is not impacted by the cover crop in the first year of establishment, however the expected yields increase throughout the NPV analysis as suggested by the SARE/CTIC survey results (Table 8 and Table 9). The cash crop yield without the cover crop's impact is determined from the regression estimates in Chapter 2 based on region and tillage type, as summarized in Table 10.

Although the farm does not receive a cost-share payment, six cost-share options were considered comparing two different cost-share amounts and three different years. First, a cost-share of $19.50/acre for one year, two years, three years. Second, a cost-share of $27/acre for one year, two years, or three years. These two cost-share amounts were determined based on the current cost-share options offered throughout Minnesota's SWCDs. Each SWCD has their own cost-share program so the payment options differ by county, but most range from $15-30/acre. Cost assistance of $19.50 is used in this analysis to study the impacts of a lower cost-share amount, and $27/acre is used to study the impacts of a high cost-share amount. In the base scenario, if the farm's cover crop costs were matched by a 1-year cost-share payment of $19.50/acre, the farm would break-even in the establishment year, show a loss of $28.66/acre in the 5-year NPV analysis, and show a loss of $30.44/acre in the 10-year NPV analysis. If the $19.50/acre cost-share is increased from a 1-year payment to a 2-year payment the farm would still break-even in the establishment year, but the 5-year NPV loss decreases to $10.10/acre, and the 10-year NPV loss shrinks to be a loss of $11.88/acre. However, when the cost-share payment is received for three years of cover cropping, the farm is able to report economic gains on cover-cropped acres over all years. Again, they break-even in the establishment year, they show a gain of $8.01/acre in the 5-year NPV analysis, and a gain of $6.23/acre in the 10-year NPV analysis. Therefore, a three-year cost-share payment of $19.50/acre is necessary for the base scenario farm to see positive cash flows in this investment.

When the farm receives $27/acre for one year, the farm makes $7.50/acre in the establishment year but shows losses in the 5-year and 10-year NPV analyses. When the $27/acre cost-share is extended over 2 and 3 years, the farm shows gains every year. The cost-share of $27/acre for more than one year is greater assistance than the farm needs. So, in this scenario, the ideal cost-share is $19.50/acre over a 3-year time period. The results of this cost-share analysis are shown in Table 12.

SENSITIVITY ANALYSIS

Given the many factors that impact the financial feasibility of cover crops on a farm that create uncertainty in the model input, a sensitivity analysis was conducted to analyze the impact of changes in user scenarios on the economic outcome calculated in the spreadsheet tool (Saltelli et al., 2004). For this analysis, the geographic location of the farm and the number of acres they plant to cover crops remain constant.

Each scenario has one, single variable that is different from the previously mentioned base scenario. Variables that were varied throughout the sensitivity analysis include the farm's tillage method, the cover crop variety planted, seeding rate, seeding method, termination method, the value of operator labor, and the presence of a cost-share payment. Additionally, three cost-share options are considered for each scenario to determine the necessity of a cost-share program and the most beneficial cost-share value and length in that scenario. The goal of this sensitivity analysis is to study how each variable impacts the overall economic decision to incorporate cover crops into a farming operation compared to the base scenario. This results of this sensitivity analysis are detailed in Table 12.

Scenario 1A: Changing the tillage method from all no-till to using strip-till after soybeans

Tillage, as analyzed in Chapter 2 of this study, is a key factor that influences yield, and ultimately the revenue received. Scenario 1A holds all farm characteristics from the base scenario constant except the tillage method used. In the base scenario no-till was used following both corn and soybeans. In Scenario 1A, no-till follows corn, but strip-till follows soybeans. The only difference in the spreadsheet between the base scenario and Scenario 1A is the estimated yield received for corn, which is 184.34 bushels per acre for the strip-till corn compared to 184.15 bushels per acre for no-till corn. The establishment year shows a loss of $19.50/acre in this scenario, the 5-year NPV shows a loss of $47.23/acre, and the 10-year NPV shows a loss of $48.04/acre.

Scenario 1B: Changing the tillage method from using all no-till to using all strip-till

All farm characteristics from the base scenario remain the same in Scenario 1B, except the use of no-till is replaced by the use of strip-till following both corn and soybeans. Similar to Scenario 1A, this change does not affect the cost analysis for the establishment year, which still shows a loss of $19.50/acre. Scenario 1B's 10-year NPV shows a loss of $48.02/acre, which is $0.02/acre lower than the base scenario.

Scenario 2: Changing the cover crop seed variety from cereal rye to cereal rye mix

In Scenario 2 the farm plants a cereal rye mix rather than planting cereal rye. This increased seed cost by $7.50/acre and results in the farm showing a loss of $27/acre in the establishment year, a loss of $82.53/acre in the 5-year NPV analysis, and a loss of $115.10/acre in the 10-year NPV analysis. Although the farm does not receive a cost-share payment, a few cost-share options were analyzed within this scenario. With the $19.50/acre cost-share option including payments for one year, two years, and three years, the farm shows cash flow losses for each of the NPV analyses. Similarly, with the $27/acre cost-share option, the farm breaks even in the establishment year, but again shows negative cash flows for the other cost-share time period options.

Scenario 3: Changing the cover crop seeding rate from 50 lbs/acre to 80 lbs/acre

Scenario 3 changes the cereal rye seeding rate from 50 lbs/acre to 80 lbs/acre. This increase in seeding rate increases the farm's cover crop seed expense by $5/acre. They need to purchase more seed since they are planting more seeds per acre. This scenario shows a loss of $24.50/acre ($5/acre more negative than the comparison scenario) in the establishment year, loss of $70.91/acre ($23.23/acre more negative than the base scenario) in the 5-year NPV analysis, and a loss of $93.22/acre ($43.76/acre more negative than the base scenario) in the 10-year NPV analysis. As shown in Table 12, a 3-year cost-share payment of $19.50/acre still results in negative cash flows for each NPV analysis; however, a 3-year cost-share payment of $27/acre has positive cash flows for the establishment year and for the 5-year NPV analysis. A $27/acre cost-share given for four years will show positive cash flows for the 10-year NPV as well.

