EXPLORING THE EFFECTS OF COVER CROP USE ON FARM PROFITABILITY IN CENTRAL INDIANA

by

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ABSTRACT

Cover crop use provides a myriad of benefits to soil health. Despite strong agronomic evidence of the benefits of using cover crops, farmers have been slow to adopt cover crop systems. Surveys show that this is due to a lack of understanding on how cover crop use will impact the farm, and limited economic analysis on the effects of cover crop use on the farm.

In this thesis, a variable-rate nitrogen study was analyzed to determine the relationship between applied nitrogen fertilizer and corn yields, and how a cover crop treatment impacts that relationship. Data were obtained from a case farm in Central Indiana. Production information was then translated into a partial budget to see how the use of the different cover crop treatments impacted net return per acre for corn production on the farm. Net returns were analyzed using both historical corn and nitrogen prices and stochastic modelling.

Results showed that the final impact on farm net return per acre associated with adoption of a cover crop system varies among cover crop species. Implementing annual rye resulted in a negative change to net return; while cereal rye and an oats and radish blend resulted in a positive change to net return. When additional benefits of cover crop use; such as drought tolerance, carbon content, and erosion reduction; are included, all three cover crop species resulted in a substantial increase in net return. This information will be of interest to farmers as a source to draw upon when making decisions regarding their own farms. Further research is needed to fully understand the relationship between cover crop use and farm profitability, particularly for farms at the early stages of adoption.

CHAPTER 1. INTRODUCTION

2015 was designated the International Year of Soils (IYS) by the 68th session of the United Nations General Assembly. One of the goals of IYS was to increase awareness of the importance of soils in regard to maintaining food security and protecting ecosystems (FAO, 2015). The importance of soil health is evident, so it would not be a stretch to assume that at the farm level, managers would take every opportunity to improve the health of their own fields. Of the many possible management practices that farmers can add to their agricultural system, there is the use of cover crops. Cover crops have been shown to increase several facets of soil health, including soil structure, organic matter, and water retention. They also reduce erosion and nitrate leaching ("Midwest Cover Crops Field Guide," 2014).

The use of cover crops is a management practice that farmers have been hesitant to adopt, despite the evidence of numerous soil health and environmental benefits. The management choices today's agricultural producers make can have a significant impact on the bottom line of the operation. There are several costs associated with implementing cover crops; however, cover crops can potentially reduce input costs and/or increase crop yields.

1.1 Motivation

Current literature does not demonstrate that the use of cover crops necessarily leads to an increase in yields, and may even show a decrease to farm profit (Plastina et al., 2018); however, the literature does support that the use of cover crops has a significant positive impact on soil health (Fageria et al., 2007). The use of cover crops has also been shown to reduce a common source of pollutants in water supplies, sediment and nutrient runoff from agricultural production (Dabney et al., 2001). Despite the evidence of these benefits, both internal and external to the farm, producers are hesitant to adopt this management practice.

Data from the 2017 Census of Agriculture showed that there were 56,649 farms with 12,909,673 acres of cropland in Indiana in 2017 (USDA, 2019). Of those farms, 5,929 reported having cropland planted to a cover crop, for a total of 936,118 acres (USDA, 2019). This represents 7.25% of Indiana's cropland. Neighboring Illinois reported 24,003,086 acres of cropland with

708,105 acres being planted to a cover crop (USDA, 2019). This is 2.95% of reported cropland in the state. These percentages reflect the low adoption rates for cover crops.

Cash crop farming operations in the United States face narrow profit margins, and with limited ability to differentiate their products, farmers must rely on low cost production and high productivity to remain profitable. Each investment and practice must be closely evaluated by farm decision makers. In the 2016-2017 Cover Crop Survey by the Conservation Technology Information Center, 30% of respondents selected "strongly agree" and 39% selected "agree" to the statement "If I better understood how cover crops would benefit my farm, I would be more likely to use them" (CTIC, 2017). Perhaps farmers would consider this management practice if there were better analysis on how the use of cover crops impacted the individual firm financially, in addition to the societal benefits.

1.2 Problem Statement

Despite evidence that cover crops can improve soil health and may provide long term financial benefits to the farm, the adoption rate among producers is low. The problem is that past evidence has not convincingly demonstrated the economic value that implementing cover crops within an agricultural system can provide; thus, farmers do not perceive the benefits of cover crops to be worth the additional cost.

1.3 Objective

The primary goal of this thesis is to utilize data from a variable nitrogen rate study to analyze the financial impacts on the use of cover crops in a farming operation. In order to achieve this, sub-objectives will need to be established.

The first objective of the study will be to identify the relationship between applied nitrogen and corn yields; as well as how that relationship is changed when cover crops are introduced to the agricultural system. Our hypothesis is that the cover crop groups will have a reduced optimal level of applied nitrogen for corn production compared to the no cover groups.

The second objective will be to demonstrate the changes in cost between a farm that utilizes cover crops and one that does not. Our hypothesis is that the changes in yield and reduction in optimal nitrogen application will offset the changes in cost for an overall net benefit shown in the partial budgets.

The final objective will be to incorporate price risk into the budget analysis in an attempt to understand the price conditions under which the use of cover crops remains, or becomes profitable. Our hypothesis is that cover crops will be profitable under higher nitrogen prices given their potential to reduce the need for nitrogen fertilizer.

1.4 Methods

The first objective will be accomplished by estimating production functions and evaluating the economic optimal level of applied nitrogen for each sample group: annual rye, cereal rye, oats/radish, and no cover, at each nitrogen application rate. The relationship between nitrogen and yield will be estimated through regression analysis, allowing the determination of the production function. Then, that production function can be used to maximize a profit function, which can be solved for the economically optimal inorganic fertilizer N application rate and optimal yield.

The second objective will follow methodology from Plastina et. al (2018), utilizing data from the case farm that details the costs of production of their agricultural system, no-till with cover crops. All line items associated with changes in revenue and changes in costs that are associated with the cover crop use will be accounted for.

The third objective will use the statistical program @risk to generate statistically likely scenarios that the farm might experience in terms of corn and nitrogen fertilizer prices. This will allow for an analysis of the risk involved, demonstrating the range of effect on total profit the farm is likely to experience.

1.5 Organization

This thesis is organized into six chapters, the first of which being this introduction. Chapter two contains the literature review which contains research on the topics of cover crops and their impacts. The third chapter details the methodology utilized in this study. Chapter four discusses the data used in the analysis. Chapter five communicates the results obtained from the analysis of the data. Lastly, chapter six contains the conclusions from the study.

CHAPTER 2. LITERATURE REVIEW

This literature review describes existing research relating to the effects the use of cover crops can have on an agricultural system, and how those effects impact the decisions that must be made by the manager of a farm. Economic studies relating to the costs and benefits of cover crop use, as well as review of the agronomic principles behind cover crops are discussed.

2.1 Defining Cover Crops

A cover crop is defined as a “close-growing crop that provides soil protection, seeding protection, and soil improvement between periods of normal crop production” (SSSA, 2008). By utilizing cover crops, farm managers extend the “green period” during which live plants are growing in a field, reducing the fallow period ("Midwest Cover Crops Field Guide," 2014). When used as part of an agricultural system, cover crops are known to provide multiple benefits to soil, agricultural production, and the environment.

In the past, cover crops have been used for the purposes of weed and pest management, nitrogen fixation, and soil conservation, however, recently, more focus is on the “potential multi-functionality” of cover crops. This refers to their role in farm economics; uses in biofuel production and livestock feed; and ability to sequester carbon and mitigate greenhouse gas emissions; all in addition to the benefits to soil health (Blanco-Canqui et al., 2015).

Commonly used cover crops fall into the categories of legumes, grasses, and other crops. Legumes are typically chosen for their ability to fix nitrogen, that is, increase the amount of usable nitrogen available in the soil and hold it, rather than allow it to be flushed from the system. Grasses typically have large root systems which makes them an ideal crop for reducing erosion and adding organic matter to the soil. Other crops include buckwheat, which is used to help suppress weeds, and brassicas that can suppress soil pests such as nematodes (Magdoff & van Es, 2010).

The following sections will examine how cover crops are able to serve these functions and how the use of cover crops can impact the whole farm, from the agronomic system to farm finances.

2.2 Agronomic Effects of Cover Crops

In order to understand why farm managers might make the choice to include cover crops as a part of their agricultural system, it is imperative to understand the effects that cover crops can have on their ecosystem. This section will discuss the agronomic implications of the use of cover crops relating to soil health, crop production, and the environment.

2.2.1 Soil Health

Cover crops have been proven to provide benefits to multiple facets of soil health. This section will explore the benefits to soil structure, moisture retention and rainfall infiltration, soil biology, and soil chemistry.

2.2.1.1 Compaction

One major problem facing farmers today is that of soil compaction, caused in part by the mismanagement of soils and intensive crop rotations, but primarily by the use of heavy agricultural equipment (Hamza & Anderson, 2005). Compaction can be defined as “the process by which the soil grains are rearranged to decrease void space and bring them into close contact with one another, thereby increasing the bulk density” (SSSA, 2008). The pore space is reduced, leading to decreased capacity for root penetration and water retention and infiltration. Thus, there can be an increase in surface water runoff and less than optimal plant growth (Hanna & Al-Kaisi, 2002).

Cover crops help to resolve the problem of compaction because certain varieties of cover crops are capable of rooting more deeply than cash crops such as corn and soybeans. In a 2004 study, Williams and Weil attempted to demonstrate how cover crop root channels may alleviate the effects of compaction on the soybean crop. The two objectives of the study were to observe soybean roots penetrating compacted soil layers through root channels made by a brassica cover crop and to compare the effects of different cover crops on the yield of soybeans of different compaction severity. They found that soybean roots directly took advantage of root channels left by the cover crop roots, which they referred to as “biodrilling.” They also found that soybean yields were significantly greater following cover crops where soils were more compact (Williams & Weil, 2004).

Another solution to compaction, chiseling, was directly compared to the use of cover crops by Calonego et al. (2017). They found that immediate results could be obtained by chiseling, increasing both macroporosity and soybean yields for the immediate cropping season, but these results did not last in the second year. Long-term results were better obtained from cover crops, with a greater increase in macroporosity and yields in the second year. Cover crops were found to improve soil structure in deeper layers compared with chiseling (Calonego et al., 2017).

2.2.1.2 Moisture Retention, Rainfall Infiltration, and Erosion

In addition to reduction in compaction, the effect that cover crops have on soil structure can concurrently improve the moisture retention and rainfall infiltration capability of the soil. This allows for a reduction in erosion. Cover crops also provide a ground cover to protect the soil against raindrop impact and wind. This effect would be more pronounced when the cover crop follows a crop that does not produce large amounts of residue on its own (Kaspar et al., 2001). In addition, the root mass of cover crops helps protect against concentrated flow erosion (De Baets et al., 2011).

The dangers of erosion are most widely known due to the Dust Bowl, which was largely the result of wind erosion. “Cover crops reduce wind erosion by physically protecting the soil surface, improving soil structural properties, and anchoring the soil with their roots when primary crops are not in place” (Blanco-Canqui et al., 2015). This was demonstrated on silt loam in southwestern Kansas. By growing cover crops during the fallow period of a wheat-fallow rotation, the wind-erodible fraction was reduced by 80% (Blanco-Canqui et al., 2013).

A 2011 study by De Baets et al. noted that after a frost, the above-ground biomass of cover crops become less effective at reducing water erosion. The study aimed to assess the erosion-reducing effect of cover crops during concentrated flow, noting root density distribution and soil depth. The results indicated that “cover crops with thick roots (e.g. white mustard and fodder radish) are less effective than cover crops with fine-branched roots (e.g. ryegrass and rye) in preventing soil losses by concentrated flow erosion” (De Baets et al., 2011).

A review by Langdale (1991) cites several studies documenting the ability of cover crops to reduce erosion on the dominant soil orders in the United States. One example from Western Kentucky showed an 88% reduction in soil erosion for conventionally tilled soybeans planted following double-cropped wheat as compared with conventional tillage with no cover crop on an alfisol soil. Langdale’s work discusses historical research in the use of cover crops to reduce wind erosion, noting two models. For water erosion, the model is the Universal Soil Loss Equation (USLE), and for wind erosion, the Wind Erosion Equation (WEQ). The USLE data showed that in LaCrosse, WI, for continuous corn, average annual runoff was 9.9 inches with average annual soil loss of 111.7 tons/acre as compared to a corn-barley-clover rotation with average annual runoff of 5.8 inches and average annual soil loss of 27.8 tons/acre (Langdale, 1991).

An article by Unger and Virgil (1998) further explores the effects of cover crops on soil and water relationships. In this review, the authors discuss four ways that winter cover crops can impact the relationship between summer crops: forming mulch to decrease evaporation, increasing the infiltration of rainfall, using stored soil water in transpiration, and changing the soil water use pattern of the summer crop. The results of the review indicate that growing cover crops can have a positive, negative, or neutral effect on the water supply available for the next crop. This effect is positive when residues are retained on the surface to improve infiltration and decrease evaporation, or the crops are allowed to grow as long as possible to enhance water extraction from overly wet soils. The effect is negative when there is not enough time to recharge the soil with water after the termination of the crop, or when the residue aggravates overly-wet conditions (Unger & Vigil, 1998).

The decrease in erosion and runoff provides an environmental benefit. As of 2007, 99 million acres were eroding above soil loss tolerance rates. This equates to 28% of all US cropland. The tolerance rate is "the maximum rate of annual soil loss that will permit crop productivity to be sustained economically and indefinitely on a given soil" (NRCS, 2010). Large amounts of this eroded soil is deposited in streams and lakes, which can cause flooding from heavy sedimentation. For example, the Mississippi and Missouri rivers experienced heavy flooding in the summer of 1993, some of which can be attributed to increased sediment deposition. Wind erosion also causes damage as airborne particles act as abrasives and air pollutants (Pimentel, 2006).

Besides the loss of the soil itself, erosion causes the loss of organic matter and essential plant nutrients from the soil, such as nitrogen, phosphorus, potassium, and calcium. From the perspective of the farmer, eroded land with nutrient depleted soils can result in yields being 15-30% lower than uneroded soils (Pimentel, 2006). To offset this nutrient loss, fertilizers are applied.

