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TWO ESSAYS IN FERTILIZER MANAGEMENT FOR IMPROVED PROFITABILITY

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TWO ESSAYS IN FERTILIZER MANAGEMENT FOR IMPROVED PROFITABILITY

THESIS

A thesis submitted in partial fulfillment of the
requirements for the degree of Master of Science in the
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By

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ABSTRACT OF THESIS

TWO ESSAYS IN FERTILIZER MANAGEMENT FOR IMPROVED PROFITABILITY

Corn production in the United States has become increasingly efficient over the years. The use of nitrogen fertilizers has played a substantial role in this efficiency. Nitrogen drives biomass production which leads to increased yields. Unlike other nutrients, nitrogen is more mobile making it easier to lose through leaching and volatilization. The first part of this analysis uses an econometric model to examine the relationship between nitrogen usage and weather data. This relationship leads to farm management decisions to reduce nitrogen fertilization expenses. In addition to the use of nitrogen fertilizers, farmers in Kentucky take advantage of an abundance of poultry litter as a fertilizer source. Traditional poultry litter fertilization methods are being challenged by new technology, sub-surface injection, which has the potential to increase corn yields as compared to other methods. The second part of this analysis uses a resource allocation linear programming model to determine the economic viability of the sub-surface injection method for both spring and fall fertilizer applications. This model also reveals both farm management implications and provides valuable information for the development and commercialization of the sub-surface injector.

KEYWORDS: Nitrogen Fertilization, El Niño/La Niña Weather Patterns, Farm Management, Linear Programming, Poultry Litter Fertilization, Sub-Surface Injection

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CHAPTER 1. INTRODUCTION

In the United States, approximately 43 million tons of fertilizers are used on 391 million acres of cropland (USDA-ERS, 2018). According to the United States Department of Agriculture National Agricultural Statistics Service in 2017, over 41 billion dollars were spent on fertilizers nationally (USDA-NASS, 2018). In 2014, 27.8 million tons of nitrogen fertilizers were used with an average value of $575 per ton. Likewise, 8.5 million tons of phosphorus fertilizers were used with an average of $616 per ton and 6.7 million tons of potassium fertilizers were used with a per ton average value of $601 (USDA-ERS, 2018). Fertilizers are used in the production of many crops but corn production relies heavily on the use of all three fertilizers mentioned. In the United States in 2017, cash receipts from corn production were over 51 billion dollars.

In 2017, the United States produced 14.6 billion bushels of corn, which is 540% more than in 1950 (USDA-NASS, 2018). Over this same period, the amount of acreage planted in corn only increased by 108%. One of the primary reasons for this increased efficiency is the increased use and improvement of fertilization (Mathers, 2016). Corn production requires several nutrients, mainly nitrogen, phosphorus, and potassium. Though all are important, nitrogen is the most important for reaching maximum yield potential (Brooks, 2018). Not only has corn production increased in efficiency, so has the use of nitrogen (Mathers, 2016). When looking at Iowa from the late 60's to early 90's, the inverse partial factor productivity (kg-grain/kg-N) was above 100% (Figure 1.1), which means that farmers were using more nitrogen than bushels of yield they were producing. Since that time, the partial factor productivity has decreased and in 2016 was 75%. This suggests that farmers are increasing yields without increasing nitrogen usage because more of the nutrient is being used by the corn crop and less is being lost to the environment.

The process of fertilization restores the necessary nutrients to the soil to maintain efficient production. There are two categories of fertilizers: organic and inorganic (Penhallegon, 2015). Inorganic fertilizers, or commercial fertilizers, are human-made and usually target a specific nutrient. Some examples include urea (nitrogen), diammonium phosphate (phosphorus), and potash (potassium). Organic fertilizers include manure as a byproduct of poultry, hog, and cattle production. These manures contain considerable levels of each of the main macronutrients (nitrogen, potassium, and phosphorus) as well as other macronutrients (sulfur, calcium, and magnesium) and organic matter.

The importance of nitrogen fertilization on corn production has been researched, and evidence has shown that nitrogen drives yields to a point but too much can be detrimental. Nitrogen, unlike phosphorus and potassium, is more mobile in the soil and therefore is much more likely to be lost by leaching or volatilization (Ferdandez and Kaiser, 2018). If nitrogen is lost, farmers potentially need to apply more to meet their desired yield goal, which in turn increases costs. By determining the impact weather patterns have on nitrogen loss, corn farmers can better manage fertilizer expenses in the coming year. The first goal of this thesis is to evaluate the impact specific weather patterns such as El Niño and La Niña have on nitrogen fertilization.

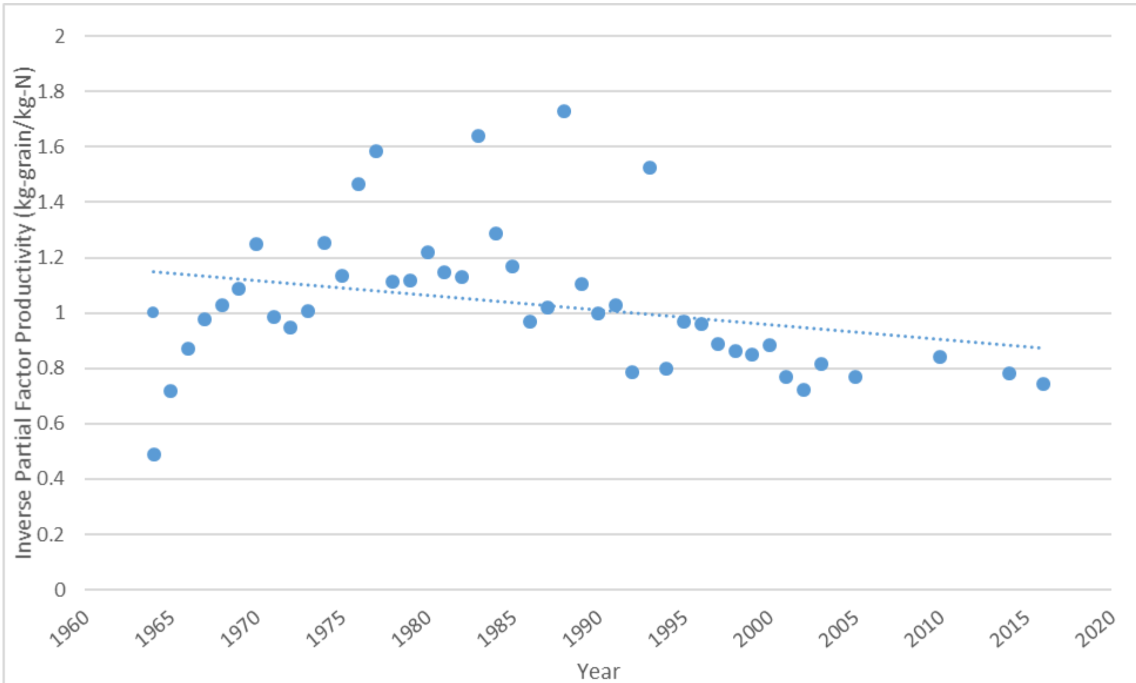
Kentucky ranks 14th in corn cash receipts with approximately 1.3 million acres planted annually resulting in 225 million bushels (USDA-ERS, 2018). Corn farmers in Kentucky benefit from having nutrient-rich organic sources of fertilizer from poultry litter because Kentucky ranks 7th in poultry production (Kerestes et al., 2017). Poultry is

Kentucky's leading commodity in cash receipts with 3200 broiler houses (Kentucky Poultry Federation). Over 640,000 tons of poultry litter is produced annually, which is enough to cover 320,000 acres of corn production (assuming 2 tons per acre). The average nutrient value of broiler litter is 50 pounds of nitrogen, 56 pounds of phosphorus, and 47 pounds of potassium per ton of litter (Rasnake, 1996). Poultry litter fertilizers, like commercial nitrogen fertilizers, can lose nutrients if not incorporated into the soil. Recently, a new poultry litter application method has been developed that injects poultry litter into the soil and reduces nitrogen volatilization. Therefore, this equipment improves nitrogen efficiency and can even increase yield. The second goal of this thesis is to evaluate the profitability of the poultry litter injector prototype and provide guidance on cost structure and performance measures to drive commercialization.