Scenario 4: Changing the cover crop seeding method from "I will plant and establish my own cover crop" to "I will pay an aerial applicator to establish my cover crop"

This scenario keeps all the farm characteristics of the base scenario the same except the cover crop seeding method. Rather than establishing the cover crops on their own, the farm pays an aerial applicator to plant and establish the cover crops. This change increases the cover crop establishment cost by $8.25/acre. Scenario 4 shows the farm losing $27.75/acre in the establishment year, $86.01/acre in the 5-year NPV analysis, and $121.67/acre over the 10-year NVP analysis. This scenario requires more cost-share assistance than the previous scenarios. A 3-year cost-share of $27/acre is not enough financial assistance as shown in Table 12. Rather, this amount needs to be provided for five years for this scenario to incur a positive cash flow in the 10-year NPV analysis.

Scenario 5A: Decreasing operator labor costs from $15/hour to $10/hour

For Scenario 5A, operator labor costs are decreased from $15/hour to $10/hour. This scenario decreases their per-acre costs by $2.50/acre compared to the base scenario. The establishment year, 5-year, and 10-year analyses are still negative, however the 10-year NPV shows a loss of $27.58/acre compared to the base scenario 10-year NPV loss of $49.46/acre. When considering the cost-share options, this scenario will see positive cash flows if given $19.50/acre of cost-share for two years.

Scenario 5B: Decreasing operator labor costs from $15/hour to $0/hour

Operator labor cost is decreased from $15/hr to $0/hour. This change in the scenario decreases per acre costs by $7.50 compared to the base scenario. Scenario 5B shows a loss of $12/acre in the first year, loss of $12.84/acre for the 5-year NPV analysis, and an overall gain of $16.18/acre in the 10-year NPV analysis. This is the lowest-cost option available within the interactive spreadsheet. A cost-share of $19.50/acre for 1 year shows the farm will have per-acre gains across all years. In this scenario, a cost-share less than $19.50/acre may be sufficient to financially assist the farm in adopting cover crops.

Table 9: Cover crop costs and benefits incurred by Minnesota farms, 2019-2020.

Input Information	Obs	Value	Response Range
Cover Crop Seed Cost		**($/Acre)**	**($/Acre)**
Cereal Rye, 30-60 lbs/acre	7	7.50	5.00 – 7.50
Cereal Rye, 60-90 lbs/acre	7	12.50	9.00 – 18.00
Cereal Rye, 90-120 lbs/acre	1	14.00	14.00
Cereal Rye Mix, 30-60 lbs/acre	3	15.00	14.00 – 16.00
Cereal Rye Mix, 60-90 lbs/acre	4	28.00	20.00 – 30.00
Cereal Rye Mix, 90-120 lbs/acre	3	30.00	23.00 – 30.00
Cover Crop Mix, 30-60 lbs/acre	3	30.00	28.00 – 30.00
Cover Crop Mix, 60-90 lbs/acre	4	35.00	30.00 – 35.00
Cover Crop Seeding Cost		**($/Acre)**	
Plant my own	40	0.00	
Pay an ag retailer or coop	1	8.00	
Pay an aerial applicator	12	12.00	
Pay a neighbor or friend	10	15.00	
Termination Cost		**($/Acre)**	**($/Acre)**
Herbicide, operator-applied, additional pass	3	9.00	9.00
Herbicide, operator-applied, no additional pass	9	4.50	0.00 – 5.00
Herbicide, custom-applied, additional pass	2	12.00	11.00 – 12.00
Herbicide, custom-applied, no additional pass	1	4.50	4.50
Tillage, done by operator, additional pass	2	8.00	8.00
Tillage, done by operator, no additional pass	2	0.00	0.00
Tillage, custom hired, additional pass	1	12.00	12.00
Tillage, custom hired, no additional pass	1	0.00	0.00
Winter kill	9	0.00	0.00
Cash Crop Yield Impact from the Cover Crop		**(% change)**	
Corn, Year 1 – Establishment year		0.0%	
Corn, Year 2	29	1.6%	
Corn, Year 3	20	3.5%	
Corn, Year 4	22	5.9%	
Corn, Year 5		5.9%	
Corn, Year 6		5.9%	
Corn, Year 7		5.9%	
Corn, Year 8		5.9%	
Corn, Year 9		5.9%	
Corn, Year 10		5.9%	
Soybeans, Year 1		0.0%	
Soybeans, Year 2	31	-0.5%	
Soybeans, Year 3	23	0.9%	
Soybeans, Year 4	21	1.0%	
Soybeans, Year 5		1.0%	
Soybeans, Year 6		1.0%	
Soybeans, Year 7		1.0%	
Soybeans, Year 8		1.0%	
Soybeans, Year 9		1.0%	
Soybeans, Year 10		1.0%	
Cost Share		**Median ($/Acre)**	**($/Acre)**
No Cost-Share Received	4	0.00	0.00
Cost-Share Received	22	34.00	15.00-62.00

Value Range is the range of responses reported by survey participants.

Cover Crop Seed Cost and Termination Cost Source: Wilts Johnson Survey.

Cover Crop Seeding Cost and Cash Crop Yield Impacts from the Cover Crop Source: SARE/CTIC Survey.