2.2.1.3 Soil Biology

Soil Biology contributes greatly to the productivity of the soil. "The major activities of soil microbes include the decomposition of organic materials, mineralization of nutrients, nitrogen fixation, suppression of crop pests and protection of roots, but also parasitism and injury to plants" (Abawi & Widmer, 2000). Soil management practices should thus help to preserve and build healthy soil biota in order to maximize soil productivity. This includes diversity of total soil microbes, high population of beneficial organisms, and a low population of crop pests (Abawi & Widmer, 2000). There is evidence that certain cover crops have the ability to help build beneficial soil biota, replenish stripped soil biota, and control crop pests.

A 2009 study designed to evaluate the impacts of integrating cover crops into a no-till corn silage system measured the microbial biomass (MB) of soil with oat plus winter rye and annual ryegrass cover crop treatments. From fall to spring, the cover crop treatments were shown to produce significant differences in retaining MB. The improved MB comes from the improved root biomass concentration provided by the cover crops (Faé et al., 2009).

In North Carolina, Kirchner, Wollum, & King (1993) examined the effect that reductions in nitrogen fertilization combined with green-mulching using crimson clover would have on the soil microorganisms. The research team used four continuous corn treatments: no till with herbicide and insecticide with either 0 or 140 kg N/ha; conventional till with nitrogen and no pesticide with 140 kg N/ha; and conventional till with clover and no herbicide or insecticide. The results showed that microbial biomass, available N, and soil enzyme activities were all higher following the clover treatment. Culturable bacteria was 120% higher than the conventional till, no clover soil (Kirchner et al., 1993).

Another study that found similar results was completed in Washington by Bolton et al. (1985). The study examined the differences between soil that received regular applications of anhydrous ammonia, phosphorus, and sulfur, and soil that received only nitrogen input from leguminous cover crops. Plate counts revealed no significant differences in the number of soil microorganisms, but the cover crop treated soil had significantly higher soil microbial biomass, indicating that this soil had a larger and more active microflora. The enzyme activity was also increased significantly as compared to the non-cover crop soil (Bolton et al., 1985).

Not only can cover crops increase the microbial activity when compared to fallow fields, they can help limit the change to microbial communities caused by the removal of crop residues, a practice necessary for cellulosic ethanol production. According to research by Lehman et al. (2014), residue removal without cover cropping decreased Fungal-to-bacterial (F:B) ratios, which indicates “gross changes in the soil microbial community” (Lehman et al., 2014). Cover crop treatments significantly increased the F:B ratios following the removal of crop residue.

The next consideration of how cover crops interact with the soil biota is the defensive role against crop pests. Rapeseed and mustard in particular have been shown to be effective at suppressing nematodes. The byproducts of their decomposition can be toxic, and bioassays show that they are effective against nematodes (Halbrendt, 1996). Studies that demonstrate this effect include Mojtahedi et al. (1991), whose research focused on rapeseed, and Riga (2011), who looked at the use of brassicas in combination with synthetic nematicides.

Another interaction, studied by Chahal and Van Eerd, is that between cover crops, the soil, and soil health tests (2018). Three soil tests, the Haney soil health test (HSHT), Solvita, and Solvita labile amino N (SLAN), were utilized to detect differences in soil health after the use of cover crops. The study used tomato yield and and soil organic carbon (SOC) concentrations as a control for changes in soil health, and then evaluated each of the soil health tests. There was an increase in average crop yields and SOC with the cover crop group, meaning that this trial was suitable to evaluate soil health tests. None of the three soil health tests consistently detected treatment differences, suggesting that the application of these tests is limited (Chahal & Van Eerd, 2018).

2.2.1.4 Soil Chemistry

Any crop will impact the chemistry of the soil. Cover crops are noted for their impacts on soil nutrient dynamics and ability to increase soil organic matter, which addresses another prominent problem in today’s agricultural world. As soil organic matter decreases, various problems associated with fertility, water availability, compaction, erosion, and disease become increasingly prevalent, and an increasing level of fertilizers, irrigation water and pesticides are needed in order to maintain desirable yields (Abawi & Widmer, 2000). Regarding nutrient management, cover crops fix atmospheric N2, scavenge nutrients, reduce nutrient leaching, and reduce nutrient erosion.

An article by Mullen et al. (1998) explains how the use of cover crops can positively contribute to the chemical properties of the soil. The crop grows, creating biomass that covers the soil surface. This is organic matter that remains on the soil, resulting in stabilized soil aggregates, easier cultivation, improved aeration, increased water holding capacity, and an increase in total organic carbon (C) in the surface soil (Fageria et al., 2007). The Mullen et al. study specifically compared soils with hairy vetch, winter wheat, and no cover, measuring soil organic C. The results showed that hairy vetch increased soil organic C with no additional N fertilizer, while winter wheat increased soil organic C only when N fertilizer was applied. It is also worth noting that the use of cover crops significantly enhanced the microbial numbers and enzyme activities as measured in this study (Mullen et al., 1998). It can be concluded that "the increase in microbial activity under cover crops is strongly and positively correlated with an increase in soil organic C" (Blanco-Canqui et al., 2015).

Cover crops, particularly legumes, are often used in organic production to provide N in a usable form to the agricultural system to reduce the use of costly fertilizers. The reason for this is twofold. First, they have a low carbon to nitrogen ratio. A breakeven C:N ratio would mean that the plant contains enough nitrogen so that as it is being decomposed, none is used from, or released into the surrounding soil (Miller, 2000). The low ratio means that when they decompose, they release nitrogen into the surrounding soil. Secondly, cover crops are effective at symbiotically fixing atmospheric N2. A study by Parr et al. (2011) examined the N accumulation of sixteen winter annual cover crops and found that all but two of those species derive between 70 and 100% of their N from the atmosphere. This effectively adds nitrogen to the agricultural system, supplementing nitrogen for the next crop, which can utilize the nitrogen released into the soil upon the decomposition of the cover crop (Blanco-Canqui et al., 2015).

Cover crops not only add nitrogen to the soil, but can help prevent the leaching of nitrogen in the form of NO3. They do this in two ways; taking up the nitrogen and therefore reducing its concentration in the soil, and by taking up water which reduces the amount of water moving through the soil. Utilizing cover crops during the fallow periods extends the period of active N and water uptake. Reductions in leaching can range from 6 to 94%. This depends on factors such as the cover crop species, cover crop growth, amount of N in the soil, and amount of water moving through the soil (Kaspar & Singer, 2011).

A study by McCracken et al. (1994) compared the ability of rye and hairy vetch to reduce winter NO3 leaching loss in corn production. The leachate was collected from underneath lysimeters in which the cover crops were planted. Leaching losses were greater under the vetch than under the rye. The researcher suggests that the rye was more effective at scavenging residual nitrogen in the fall. Both cover crops showed improvement at preventing leaching than the fallow control, which in the year of its most leaching, had losses equivalent to 37.3 kg N/ha/year. The rye cover crop for that year had losses of 1.5 kg N/ha/year (McCracken et al., 1994). A meta-analysis by Quemada et al. (2013) identified 279 observations on nitrate leaching that when analyzed together, showed that “replacing a fallow with a non-legume cover crop reduced nitrate leaching by 50%” (Quemada et al., 2013).

Another study with similar observations was conducted by Kaspar et. al. in 2012. Oat fall cover crop and rye winter cover crop were evaluated in “subsurface-drained field plots with an automated system for measuring drainage flow and collecting proportional samples for analysis of NO3 concentrations” (Kaspar et al., 2012). The cover crops were planted in fields using a corn and soybean rotation. Results showed that over five years, the rye reduced drainage water NO3 concentrations by 48%, while the oat cover crop reduced NO3 concentrations by 26%. Both of these management options significantly reduce the NO3 losses through agricultural drainage systems (Kaspar et al., 2012).

This reduction in leaching is due to the cover crops’ ability to scavenge nutrients. Grass and brassicas are more effective at absorbing nitrogen (Dabney et al., 2001). The scavenged nutrients are released slowly after cover crop termination, improving nutrient use efficiency compared to inorganic fertilizers (Blanco-Canqui et al., 2015). A study in Illinois showed that cover crops (hairy vetch and cereal rye) are also effective at scavenging phosphorous from the soil, converting it into organic forms (Villamil et al., 2006).

In order to understand the importance of these abilities, one must note the environmental impacts they can have. A study on edge-of-field water quality measured nitrate, nitrite, total nitrogen, phosphate, total phosphorus, and suspended sediment concentration from four fields in the Mississippi Delta region of eastern Arkansas. Cover crops were grown in two years, and the third was the control. The cover crops reduced nitrate concentrations by 86% and phosphate by 53%, “indicating the significance of applying conservation practices to reduce nutrient during winter” (Aryal et al., 2018).

2.2.2 Weeds

Cover crops can be used as a tool for weed management because they compete with weeds for the essentials for plant growth; water, nutrients, and light, and some release allelochemicals, which inhibit the growth of weeds. Cover crops that directly compete with weeds are called "smother crops" or "living mulch." The extent to which cover crops are effective at suppressing weeds depends on the cover crop management and the species of cover crop (Blanco-Canqui et al., 2015).

A study by Adam Davis evaluated the effects of cover crop interference on post emergence glyphosate application rate after using the roller-crimper method of termination rather than the herbicide burndown method. This study found that the biomass of weeds following either a vetch or rye cover crop was reduced by 26% and 56% respectively from the burndown method to the roller-crimper method. The population density of weeds was reduced even more from bare fallow (Davis, 2010).

Ryan et al. (2011) explored the impacts of seeding rate on the ability of cereal rye to reduce weed biomass. The theory tested in the study was that by increasing the seeding rate of the cereal rye, the biomass of the rye would increase, leading to a decrease in weed biomass production in the field. The results found that an increase in seeding rate led to a decrease in weed biomass, from approximately 30 g/m2 to less than 10 g/m2. This experiment also tested the effectiveness of decreasing weed biomass by increasing rye biomass by applying poultry litter as fertilizer. That portion of the study did not prove to decrease weed biomass, which indicates that the weed suppression effect from the rye cover crop may be partially due to decreased nitrogen availability (Ryan et al., 2011).

The second method by which cover crops help to control weeds, allelopathy, is harder to discern from the smother method. Putnam, DeFrank, and Barnes (1983) initially investigated this phenomenon, "an important component of plant interference capability" by adding weed seeds to soil with rye residues, noting greatly decreased germination, a reduction between 43 and 100 percent. From this research, they speculate that numerous chemical inhibitors may be present.

More recent studies have used a laboratory-based approach to analyze the allelopathic abilities of cover crops. Bioassays from a cover crop with allelopathic potential and a weed were grown in a petri dish (Caamal-Maldonado et al., 2001). Legumes velvetbean, jackbean, jumbiebean, and wild tamarind all had a strong phytotoxic effect on the radicle growth of the weeds (Caamal-Maldonado et al., 2001). The radicle is the part of the seedling that develops into the root, and is the first part to emerge from the seedling. In another study, it was found that germinating sorghum reduced the radicle length of weeds while germinating rye increased the radicle length (Hoffman et al., 2017).

2.2.3 Yield Impacts

With all the evidence of the positive effects that cover crops can have on soil health, intuitively, cover crops would be positively correlated with an increase in crop yields. However, this is not conclusively the case. Research to date is quite divided over the effects that cover crops can have on crop yields, with studies resulting in yield increases, stagnation, and decreases. Ultimately, the impact that cover crops have on the subsequent crop yields depend on annual precipitation, cover crop species, tillage system, and the number of years of cover crop management (Blanco-Canqui et al., 2015).

The regional climate seems to have an impact on how cover crops are able to impact yields of subsequent crops. Nielsen and Vigil (2005) studied the effect of growing a legume cover in a semiarid region, Colorado, over six years and found that the subsequent wheat yields decreased. Similar results were observed by Zentner et. al. (1996), who tested the use of Indianhead black lentil on the Canadian prairies, and Schlegel and Havlin (1997), who tested eleven legumes in Kansas. Schlegel and Havlin (1997) found that the water needed for the legumes depleted the soil beyond what could be replenished before the subsequent crop, and that for every millimeter of soil water depleted by hairy vetch, grain yields decreased by 15 kg/ha. Conversely, research in Wisconsin, a region that gets higher levels of precipitation, showed a yield enhancement for corn following oats and winter rye (Andraski & Bundy, 2005).

Another factor to consider is the species of cover crop. Research shows that "summer legume cover crops are more effective at increasing crop yields than winter cover crops because of higher potential biomass and nitrogen inputs in fall" (Blanco-Canqui et al., 2015). Zhang and Blevins (1996) compared corn yield response to hairy vetch (legume) and rye (grass) and found that yields were significantly higher under hairy vetch. Research by Blackshaw, Molnar, and Moyer (2010) demonstrated that fall-planted alfalfa added 18-20 kg/ha of available soil N at the time of planting the succeeding canola, and significantly increased the canola yield. However, this study also tested red clover and Australian winter pea, neither of which performed at the same level, which serves to demonstrate that the species of the cover crop will affect yield outcomes.

Tillage systems also effect yield response to cover crops. Zhang and Blevins (1996) found that corn yields for all levels of fertilizer treatment, except for 0 kg N/ha, were significantly higher under no till than conventional tillage. Both rye and hairy vetch were planted under conventional and no-till conditions over the course of two years. The subsequent corn may be able to use the fertilizer nitrogen, as well as the cover crop provided nitrogen more efficiently under the no-till system.

The final factor to consider in how cover crops might impact crop yields in the amount of years of cover crop management. A study by Blanco-Coqui et al. (2012) found that cover-crop induced changes in soil compactibility, soil organic carbon, total nitrogen concentration, aggregate stability, water content, and soil temperature were all significantly related to crop yields. As these changes aggregate over multiple crop years, the effects on crop yield would become visible. This effect is demonstrated in a study by Decker et al. (1994) that examined corn yields following legume cover crops. In the three-year study, the maximum yield of the agricultural system was increased by utilizing hairy vetch, and the economically optimal nitrogen application rate was reduced.

Another angle from which to examine yield response to the use of cover crops is the yield variance. Reducing the variance means that yield levels would be more consistent. A study out of Purdue found the use of cover crops in a corn-soybean rotation can actually reduce the spatial yield variation in corn, and the yield uniformity across the field (Anderson, forthcoming). This study used a standard deviation ratio test, Levene's test, and coefficient of variation t-test. In addition, t-tests in "a method similar to a stock beta, a technique commonly accepted in finance to measure the volatility of an investment" were used to analyze the yield variation. The stock beta methodology suggests that a no-till cover crop rotation also had a lower temporal yield volatility compared to the benchmark yield from conventional till no cover fields, however, these results were not statistically significant.