The structure of the rest of this thesis is as follows: Chapter two includes the econometric modeling of weather impact on nitrogen usage and its implications. Chapter three consists of a linear programming profit maximization model of poultry litter fertilization and the farm management implications. Chapter four provides a summary of the analyses and conclusion of the results.

1.1 Tables and Figures

Figure 1.1: Partial factor productivity for Iowa corn production



*Note: missing data for years without points (2004, 2006-2009, 2011-2013, 2015)

CHAPTER 2. USING WEATHER FORECASTS TO MANAGE NITROGEN FERTILIZER EXPENSES

2.1 Introduction

Over the years, corn producers have experienced increasing efficiency primarily due to the advancement in agricultural technology. Arguably the development that has had one of the most noteworthy impacts on the increased efficiency of corn production is the use of commercial fertilizers. Before commercial fertilizers, farmers used a combination of manure, ground bone, fish, and other naturally occurring nutrients to improve soil health and crop yields (Collings, 1955). Corn production utilizes all three of the primary nutrients: nitrogen, phosphorus, and potassium. Nitrogen is the foremost nutrient that drives biomass production and in turn drives yields, therefore is the most important when discussing efficient production (Brooks, 2018). The United States Department of Agriculture Economic Research Services (USDA-ERS, 2018) reports that farmers in the United States used over 27 million tons of nitrogen in 2014. According to the National Corn Growers Association, the Corn Belt region (Ohio, Indiana, Illinois, Iowa, and Missouri) is home to approximately 40% of the total corn production in the United States. This region applies commercial nitrogen to 96-99% of the acres in corn production with an average application rate of 159 pounds per acre (USDA-ERS, 2018).

Commercial nitrogen fertilizers were developed in the 19th century (Russel and Williams, 1977) and now come in all three forms of matter: solid, liquid, and gas. Of these, liquid nitrogen (nitrogen solutions) has become the most popular source with over 11 million tons used yearly. Urea the solid form of nitrogen and anhydrous ammonia the gas form of nitrogen has yearly usages of 6 million and 4 million tons, respectively. The price of these fertilizers is continually changing as the price of crude oil fluctuates (Chen et al., 2012). Nationally in 2014, the least expensive source of nitrogen is anhydrous ammonia at $0.52 per pound of actual N followed by nitrogen solutions ($0.60 per pound of actual N) and urea ($0.62 per pound of actual N) according to recent statistics (NASS, 2014). Historically, anhydrous ammonia has remained the cheapest while nitrogen solutions and urea have continually switched places for the most expensive as shown in Figure 2.1. Over the period studied, the average price difference between anhydrous ammonia and urea is $0.08 and the difference between anhydrous ammonia and nitrogen solutions is $0.09. In 2014 alone, 7.8 billion dollars were spent on nitrogen fertilizers.

Since these fertilizers are crucial to profitbability, the farmer must ensure ways to acquire the quantity they need at the best price possible. It is known that several farmers pre-order nitrogen fertilizer in the fall to lock in a lower price. Though this price discount varies from year to year, farmers can save approximately 20% when pre-ordering (Mattingly, 2018). Along with the timing of purchase, farmers must also consider application strategies. Typically, there are three different fertilizer application methods: fall application of fertilizer, apply all fertilizer just prior to planting, or split apply fertilizer with some being applied prior to planting and the remainder applied later in the season. Applying all the fertilizer upfront results in lower operating costs than split application because the farmer only needs to make one pass through the field (Sawyer et al., 2016). Split application has a higher operating cost, but this method can increase nutrient efficiency due to the fertilizers being applied when the plant needs it most as compared to applying it all up front. When considering which method to use one of the most important things a farmer must consider is the uncertainty of the weather.

Weather plays an essential role in crop production. Too much precipitation for a given area could drown the plant and wash away nitrogen needed for crop growth, also known as leaching. Likewise, not enough precipitation or drought-like situations lead to delayed crop growth and possible nitrogen loss due to volatilization. Either situation can have detrimental effects on crop yields. The loss of nitrogen results in lower yields unless the farmer applies more nitrogen fertilizers to ensure that plant nutrient needs are fulfilled. Improper planning for nitrogen loss could delay application because farmers probably won't have the extra nitrogen on hand. This delay could in turn have a negative effect on yield. In addition to the added input costs, if farmers apply all the nitrogen before planting, they now have double the operating cost for re-application because they must make an additional pass over the field.

Weather unpredictability is one of the most challenging aspects that any farm manager must consider. Advancements in technology now allow researchers to look at oceanic patterns and can forecast precipitation and temperatures from year to year in different regions of the world. Corn producers can use these forecasts to determine their future operations. If, for example, farmers know in advance that it is going to be a wet spring, they can purchase additional nitrogen fertilizer in the fall before spring planting and use a split application method. By using forecasts, the farmer can better ensure that required plant nutrients levels are met and that there are no delays due to lack of nitrogen.

The purpose of this study is to determine if nitrogen fertilization usage changes based on the El Niño and La Niña weather patterns. The motivation behind this analysis is to evaluate if farmers can use predictive weather technologies to manage fertilization expenses. The study objectives are:

1) Develop an econometric model to determine the impact weather patterns have on total nitrogen usage across all sources;

2) Assess the impact weather patterns have on usage of individual sources of nitrogen (nitrogen solutions, urea, and anhydrous ammonia);

3) Determine the relationship of the monthly quantity of nitrogen used in the occurrence of El Niño or La Niña; and

4) Decide which farm management strategies best help farmers prevent the loss of nitrogen as guided by occurrence of El Niño or La Niña.

2.2 Background

The application of nitrogen fertilizers has long been researched and proven to increase corn yields when applied appropriately. An increase in nitrogen applied results in higher yields received until a certain point, usually between 150 -200 pounds of nitrogen per acre (Sawyer and Randall, 2008). Traditionally, this response rate has been presented as a quadratic-plus-plateau, linear-plus-plateau, quadratic, exponential, and square root production function with quadratic-plus-plateau being the one that best describes yield responses (Cerrato and Blackmer, 1990). Most farmers apply nitrogen based on the desired yield level to maximize profits (Shapiro et al., 2008). Like application rate, application timing has also been debated heavily. Typically, nitrogen application occurs prior to planting, though field trials have proven that application can be applied as late as the V10 growth stage without a reduction in yield (Sawyer et al., 2016).

Since nitrogen plays an essential role in the production of corn, it is vital for farmers to understand the potential nitrogen loss due to leaching (lost to the ground) and volatilization (lost to the air). It is hard to know precisely how much of the nutrient is lost because it depends on the form of nitrogen applied and soil type among other factors. There are multiple tools available for farmers to examine the plants to determine N stress. One popular device is the chlorophyll meter which measures the greenness of corn leaves and evaluates if additional nitrogen is needed (Sawyer et al., 2011).