Table 10: Estimated Cash Crop Yields (without cover crops), 2019-2020

Input Information	**Observations**	**Value**
Cash Crop Yield		**(Bu/Acre)**
Corn, northwest region, no-till	37	128.80
Corn, northeast region, no-till	104	134.47
Corn, central region, no-till	33	144.72
Corn, southwest region, no-till	161	184.15
Corn, south central region, no-till	73	187.00
Corn, southeast region, no-till	116	166.53
Corn, northwest region, chisel-till	14	154.55
Corn, northeast region, chisel-till	12	148.66
Corn, central region, chisel-till	158	174.75
Corn, southwest region, chisel-till	288	182.72
Corn, south central region, chisel-till	231	188.03
Corn, southeast region, chisel-till	76	182.74
Corn, northwest region, strip-till	1,790	146.60
Corn, northeast region, strip-till	972	153.55
Corn, central region, strip-till	3,883	182.15
Corn, southwest region, strip-till	7,363	184.34
Corn, south central region, strip-till	7,213	184.84
Corn, southeast region, strip-till	3,022	178.87
Soybeans, northwest region, no-till	93	37.08
Soybeans, northeast region, no-till	95	39.44
Soybeans, central region, no-till	79	46.81
Soybeans, southwest region, no-till	433	52.01
Soybeans, south central region, no-till	172	51.41
Soybeans, southeast region, no-till	278	49.57
Soybeans, northwest region, chisel-till	7	37.58
Soybeans, northeast region, chisel-till	5	36.80
Soybeans, central region, chisel-till	129	46.52
Soybeans, southwest region, chisel-till	130	52.54
Soybeans, south central region, chisel-till	206	53.29
Soybeans, southeast region, chisel-till	39	52.22
Soybeans, northwest region, strip-till	3,655	23.62
Soybeans, northeast region, strip-till	658	44.86
Soybeans, central region, strip-till	2,931	49.94
Soybeans, southwest region, strip-till	6,595	52.75
Soybeans, south central region, strip-till	5,804	50.82
Soybeans, southeast region, strip-till	1,947	52.20
Expected Selling Price		**($/Acre)**
Corn		3.41
Soybeans		8.99

Cash Crop Yield Source: Chapter 2 Regression Estimates.

Expected Selling Price Source: FINBIN average price/bushel across all regions, 2015-2019

Table 11: Assumptions for the base comparison scenario

Variable	**Base Scenario Assumption**
Tillage following soybeans	No-till
Tillage following corn	No-till
Cover crop variety following soybeans	Cereal Rye
Cover crop variety following corn	Cereal Rye
Seeding rate	50 lbs/acre
Seeding method	I will plant and establish my own
Termination method	Existing herbicide pass
Value of operator labor	$15/hour
Operator labor hours for seeding	0.25 hours/acre
Operator labor hours for termination	0.25 hours/acre
Cost-share payment	None received
NPV discount rate	2.5%

Table 12: Sensitivity Analysis Scenario Results, Cost Increase/Decrease from Cover Crops ($/Acre)

Scenario	**Variable**	**Establishment Year Value ($/Acre)**	**5-Year NPV ($/Acre)**	**10-Year NPV ($/Acre)**	**Establishment Year Value ($/Acre)**	**5-Year NPV ($/Acre)**	**10-Year NPV ($/Acre)**
		$19.50/Acre Cost Share			$27/Acre Cost Share		
Base Scenario	-	($19.50)	($47.68)	($49.46)	($19.50)	($47.68)	($49.46)
1-Year Cost Share	-	$0.00	($28.66)	($30.44)	$7.50	($21.34)	($23.12)
2-Year Cost Share	-	$0.00	($10.10)	($11.88)	$7.50	$4.36	$2.58
3-Year Cost Share	-	$0.00	$8.01	$6.23	$7.50	$29.43	$27.65
Scenario 1A	Tillage: Strip-Till Following Soybeans	($19.50)	($47.23)	($48.04)	($19.50)	($47.23)	($48.04)
1-Year Cost Share	Tillage: Strip-Till Following Soybeans	$0.00	($28.20)	($29.01)	$7.50	($20.88)	($21.70)
2-Year Cost Share	Tillage: Strip-Till Following Soybeans	$0.00	($9.64)	($10.45)	$7.50	$4.81	$4.00
3-Year Cost Share	Tillage: Strip-Till Following Soybeans	$0.00	$8.47	$7.65	$7.50	$29.89	$29.07
Scenario 1B	Tillage: Strip-Till Following Corn & Soybeans	($19.50)	($47.21)	($48.02)	($19.50)	($47.21)	($48.02)
1-Year Cost Share	Tillage: Strip-Till Following Corn & Soybeans	$0.00	($28.19)	($28.99)	$7.50	($20.87)	($21.68)
2-Year Cost Share	Tillage: Strip-Till Following Corn & Soybeans	$0.00	($9.63)	($10.43)	$7.50	$4.83	$4.02
3-Year Cost Share	Tillage: Strip-Till Following Corn & Soybeans	$0.00	$8.48	$7.68	$7.50	$29.90	$29.10

Table 12: Sensitivity Analysis Scenario Results, Cost Increase/Decrease from Cover Crops ($/Acre)