2.3 Economic Effects of Cover Crops

Frye et al. (1985) examined the effect of cover crops on net returns of corn. In this study, corn was no-till planted into hairy vetch, big flower vetch, crimson clover, and corn residue with varying levels of fertilizer nitrogen applied. The results showed that net returns were highest each of the five years (1977-1981) for hairy vetch with 100kg/ha N, with the five-year average returns being $512/ha. This was an additional $157/ha over planting into corn residue.

A study by Morton et al. (2006) analyzed the economics of cover crops from a different perspective, examining the level of cover crop biomass necessary for the cover crop benefits to exceed their costs. Benefits include increased levels of cash crop biomass, weed response, and ground cover. The direct and indirect effects of the cover crops were estimated in a corn-cotton conservation tillage system. Rye and crimson clover can be profitable in this system if the minimum economically viable levels of biomass are obtained. For rye prior to cotton, this was estimated at 4,897lbs/acre and for crimson clover prior to corn, this was 2,680 lbs/acre (Morton et al., 2006).

In Stoneville, Mississippi, cover crops including Italian ryegrass, oat, rye, wheat, hairy vetch, crimson clover, and subterranean clover were evaluated for net return in soybean crop compared with no cover crop conventional tillage and no cover crop no tillage. The study found the net returns were negative for all the cover crop systems, with losses being highest in crimson clover (-$62/ha) and subterranean clover (-$161/ha). Returns were positive in both the no cover crop/no-till ($105/ha) and no cover crop/conventional till ($76/ha) systems (Reddy, 2001).

A similar economic analysis was conducted on corn grown in field experiments in Kansas to determine the response to leguminous cover crops on net returns. The results of this study showed positive net returns for corn after cowpea ($235.10/ha) and pigeonpea ($15.99/ha), but negative net returns for sunn hemp (-$292.60/ha). These net returns fall short of corn after double-cropped soybean at $1056/ha (Mahama et al., 2016). It is worth noting that the double-cropped soybean is able to generate such a high net return in part because of its status as a cash crop, $1190/ha of gross return while the cover crops will have $0 gross return as they cannot be sold for profit.

A cost analysis approach was taken by (Roth et al., 2018) in a case study in central Illinois. The objective was to quantify environmental and nitrogen cycling benefits of cover crop implementation, and determine the potential of those benefits to offset the cost of implementation.

This model included input variables that quantified the reduction in N loss, the return of N after termination, and reduction in soil erosion. The estimated cost recovery was 61% of implementation costs (Roth et al., 2018). This study was unique in that it provided an economic value to the potential nitrogen cycling from cover crop residue.

In one study from Iowa State, a survey was distributed to gather information from farmers to identify information which was used to generate average partial budgets that represented two farm groups, cover crop users and non-cover crop users. From there, the change between the two groups was calculated to estimate the overall changes in net returns due to the use of cover crops followed by corn and overall changes in net returns due to the use of cover crops followed by soybeans. The partial budgets broke down each possible line item from the farm's whole budget which might be impacted by the use of cover crops, positively or negatively. The results showed that so long as the cover crops are not used for grazing or forage, the net returns are consistently negative across all partial budgets. The authors suggest that this finding might explain why there is a low adoption rate of cover crops in the state of Iowa (Plastina et al., 2018).

Thompson et. al. (forthcoming) utilized experimental data from fields in Lexington, IL to generate simulations of the costs and benefits of adopting a predominantly cereal rye cover crop. A spring dominated and a fall dominated nitrogen application system were each applied to cover and no cover treatments preceding a corn and soybean rotation. Using Monte Carlo simulations and a partial budgeting approach, stochastic net returns were evaluated. A baseline scenario, a scenario accounting for potential fertilizer cost savings, and a scenario in which cover crop biomass is valued as feedstuff were evaluated. The tile nitrate load for each plot was used to "quantify the environmental/societal benefit associated with improved water quality from reduced nitrate loading" (Thompson et al., forthcoming). This was used to estimate a breakeven subsidy kg^{-1} of abated nitrate load. Results show that net returns to cover crops tended to be negative. Using cover crop biomass as feedstuff increased returns. The breakeven subsidy needed to make the producer indifferent to planting cover crops was found to be between \$13-\$23 kg^{-1} of nitrate saved from leaving the field per year (Thompson et al., forthcoming).

A study on cotton production analyzed the effects of no-till and conventional tillage, as well as the use of cover crops including winter wheat, crimson clover, Austrian winter field pea, hairy vetch, and a mix. The results evaluated the effects on net returns, finding that switching from conventional to no-till increased the probability of a higher net return, with average net returns of

$454 and $461/ha respectively. Net returns ranged from $346 to $389/ha when the cover crops were used, a decrease when compared to no cover crop. Risk analysis showed that no-till with no cover crop was preferred by risk-neutral, somewhat, and rather risk averse producers. The very and extremely risk averse producers preferred no-till with crimson clover (Fan et al., 2020).

2.4 Relationships Between Management and Cover Crop Benefits

A study out of Michigan State reviews the literature regarding the economic costs and benefits to the farm associated with integrating cover crops into a cropping system. Benefits internal to the farm include an increased yield of the marketable crop, greater yield stability, reduced fertilizer inputs, weed control, and reduction in disease and pest management were all shown (Snapp et al., 2005). Discussion related to how management decisions pertaining to cover crop use impact the agricultural system, and ultimately the bottom line.

Costs internal to the farm were broken down into direct, indirect, and opportunity costs. The direct costs constitute those of establishment: seed, dispersal, tillage, irrigation, and fertilizer. Indirect costs include the hindering of the establishment of the cash crop or unexpected management problems with the cover crops. Hindering of establishment can come from slow soil warming due to the shading of soil, or from the delayed release of nitrogen into the soil for cash crop to use. Cover crop management problems would occur if a cover crop is not killed off in time and becomes a weed. The opportunity cost would come from establishing cover crops during a period when a cash crop could be grown (Snapp et al., 2005).

An example of a benefit internal to the farm is a reduction in herbicide application. A study by Reddy (2001), previously discussed, investigated soybean net return responses to various cover crop systems also thoroughly analyzed herbicide responses. Each system was tested with preemergence only (PRE-only), post-emergence only (POST-only), or PRE + POST emergence herbicide to determine if the use of cover crops can in fact reduce the need for herbicide applications. The results showed that the soybean yield from the POST-only program was similar to the PRE + POST program, and thus there is the potential for eliminating preemergence herbicide application when using cover crops (Reddy, 2001).

A study by Frye et al. (1985) also examined benefits to the farm beyond financial returns. His study on the economics of winter cover crops as a source of nitrogen for no-till corn found that the yields for hairy vetch increased over time relative to the control group of corn residue for all the N rates. Without fertilizer N, the yield ratio of hairy vetch to corn residue yield increased more rapidly. The yields with corn residue did not decline relative to the other cover crops in the study, thus hairy vetch appears to have increased soil productivity over the time. Frye et al. (1985) theorizes that the increased N supply in the soil as well as improved physical conditions and water relations of the soil contribute to the increase in soil productivity.

The decisions of farm managers can impact the level of benefit that cover crops are able to achieve. This is demonstrated by a study where a rye cover crop was grazed by cattle or roller-crimped prior to planting cotton. The researchers found that the cotton yields "tended to be better in the non-grazed treatment" but were only significantly higher in one year of the study, when compaction caused the grazed treatment yields to be reduced. Returns from grazing "have the potential to offset establishment costs of a rye cover crop and increase profits for cotton producers" (Schomberg et al., 2014).

2.5 Estimating Production Functions

Variable N rates have been examined in relation to cover crops by Zhang and Blevins (1996). Corn yield response to N treatments of 0, 84, 168, and 336 kg N/ha was compared between groups of conventional till or no-till, and hairy vetch or rye. The regression analysis used the General Linear Models Procedure. Yields under the hairy vetch treatment were always higher than the yield under rye, but the differences between the groups decreased as N rates increased, implying that hairy vetch is a factor at increasing corn yields at lower N rates. The NT corn yield was significantly higher than the CT yield, indicating a "more efficient utilization of fertilizer N" (Zhang & Blevins, 1996).

CHAPTER 3. METHODOLOGY

In this chapter, the methodology used in this analysis is discussed. The analysis can be divided into three parts, the first of which uses variable-rate nitrogen study data to find the production and profit maximizing applied nitrogen levels for various cover crop treatments. The second part utilizes data from the case farm, farm standards, and the first portion of analysis to generate a partial budget which reflects the financial impacts of the cover crop use on the farm's finances. The last piece of analysis uses @Risk to undergo sensitivity analysis which helps identify the price conditions for which the static results hold true.

3.1 Production and Profit Maximization

In order to optimize production and profit in terms of nitrogen application, the relationship between nitrogen and yield must be examined. A series of regressions were run to generate production functions which could then be optimized following principles of microeconomic theory.

3.1.1 Generation of Production Functions

The agricultural production of a firm can be represented as a table, graph, or mathematical equation (Kay et al., 2016). For the purpose of this study, the components of the mathematical equation were estimated through regression analysis using four different models. These equations were then used to graph the production functions.

A study by Cerrato and Blackmer (1990) compares models that describe corn yield response to nitrogen fertilizer. The models compared in the study are the linear-plus-plateau, quadratic-plus-plateau, quadratic, exponential, and square root. They were each evaluated by the R^2 statistic, and found to fit the data "equally well" (Cerrato & Blackmer, 1990). The models all predicted similar maximum yields, but differed when predicting the economically optimal rates of fertilizer application, with the quadratic model tending to indicate an optimum that was too high. The quadratic-plus-plateau "best described the yield responses observed in this study" (Cerrato & Blackmer, 1990). There is precedent in the literature for using a linear or quadratic model when estimating yield response to applied N (Halvorson et al., 2005; Shapiro & Wortmann, 2006).

Due to this precedent in the literature for utilizing different regression models, three models were estimated and compared for best fit; linear plateau, quadratic, and quadratic plateau. Equations 1 represents the regression used for the quadratic model.

$$yield_{corn} = \beta_0 + \beta_1 N + \beta_2 N^2 \qquad \text{(Equation 1)}$$

Corn yield is the dependent variable. The independent variables are applied nitrogen fertilizer and applied nitrogen squared. The squared variable allows decreasing returns to be reflected in the model. The variables are described in Table 3.1.

Table 3.1. Variable Descriptions for the Regression of Yield on Nitrogen Application

Variable	**Meaning**	**Source**
$yield_{corn}$	The reported yield of corn in bushels/acre	Case Farm
N	The reported level of applied nitrogen in pounds/acre	Case Farm
N^2	The square of N	Case Farm

The linear plateau and quadratic plateau models were slightly more complex to estimate. Since these models are segmented, they cannot be fitted with a traditional regression equation.

To fit the segmented model for the quadratic plateau, the NLIN procedure as outlined in the SAS/STAT(R) 9.3 User's Guide was followed. It is similar to the quadratic model, but values of N greater than N_0 will return a constant Y value. The model is shown by Equation 2. This code forces a solution that satisfies continuity (Equation 3) and smoothness (Equation 4) conditions, which dictate that the two line segments meet at x_0 and that the first derivatives with respect to x coincide at x_0 (Gebremariam et al., 2011).

$$E(Y|N) = \begin{cases} \alpha + \beta N + \gamma N^2, & x < N_0 \\ c, & x \geq N_0 \end{cases} \qquad \text{(Equation 2)}$$

$$p = E(Y|N_0) = \alpha + \beta N_0 + \gamma N_0^2 \qquad \text{(Equation 3)}$$

$$\frac{\partial E(Y|N_0)}{\partial N} = \beta + 2\gamma N_0 \equiv 0 \qquad \text{(Equation 4)}$$

Descriptions for the variables can be found in Table 3.2. Solving for x_0 and substituting the expression in for c allows the development of the code which will generate the quadratic plateau production functions, shown in Figure 3.1.

Table 3.2. Variable Descriptions for Plateau Estimations

Variable	**Meaning**	**Source**
Y	The reported yield of corn in bushels/acre	Case Farm
N	The reported level of applied nitrogen in pounds/acre	Case Farm
N^2	The square of N	Case Farm
c	The fitted value of corn yield at x_0	Estimated

```
proc nlin data=work.nratedata;
x = nitrogenrate;
y = yield;
   parms alpha = .45 beta = .05 gamma = -.0025;
   x0 = -.5*beta / gamma;
   if (x < x0) then
      model y = alpha+beta*x+gamma*x*x;
   else model y = alpha+beta*x0+gamma*x0*x0;
run;
```

Figure 3.1: Quadratic Plateau SAS Code

The same code can be used to generate the linear plateau production functions with one change. As the quadratic term is removed, the x_0 disappears from the smoothness condition. Thus, the code was run with trial and error, substituting converging levels of applied nitrogen into the x_0 position until the statistical significance, measured by F-value, was maximized.

3.1.2 Production Maximization

Once the equation of the production function has been determined, Equation 5 for the quadratic model and Equation 6 for the quadratic plateau, we can use calculus to determine key points, including the production maximum of the quadratic and quadratic plateau models. The theory behind this is that by taking the partial derivative of the production equation with respect to the variable representing nitrogen, we obtain the marginal product of nitrogen application, Equation 7 for the quadratic model and the quadratic plateau. This represents the rate of change in the total production for a marginal change in the factor, or nitrogen (Beattie & Taylor, 1993). Variables from Equations 6-8 are explained in Table 3.3.

$$Y = \beta_0 + \beta_1 N + \beta_2 N^2 \qquad \text{(Equation 5)}$$

$$Y = \begin{cases} \beta_0 + \beta_1 N + \beta_2 N^2, & N \leq N_0 \\ Y(N_0), & x > N_0 \end{cases} \qquad \text{(Equation 6)}$$

$$\frac{\partial y}{\partial N} = \beta_1 + 2\beta_2 N \qquad \text{(Equation 7)}$$

Table 3.3. Variable Descriptions for Production Functions

Variable	**Meaning**	**Source**
Y	The estimated yield of corn in bushels/acre	Computed
β_0	The estimated intercept	Regression
β_1	The nitrogen coefficient	Regression
β_2	The nitrogen squared coefficient	Regression
N	The level of applied nitrogen in pounds/acre	Case Farm
N^2	The square of N	Case Farm
N_0	The level of applied nitrogen at which the plateau begins	Regression

The quadratic nature of these models implies that at some value of x, the function will begin to experience decreasing returns to scale, where a "proportionate increase in all inputs results in a less than proportionate increase in output" (Coelli et al., 2005), and actually begin to have a negative impact on production. Setting the marginal product equal to zero and solving for x will thus result in the production maximizing value of x. To find the production maximum, this value of x should be substituted back into the production function. The production maximum for the linear plateau is simply the plateau value of production.