Though nitrogen management is imperative in the successful production of crops, weather conditions are undoubtedly the biggest factor influencing total production and have been the topic of research for hundreds of years. In the United States, agriculture production has taken a hit during extreme drought situations like the one experienced in 2012. During this time, over 80% of the mid-western United States was categorized as abnormally dry with about 50% of the region being in the extreme drought category according to the United States Drought Monitor produced by the National Drought Mitigation Center at the University of Nebraska-Lincoln, the United States Department of Agriculture, and the National Oceanic and Atmospheric Administration (NDMC). Average corn yield across the region dropped from 149 bushels per acre in 2011 to 114 bushels per acre in 2012 (USDA-NASS, 2018). From 2040-2060, researchers suggest that climate change will decrease corn yields by 10-15% and reduce farm profits by nearly 20% (Burke et al., 2011).

The Southern Oscillation is the heating and cooling of the oceans (National Oceanic and Atmospheric Administration, 2018). El Niño and La Niña are the two patterns in which occur based on the ocean temperatures. At any given time, one part of the world is experiencing El Niño conditions while the other part is experiencing La Niña conditions. In the Midwestern United States, which is where the majority of the corn is produced, El Niño usually presents a drier, warmer season. Likewise, La Niña usually is wetter and cooler (Lindsey, 2017). A visual representation of how the two patterns affect the United States is presented in Figures 2.2 and 2.3. The primary concern to agriculturalists is when these patterns hit the Midwest during the planting and early growing stages of the crop season. Excess rains pose numerous problems for farmers such as fewer days available for field work and the loss of key nutrients such as nitrogen due to leaching and runoff. Similarly, lack of rain prevents the crop from reaching its maximum potential.

In the United States, nitrogen is applied to several different crops and application time varies greatly depending on the region. In the Midwest, corn is the primary crop receiving nitrogen which is applied prior to planting in March and April typically followed by an additional application in the growing season of May and June (Shapiro et al., 2008). In the South East, primary crops which receive nitrogen fertilizers include cotton and tobacco. Cotton is typically fertilized prior to planting in March and April as well as during the early growth period in May and June (Hons et al., 2004). Similarly, tobacco also usually receives a split fertilization method with initial fertilization timing occurring in April and extending into July (UKY: AGR-1). In the Great Plains region and Texas, sorghum, hard red winter wheat, and hard red spring wheat receive nitrogen fertilizer. Sorghum receives nitrogen via split application method between March and July (Wortmann et al., 2006). Winter wheat occasionally is fertilized at planting in October and November. Most of the nitrogen is applied for both wheat varieties between

February and May (Alley et al., 2009). Lastly, in the North West, nitrogen is used for fertilizing barley. Again, this is usually done by split application method from February to May (Robertson and Stark, 1993).

Over the year's farmers have adapted to changes in weather patterns (more/less precipitation, increased seasonal temperatures, etc.) and produce at increasingly efficient levels. Weather forecasting using deterministic modeling began in the early 1990s and have since been proven very effective especially in precision agriculture (Bendre et al., 2015). Today, there are numerous technologies available to farmers in which predict weather patterns to a certain degree of precision. These include the National Oceanic and Atmospheric Administration, Farmers Edge, the Farmer's Almanac, and on-farm weather stations, to name a few. The farmer can narrow the search down to the specific area that pertains to him/her.

The prior literature on nitrogen usage has focused mainly on application timing (Sawyer et al., 2016), application rate and source (Spackman, 2018), and how nitrogen affects corn yields (Scharf et al., 2015). Likewise, the literature on the weather as it relates to agricultural production has primarily focused on climate change and how production has been affected in the U.S. (Mase et al., 2016) and in other countries (Pio et al., 2010). To counteract the effects of climate change or shift in weather patterns, research suggests farmers should alter production practices, invest in advanced technologies, improve farm financial management strategies, and take advantage of the many government programs and insurances available (Mase et al., 2016). Additionally, there have been some decision-making tools designed to help farmers manage their nitrogen fertilization strategies during climate risk situations (Gramig et al., 2016). This analysis looks at the relationship between weather patterns and nitrogen usage to help producers make more informed farm management decisions.

2.3 Materials and Methods

In an effort to evaluate the significance of weather patterns on nitrogen usage, an econometric model is developed. A log-log model is implemented because it makes the interpretation of the results straightforward and consistent. The theoretical framework of this analysis is presented in the following equation:

$$y_{Nusage} = f(\theta, \gamma, \alpha)$$

where the dependent variable is nitrogen fertilizer usage (y_{Nusage}). The independent variables include three vectors: $\theta, \gamma, and\ \alpha$. The first, $\theta,$ is a vector of corn production variables such as the number of acres planted, corn yield lagged, and the 1996 Farm Bill variable. The second, γ, is a vector of price variables such as the price received for corn and the price of nitrogen. The final, $\alpha,$ is a vector of weather variables which depict the presence of the La Niña and El Niño patterns. Four models, representing different N sources, were developed from this framework to help explain nitrogen fertilizer usage. The first model includes all N sources and is depicted as:

$$
\begin{aligned}
y_{totalusage} = \; & \beta_0 + \beta_1 ln\, Corn\, Price + \beta_2 ln\, Nitrogen\, Price + \beta_3 \ln Corn\, Acres \\
& + \beta_4 \ln Corn\, Yield\, Lagged + \beta_5 Farm\, Bill + \beta_6\, January\, El\, Niño \\
& + \beta_7 January\, La\, Niña + \beta_8 February\, El\, Niño \\
& + \beta_9 February\, La\, Niña + \beta_{10} March\, El\, Niño + \beta_{11} March\, La\, Niña \\
& + \beta_{12} April\, El\, Niño + \beta_{13} April\, La\, Niña + \beta_{14} May\, El\, Niño \\
& + \beta_{15} May\, El\, Niña + \beta_{16} June\, El\, Niño + \beta_{17} June\, La\, Niña \\
& + \beta_{18} July\, El\, Niño + \beta_{19} July\, La\, Niña + \beta_{20} August\, El\, Niño \\
& + \beta_{21} August\, La\, Niña + \varepsilon
\end{aligned}
$$

In model one, total usage represents nitrogen usage across all sources. This model also includes a variable representing the Federal Agriculture Improvement and Reform Act of 1996, also known as the 1996 Farm Bill. This variable was included to see if the less restrictive policies of the New Farm Act, which allowed farmers greater flexibility to plant any crop on contracted acres (Young and Shields, 1996), helped lead to a change in nitrogen fertilizer usage since that time. Models two through four examine specific nitrogen sources as the dependent variables (anhydrous ammonia, urea, and nitrogen solutions respectively) with the independent variables remaining the same. Thus, models two through four incorporate a dependent variable for anhydrous ammonia ($y_{anhydrous\ ammonia}$), urea (y_{urea}), and nitrogen solutions ($y_{nitrogen\ solutions}$) respectively. The policy variable was dropped for the individual source models because it was not believed to have as large of impact on individual sources like overall N usage. The individual source usage is more driven by price than policy.

Data used for this analysis is a time series spanning from 1960-2014. Multiple sources were used, though most of the information came from the United States

Department of Agriculture National Agricultural Statistics Service (USDA-NASS, 2018). Nitrogen usage data is presented in total tons consumed on a national level and is also broken down by the different nitrogen fertilizers (Figure 2.4). Usage values, which are in amount of material, were adjusted to equivalent amounts of actual N using a given percentage of actual N within each fertilizer source to ensure valid comparisons across sources (Table 2.1). Nitrogen prices are also adjusted to represent the dollar per pound of actual N. Corn acreage data was presented in total acreage planted in corn nationally. Corn price is an United States average of the real cash price per bushel. Finally, corn yield was a United States average of bushels received per acre for the previous year.

The final explanatory variable vector required weather data which was gathered using the NOAA database. These data are referred to as the Oceanic Niño Index and represent when months are warm, cold, or neutral based on a given threshold. The warming of the Pacific Ocean represents La Niña, while the cooling is El Niño. For this analysis, the numerical values did not provide valuable information, so the data was converted to binomial variables with one being true (e.g. February Niño) and zero being false. This data is on a monthly basis over the same time frame as stated before (1960-2014). Monthly information allows for within year timing to be considered in offering insights on nitrogen usage throughout the growing period of corn.