Scenario	**Variable**	**Establishment Year Value ($/Acre)**	**5-Year NPV ($/Acre)**	**10-Year NPV ($/Acre)**	**Establishment Year Value ($/Acre)**	**5-Year NPV ($/Acre)**	**10-Year NPV ($/Acre)**
		$19.50/Acre Cost Share			$27/Acre Cost Share		
Scenario 2	Seed Variety: Cereal Rye Mix	($27.00)	($82.53)	($115.10)	($27.00)	($82.53)	($115.10)
1-Year Cost Share	Seed Variety: Cereal Rye Mix	($7.50)	($63.50)	($96.08)	$0.00	($56.18)	($88.76)
2-Year Cost Share	Seed Variety: Cereal Rye Mix	($7.50)	($44.94)	($77.52)	$0.00	($30.49)	($63.06)
3-Year Cost Share	Seed Variety: Cereal Rye Mix	($7.50)	($26.83)	($59.41)	$0.00	($5.41)	($37.99)
Scenario 3	Seeding Rate: 80 lbs/acre	($24.50)	($70.91)	($93.22)	($24.50)	($70.91)	($93.22)
1-Year Cost Share	Seeding Rate: 80 lbs/acre	($5.00)	($51.89)	($74.20)	$2.50	($44.57)	($66.88)
2-Year Cost Share	Seeding Rate: 80 lbs/acre	($5.00)	($33.33)	($55.64)	$2.50	($18.87)	($41.18)
3-Year Cost Share	Seeding Rate: 80 lbs/acre	($5.00)	($15.22)	($37.53)	$2.50	$6.20	($16.11)
Scenario 4	Seeding Method: Paying an Aerial Applicator	($27.75)	($86.01)	($121.67)	($27.75)	($86.01)	($121.67)
1-Year Cost Share	Seeding Method: Paying an Aerial Applicator	($8.25)	($66.99)	($102.64)	($0.75)	($59.67)	($95.67)
2-Year Cost Share	Seeding Method: Paying an Aerial Applicator	($8.25)	($48.43)	($84.08)	($0.75)	($33.97)	($69.63)
3-Year Cost Share	Seeding Method: Paying an Aerial Applicator	($8.25)	($30.32)	($65.98)	($0.75)	($8.90)	($44.56)

Table 12 Continued: Sensitivity Analysis Scenario Results, Cost Increase/Decrease from Cover Crops ($/Acre)

Scenario	**Variable**	**Establishment Year Value ($/Acre)**	**5-Year NPV ($/Acre)**	**10-Year NPV ($/Acre)**	**Establishment Year Value ($/Acre)**	**5-Year NPV ($/Acre)**	**10-Year NPV ($/Acre)**
		$19.50/Acre			$27/Acre		
Scenario 5A	Operator Labor: $10/hr	($17.00)	($36.07)	($27.58)	($17.00)	($36.07)	($27.58)
1-Year Cost Share	Operator Labor: $10/hr	$2.50	($17.04)	($8.56)	$10.00	($9.73)	($1.24)
2-Year Cost Share	Operator Labor: $10/hr	$2.50	$1.52	$10.00	$10.00	$15.97	$24.46
3-Year Cost Share	Operator Labor: $10/hr	$2.50	$19.62	$28.11	$10.00	$41.04	$49.53
Scenario 5B	Operator Labor: $0/hr	($12.00)	($12.84)	$16.18	($12.00)	($12.84)	$16.18
1-Year Cost Share	Operator Labor: $0/hr	$7.50	$6.19	$35.20	$15.00	$13.50	$42.52
2-Year Cost Share	Operator Labor: $0/hr	$7.50	$24.75	$53.76	$15.00	$39.20	$68.22
3-Year Cost Share	Operator Labor: $0/hr	$7.50	$42.85	$71.87	$15.00	$64.27	$93.29

Estimates calculated from the interactive spreadsheet tool.
The cost-share assistance programs in this comparison are $19.50/acre and $27/acre.
The first line of every scenario shows the cash flows of the scenario without cost-share assistance.

VII. Discussion and Conclusions

The objective of this research was to understand the impact of cover crops on the profitability of Minnesota row crop farms. Influential factors of cover crop establishment and termination were analyzed to determine the economic magnitude of cover crops on a farm. The results of this study indicate that per-acre cover crop costs vary significantly based on management decisions. Seed expense depends on which cover crop seed variety is planted and the seeding rate, seeding expense is impacted by the method used to plant the cover crop, and termination expense changes based on the method selected to terminate the cover crop. Soil type, weather conditions, and growing degree days that are impacted by the geographic location of the farm and all play a role in the financial impact of cover crops as well. There is an infinite variety in the expenses tied to cover crop adoption given the differences in cover crop seed mixes, seeding rates, and termination methods. Considering the variability in each of these decisions, the financial impacts of cover crops is unique to each farm's situation. The costs analyzed in this paper represent a defensible range of expenses within the overall variation.

The primary and secondary data collected and analyzed in this study suggests that cover crops can be economically beneficial based on the farm's management decisions. Our results confirm that cover crops have large up-front costs; however, certain management decisions result in low per-acre costs while other cover crop management decisions produce large per-acre costs. For example, a farm that pays an agricultural retailer or cooperative to plant cereal rye at 50 lbs/acre incurs an establishment cost of \$15.50/acre, but a farm that pays an aerial applicator to plant a cereal rye mix at 90 lbs/acre incurs an establishment cost of \$36/acre. Understanding the financial implications of these variations will ensure farmers consider finically feasible cover crop establishment and termination options.

In many scenarios without cost-share assistance, the financial impact of cover crops is negative both in the short-term and long-term. This is in line with Plastina's research on cover crop economics (2018). We confirm that cover crops have large up-front costs. Yield benefits that are a function of cover crops grow over time, but are not large enough in the first few years of cover crop establishment to overcome the costs of this non-revenue stream investment. However in most scenarios, cover crops show economic per-acre gains when a \$15-\$25/acre cost-share payment is received for the first 3-5 years of cover crop establishment. By the end of the cost-share, yield benefits are large enough to financially support the costs of establishing and terminating cover crops.