3.1.3 Profit Maximization

A study by Lagae et al. (2009) clearly outlines the process for estimating a production function and using it to determine the economically optimal level of biosolids application on Eastern Colorado wheat. In this study, “multiple regression analysis was used to estimate the effect of various independent variables, including biosolids, on the dependent variable, wheat grain yield” (Lagae et al., 2009). Inorganic nitrogen application was also evaluated. The multiple regression analysis was used to estimate a production function, which in turn was used to determine optimal biosolids and N rates by plugging it into and maximizing a profit equation. The results of this analysis showed that “the biosolids response function explained >83% of the wheat yield variation” and that the “maximum wheat yield was achieved at a biosolids application rate of 9.0 Mg/ha when all variable in the regression equation other than biosolids were set at their mean” (Lagae et al., 2009). Economically optimal levels of biosolids application depended on wheat prices and input and application costs (Lagae et al., 2009). The methods used in this study follow the precedent set by Lagae for profit maximization.

3.1.3.1 Linear Plateau Profit Maximization

The profit maximization for the linear plateau model is significantly simpler. The linear plateau model is unbounded on the plateau, so there are only two points which can be the profit maximizing level of nitrogen; 0 or x_0. Applying any nitrogen beyond x_0, would fail to increase yield. To determine the profit maximum, the profit must be calculated at N=0 and N=x_0. Whichever point yields the higher profit is the profit maximizing level of applied nitrogen for this model.

3.1.3.2 Quadratic and Quadratic Plateau Profit Maximization

The method utilizes a standard profit function which is shown in Equation 8. When the production equation is substituted for Y (Equation 9), the profit equation has only one unknown variable remaining, N. The rest of the variables have known integers which can be substituted. Taking the partial derivative of this equation with respect to N will yield the first-order condition demonstrated in Equation 10 (Coelli et al., 2005). Solving the first-order condition results in the input demand function for the endogenous variable, applied nitrogen (Equation 11). Integer terms are known for all of the variables remaining in this equation, and can be substituted to return the profit maximizing applied nitrogen level. This nitrogen level can then be substituted into the production function to determine what the projected corn yields will be when using the profit maximizing nitrogen fertilizer levels. Equations 9-11 demonstrate the profit maximization for the quadratic and quadratic plateau models. The variables used in this series of equations are described in Table 3.4.

$$\pi = pY - rN \qquad \text{(Equation 8)}$$

$$\pi = p(a + bN + cN^2) - rN \qquad \text{(Equation 9)}$$

$$0 = pb + 2pcN - r \qquad \text{(Equation 10)}$$

$$N^* = \frac{r}{2pc} - \frac{b}{2c} \qquad \text{(Equation 11)}$$

Table 3.4. Variable Descriptions for Profit Equation

Variable	**Meaning**	**Source**
π	The profit	Computed
p	The price of corn per bushed	USDA-NASS
Y	The estimated corn yield represented by the production function	Regression
r	The price of nitrogen fertilizer per pound	USDA-NASS
N*	The level of applied nitrogen in pounds/acre	Computed
a	The intercept of the production function	Regression
b	The coefficient of the linear term of the production function	Regression
c	The coefficient of the quadratic term of the production function	Regression

3.2 Partial Budgets and Static Analysis

The next portion of analysis required the construction of partial budgets to quantify the effects of the cover crops financially. The budget line items that are affected by cover crop utilization were compiled and then filled in as appropriate. Table 3.5 below lists the line items and a brief description of how it was calculated.

With the introduction of a cover crop, it is expected that the corn yield will increase, and the nitrogen costs will decrease. These changes were calculated by comparing the difference in profit maximizing corn yield between the cover crop and no cover treatments, as well as the difference between the applied nitrogen levels needed to achieve those yields.

There will be an introduction of costs for seeds and other planting costs. In some cases, costs associated with termination might be introduced. There is also potential for reduction in cost associated with application of other fertilizers, which is accounted for in this study. To address other benefits to cover crop use, four benefits estimated by the manager of the case farm were included in a partial budget utilizing the quadratic model.

The budget process was repeated in the quadratic, linear plateau, and quadratic plateau models for each cover crop group across all years of data collection. In order to complete the static analysis, the price combinations from the years over which the study was run were entered, and the resulting change in net profits per acre were compared.

Table 3.5. Description of Budget Line Items

Line Item	Calculation	Source
Changes in Revenues		
Change in cash crop yield- Corn	(Yield with cover - Yield with no cover)*Corn Price	Regression/USDA-NASS
Changes in Costs		
Cover Crop Planting		
Seeds	Cost of Seed per Acre	Case Farm
Planting Costs		
Tractor Hours	Rate of Input per Unit * Units of Input per Acre	Case Farm
Labor	Rate of Input per Unit * Units of Input per Acre	Case Farm
Fuel	Rate of Input per Unit * Units of Input per Acre	Case Farm
Planter Repairs/wear	Rate of Input per Unit * Units of Input per Acre	Case Farm
Cover crop Termination		
Herbicide Cost	Cost of Herbicide per Acre	Case Farm
Cost to Apply	Rate of Input per Unit * Units of Input per Acre	Case Farm
Other Termination Costs	Rate of Input per Unit * Units of Input per Acre	Case Farm
Changes to Other Costs		
Nitrogen Costs	(Nitrogen with cover - Nitrogen with no cover)*Nitrogen Price	Regression/USDA-NASS
Other Fertilizer Costs (P&K)	(Other costs with cover - Other Costs with no cover)*Price of Other	Case Farm
Net Change in Profits	**Change in Revenues - Change in Costs**	**Budget**

3.3 Sensitivity Analysis

In this analysis, we want to identify how a change in corn and/or nitrogen prices will impact the profitability of the farm. Utilizing the Microsoft Excel add-in, @Risk, we are able to show the probable price outcomes and how likely they are to occur, creating a distribution of the potential net change in profits.

@Risk utilizes a Monte Carlo simulation. By substituting a probability distribution for factors that have inherent uncertainty, the simulation produces distributions of possible results. In this analysis, the corn price and nitrogen fertilizer price were substituted with the probability distribution. The output values that were tracked are the Net Change in Profits per Acre and the Total Net Change in Profits.

The distribution fitting tool was utilized to generate the distributions for both corn price and nitrogen. A pareto distribution was determined as the best fit for the historical corn prices, and a uniform distribution was selected for the historical nitrogen prices. The correlation between corn prices and nitrogen prices was accounted for by using the define correlation tool. Simulations were also run using a normal distribution for both price sets and using a triangular distribution for both price sets.

CHAPTER 4. DATA

This chapter includes a description of the data used in this analysis. First, the data from the variable nitrogen rate study will be discussed. This will be followed by a discussion of the price data used for corn and nitrogen.

4.1 Variable Nitrogen Rate Study

The data for the regressions described in Chapter Three were obtained from a farmer-led variable nitrogen rate study that took place in Hamilton County, Indiana. This study was administered from 2011 to 2017, with a corn-soybean rotation, so data were collected on the odd years when corn was planted: 2011, 2013, 2015, and 2017. Data for 2019 were not available due to the unusual weather circumstances that led to restrictions in planting throughout the United States.

In the experiment, variable nitrogen rates were applied to four test groups with a different cover crop treatment: no cover, annual rye, cereal rye, or oats and radish. The nitrogen rates varied throughout the study. Table 4.1 lists the nitrogen rates applied in year of the study. For each nitrogen rate, there were 1-2 repetitions available.

Table 4.1. Applied Nitrogen Rates (lbs.) by Year

2011	**2013**	**2015**	**2017**
0	55	55	95
65	95	115	115
112	115	135	135
150	135	175	175
160	175	-	-
206	-	-	-

Descriptive statistics for corn yield for each year of the study, and then all years combined are shown in tables 4.2 – 4.6. This statistics were calculated across all nitrogen rates.

Table 4.2. Descriptive Statistics for 2011

	No Cover	Annual Rye	Cereal Rye	Oats/Radish
Mean	150.38	149.15	141.74	149.67
St. Dev.	18.85	20.60	24.07	23.27
Range	108.40 to 176.30	109.50 to 173.90	93.40 to 166.00	101.60 to 180.20

Table 4.3. Descriptive Statistics for 2013

	No Cover	Annual Rye	Cereal Rye	Oats/Radish
Mean	173.59	178.31	176.78	192.29
St. Dev.	15.05	14.55	19.20	17.41
Range	148.80 to 194.40	148.90 to 191.70	139.00 to 194.60	153.00 to 208.40

Table 4.4. Descriptive Statistics for 2015

	No Cover	Annual Rye	Cereal Rye	Oats/Radish
Mean	164.32	166.90	176.82	177.15
St. Dev.	13.96	21.80	16.71	17.05
Range	126.55 to 184.70	125.82 to 187.65	146.48 to 196.58	150.66 to 203.39

Table 4.5. Descriptive Statistics for 2017

	No Cover	Annual Rye	Cereal Rye	Oats/Radish
Mean	209.65	205.41	203.77	218.97
St. Dev.	10.34	14.29	13.87	13.00
Range	191.24 to 221.97	181.90 to 219.38	183.37 to 218.82	195.53 to 233.66

Table 4.6. Descriptive Statistics for All Years

	No Cover	Annual Rye	Cereal Rye	Oats/Radish
Mean	172.86	171.39	171.68	180.46
St. Dev.	26.75	26.66	29.12	31.34
Range	108.40 to 221.97	109.50 to 219.38	93.40 to 218.82	101.60 to 233.66

4.2 Price Data

4.2.1 Corn Prices

The corn price data used in this analysis came from the USDA National Agricultural Statistics Service. Using the Quick Stats tool, a query was made for the average price received per marketing year by producers in Indiana for grain corn ("Quick Stats,"). Table 4.7 shows the corn prices used in this study. Nominal prices are used.

4.2.2 Nitrogen Prices

Historical nitrogen fertilizer price data is not readily available. In order to obtain the information necessary to complete the risk analysis, a producer price index from the USDA Economic Research Service for nitrogen fertilizer was used, along with the reported average U.S. farm price of Nitrogen Solutions (30%) per material short ton for 2011 ("Fertilizer Use and Price,"). To calculate each year's nitrogen price per material short ton, the 2011 price was multiplied by the index value and divided by 100. Then, to convert into nitrogen price per pound, the material short ton value was divided by 2000 and divided by 30%. Table 4.8 shows the index and price through the conversion process. Again, prices are nominal.

4.2.3 Adjusting Prices

Around 2006-2008, there was a large increase in demand for U.S. corn for ethanol production, and thus and expansion in corn production. This, along with other market factors, led to a significant increase in corn prices (Wallander et al., 2011). To account for this break in prices, the pre-2007 corn and nitrogen prices were adjusted. This adjustment was made by calculating the mean of the pre-2007 prices and the mean of the 2007-2018 prices. The difference between the two means was added to the pre-2007 prices. This process was applied to both corn and nitrogen prices. The resulting set of corn and nitrogen prices that were ultimately used in the analysis is reported in Table 4.9.

Table 4.7. Historical Corn Prices Received By Indiana Producers

Year	**Corn Price ($/bu)**
1996	$ 2.78
1997	$ 2.53
1998	$ 2.11
1999	$ 1.88
2000	$ 1.90
2001	$ 1.98
2002	$ 2.41
2003	$ 2.53
2004	$ 1.99
2005	$ 2.00
2006	$ 3.17
2007	$ 4.39
2008	$ 4.10
2009	$ 3.66
2010	$ 5.38
2011	$ 6.31
2012	$ 7.23
2013	$ 4.47
2014	$ 3.75
2015	$ 3.92
2016	$ 3.63
2017	$ 3.56
2018	$ 3.78
Mean	$ 3.75
St. Dev.	$ 1.41

Table 4.8. Historical Nitrogen Prices

Year	**PPI Nitrogen Fertilzer (2011 = 100)**	**Price Received ($/MST)**	**Nitrogen Price ($/lb)**
1996	39.61	$ 139.02	$ 0.23
1997	39.93	$ 140.16	$ 0.23
1998	33.26	$ 116.74	$ 0.19
1999	29.52	$ 103.63	$ 0.17
2000	36.02	$ 126.44	$ 0.21
2001	42.74	$ 150.03	$ 0.25
2002	32.76	$ 114.99	$ 0.19
2003	44.06	$ 154.66	$ 0.26
2004	50.76	$ 178.17	$ 0.30
2005	58.97	$ 207.00	$ 0.35
2006	61.14	$ 214.60	$ 0.36
2007	69.33	$ 243.35	$ 0.41
2008	106.30	$ 373.11	$ 0.62
2009	68.56	$ 240.64	$ 0.40
2010	71.77	$ 251.91	$ 0.42
2011	100.00	$ 351.00	$ 0.59
2012	107.97	$ 378.96	$ 0.63
2013	103.93	$ 364.81	$ 0.61
2014	96.04	$ 337.11	$ 0.56
2015	90.69	$ 318.32	$ 0.53
2016	73.61	$ 258.38	$ 0.43
2017	70.45	$ 247.28	$ 0.41
2018	75.93	$ 266.50	$ 0.44
Mean	65.36	$ 229.43	$ 0.38
St. Dev.	25.95	$ 91.10	$ 0.15

Table 4.9. Means Altered Corn and Nitrogen Prices

Year	Altered Corn Price ($/bu)	Altered Nitrogen Price ($/lb)
1996	$ 5.00	$ 0.49
1997	$ 4.75	$ 0.49
1998	$ 4.33	$ 0.45
1999	$ 4.10	$ 0.43
2000	$ 4.12	$ 0.47
2001	$ 4.20	$ 0.51
2002	$ 4.63	$ 0.45
2003	$ 4.75	$ 0.51
2004	$ 4.21	$ 0.55
2005	$ 4.22	$ 0.60
2006	$ 5.39	$ 0.61
2007	$ 4.39	$ 0.41
2008	$ 4.10	$ 0.62
2009	$ 3.66	$ 0.40
2010	$ 5.38	$ 0.42
2011	$ 6.31	$ 0.59
2012	$ 7.23	$ 0.63
2013	$ 4.47	$ 0.61
2014	$ 3.75	$ 0.56
2015	$ 3.92	$ 0.53
2016	$ 3.63	$ 0.43
2017	$ 3.56	$ 0.41
2018	$ 3.78	$ 0.44
Mean	$ 4.52	$ 0.50
St. Dev.	$ 0.88	$ 0.08

4.2.4 Partial Budget Line Items

Cover crop seed costs, tractor hours, labor, fuel, planter repairs/wear, cover crop termination, and other fertilizer costs were all provided from the case farm which conducted the nitrogen rate study. The farmer reported no costs associated with cover crop termination as cover crops were terminated by the annual spring burndown already utilized by the farm. The other costs are summarized in Tables 4.10-4.12 below. In Table 4.12, the fertilizer pounds per acre are reported as a decrease because the farmer reported decreasing the application of those nutrients. Additional benefits estimated and reported by the farmer are listed in Table 4.13.