In this dataset, there are 55 observations with a total of 36 variables, though not all of these variables are present in every model. The monthly weather data consists of 24 out of the 36 variables. Over the 55-year time frame, 56% of the years were neutral years, 24% were La Niña years, and 20% were considered El Niño years. January had the most

El Niño conditions with 36%, January and February had the most La Niña conditions with 34.5%, and June had the most neutral conditions with 58%.

Other important data statistics include the nitrogen and corn production variables. Summary statistics on all variables from 1960-2014 are presented in Table 2.2. The average total nitrogen usage (actual N) is just over 9 million tons. For the individual sources, anhydrous ammonia had the highest actual N usage at 3.2 million followed by urea (3 million) and nitrogen solutions (2.1 million). Price per pound of actual N averaged $0.19, with urea being the cheapest at $0.04 per pound actual N. United States average corn price was $2.48 per bushel, and average yield was 109 bushels per acre. Over the 55 years, the average annual corn acreage planted was 77.4 million acres.

Of the variables included in the model, the hypothesis is that months around main fertilizer application, March through June, will be statistically significant. Likewise, the price of nitrogen should also be significant and have a negative relationship with nitrogen usage (as price increases, N usage decreases). Additionally, the corn acreage and yield from the previous year (lagged) variables are believed to be significant and have a positive relationship with nitrogen usage (as acreage increases, N usage increases). Lastly, individual source models are predicted to be significant and offer insights into which sources are preferred at different times of the year.

Econometric modeling allows for many tests to be conducted to determine the validity of the data and model itself. Initially, the data were tested for stationarity, a constant long-term mean and variance, revealing the data were not stationary which was then corrected by the first difference estimation. Given the variables used in the model, there was a concern of endogeneity which means that the explanatory variable is correlated with the error term. The Hausman test was conducted which revealed there were no endogenous variables. The variance inflation factor (VIF) was used to determine the level of which others can linearly predict one variable, referred to as multicollinearity, within the regression. Results showed that the model did not have a multicollinearity issue. Finally, robust standard errors were run to test for heteroscedasticity, which is data with unequal variability across a range of values of a predictor variable. Again, this test revealed that heteroscedasticity was not a problem in these models. Upon completion of all tests, the models were completed, and the results were retrieved.

2.4 Results

Regression results indicated that two of the four models were significant: total nitrogen usage and anhydrous ammonia usage. Regression results of the total nitrogen usage model suggested that the model explains 59% of the variation in nitrogen usage. Table 2.3 displays the summary statistics of the model. The Farm Bill variable was significant at the 90% confidence level, while January El Niño, March El Niño, and July La Niña were all significant at the 95% confidence level.

Since this is a Log-Log model, the results are interpreted as elasticities. After the 1996 Farm Bill, 5% fewer nitrogen fertilizers were used. This variable was only significant at the 90% confidence level and it was the opposite of expectation. Initially, it was thought that after the Farm Bill production in crops requiring added nitrogen increased, therefore, nitrogen usage should have increased. This opposing result can be explained by looking at soybean production. In the ten years before 1996, national soybean production hovered around 60,000,000 acres. In the ten years since 1996, production jumped to 70,000,000 acres and steadily increased to 75,000,000. Soybean production competes with corn production, and since it does not require any added nitrogen fertilizers, usage of nitrogen fertilizers decreased.

Weather variables are also interpreted as elasticities and since the goal is to look at predictive weather technology, are especially important to this analysis. If January is El Niño, 11.5% less nitrogen fertilizer is used as compared to a neutral January case. This variable is significant at the 95% confidence level and was predicted to be insignificant. Since January is typically a month in which little fertilizer is being applied due to frozen grounds, it is surprising that this month has a substantially significant result. This result is an anomaly, nevertheless, it may be partially explained. As discussed previously, wheat is the primary crop receiving nitrogen during this time and is most usually in the southern plains and Texas due to the unfrozen ground as compared to the northern plains. An El Niño January in Texas is wet which means that farmers are unable to get into the fields to apply the needed nitrogen, which may partially explain the negative usage.

Unlike the January result, the March result is one that was expected (95% confidence level) and can easily be explained by looking at corn production in the Midwest. If March is El Niño, 13% more nitrogen fertilizer is used as compared to the March neutral case. In March, corn is the primary crop receiving nitrogen, and the highest amount of production is in the Midwest. An El Niño March in the Midwest is drier which means farmers are more likely able to get into the field to apply nitrogen. During this time frame, the plants need initial nutrients to carry through the early growing period so that combined with dry conditions means the farmers can apply the fertilizer without the threat of nutrient loss due to excessive rains.

Additionally, if July is La Niña, 24.6% more nitrogen fertilizers are used compared to the July Neutral case. Like the other two weather variables, this result was significant at the 95 % confidence level. Again, most of the nitrogen used during this time is likely used on corn in the Midwest; therefore, a July La Niña is wet in this region. Depending on when the corn is planted, July could be the last time to apply nitrogen fertilizers before the corn has begun to tassel. The timing of the growth stage in corn combined with the wet month helps explain why so much more nitrogen fertilizers are used. Though an estimate of nearly 25% is questionable; this is a reasonable explanation of the result.

This model yielded useful, statistically significant results, though several variables were not significant that are worth discussing. One of those being the price of nitrogen. An underlying assumption is that if the price of nitrogen increases, farmers will purchase less and vice versa. According to the results of this model, despite economic theory, the change of the price of nitrogen does not change purchasing behavior. Nitrogen fertilizers are necessary for efficient corn production; therefore, farmers do not dramatically alter their purchasing behavior due to a change in price.

Likewise, the corn acreage and corn yield lagged variables were not significant but are deemed necessary enough to discuss. Both of these variables yielded signs that were opposite of the expectation but insignificant from zero. It is expected that as corn acreage increases, nitrogen usage should also increase. Similarly, we expect nitrogen usage to increase with increasing yields. The model resulted in negative signs, which are interpreted as decreasing values. One potential justification is that over time nitrogen efficiencies have increased therefore not needing as much nitrogen.

When looking at the individual source models of nitrogen usage, only the anhydrous ammonia model was significant. The model explained 43% of the variation of nitrogen usage. In this model, only two variables were significant and both at the 90% confidence level (Table 2.3): corn acreage and July La Niña. An increase in corn acreage decreases anhydrous ammonia usage by 34%. The overall usage of anhydrous has been steadily declining since the 1980s which is when its usage peaked. This variable had an opposite sign than expected, and was questionably large.

The July La Niña result can be described as it was in the total usage model but with more caution. A La Niña July (wet in the Midwest), leads to a 27.5% increase in anhydrous usage. Again, farmers are applying as much nitrogen as they can before the corn gets to a stage in growth in which it does not utilize it very well. However, in reality, anhydrous ammonia would not be the source of N applied in late season it would be the liquid form (nitrogen solutions). This result is a prime reason why production agriculture knowledge, in this case fertilization practices, is important for interpreting econometric results.

The individual source models of urea and nitrogen solutions yielded results that were insignificant. Results of both of these models are presented in Tables 2.5 and 2.6. Given the data and models, there was not as much explanatory power as expected. In this situation, it can be concluded that individual sources of nitrogen do not explain the overall usage of nitrogen fertilizers as was anticipated.