The assistance of cost-share programs is crucial for farms to show positive cash flows when adopting cover crops. However, cost-share payments often limit either the amount of acres receiving the cost-share, the amount of money received per acre, or the number of years a farm is eligible for receiving assistance. For example, the Dakota County SWCD cost-share program offers either (1) assistance of \$25/acre for 1 year with a maximum assistance payment of \$2,500/acre or 100 acres, or (2) assistance of \$35/acre per year for three years with a maximum of \$10,500 or 100 acres (SWCD, 2020). This is a substantial amount of cost-share for 100 acres, however this cost-share has much less benefit for a farm considering cover crops on more than 100 acres. An option for a lower \$/acre spread over larger acreage limits or distributed to a farm for more years could be a considerable and beneficial cost-share option.

Limited variability in the primary and secondary data restricted the scope of the interactive spreadsheet that was created as part of this research. A majority of respondents were corn and soybean growers, thus there was not enough data to for other crop species to be included in the cover crop spreadsheet decision tool. The data suggests cover crops are grown more on corn or soybean acres than on wheat acres. However, wheat acreage devoted to cover crops will continue to be limited if farmers remain uncertain of the financial impact of cover crops on these acres. Data with more detailed cover crop information on wheat operations could improve the scope and effectiveness of the interactive spreadsheet tool.

Cover crops are a non-revenue stream investment, where single-year profits in early years of the investment are exchanged for maximized profits in later years. It is important to analyze the economic implications of cover crops in a single-year analysis and over multiple years to account for the large up-front investment costs that are balanced by long-run financial benefits. Since there is little economic data available showing the payback period of cover crops, this decision is difficult for farmers to consider. This research emphasizes the importance of analyzing the economics of cover crops as a both a single-year and multi-year decision as more research is done regarding the impact of cover crops on farm profitability.

CHAPTER 4: CONCLUSION

Rising environmental concerns over the past decade have spurred interest in environmentally sustainable agriculture practices including reduced tillage and cover crops. Soil scientists and conservationists are encouraging farmers to plant cover crops and use conservation tillage to reduce the negative impacts of production agriculture on the environment. The increased emphasis on these sustainability practices has farmers questioning how they will impact farm profitability. Farmers are leery about incorporating cover crops and conservation tillage on their farms due to the uncertainty of costs and returns associated with practices. Currently in agriculture production, profit margins are small and many farmers are losing money. With small profitability margins, farmers cannot afford to increase their cost of production unless the increase in cost is off-set by an increase in revenue.

Analyzing both the environmental and economic impacts of reduced tillage is crucial to assisting farmers in understanding the impact on their bottom line. Analyzing the costs and benefits of reduced tillage and conventional tillage suggests strip-till has the most benefits in both environmental and economic sustainability. Strip-till has environmental benefits of increasing soil organic matter and minimizing erosion, coupled with its high crop yields that come from proper seedbed preparation. However, every farm is unique, thus the tillage method chosen for each farm differs depending on farm characteristics such as its geographic location, soil type, weather patterns, existing equipment and farm labor.

Similarly, many of these same farm characteristics impact the financial feasibility of incorporating cover crops into a farming operation. Additionally, adopting cover crops is a long-term decision and can be viewed similarly to purchasing equipment; the up-front cost is high but the long-term benefits are worth the investment. The limited research on the long-term financial impacts of cover crops make this investment difficult for farmers to commit to. This analysis used primary and secondary data coupled with yield estimates that were calculated using FINBIN farm financial data to generate an interactive spreadsheet decision tool. The decision tool uses an NPV analysis to predict the economic impact of cover crops on a farm both as a single-year and multi-year decision while also accounting for the unique characteristics and management decisions on every farm. The goal of this tool is to assist farmers in analyzing the impacts of cover crops on farm profitability, leading them to make informed and confident decisions about incorporating cover crops onto their farming operations.

Furthermore, the results of this work provide further justification for local cost-share opportunities, and environmental improvement grants. Movements in environmental sustainability in agriculture will continue to struggle gaining momentum until these practices become more economically possible for farms. Policies to assist with these movements would act as a catalyst in this process.

REFERENCES

Anderson, R. L., Bowman, R. A., Nielsen, D. C., Vigil, M. F., Aiken, R. M., & Benjamin, J. G. (1999). Alternative crop rotations for the central Great Plains. *Journal of Production Agriculture*, *12*(1), 95-99.

Al-Kaisi, M., & Hanna, H. M. (2008). Resource Conservation Practices: Consider the Strip-Tilling Alternative.

Albouy, D. (2005). The Neoclassical Firm. Retrieved November 12, 2020, from https://eml.berkeley.edu/~webfac/card/e101a_s05/neoclassicalfirm.pdf

Angelo, M. J. (2009). Corn, carbon, and conservation, rethinking US agricultural policy in a changing global environment. *Geo. Mason L. Rev.*, *17*, 593.

Bergtold, J. S., Ramsey, S., Maddy, L., & Williams, J. R. (2017). A review of economic considerations for cover crops as a conservation practice. *Renewable Agriculture and Food Systems*, *34*(1), 62-76.

Bergtold, J., & Sailus, M. (2020). Conservation Tillage Systems in the Southeast. Retrieved from https://www.sare.org/wp-content/uploads/Conservation-Tillage-Systems-in-the-Southeast.pdf

Chatterjee, A. (2013). North-Central US: Introducing cover crops in the rotation. *Crops and Soils*, *46*(1), 14-15.

Claassen, R., Breneman, V. E., Bucholtz, S., Cattaneo, A., Johansson, R. C., & Morehart, M. J. (2004). *Environmental compliance in US agricultural policy: past performance and future potential* (No. 1473-2016-120702).