Table 4.10. Cover Crop Planting Costs as Reported by the Case Farm

	$/Unit	**Unit/Acre**
Tractor Hours	$ 35.00	0.04
Labor	$ 15.00	0.06
Fuel	$ 3.50	0.20
Planter Wear/Repairs	$ 5.00	0.58

Table 4.11. Cover Crop Seed Costs as Reported by the Case Farm

	$/50 lbs	**lb/Acre**	**$/Acre**
Annual Rye	$ 53.00	15	$ 15.90
Cereal Rye	$ 18.00	40	$ 14.40
Oats/Radish	$ 34.00	34	$ 23.12

Table 4.12. Other Fertilizer Costs as Reported by the Case Farm

	$/lb	**lb/Acre**
Phosphorus	$ 0.38	-20
Potassium	$ 0.23	-30

Table 4.13. Additional Cover Crop Benefits as Estimated by the Farmer

Benefit	**Savings Per Acre**
Carbon Content	$ 10.80
Drought Tolerance	$ 24.00
Erosion Reduction	$ 8.00
CSP Program Payment	$ 7.69

CHAPTER 5. RESULTS AND DISCUSSION

In this chapter, the results of the analysis will be presented and discussed. First, the production functions will be discussed. Next, the results will be shown from the static budget analysis, as well as from the risk-incorporated stochastic simulations.

5.1 Production Functions

The first goal of the study was to identify the relationship between applied nitrogen and corn yield, and how this relationship changes when cover crops are introduced to the system. This was accomplished by a series of regressions. In this section, the results of the regressions and their significance will be reported. Significance of coefficients is determined by dividing the coefficient by the standard error to calculate a t-statistic. Then, the t-statistic is compared to the Student t Distribution Table to determine the level of significance.

5.1.1 Quadratic Model

The results of the quadratic model are shown in Table 5.1 below. These regressions were run using data from all years of the study. All values are statistically significant at the 1% level, and the sign for each coefficient was as expected.

Using these resulting equations that define corn production as a function of nitrogen application, the yields were optimized following the procedure in Chapter Three. The prices used in the optimization were the averages of the four years of the study. The production and profit maximums were found. These yields and the associated applied nitrogen levels are presented in Table 5.2 and Figure 5.1. The profit maximizing yield levels are slightly lower than the maximum yield that can be produced, but require a lower nitrogen input.

Table 5.1. Regression Results for Quadratic Model Across All Years

Variable	Coefficient (Standard Error)			
	No Cover	Annual Rye	Cereal Rye	Oats/Radish
N	1.142***	1.052***	1.353***	1.164***
	(0.302)	(0.204)	(0.216)	(0.268)
N^2	-0.00374***	-0.00332***	-0.00471***	-0.00375***
	(0.00126)	(0.000913)	(0.000959)	(0.00119)
Constant	96.70***	101.4***	88.73***	103.5***
	(17.47)	(11.06)	(11.78)	(14.78)
Observations	37	38	40	38
R-Squared	0.387	0.575	0.594	0.469
*** p<0.01, ** p<0.05, * p<0.1				

Table 5.2. Quadratic Model Production and Profit Maximizing Yield and Nitrogen Levels

Test Group	Production Maximizing Nitrogen Rate (lbs/acre)	Production Maximizing Yield (bu/acre)	Profit Maximizing Nitrogen Rate (lbs/acre)	Profit Maximizing Yield (bu/acre)
No Cover	152.83	183.98	133.00	182.51
Annual Rye	158.64	184.88	136.30	183.23
Cereal Rye	143.66	185.92	127.92	184.75
Oats/Radish	155.20	193.91	135.44	192.44

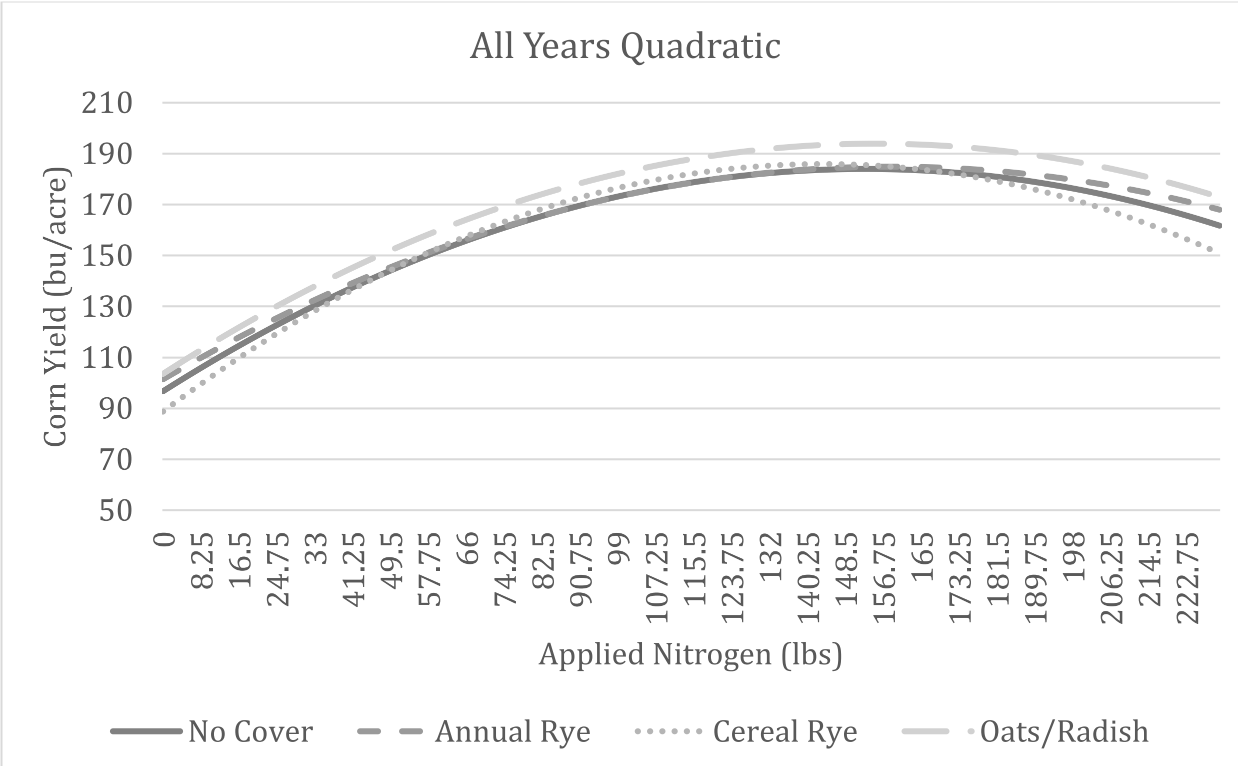

Figure 5.1: Quadratic Production Graph

5.1.2 Linear Plateau Model and Quadratic Plateau Model

The regression results for the linear plateau and quadratic plateau models are reported in Table 5.3 and Table 5.4 below. The significance of the model as a whole is reported in Table 5.5. These results denote the significance of how well the model accounts for the behavior of corn yield. The significance probabilities indicate that these models are significant in predicting corn yield based on the applied nitrogen input.

Using the production functions represented by these results, the production and profit maximizing yield levels were calculated. The procedure in chapter three was followed, and results are presented in tables 5.6 and 5.7 below. Figures 5.2 and 5.3 display the graphs of the production functions, demonstrating the change in the applied nitrogen and yield relationship across treatment groups. For the linear plateau model, the production and profit maximizing levels are the same. The linear relationship does not reflect any diminishing returns on applied nitrogen, so without the limit of the plateau, production and profit would be infinite.

Table 5.3. Regression Results for the Linear Plateau Model

Variable	**Coefficient (Standard Error)**			
	No Cover	Annual Rye	Cereal Rye	Oats/Radish
N	0.5817***	0.6244***	0.9297***	0.8476***
	(0.1281)	(0.0891)	(0.1256)	(0.1517)
Constant	112.1***	109.4***	92.2795***	105.6***
	(13.8305)	(9.302)	(11.1343)	(13.9266)
Observations	37	38	40	38
*** p<0.01, ** p<0.05, * p<0.1				

Table 5.4. Regression Results for the Quadratic Plateau Model

Variable	**Coefficient (Standard Error)**			
	No Cover	Annual Rye	Cereal Rye	Oats/Radish
N	1.0939***	1.0232***	1.3629***	1.2***
	(0.4083)	(0.2591)	(0.3279)	(0.3696)
N^2	-0.0036**	-0.00322***	-0.00496***	-0.00407**
	(0.00207)	(0.00134)	(0.00193)	(0.00206)
Constant	99.3444***	102.8***	89.2421***	103.4***
	(19.5639)	(11.8894)	(13.1916)	(15.9057)
Observations	37	38	40	38
*** p<0.01, ** p<0.05, * p<0.1				

Table 5.5. Regression Significance for Linear Plateau and Quadratic Plateau Models

	Pr > F Value	
Test Group	**Linear Plateau**	**Quadratic Plateau**
No Cover	<.0001***	0.0004***
Annual Rye	<.0001***	<.0001***
Cereal Rye	<.0001***	<.0001***
Oats/Radish	<.0001***	<.0001***
*** p<0.01, ** p<0.05, * p<0.1		

Table 5.6. Linear Plateau Model Production and Profit Maximizing Yield and Nitrogen Levels

	Production Maximizing		**Profit Maximizing**	
Test Group	**Nitrogen Rate (lbs/acre)**	**Yield (bu/acre)**	**Nitrogen Rate (lbs/acre)**	**Yield (bu/acre)**
No Cover	122.50	183.36	122.50	183.36
Annual Rye	119.50	184.02	119.50	184.02
Cereal Rye	96.00	181.53	96.00	181.53
Oats/Radish	99.50	189.94	99.50	189.94

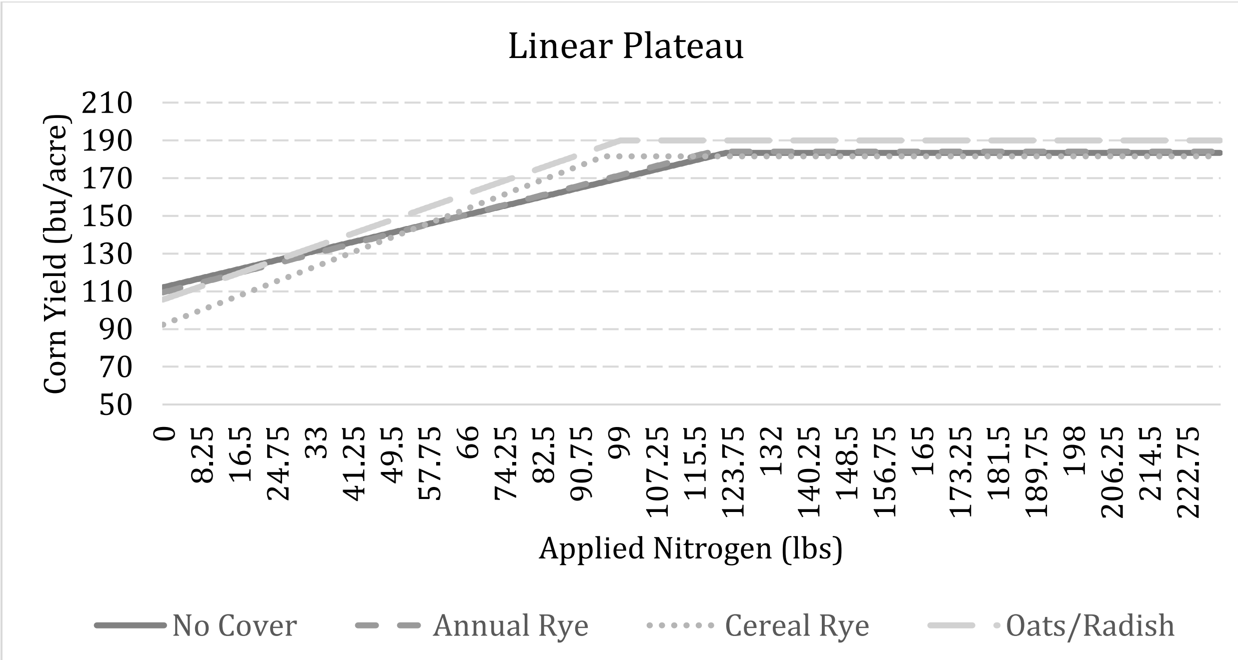

Figure 5.2: Linear Plateau Production Graph

Table 5.7. Quadratic Plateau Model Production/Profit Maximizing Yield and Nitrogen Levels

Test Group	**Production Maximizing Nitrogen Rate (lbs/acre)**	**Production Maximizing Yield (bu/acre)**	**Profit Maximizing Nitrogen Rate (lbs/acre)**	**Profit Maximizing Yield (bu/acre)**	**Plateau Nitrogen Rate (lbs/acre)**	**Plateau Yield (bu/acre)**
No Cover	151.93	182.44	131.34	180.92	151.93	182.44
Annual Rye	158.88	184.08	135.86	182.38	158.88	184.08
Cereal Rye	137.39	182.87	122.45	181.76	137.39	182.87
Oats/Radish	147.42	191.85	129.21	190.50	147.42	191.85

The plateau columns describe the point at which the plateau joins the existing curve, and the yield level that is sustained at the plateau.