Overall, the results suggest that weather may play an important role in nitrogen usage during certain months. This information could be beneficial to farm managers when forecasting fertilizer needs in the upcoming year. They can use predictive weather forecasts that are available to them to determine the quantities of fertilizer to purchase to ensure the desired nitrogen levels are met to obtain maximum yields. For example, say a farmer applies 150 pounds of actual N per acre and locks in a fall pre-order price of $300 per ton or $0.33 per pound of actual N, making fertilizer costs roughly $50 per acre. Going by the results of the regression, in July the farmer will need to apply 25% more (188 pounds of actual N). If he/she does not pre-order the extra 38 pounds of nitrogen, the per acre fertilization expense will increase to $66. Had they pre-ordered extra their costs would be $63 per acre. On a per acre basis, it does not seem like a big difference but when you assume 2,000-acre production that is a $6,000 added cost that could be prevented if the farmer used weather forecasts to assist in fertilization decisions.

When looking at the results from a macroeconomic standpoint, agribusinesses may benefit from the results of this study as well. They can use the same forecasts and make production decisions for the company to ensure they have enough product to meet their customer's needs. They are then able to capitalize on the farmers who did not pre-order a large enough quantity because they will have it on hand which might give them a competitive edge over the other agribusinesses who did not ensure they had enough product.

In addition to the decisions that may be made in regards to fertilizer quantity, the farmer could also use this predictive technology to determine what application strategy will work best for that specific year. For example, if the forecast is calling for a wet spring, a split application fertilizer technique would be the better option for the crop to receive the most nitrogen. In contrast, if the spring is predicted to be reasonably dry, perhaps applying all of the nitrogen fertilizer up front is best because the costs are reduced by not making another pass in the field. Likewise, the application strategy argument is especially valid when looking at custom applicators. They can use these forecasts to know which strategy to use to make the most profit. Both farmers and custom applicators will need to be more adaptive and change strategy from year to year to maximize returns.

2.5 Conclusions

The goal of this analysis was to examine the relationship between nitrogen usage and weather patterns across all nitrogen sources and three individual sources. To complete the regression, a log-log model was used yielding results that were interpreted using elasticities. Total nitrogen usage and anhydrous ammonia usage models were significant. In the total nitrogen usage model, the variables Farm Bill, January El Niño, March El Niño, and July La Niña were all significant. In the Anhydrous ammonia model, corn acreage and July La Niña were significant. In sum, most of the results did not match expectation. Due to the inconsistency of results, no formal conclusions can be made but light interpretations of the results are necessary for this type of analysis.

Perhaps the most critical objective of this analysis was to determine the farm management implications. Upon receiving results, some farm management decisions may be made. By using predictive weather technology, the farmer could decide on what strategy is best to apply nitrogen given the weather situation. They might also be able to determine the precise amounts of nitrogen that will be needed after considering the potential loss due to weather. These decisions could ultimately affect the farms net returns and in years of small profit margins, be the difference in ending in red or black.

Upon further consideration, farmers are not the only ones who can potentially benefit from this information. Agribusinesses that produce and sell nitrogen fertilizers may use the weather forecasts and determine the amounts of fertilizers they need to keep in supply for the upcoming year. Similarly, custom applicators who are hired to apply nitrogen fertilizers can determine which application strategy might work best given the weather forecasts. This may then allow them to capitalize on that and increase their profit margins as well.

The use of time-series data in this analysis is both beneficial and disadvantageous. The data allowed for many observations since it goes back to 1960. However, the initial purpose of this study was to look at a specific region, the Corn Belt. The majority of the data used for the analysis was only presented nationally, and the limited state data that was available had too many gaps, not allowing for the desired regionally based results. Nevertheless, the results still generated assumptions that can be applied to specific regions even though the data itself did not specifically represent that region.

Future work should include obtaining propriety data sets which will hopefully provide data on a more disaggregated level. This type of data would allow the analysis to focus on a specific region, not the entire U.S. Being able to reproduce this model on a state or regional basis would allow for more precise farm management implications, which will greatly benefit farmers and agribusinesses alike.

2.6 Tables and Figures

Table 2.1: Percent of actual N for individual nitrogen sources

Nitrogen Source	***Percent Nitrogen***
Anhydrous Ammonia	82%
Urea	46%
Nitrogen Solutions	30%
Aqua Ammonia	20%
Nitrate	34%
Sulfate	21%
Sodium Nitrate	16%

Table 2.2: Descriptive statistics of variables

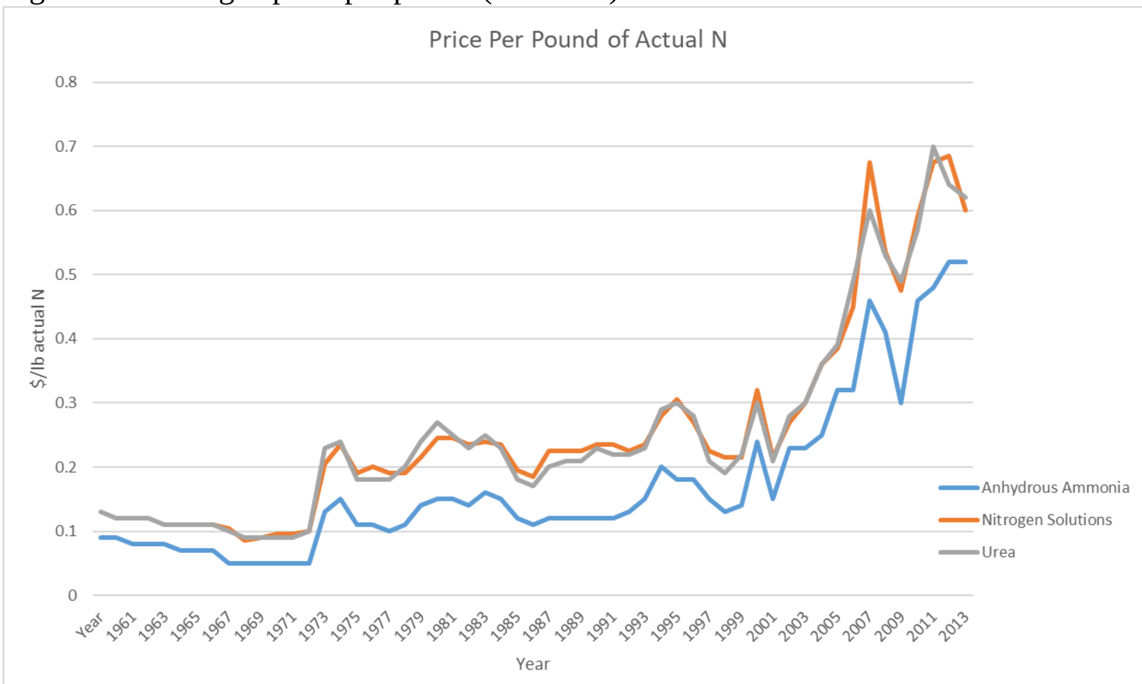
Variable (units)	Average	Standard Deviation	Minimum	Maximum
Total Nitrogen Usage (pounds)	9,045,332.94	3,518,798.00	1,924,920.01	16,548,501.15
Anhydrous Ammonia Usage (pounds)	3,236,102.51	998,148.00	581,214.36	4,661,376.92
Nitrogen Solutions Usage (pounds)	2,126,842.68	1,029,389.06	195,077.70	3,742,344.60
Urea Usage (pounds)	3,055,895.36	2,008,908.79	142,198.00	6,696,142.00
Total Nitrogen Price (per pound)	$ 0.19	$ 0.12	$ 0.06	$ 0.55
Anhydrous Ammonia Price (per pound)	$ 0.06	$ 0.03	$ 0.02	$ 0.14
Nitrogen Solutions Price (per pound)	$ 0.06	$ 0.05	$ -	$ 0.20
Urea Price (per pound)	$ 0.04	$ 0.04	$ 0.00	$ 0.16
Corn Price (per bushel)	$ 2.48	$ 1.28	$ 1.00	$ 6.67
Corn Acreage (total acres)	77,408,436.36	8,521,358.68	60,207,000.00	97,291,000.00
Corn Yield Lagged (bushels per acre)	109	30.41	53.1	164.4
Farm Bill	0.33	0.47	0	1
January Nino	0.25	0.44	0	1
January Nina	0.36	0.48	0	1
January Neutral	0.35	0.48	0	1
February Nino	0.38	0.49	0	1
February Nina	0.27	0.45	0	1
February Neutral	0.35	0.48	0	1
March Nino	0.51	0.50	0	1
March Nina	0.16	0.37	0	1
March Neutral	0.33	0.47	0	1
April Nino	0.67	0.47	0	1
April Nina	0.15	0.35	0	1
April Neutral	0.18	0.39	0	1
May Nino	0.55	0.50	0	1
May Nina	0.22	0.41	0	1
May Neutral	0.24	0.42	0	1
June Nino	0.58	0.49	0	1
June Nina	0.22	0.41	0	1
June Neutral	0.20	0.40	0	1
July Nino	0.55	0.50	0	1
July Nina	0.22	0.41	0	1
July Neutral	0.24	0.42	0	1
August Nino	0.53	0.50	0	1
August Nina	0.22	0.41	0	1
August Neutral	0.25	0.44	0	1