Coppess, J., & Gramig, B. (2018). Reviewing Directions in Conservation Policy: CSP and EQIP in the House Farm Bill. *farmdoc daily*, *8*.

Cruse, R. M., Linden, D., Radke, J. K., Larson, W. E., & Larntz, K. (1980). A model to predict tillage effects on soil temperature. *Soil Science Society of America Journal*, *44*(2), 378-383.

CTIC. (2017). Report of the 2016–17 national cover crop survey. *Joint publication of the Conservation Technology Information Center, the North Central Region Sustainable Agriculture Research and Education Program, and the American Seed Trade Association*.

CTIC. (2020). Annual Report 2019-2020, National Cover Crop Survey August 2020. Retrieved September 23, 2020, from https://www.sare.org/wp-content/uploads/2019-2020-National-Cover-Crop-Survey.pdf

Curell, C. (2014). Tillage practices have a direct correlation to soil health. Retrieved December 16, 2020, from https://www.canr.msu.edu/news/tillage_practices_have_a_direct_correlation_to_soil_health

Dalzell, B. J., Johnson, J. M., Tallaksen, J., Allan, D. L., & Barbour, N. W. (2013). Simulated impacts of crop residue removal and tillage on soil organic matter maintenance. *Soil Science Society of America Journal*, *77*(4), 1349-1356.

Debertin, D. L. (2012). Agricultural production economics.

DeJong-Hughes, J. (2019). Four years of tillage research wraps up. Retrieved December 14, 2020, from https://blog-crop-news.extension.umn.edu/2019/11/four-years-of-tillage-research-wraps-up.html

DeJong-Hughes, J., & Vetsch, J. (2007). On-farm comparison of conservation tillage systems for corn following soybeans.

Dobermann, A. R., Arkebauer, T. J., Cassman, K. G., Drijber, R. A., Lindquist, J. L., Specht, J. E., ... & Wortmann, C. S. (2003). Understanding corn yield potential in different environments.

Dooley, K. (2018). Soil Health Case Studies.

Ehlke, N. (2018). Agronomic Value of Crop Rotations in NW Minnesota. Retrieved December 16, 2020, from http://www.mncanola.org/pdf/MDAAgronomicValue14-17.pdf

Emas, R. (2015). The concept of sustainable development: definition and defining principles. *Brief for GSDR, 2015*.

Fageria, N. K., Baligar, V. C., & Bailey, B. A. (2005). Role of cover crops in improving soil and row crop productivity. *Communications in soil science and plant analysis*, *36*(19-20), 2733-2757.

Farmer's Guide to the Conservation Stewardship Program. (2015). Retrieved January 20, 2021, from http://sustainableagriculture.net/wp-content/uploads/2015/02/CSP-Farmers-Guide-2015-final.pdf

FINBIN (2020). *Crop Enterprise Analysis*. Center for Farm Financial Management: University of Minnesota. Retrieved June 30, 2020, from http://finbin.umn.edu

Frye, W. W., Smith, W. G., & Williams, R. J. (1985). Economics of winter cover crops as a source of nitrogen for no-till corn. *Journal of Soil and Water Conservation*, *40*(2), 246-249.

Gonzalez-Ramirez, M. J., Kling, C., Arbuckle, J. G., Morton, L. W., McGuire, J., & Benning, J. (2017). Cover crop adoption decisions in Iowa: Insights from an in-person survey. *Agricultural Policy Review*, *2017*(2), 3.

Gullickson, G. (2017). Strip-till merges benefits of tillage and no-till. Retrieved July 12, 2020, from https://www.agriculture.com/crops/corn/strip-till-merges-benefits-of-tillage-and-no-till

Hamilton, A. V., Mortensen, D. A., & Allen, M. K. (2017). The state of the cover crop nation and how to set realistic future goals for the popular conservation practice. *Journal of Soil and Water Conservation*, *72*(5), 111A-115A.

Helsel, Z. R. (2007). Fuel requirements and energy savings tips for field operations.

Higgs, R. L., Peterson, A. E., & Paulson, W. H. (1990). Crop rotations sustainable and profitable. *Journal of Soil and Water Conservation*, *45*(1), 68-70.

Hofstrand, D. (2009). Cost Terms. Retrieved November 14, 2020, from https://www.extension.iastate.edu/agdm/crops/pdf/a2-06.pdf

Hughes, M., & Langemeier, M. (2020). Cover Crops and Farm Profitability in Central Indiana. *farmdoc daily, (10):81*

Jory, S. R., Benamraoui, A., Boojihawon, D. R., & Madichie, N. O. (2017). Net present value analysis and the wealth creation process: A case illustration. *The Accounting Educators' Journal*, *26*.

Krueger, E. S., Ochsner, T. E., Porter, P. M., & Baker, J. M. (2011). Winter rye cover crop management influences on soil water, soil nitrate, and corn development. *Agronomy journal*, *103*(2), 316-323.

Lagae, H. J., Langemeier, M., Lybecker, D., & Barbarick, K. (2009). Economic value of biosolids in a semiarid agroecosystem. *Agronomy journal*, *101*(4), 933-939.

Looker, D. (2018). The Economics of Cover Crops. Retrieved July 29, 2020, from https://www.agriculture.com/crops/cover-crops/the-economics-of-cover-crops

Mahama, G. Y., Prasad, P. V., Roozeboom, K. L., Nippert, J. B., & Rice, C. W. (2016). Cover crops, fertilizer nitrogen rates, and economic return of grain sorghum. *Agronomy Journal*, *108*(1), 1-16.