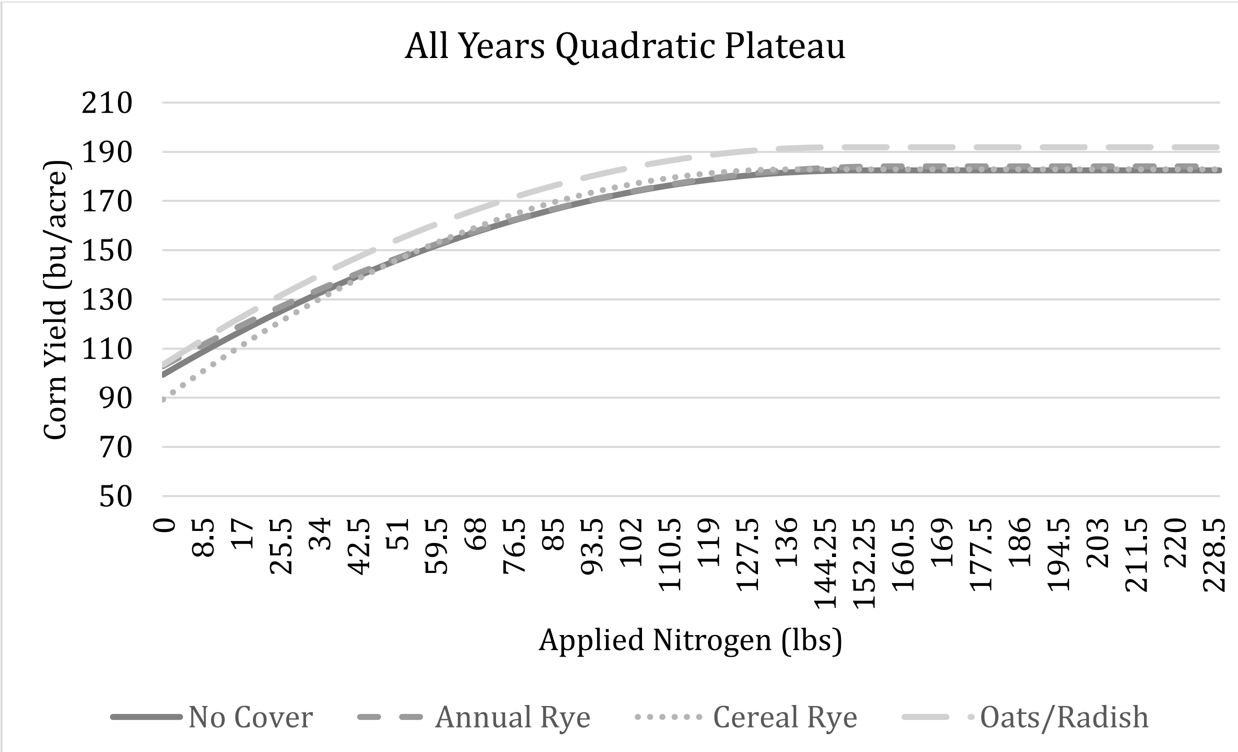

Figure 5.3: Quadratic Plateau Production Graph

5.1.3 Discussion of Profit Maximization

Table 5.8 and Table 5.9 place the estimation of the profit maximizing levels of corn yield and applied nitrogen side by side so that comparisons can be readily made. The models vary slightly, but lend the same overarching conclusions about how adding a cover crop changes the relationship between applied nitrogen and corn yields. For the quadratic and quadratic-plateau production functions, the profit maximizing corn yields for the cover crop treatments were higher than the profit maximizing yields for the no cover crop treatment. For the quadratic production function, cereal rye had a 3.8% lower profit maximizing nitrogen level than the no cover crop treatment. For the quadratic-plateau production function, the cereal rye treatment had a 6.8% lower profit maximizing nitrogen level than the no cover group, and the oats/radish treatment optimum nitrogen level was 1.6% lower than the no cover crop treatment.

Table 5.8. Profit Maximizing Corn Yield Comparison Across Regression Models

	Corn Yield (bu/acre)		
	Quadratic	**Linear Plateau**	**Quadratic Plateau**
No Cover	182.51	183.36	180.92
Annual Rye	183.23	184.02	182.38
Cereal Rye	184.75	181.53	181.76
Oats/Rad	192.44	189.94	190.50

Table 5.9. Profit Maximizing Applied Nitrogen Level Comparison Across Regression Models

	Nitrogen Level (lbs/acre)		
	Quadratic	**Linear Plateau**	**Quadratic Plateau**
No Cover	133.00	122.50	131.34
Annual Rye	136.30	119.50	135.86
Cereal Rye	127.92	96.00	122.45
Oats/Rad	135.44	99.50	129.21

5.2 Static Partial Budgets

Once the yield/nitrogen relationships were mathematically identified, they became quantifiable in terms of financial impact. A partial budget was developed to capture all of the changes to annual net income or net returns that occur as a result of cover crop implementation on the case farm. In this section, the results obtained from the static analysis of the budget will be presented.

5.2.1 Discussion of Line Items

Figure 5.4 below is an example of the partial budget that was used for all models across all scenarios. The budget is reported as changes from the no cover scenario to crop budget line items. For example, the sum total line reports the Net Change in Profits per acre. This means that the Net Profits per acre of the enterprise will change by the reported value. A positive reported value in this table indicated an increase to the dollar value of that line item. A negative reported value in this table indicates that line item decreased in dollar value. A decrease under "Changes in Costs" would mean that those costs decreased, representing a potential increase in net profit.

The scenario presented in the example is the quadratic regression using all years of data with corn revenue and nitrogen costs calculated using 2011 prices. The only line items that change when different scenarios are analyzed are the Changes in Revenues due to corn yield changes and the nitrogen costs, and the seed cost associated with the different cover crop varieties.

This partial budget is based on information provided by a case farm managed by industry experts. They provided data on the increase in planting costs associated with implementing a cover crop program. It is important to note that this sample budget does not attribute any cost to cover crop termination. On this farm, termination is successfully managed by the farm's spring burndown, which they account for with or without cover crops. Therefore, no additional cost is incurred.

	All Years/2011 Prices		
	Annual Rye Per Acre	Cereal Rye Per Acre	Oats/Rad Per Acre
Changes in Revenues	$ 4.54	$ 14.15	$ 62.68
Change in cash crop yield- Corn	$ 4.54	$ 14.15	$ 62.68
Changes in Costs	$ 9.40	$ 2.96	$ 16.11
Cover Crop Planting			
Seeds	$ 15.90	$ 14.40	$ 23.12
Planting Costs			
Tractor Hours	$ 1.40	$ 1.40	$ 1.40
Labor	$ 0.90	$ 0.90	$ 0.90
Fuel	$ 0.70	$ 0.70	$ 0.70
Planter Repairs/wear	$ 2.90	$ 2.90	$ 2.90
Cover Crop Termination			
Herbicide Cost	$ -	$ -	$ -
Cost to Apply	$ -	$ -	$ -
Other Termination Costs	$ -	$ -	$ -
Changes to Other Costs			
Nitrogen Costs	$ 1.95	$ (2.99)	$ 1.44
Other Fertilizer Costs (P&K)	$ (14.35)	$ (14.35)	$ (14.35)
Net Change in Profits	$ (4.85)	$ 11.19	$ 46.57

Figure 5.4: Example of Partial Budget, Quadratic Regression/All Years/2011 Prices

5.2.2 Static Partial Budget Results Tables

The tables below report the per acre change estimated by each model under each scenario of this analysis. Corn and nitrogen prices from the respective year of the study were used in the cost calculations. Annual rye was projected to decrease net profits under every scenario that was estimated. The oats and radish blend, conversely, significantly increased net profits under every scenario. This is likely due to the rapid decomposition of radishes; they release nitrogen rapidly early in the spring, increasing the nitrogen available to the cash crop (Gruver et al., 2019). The cereal rye tended to increase profits, but decreases profits in two years of the linear plateau estimation. The impact of the cereal rye is milder than that of the oats and radish blend.

Table 5.13 uses the quadratic model and includes the farmer estimated additional benefits that are listed in Table 4.13; carbon content, drought tolerance, erosion reduction, and CSP program payments. When the additional benefits are considered, all of the cover crops become profitable, including cereal rye. The already positive estimations become even more profitable.

Table 5.10. Net Change in Profit per Acre in Annual Rye Estimations

	Annual Rye All Years		
	Quadratic	**Linear Plateau**	**Quadratic Plateau**
2011	$ (4.85)	$ (1.53)	$ (0.90)
2013	$ (6.25)	$ (2.68)	$ (3.68)
2015	$ (6.38)	$ (3.28)	$ (4.12)
2017	$ (6.24)	$ (3.88)	$ (4.10)

Table 5.11. Net Change in Profit per Acre in Cereal Rye Estimations

	Cereal Rye All Years		
	Quadratic	Linear Plateau	Quadratic Plateau
2011	$ 11.19	$ (1.85)	$ 4.61
2013	$ 7.17	$ 2.05	$ 3.24
2015	$ 5.53	$ 0.93	$ 2.06
2017	$ 4.11	$ (1.59)	$ 0.69

Table 5.12. Net Change in Profit per Acre in Oats/Radish Estimations

	Oats/Radish All Years		
	Quadratic	Linear Plateau	Quadratic Plateau
2011	$ 46.57	$ 40.41	$ 47.07
2013	$ 28.24	$ 28.76	$ 29.48
2015	$ 22.97	$ 23.31	$ 24.04
2017	$ 19.69	$ 18.18	$ 20.33

Table 5.13 Net Change in Profit per Acre Using Additional Farmer Estimated Benefits

	Annual Rye	Cereal Rye	Oats/Radish
2011	$ 45.64	$ 61.68	$ 97.06
2013	$ 44.24	$ 57.66	$ 78.73
2015	$ 44.11	$ 56.02	$ 73.46
2017	$ 44.25	$ 54.60	$ 70.18

5.3 Stochastic Analysis

The final step in the analysis is to incorporate risk. Using stochastic modeling, this analysis accounts for many different price combinations, creating a distribution of possible results. The Normal-Normal distribution pattern stochastic model will be examined in depth, and the Pareto-Uniform and Triangular-Triangular will be included in the comparisons section (5.3.5). In each stochastic model, corn and nitrogen prices were correlated by a coefficient of .46. All three regression models were included in the stochastic analysis because each model was found to be equally statistically significant.

5.3.1 Price Distributions

Before analyzing the cover crop groups, the price distributions used in each stochastic model are reported in Tables 5.14-5.16, and Figures 5.5-5.7 below. Each of the three simulations were named after the distributions used to simulate the stochastic variable inputs (corn and nitrogen).

Table 5.14. Normal-Normal Price Distribution

	Normal-Normal				
	Min	**Mean**	**Max**	**5%**	**95%**
Corn Prices	$ 1.81	$ 4.54	$ 7.42	$ 3.06	$ 5.97
Nitrogen Prices	$ 0.24	$ 0.50	$ 0.74	$ 0.37	$ 0.63

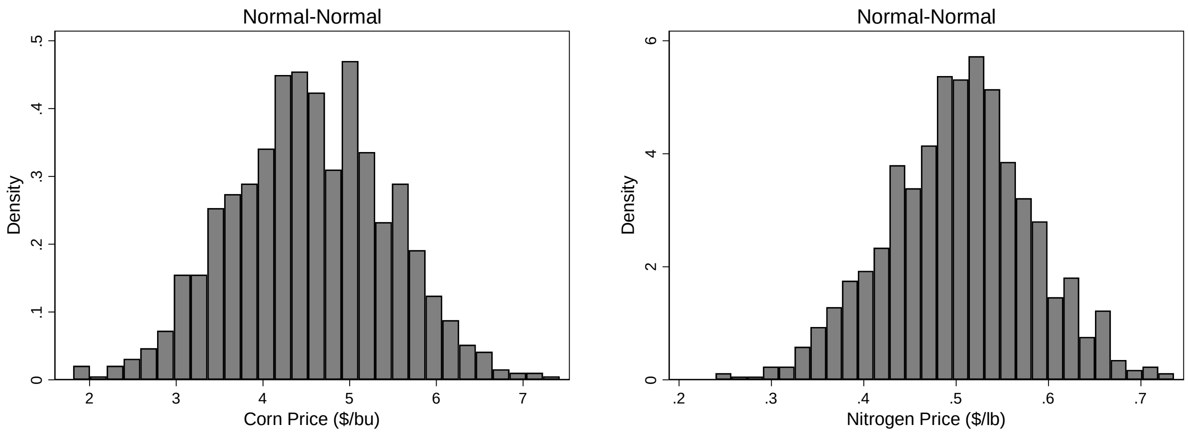

Figure 5.5: Input distribution histograms for Normal-Normal stochastic variables

Table 5.15. Pareto-Uniform Price Distribution

	Pareto-Uniform									
	Min		Mean		Max		5%		95%	
Corn Prices	$	3.56	$	4.59	$	23.59	$	3.60	$	7.13
Nitrogen Prices	$	0.39	$	0.52	$	0.64	$	0.41	$	0.63

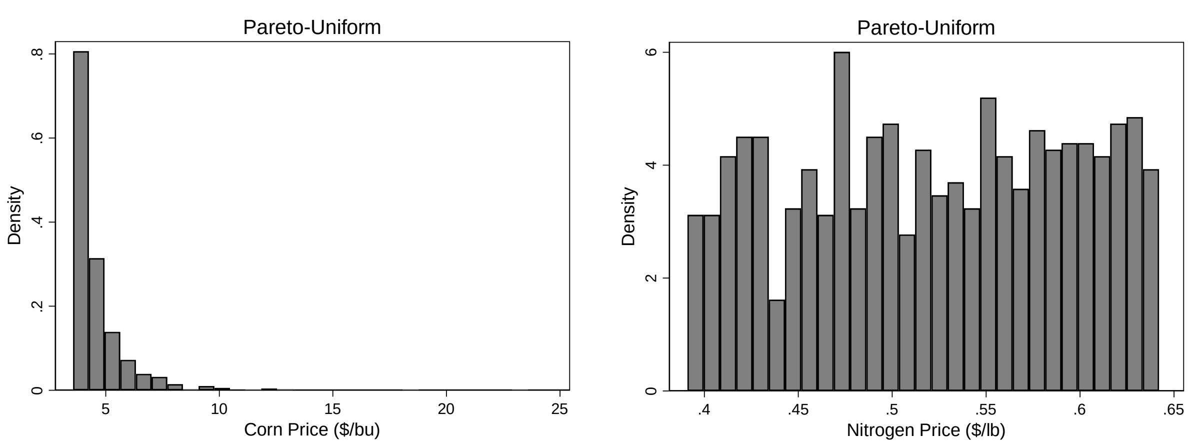

Figure 5.6: Input distribution histograms for Pareto-Uniform stochastic variables