Table 2.3: Regression results (Standard Error in parenthesis)

	Total Nitrogen Usage (across all sources)	Anhydrous Ammonia Usage
Intercept	0.362	6.302
	(1.975)	(3.014)
Corn Price	0.012	-0.14
	(0.065)	(0.096)
Nitrogen Price	-0.052	0.09
	(0.091)	(0.118)
Corn Acreage	-0.016	-0.343 *
	(0.109)	(0.166)
Corn Yield Lagged	-0.027	-0.071
	(0.088)	(0.156)
Farm Bill	-0.054 *	-
	(0.027)	-
January Nino	-0.115 **	-0.031
	(0.042)	(0.079)
January Nina	-0.014	-0.014
	(0.039)	(0.057)
February Nino	0.069	-0.026
	(0.050)	(0.079)
February Nina	-0.070	-0.122
	(0.080)	(0.116)
March Nino	0.130 **	0.134
	(0.049)	(0.091)
March Nina	0.017	0.091
	(0.076)	(0.119)
April Nino	-0.106	-0.127
	(0.061)	(0.109)
April Nina	0.048	0.03
	(0.072)	(0.116)
May Nino	-0.047	-0.01
	(0.067)	(0.121)
May Nina	0.073	-0.002
	(0.072)	(0.098)
June Nino	-0.056	-0.125
	(0.060)	(0.116)
June Nina	-0.161	-0.067
	(0.092)	(0.092)
July Nino	0.072	0.137
	(0.070)	(0.112)
July Nina	0.246 **	0.275 *
	(0.082)	(0.119)
Aug Nino	-0.025	-0.053
	(0.070)	(0.113)
Aug Nina	-0.159	-0.229
	(0.079)	(0.134)

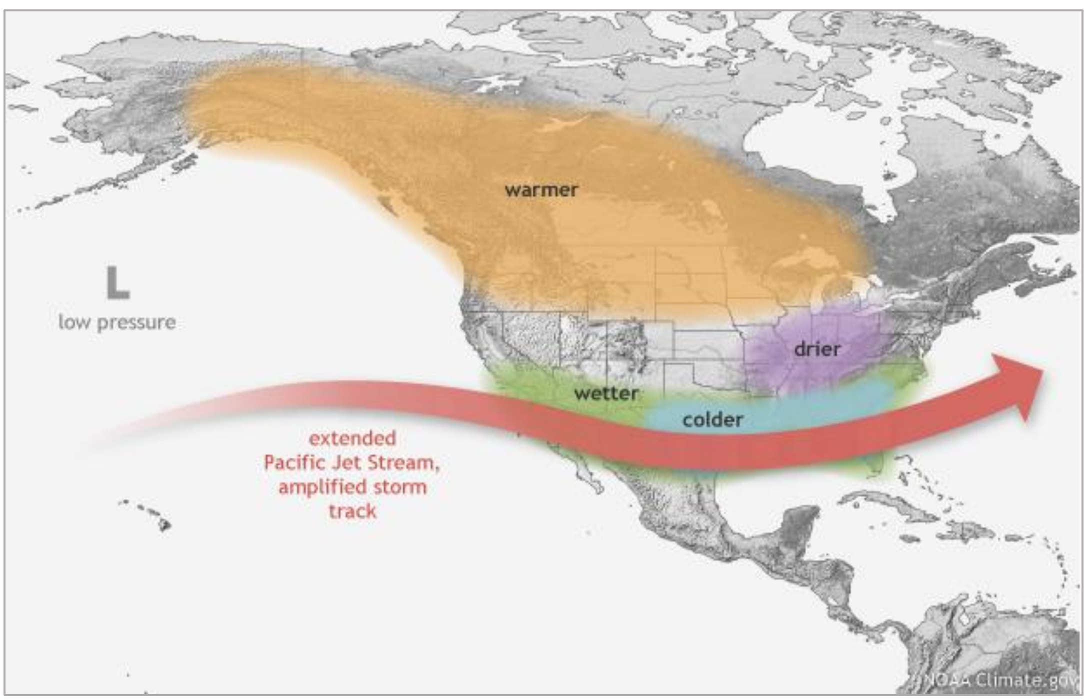
* $p<0.05$, ** $p<0.01$, *** $p<0.001$

Figure 2.1: Nitrogen price per pound (Actual N)



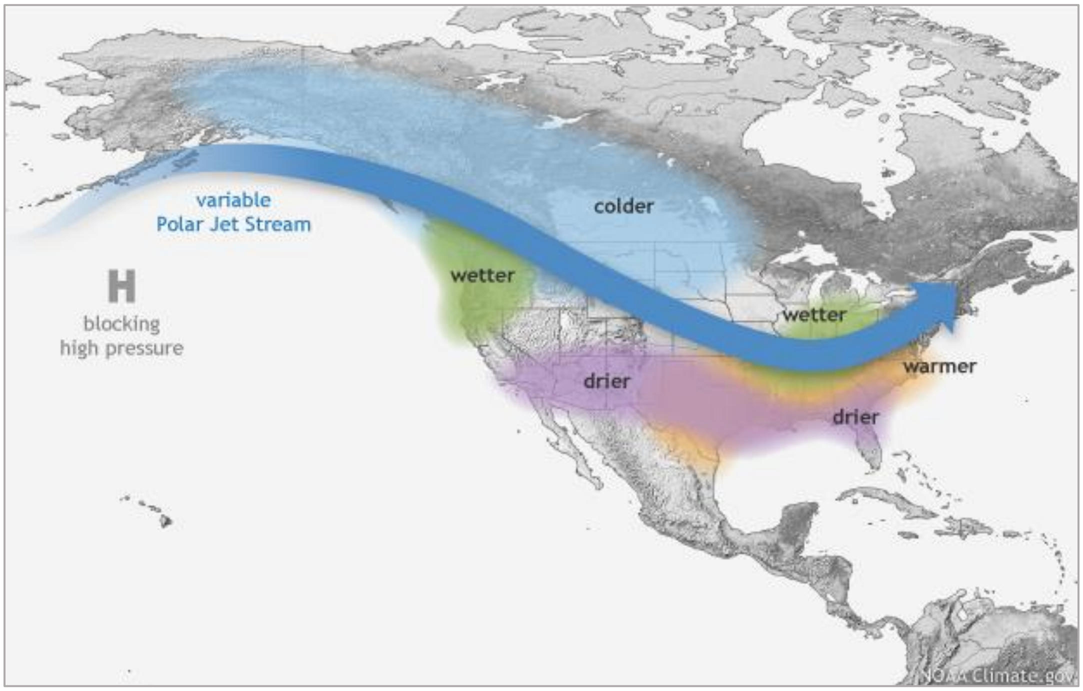
Source: USDA National Agricultural Statistics Service