Minnesota BWSR. (2019). Erosion Control and Water Management Program Policy. Retrieved January 12, 2021, from https://bwsr.state.mn.us/sites/default/files/2019-09/FY20%20Erosion_Control_and_Water_Management%20Program_Policy.pdf

Minnesota BWSR. (2018). Conservation, cover crops & communication. Retrieved June 16, 2020, from https://bwsr.state.mn.us/sites/default/files/2018-12/Snapshots-story-2-October-2018-LocalCapacity_0.pdf

Mold, D., & Rhees, S. (2020). Vegetative Cover in Minnesota: Prospects and Challenges. Retrieved December 14, 2020, from https://www.leg.mn.gov/docs/2020/other/200863.pdf

Myers, R., Weber, A., & Tellatin, S. (2019). Cover Crop Economics: Opportunities to Improve Your Bottom Line in Row Crops. *Sustainable Agriculture Research and Extension Technical Bulletin. Washington DC: US Department of Agriculture. https://www. sare. org/Learning-Center/Bulletins/Cover-Crop-Economics*.

NASS. (2019). 2019 STATE AGRICULTURE OVERVIEW. Retrieved July 7, 2020, from https://www.nass.usda.gov/Quick_Stats/Ag_Overview/stateOverview.php?state=MINNESOTA

NASS and MDA. (2008). Minnesota Agricultural Statistics 2008. Retrieved from https://www.leg.mn.gov/docs/2008/other/080865.pdf

Plastina, A., Liu, F., Sawadgo, W., Miguez, F. E., Carlson, S., & Marcillo, G. (2018). Annual net returns to cover crops in Iowa.

Plastina, A., Liu, F., Miguez, F., & Carlson, S. (2020). Cover crops use in Midwestern US agriculture: perceived benefits and net returns. *Renewable Agriculture and Food Systems*, *35*(1), 38-48.

Prices, M., Batts, R., Coppess, J., Ellison, B., Endres, A. B., Franken, J., ... & Month, B. Costs and Benefits of Cover Crops: An Example with Cereal Rye.

Randall, G., & Vetsch, J. (2005). Optimum Tillage Systems for Corn and Soybean Production and Water Quality Protection in South Central Minnesota--Minnesota River Basin.

Randall, G. W. (2002). Tillage Best Management practices for water quality protection in southeastern Minnesota.

Randall, G. W., Evans, S. D., Moncrief, J. F., & Lueschen, W. E. (1996). Tillage best management practices for continuous corn in the Minnesota River Basin.

Reimer, A. P., Gramig, B. M., & Prokopy, L. S. (2013). Farmers and conservation programs: Explaining differences in Environmental Quality Incentives Program applications between states. *Journal of Soil and Water Conservation*, *68*(2), 110-119.

Roberts, R. K., Larson, J. A., Tyler, D. D., Duck, B. N., & Dillivan, K. D. (1998). Economic analysis of the effects of winter cover crops on no-tillage corn yield response to applied nitrogen. *Journal of Soil and Water Conservation*, *53*(3), 280-284.

Saltelli, A., Tarantola, S., Campolongo, F., & Ratto, M. (2004). *Sensitivity analysis in practice: a guide to assessing scientific models* (Vol. 1). New York: Wiley.

Senjem, N. B., Moncrief, J. F., Randall, G. W., & Evans, S. D. (1996). Sediment problems and solutions for the minnesota river.

Slaper, T. F., & Hall, T. J. (2011). The triple bottom line: What is it and how does it work. *Indiana business review*, *86*(1), 4-8.

Snapp, S. S., Swinton, S. M., Labarta, R., Mutch, D., Black, J. R., Leep, R., ... & O'neil, K. (2005). Evaluating cover crops for benefits, costs and performance within cropping system niches. *Agronomy journal*, *97*(1), 322-332.

Steinhardt, G. C., Griffithand, D. R., & Mannering, J. V. (2006). Adaptability of tillage planting systems to indiana soils. *Agronomy Department, Purdue University. Cooperative Extension Service West Lafayette, IN*, *47907*, 21.

SWCD, Dakota County. (2020). Cover Crop Inventives. Retrieved June 14, 2020, from http://www.dakotaswcd.org/pdfs/Cover%20Crop%20Fact%20Sheet.pdf

Tilman, D., Cassman, K. G., Matson, P. A., Naylor, R., & Polasky, S. (2002). Agricultural sustainability and intensive production practices. *Nature*, *418*(6898), 671-677.

United Nations General Assembly. (1987). Report of the world commission on environment and development: Our common future. Oslo, Norway: United Nations General Assembly, Development and International Co-operation: Environment.

USDA and NASS. (2014). 2012 Census of Agriculture. Retrieved December 12, 2020, from https://www.nass.usda.gov/Publications/AgCensus/2012/Full_Report/Volume_1,_Chapter_1_US/usv1.pdf

USDA and NASS. (2019). 2017 Census of Agriculture. Retrieved December 21, 2020, from https://www.nass.usda.gov/Publications/AgCensus/2017/Full_Report/Volume_1,_Chapter_1_US/usv1.pdf

Van Donk, S. J., Martin, D. L., Irmak, S., Melvin, S. R., Petersen, J. L., & Davison, D. R. (2010). Crop residue cover effects on evaporation, soil water content, and yield of deficit-irrigated corn in west-central Nebraska. *Transactions of the ASABE*, *53*(6), 1787-1797

Vyn, T. (2000). Tillage and Soil Temperatures in 2000. Retrieved December 21, 2020, from https://www.agry.purdue.edu/ext/corn/news/articles.00/Tillage_Soil_Temp-0419.html

White, P. A. (2014). The growing business of cover crops. *National Wildlife Federation*, *August*.