Table 5.16. Triangular-Triangular Price Distribution

	Triangular-Triangular				
	Min	**Mean**	**Max**	**5%**	**95%**
Corn Prices	$ 3.56	$ 4.85	$ 7.41	$ 3.65	$ 6.61
Nitrogen Prices	$ 0.40	$ 0.50	$ 0.68	$ 0.41	$ 0.62

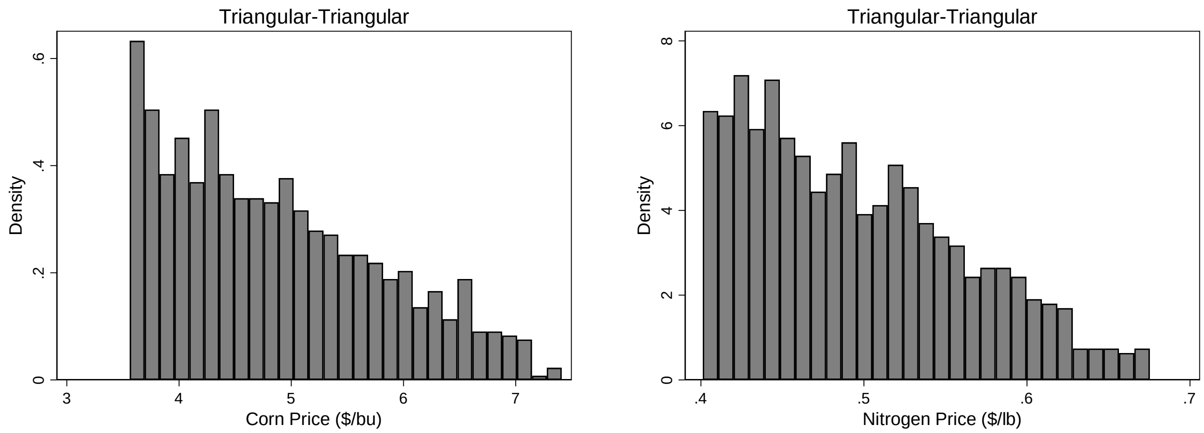

Figure 5.7: Input distribution histograms for Triangular-Triangular stochastic variables

5.3.2 Annual Rye

The overall annual rye simulation projections suggest that this variety is a poor performer in terms of impact on net profit per acre. Table 5.17 shows the descriptive statistics across the regression models under the Normal-Normal stochastic simulation, and distribution histograms are shown in Figure 5.8. The 5% and 95% levels indicate that 90% of scenario results fell between those two values. For annual rye, we see that there is a 95% chance that the impact on net profit will be negative, predicted across all three regression models.

Table 5.17. Description of Distributions of Annual Rye Stochastic Simulations

	Min	**Mean**	**Max**	**5%**	**95%**
Quadratic	$ (7.63)	$ (5.84)	$ (4.37)	$ (6.80)	$ (4.93)
Linear Plateau	$ (5.16)	$ (2.95)	$ (0.44)	$ (4.17)	$ (1.76)
Quadratic Plateau	$ (6.74)	$ (3.09)	$ 0.18	$ (5.02)	$ (1.18)

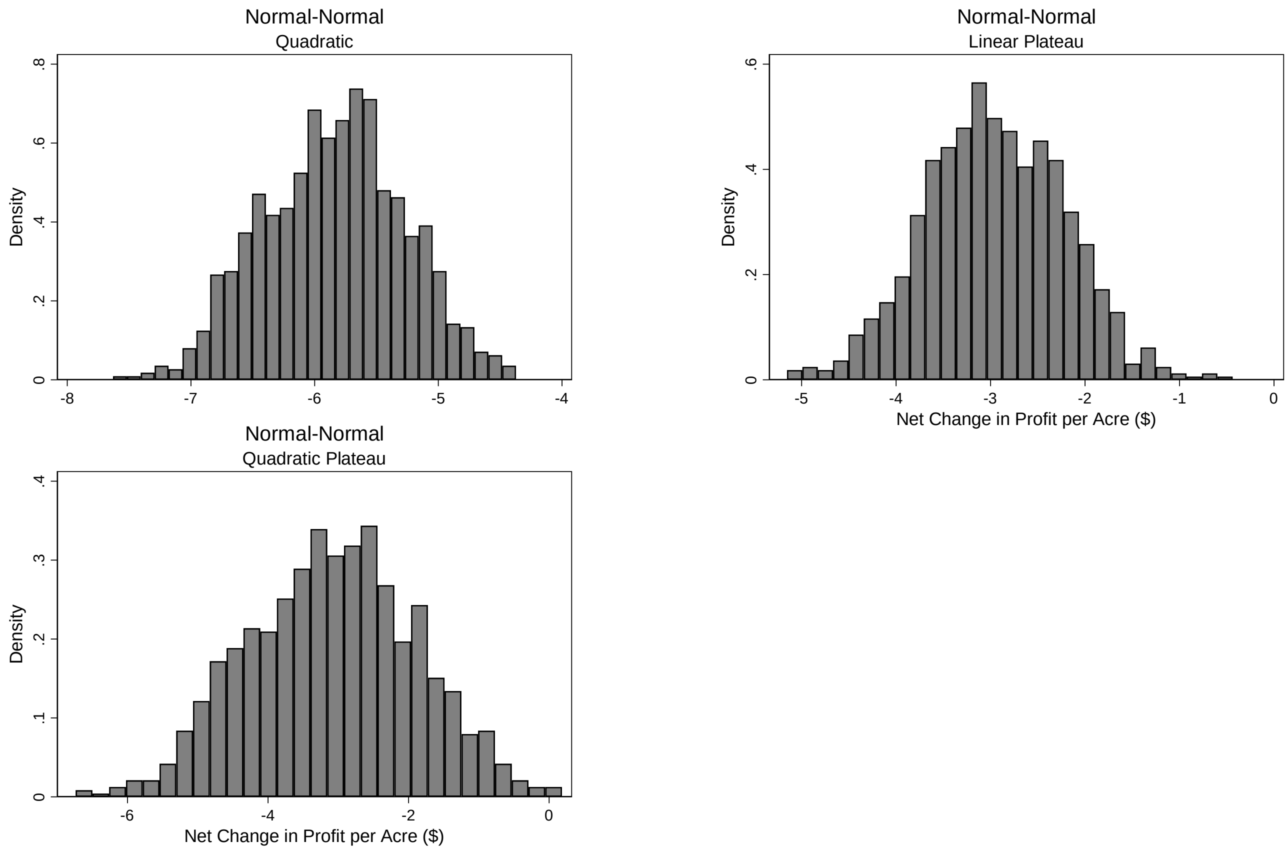

Figure 5.8: Output distribution histograms for N-N annual rye stochastic variables

5.3.3 Cereal Rye

Under the Normal-Normal stochastic simulation, cereal rye is projected to perform moderately well. The three regression models provide varying results, as shown in Table 5.18. Distribution histograms are shown in Figure 5.9. The quadratic and quadratic plateau models predict increases to net profit per acre in at least 95% of scenarios. Conversely, the linear plateau model predicts a $0.91 decrease in net profit per acre on average.

Table 5.18. Description of Distributions of Cereal Rye Stochastic Simulations

	Min	**Mean**	**Max**	**5%**	**95%**
Quadratic	$ 0.04	$ 6.79	$ 14.30	$ 3.12	$ 10.41
Linear Plateau	$ (7.59)	$ (0.91)	$ 4.56	$ (4.09)	$ 2.18
Quadratic Plateau	$ (1.53)	$ 2.35	$ 6.62	$ 0.24	$ 4.33

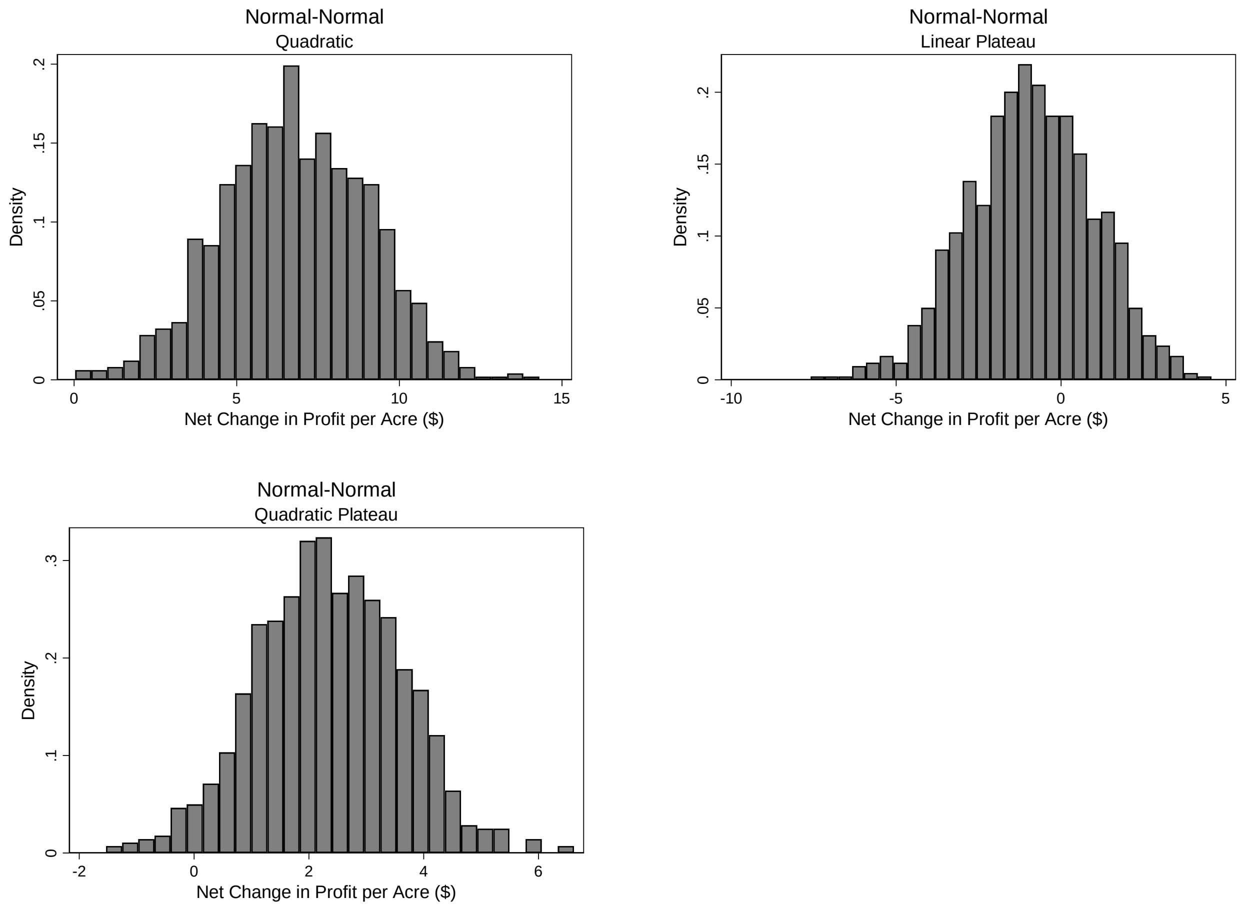

Figure 5.9: Output distribution histograms for N-N annual rye stochastic variables

5.3.4 Oats and Radish

The oats and radish blend predicted a significant increase to net profit per acre across all regression models. Table 5.19 shows the results of the Normal-Normal stochastic simulation, and Figure 5.10 shows the distribution of projected changes to net profit. As the minimum projected change to net profit is positive for all regression models, we can say that the oats and radish blend always increased net profits regardless of corn and nitrogen prices during this simulation.

Table 5.19. Description of Distributions of Oats/Radish Stochastic Simulations

	Min	Mean	Max	5%	95%
Quadratic	$ 2.39	$ 29.23	$ 57.33	$ 14.80	$ 43.21
Linear Plateau	$ 5.88	$ 26.80	$ 50.50	$ 15.37	$ 38.17
Quadratic Plateau	$ 3.50	$ 29.95	$ 58.00	$ 15.48	$ 43.68

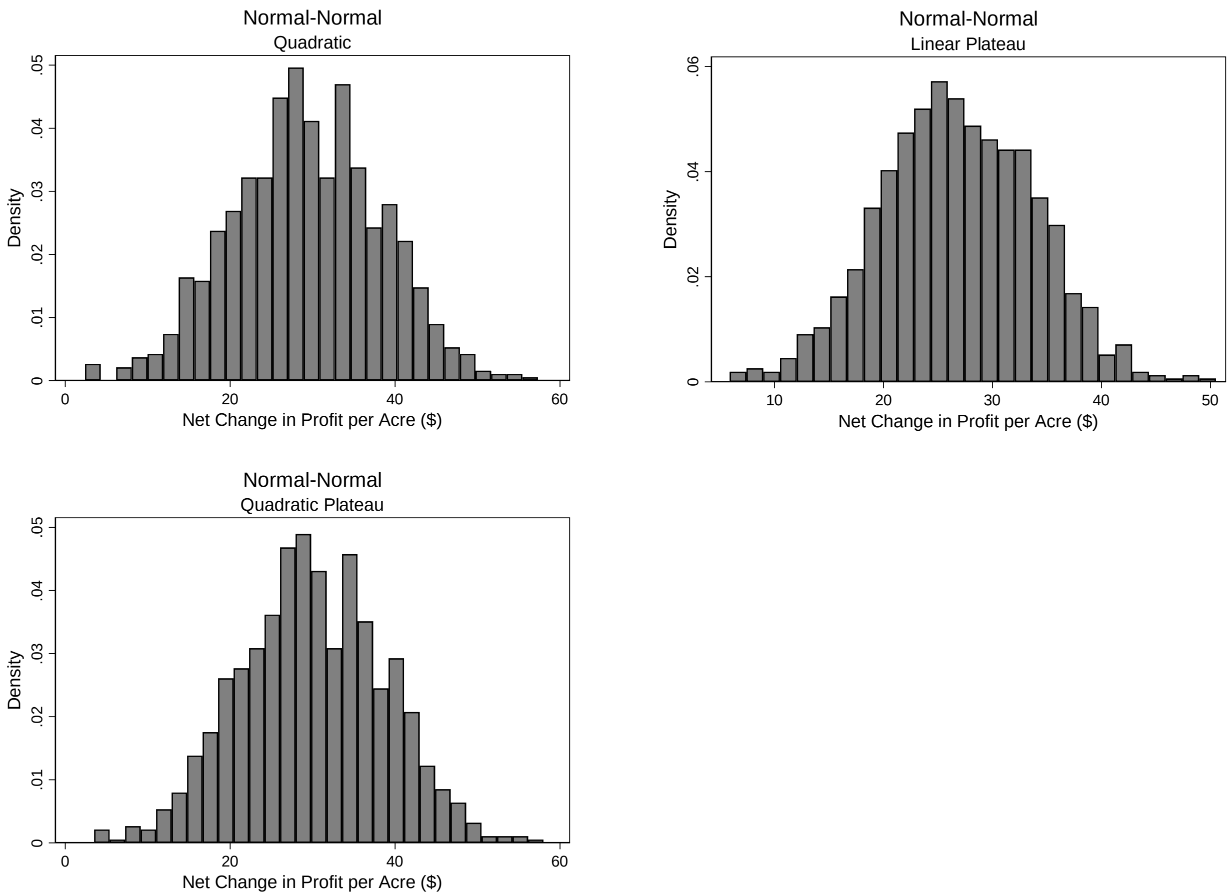

Figure 5.10: Output distribution histograms for N-N annual rye stochastic variables

5.3.5 Comparisons

Table 5.20 shows the results from the stochastic analysis across each of the stochastic simulations using all three regression models. With all the parameters used, each cover crop is analyzed nine times for the percentage of 1000 price combinations that the use of that cover crop resulted in a positive change to net income.