Figure 2.2: Typical El Niño pattern



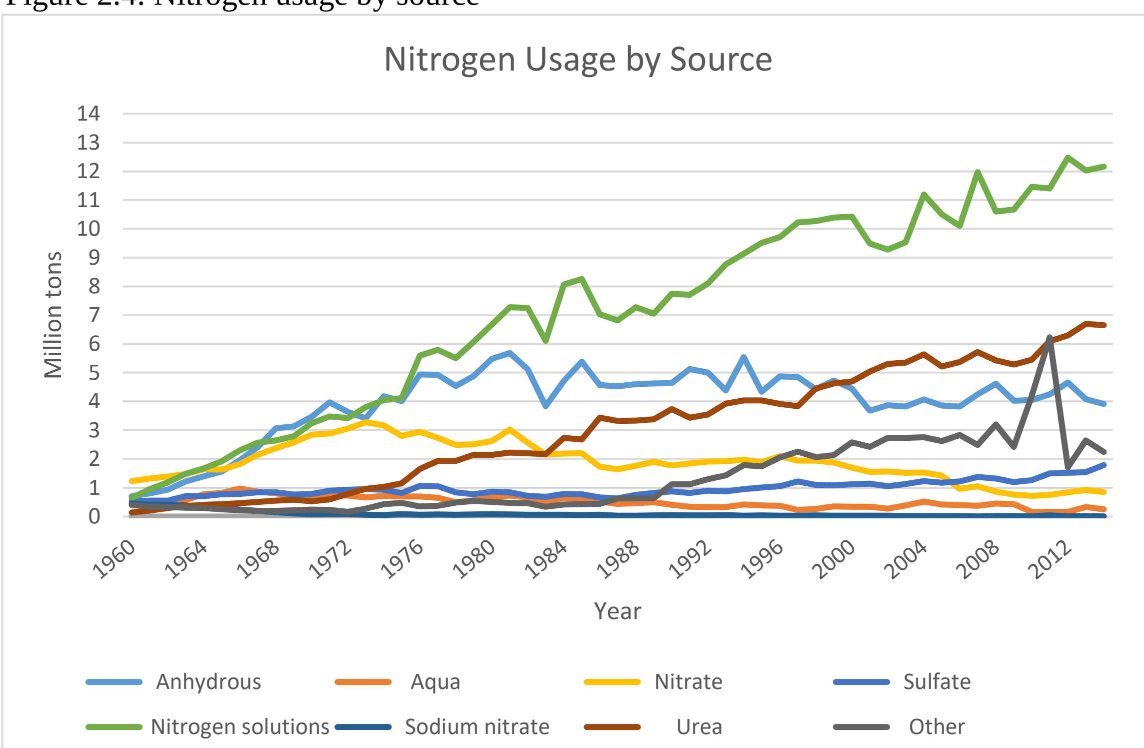
Source: National Oceanic and Atmospheric Administration

Figure 2.3: Typical La Niña pattern



Source: National Oceanic and Atmospheric Administration

Figure 2.4: Nitrogen usage by source



Source: USDA Economic Research Service Fertilizer Use and Source

CHAPTER 3. EVALUATING THE PROFITABILITY OF POULTRY LITTER SUB-SURFER TECHNOLOGY

3.1 Introduction

In recent years, grain farmers have seen low market prices and rising input prices leading to a reduction in profit margins. In efforts to manage costs, grain producers use poultry litter as a cheap fertilizer source when available. Poultry, specifically broilers, are produced mainly in the Southeast U.S. While Kentucky ranks 7th in the nation in broiler production, poultry is the number one commodity in cash receipts for the state (Kerestes et al., 2017). The Kentucky Poultry Federation estimates there are 3,200 broiler houses in Kentucky. With each house producing approximately 200 tons of litter per year, Kentucky produces 640,000 tons of broiler litter annually, valued at $16 million (Rasnake, 1996). Unlike some states that are heavily regulated, such as Maryland, there are limited regulations in Kentucky regarding the application of poultry litter for grain crop production. Therefore, it is important to be good stewards to the land and reduce/prevent environmental concerns of poultry litter fertilization all while maximizing the economic and agronomic benefits.

One key management practice is the timing of the application. Research has shown that the optimal litter application timing to recoup the most nutrients is in the spring before planting (Rasnake et al., 2000). However, due to time constraints in the spring with planting and the number of suitable field days available, many of farmers using litter will apply litter in the fall or winter (Tewolde et al., 2013). By broadcasting litter on the fallow ground in the fall or winter, nearly all of the nitrogen in the litter is lost due to leaching or volatilization. Consequently, the complete economic benefit of nitrogen in poultry litter is not realized, and environmental concerns arise. Furthermore, traditional application methods using a spin spreader to broadcast litter on top of the soil allow for nutrients to be lost when not incorporated using tillage methods or a timely rainfall event. Ideally, producers could apply poultry litter in the fall or winter and recoup the same amount (or more) nutrients as when applied in the spring. Alternatively, producers could apply in the spring using a different application method and recoup more nutrients from poultry litter than when broadcast on top of the soil. Both management strategies potentially improve the economic benefit of poultry litter and reduce environmental impacts from nutrient runoff.

A new application technology, the poultry litter sub-surfer, has the potential to increase nutrient availability to the crop. This prototype technology injects poultry litter directly into the soil preventing nutrient loss due to excessive runoff. The prototype, invented by ARS soil scientist Dan Pote in 2010, has been tested in the Chesapeake Bay region, Arkansas, Pennsylvania, Oklahoma, and Kentucky. Early indications suggest this new technology is superior to traditional broadcast methods from an agronomic and environmental standpoint, yet the economic benefits are unknown. Therefore the objectives of this study are: (1) develop a whole farm, resource allocation model to determine the economic viability of the poultry litter sub-surfer technology compared to traditional broadcast methods; (2) assess the impact fertilization strategies have on planting date, and whole farm net returns; (3) determine how days suitable for fieldwork risk impact the economic viability of the poultry litter sub-surfer technology; and (4) conduct break-even analyses on key poultry litter sub-surfer assumptions (performance rate, purchase price, and agronomic benefits).

3.2 Background

Agronomists have studied the effects of poultry litter on the soil, and on the different crops, in which it is applied. Results suggest that poultry litter as a fertilizer source will increase soil health over time as compared to commercial fertilizers and eventually increased yields will be realized. Specifically, the organic matter contained in the litter could be especially beneficial to places where topsoil is lost due to erosion (Rasnake, 1996). Another advantage of using poultry litter is that it does not acidify the soil as commercial fertilizer does. Poultry litter offers a range of benefits starting with providing nutrients to the land, eases some environmental concerns, and is often cost-effective (Pratt, 2014).

The timing of applying poultry litter has also been studied. Applying the litter in the spring instead of the fall is beneficial because more nutrients will be captured. Most farmers fall apply because of the time availability (Tewolde et al., 2013). At any time of application, incorporation of the litter into the soil will increase nitrogen available for the crops (Rasnake et al., 2000). When litter is applied in the fall without a cover crop, only about 15% of nitrogen is available to the corn crop in the following year. Likewise, if it is applied in the spring and incorporated within five days or by small amounts of rain, an estimated 50% of nitrogen will be available to the corn crop in the following year (Rasnake et al., 2000). However, maximizing nitrogen availability can be an issue in no-till production systems nutrients aren’t manually incorporated into the soil leaving it to nature to determine if the nitrogen will be available.