Widmar, D. (2018). What About Higher Yields? A Closer Look at Changing Seed Expense. Retrieved July 12, 2020, from https://aei.ag/2018/10/29/what-about-higher-yields-seed-expense/

Wilson, M. L., Allan, D. L., Baker, J. M., & Pagliari, P. H. (2019). Comparing methods for overseeding winter rye into standing soybean. *Agrosystems, Geosciences & Environment*, *2*(1), 1-7.

Wilson, M. L. (2012). Factors affecting the successful establishment of an overseeded winter rye cover crop in northern climates.

Wilson, M. L., Baker, J. M., & Allan, D. L. (2013). Factors affecting successful establishment of aerially seeded winter rye. *Agronomy Journal*, *105*(6), 1868-1877.

Wortmann, C. S., & Jasa, P. J. (2009). *Management to minimize and reduce soil compaction*. Cooperative Extension, Institute of Agriculture and Natural Resources, University of Nebraska-Lincoln.

Zulauf, C., & Brown, B. (2019). Cover crops, 2017 US census of agriculture. *farmdoc daily*, *9*(135).

APPENDIX

Table A1. Inflation rates from the Consumer Price Index, 2009-2019

Year	Annual Average	Inflation Rate
2009	214.5	-0.4%
2010	218.1	1.6%
2011	224.9	3.2%
2012	229.6	2.1%
2013	233.0	1.5%
2014	236.7	1.6%
2015	237.0	0.1%
2016	240.0	1.3%
2017	245.1	2.1%
2018	251.1	2.4%
2019*	255.7	1.8%

Source: Consumer Price Index (2009-2019).
*An estimate for 2019 is based on the change for CPI from second quarter 2018 to second quarter 2019.

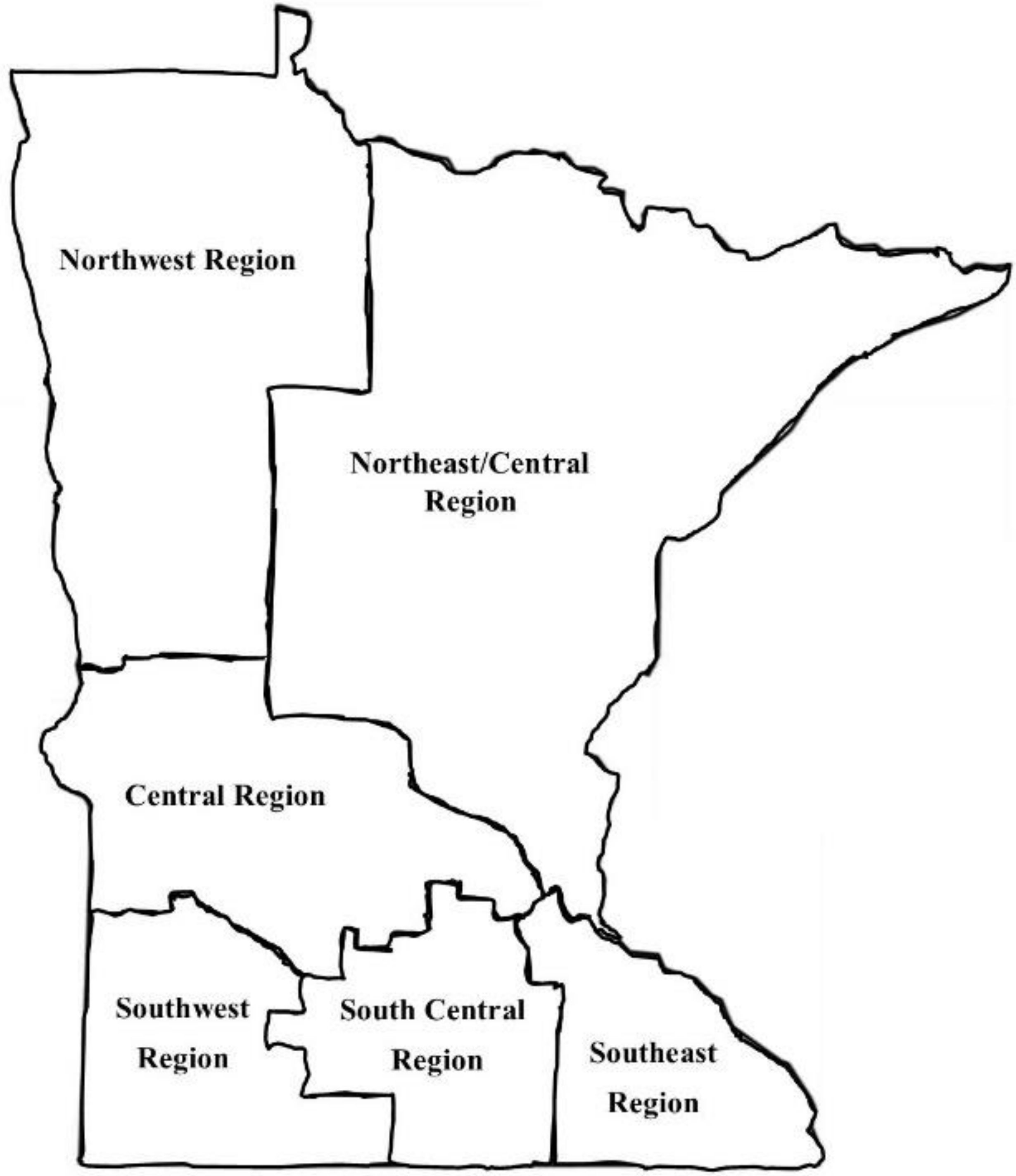

Figure 1: Minnesota Regions