The annual rye results are consistent with those in the static analysis. The likelihood of a positive change in net profit is low, projected between 0% and 5.7%. Standard deviations across each scenario were tight, with the highest being $1.28 per acre meaning that results did not vary substantially across iterations. In the Normal-Normal/Quadratic Plateau model, a positive change in net profit ($0.03) was achieved at a corn price of $6.87 and nitrogen price of $0.57. In the Triangular-Triangular/Quadratic Plateau model, a zero change to net profit was achieved at a corn price of $6.81 and nitrogen price of $0.55.

The cereal rye results are not consistent across the regression models. The quadratic and quadratic plateau models predict that cereal rye will cause an increase to net profit under 96.4%-100% scenarios. However, the linear plateau model only predicted an increase to net profit 17.2%-44.2% of the time. Variation across the regression models was consistent.

The oats and radish blend was predicted to provide a positive, and large change to net profit per acre under all scenarios estimated. The standard deviations for these models were found to be on the relatively large, ranging from $7.03 to $14.31. Despite the variation, net profit did not drop below $0 for any of the iterations.

In the cases where the percentage of positive changes was between 0 - 100%, Tables 5.21 and 5.22 further examine the distributions of change to net income. These price combinations show that for annual rye, a high corn price and mid-range nitrogen price combination still does not result in a positive change to net profits under most models. For cereal rye, the scenarios under which there is a large chance of a negative change to net profit occurs only using the linear plateau model. Table 5.23 shows the average corn and nitrogen prices over the scenarios with a positive change to net income. The annual rye treatment required a high corn price, well above recent price trends, to result in a positive change. The cereal rye group had average corn prices in the $4.00 range, which are achievable in terms of recent price trends. The cases that transverse from a negative to positive change to net income tended to have an average nitrogen price that was higher than the cases that always had a positive result.

Table 5.20. Results Comparing Across Stochastic Models

Cover Crop	**Stochastic Model**	**Regression Model**	**Mean Change to Net Income**	**Standard Deviation**	**Percentage of Positive Changes**
Annual Rye	Normal-Normal	Quadratic	$ (5.84)	$ 0.57	0.0%
Annual Rye	Normal-Normal	Linear-Plateau	$ (2.95)	$ 0.74	0.0%
Annual Rye	Normal-Normal	Quadratic-Plateau	$ (3.09)	$ 1.19	0.3%
Annual Rye	Pareto-Uniform	Quadratic	$ (5.87)	$ 0.99	0.2%
Annual Rye	Pareto-Uniform	Linear-Plateau	$ (2.87)	$ 1.05	2.1%
Annual Rye	Pareto-Uniform	Quadratic-Plateau	$ (3.11)	$ 2.03	5.7%
Annual Rye	Triangular-Triangular	Quadratic	$ (5.59)	$ 0.62	0.0%
Annual Rye	Triangular-Triangular	Linear-Plateau	$ (2.77)	$ 0.72	0.0%
Annual Rye	Triangular-Triangular	Quadratic-Plateau	$ (2.60)	$ 1.28	3.6%
Cereal Rye	Normal-Normal	Quadratic	$ 6.79	$ 2.26	100.0%
Cereal Rye	Normal-Normal	Linear-Plateau	$ (0.91)	$ 1.91	32.3%
Cereal Rye	Normal-Normal	Quadratic-Plateau	$ 2.35	$ 1.26	96.4%
Cereal Rye	Pareto-Uniform	Quadratic	$ 6.98	$ 3.39	100.0%
Cereal Rye	Pareto-Uniform	Linear-Plateau	$ (0.51)	$ 2.67	44.2%
Cereal Rye	Pareto-Uniform	Quadratic-Plateau	$ 2.55	$ 1.56	100.0%
Cereal Rye	Triangular-Triangular	Quadratic	$ 7.45	$ 2.26	100.0%
Cereal Rye	Triangular-Triangular	Linear-Plateau	$ (1.68)	$ 1.89	17.2%
Cereal Rye	Triangular-Triangular	Quadratic-Plateau	$ 2.55	$ 1.16	100.0%
Oats/ Radish	Normal-Normal	Quadratic	$ 29.23	$ 8.91	100.0%
Oats/ Radish	Normal-Normal	Linear-Plateau	$ 26.80	$ 7.03	100.0%
Oats/ Radish	Normal-Normal	Quadratic-Plateau	$ 29.95	$ 8.77	100.0%
Oats/ Radish	Pareto-Uniform	Quadratic	$ 29.61	$ 14.31	100.0%
Oats/ Radish	Pareto-Uniform	Linear-Plateau	$ 27.50	$ 10.21	100.0%
Oats/ Radish	Pareto-Uniform	Quadratic-Plateau	$ 30.41	$ 13.93	100.0%
Oats/ Radish	Triangular-Triangular	Quadratic	$ 32.34	$ 9.26	100.0%
Oats/ Radish	Triangular-Triangular	Linear-Plateau	$ 28.66	$ 7.03	100.0%
Oats/ Radish	Triangular-Triangular	Quadratic-Plateau	$ 32.92	$ 9.06	100.0%

Table 5.21. 5th Percentile Values For Models Where Change to Net Income Transverse from Negative to Positive

Cover Crop	Stochastic Model	Regression Model	5% Change to Net Income	Corn Price 5%	Nitrogen Price 5%
Annual Rye	Normal-Normal	Quadratic-Plateau	$ (5.02)	$ 3.24	$ 0.51
	Pareto-Uniform	Quadratic	$ (6.65)	$ 3.56	$ 0.53
		Linear-Plateau	$ (3.79)	$ 3.60	$ 0.43
		Quadratic-Plateau	$ (4.57)	$ 3.59	$ 0.52
	Triangular-Triangular	Quadratic-Plateau	$ (4.22)	$ 3.65	$ 0.47
Cereal Rye	Normal-Normal	Linear-Plateau	$ (4.09)	$ 4.38	$ 0.37
	Normal-Normal	Quadratic-Plateau	$ 0.24	$ 3.55	$ 0.36
	Pareto-Uniform	Linear-Plateau	$ (4.12)	$ 4.83	$ 0.40
	Triangular-Triangular	Linear-Plateau	$ (4.89)	$ 5.63	$ 0.43

Table 5.22. 95th Percentile Values For Models Where Change to Net Income Ranges from Negative to Positive

Cover Crop	Stochastic Model	Regression Model	95% Change to Net Income	Corn Price 95%	Nitrogen Price 95%
Annual Rye	Normal-Normal	Quadratic-Plateau	$ (1.18)	$ 6.24	$ 0.63
	Pareto-Uniform	Quadratic	$ (4.27)	$ 7.20	$ 0.61
		Linear-Plateau	$ (0.99)	$ 7.00	$ 0.62
		Quadratic-Plateau	$ 0.19	$ 6.95	$ 0.56
	Triangular-Triangular	Quadratic-Plateau	$ (0.23)	$ 6.25	$ 0.42
Cereal Rye	Normal-Normal	Linear-Plateau	$ 2.18	$ 3.52	$ 0.55
	Normal-Normal	Quadratic-Plateau	$ 4.33	$ 5.28	$ 0.66
	Pareto-Uniform	Linear-Plateau	$ 2.87	$ 4.24	$ 0.63
	Triangular-Triangular	Linear-Plateau	$ 1.55	$ 5.69	$ 0.68

The key takeaway from these tables (5.21 and 5.22) is that in cases like annual rye, a positive change to net income is not achieved until, or after the 95th percentile, and only at uncharacteristically high corn prices.

Table 5.23. Average Corn and Nitrogen Prices for Positive Change Scenarios

Cover Crop	Stochastic Model	Regression Model	Percentage of Positive Changes	Average C Price (When Positive)	Average N Price (When Positive)
Annual Rye	Normal-Normal	Quadratic	0.0%	N/A	N/A
		Linear-Plateau	0.0%	N/A	N/A
		Quadratic-Plateau	0.3%	$ 7.16	$ 0.64
	Pareto-Uniform	Quadratic	0.2%	$ 20.99	$ 0.58
		Linear-Plateau	2.1%	$ 11.38	$ 0.60
		Quadratic-Plateau	5.7%	$ 8.91	$ 0.59
	Triangular-Triangular	Quadratic	0.0%	N/A	N/A
		Linear-Plateau	0.0%	N/A	N/A
		Quadratic-Plateau	3.6%	$ 6.91	$ 0.52
Cereal Rye	Normal-Normal	Quadratic	100.0%	$ 4.54	$ 0.50
		Linear-Plateau	32.3%	$ 4.15	$ 0.56
		Quadratic-Plateau	96.4%	$ 4.61	$ 0.51
	Pareto-Uniform	Quadratic	100.0%	$ 4.59	$ 0.52
		Linear-Plateau	44.2%	$ 4.16	$ 0.57
		Quadratic-Plateau	100.0%	$ 4.59	$ 0.52
	Triangular-Triangular	Quadratic	100.0%	$ 4.85	$ 0.50
		Linear-Plateau	17.2%	$ 4.37	$ 0.57
		Quadratic-Plateau	100.0%	$ 4.85	$ 0.50
Oats/ Radish	Normal-Normal	Quadratic	100.0%	$ 4.54	$ 0.50
		Linear-Plateau	100.0%	$ 4.54	$ 0.50
		Quadratic-Plateau	100.0%	$ 4.54	$ 0.50
	Pareto-Uniform	Quadratic	100.0%	$ 4.59	$ 0.52
		Linear-Plateau	100.0%	$ 4.59	$ 0.52
		Quadratic-Plateau	100.0%	$ 4.59	$ 0.52
	Triangular-Triangular	Quadratic	100.0%	$ 4.85	$ 0.50
		Linear-Plateau	100.0%	$ 4.85	$ 0.50
		Quadratic-Plateau	100.0%	$ 4.85	$ 0.50

CHAPTER 6. CONCLUSION

This analysis sought to investigate the impacts that the use of cover crops can have on farm profitability. This was achieved utilizing variable nitrogen rate data from an Indiana case farm, as well as financial information and historical price data from the USDA. The motivation was to provide analysis on how the use of cover crops can impact farm finances so that decision-makers have more information available as they plan their agricultural systems.

6.1 Summary

Results showed that the use of an annual rye cover crop treatment can have a negative impact on farm net income, and that a cereal rye or oats and radish blend treatment is likely to have a positive effect on net farm income. Using a static test, the annual rye treatment caused a negative change to net income under all test models. Using the stochastic test, an annual rye treatment had a probability of causing a positive change to net income projected between 0-5.7%. The cereal rye treatment indicated a positive change under most circumstances in the static test. In the stochastic test, the cereal rye either projected a probability of positive change to net income between 96.4-100% in the quadratic and quadratic plateau models or between 17.2-44.2% in the linear plateau model. The oats and radish treatment projected a positive change to net income under all testing parameters included in this analysis.

This analysis demonstrates that the use of cover crops can have an impact on farm profits that varies based on what cover crop species is used. The results are based on four years of yield and cost data from one case farm in Central Indiana. This case farm has a history of cover crop use, and is no-till. The implications of the study are relevant to regions with a similar agricultural climate.

6.2 Limitations

A primary limitation of this study lies in the data. Only four years of data were available for analysis, with only two trials per year for each treatment group. The lack of data prevented analysis on changes from year to year. Another limitation is the scope of analysis. This study only accounts for changes to corn yield or nitrogen application. There are many more benefits to cover crop use that are uncaptured by this study. Also, data were obtained from only one farm. Whether similar results could be obtained on other farms under different management regimes remains an open question.

6.3 Variations from Literature

Previous literature has attempted to identify the financial effects of using cover crops. The most similar work by Plastina found that cover crops only provide a positive return to net income when the cover crop is used for forage and grazing (2018). Our results found that two of our three cover crop treatments are likely to provide a positive return. Thompson found that net returns to a cereal rye cover crop tend to be negative, which is consistent with our results (forthcoming).

Possible explanations for the differences in our results compared to Plastina include that our study was based off of a farmer-run agronomic experiment and the financial data of a single farm. Plastina's results were generated from survey results, aggregating the experience of many farms. Another important feature of our study is that the case farm has strongly established cover crop use. The cumulative effects of cover crop use might be more pronounced than in other studies.

6.4 Future Research

This study could be expanded by including more years in the experiment, and a greater number of trials in each treatment group per year. Increasing the number of data points will increase the validity of the study. With more data points in each year, the data could then be examined to determine changes from year to year within each treatment group. This would give a measure to the cumulative effects of cover crop use, and allow them to be compared across treatments.

Further research is needed to estimate the financial impacts cover crops might have on a farm that is just beginning a cover crop program, using a different tillage system, or different crops/crop rotations. This farm has a strongly established cover crop program, which may generate a different return than a newly established program. There might also be a difference between no-till and conventional till on the impacts that cover crops can have. Continuous corn or continuous soybean cropping might also respond differently to the addition of cover crops than the corn-soybean rotation used in this study.

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