There are environmental concerns with utilizing poultry litter in grain crop production, primarily when managed inappropriately. Broadcast poultry litter can run off the field and cause nonpoint source pollution through the buildup of phosphorus and nitrogen in water sources. These spots are known as dead zones where little to no aquatic life is present (Gerber et al., 2009). Since poultry litter has been identified as one source of the nutrients contributing to dead/hypoxic zones, the Environmental Protection Agency (EPA) and the United States Department of Agriculture (USDA) have implemented nutrient management strategies that help prevent the overuse of poultry litter and other fertilization techniques.

Traditional poultry litter application methods (broadcast) leads to a loss of the valuable nutrients through volatilization and leaching. Current research is investigating ways to combat this problem. The newest application method, sub-surface injection, operates like a no-till planter. This piece of equipment pulverizes the litter into ultra-fine particles just before slicing the ground about 3 inches deep, allowing the litter to flow right in before another blade moves the dirt over it, keeping the litter from being exposed. This technique is unique in the fact that it incorporates the litter into the soil without unearthing the ground. Many Kentucky grain farmers have adopted no-till methods making this injector an appropriate solution for the runoff of nutrients caused by not incorporating the poultry litter.

Previous research suggests that sub-surface injection of poultry litter has the potential to increase yields because less of the nutrients are lost to volatilization or leaching (Crummett, 2015). Studies have shown that near the end of corn growth, biomass and nutrient uptake was greater with the injector as compared to the spreader which explains the increase in yields (Pratt, 2014). Though an exact yield increase has yet to be determined, some studies report a yield increase of 20-36% (Pote et al., 2011).

Also, the sub-surface application has also been shown to reduce the runoff of nitrogen and phosphorus by nearly 90% as compared to other methods (Pote et al., 2011; Watts et al., 2011). Less runoff means less pollution to nearby water sources, making this method more environmentally friendly. Additionally, the typical application method of broadcasting litter on top of the soil has received some complaints such as an unpleasant smell. With the injector, air quality around the areas of the application has improved because the amount of ammonia released into the air is reduced by about 95% as compared to broadcasting (Pratt, 2014).

Many analyses have been conducted looking at the economic and environmental impact of poultry litter. The transportation of litter has been studied primarily in areas of high concentration of poultry production (Govindasamy and Cochran, 1995; Carreira et al., 2007; Jones and D'Souza, 2001; Mullen et al., 2011). Likewise, policies on poultry litter have been debated and put into action in some areas (Govindasamy and Cochran, 1998; Fritsch and Collins, 1993). Similarly, the discussion of poultry litter value and markets have been discussed but have yet to be entirely determined (Carriera et al., 2006). While the literature on poultry litter has grown recently, currently no studies looking at new application methods from both an economic and environmental standpoint exist. This paper will contribute to the current literature by assessing the economic feasibility of sub-surface injection of poultry litter.

3.3 Material and Methods

To determine the economic feasibility of the poultry litter sub-surfer technology, this study follows the resource allocation model presented in Shockley et al. (2011). Modifications are made to the model by reflecting various fertilization strategies and associated costs (broadcast poultry litter and sub-surfer poultry litter) to determine which is economically optimal.   A mathematical description of the model is presented in the Appendix.

The objective of the model was to maximize net returns above selected costs for a hypothetical no-till grain farm in Henderson County, Kentucky. The selected costs included in the model are input variable costs for growing corn and soybeans in Kentucky, operating costs, and the ownership costs of equipment for each fertilization strategy. This study investigates four fertilization strategies, resulting in four separate resource allocation models. The four fertilization strategies are: (1) fall broadcast of poultry litter with supplemental nitrogen (UAN 32) in spring, (2) spring broadcast of poultry litter with supplemental nitrogen (UAN 32) in spring, (3) fall sub-surface injection of poultry litter with supplemental nitrogen (UAN 32) in spring, and (4) spring sub-surface injection of poultry litter with supplemental nitrogen (UAN 32) in spring. All methods meet the total fertilizer requirement for a corn and soybean rotation of 180 lbs. of actual nitrogen, 60 lbs. of phosphorus, and 55 lbs. of potassium for corn and 50 lbs. each of phosphorus and potassium for soybeans based on the recommendations given in the University of Kentucky's Cooperative Extension publication AGR-1 2014-2015. Reference Table 3.1 for fertilizer application information. Also included in the model are decision variables, constraints, and associated data.

The decision variables for these models are the number of corn and soybean acres produced based on planting date and fertilization method. The models include various constraints which limited land, labor by week, and a restricted supply of poultry litter only allowing 400 acres to be fertilized. Based on phone surveys conducted by soil specialists at the University of Kentucky, producers in Western Kentucky currently only use poultry litter to fertilize 40% of their total corn acreage. By limiting this model only to allow 400 acres of 1000 acres of corn available in the model assumptions to be fertilized with poultry litter, the most accurate description of current production practices is being presented.

Based on data presented by the Kentucky Farm Business Analysis group, the average grain farm size in Western Kentucky is 2000 acres (Peirce, 2017). Assuming a 50/50 crop rotation, 1000 acres will be devoted to each corn and soybeans. Production practices identified for the selected crops include planting, spraying herbicides and insecticides, fertilizing, and harvesting. Poultry litter fertilization timing was not restricted to certain weeks. In the spring methods, fertilization could occur anywhere from week 11 to the week of planting. Similarly, in the fall methods, poultry litter could be applied any time after harvest took place.

Suitable field day risk data from Shockley and Mark (2017) are included to evaluate weather risk. The initial models used the median numbers of suitable field days that have been collected by week since 1996 by the USDA NASS. When assessing suitable field day risk, two additional percentiles are considered; 15th and 35th. These percentiles are a good representation of risk aversion and are the common percentiles used in Extension literature. The days suitable are multiplied by an assumed 12-hour work day (assuming a one-person operator) resulting in the hours available to conduct farming operations on a per week basis. The Charnes and Cooper method, a chance-constrained formulation for right-hand side risk, is used to evaluate days suitable for fieldwork (Charnes and Cooper, 1962).

Additional data included market prices for both corn and soybeans, commercial fertilizers, and poultry litter. From 2012 to 2016, USDA reports an average market price of $4.64 per bushel and $11.44 per bushel for corn and soybeans, respectively. Commercial fertilizer prices over the same period were $0.40 per pound of UAN, $0.49 per pound of DAP, and $0.51 per pound of potash. Typically, poultry litter prices for Kentucky range from $20-$30 per ton which includes the cost of removal and hauling (Shockley, 2016). Therefore, an estimated price of $25 per ton is used in this analysis.

In addition to price and fertilizer data, yield data based on planting date is required. Average yield between 2012 and 2016 in Henderson County, Kentucky was 147 bushels per acre for corn and 48 bushels per acre for soybeans (USDA-NASS, 2018). However, yields for both crops depend heavily on the time of planting. For this analysis, there are 14 weeks available for planting beginning the week of March 16th till June 23rd. For both corn and soybeans, each of these weeks has either a yield increase or decrease based on a 13-year optimum planting window study conducted by Becks Hybrids. For both corn and soybeans, optimal planting date is between April 16th and April 23rd increasing yields by 110% and 107%, respectively (Schwartz et al., 2017) move to front of sentence. Figure 3.1 presents the yield curves based on planting date over the 13-year period. For this model, the average historical yield was multiplied by the yield percentages to attain a weighted yield estimate.

Information on broadcast poultry litter application is readily available. However, since the poultry litter sub-surfer is a prototype, commercial pricing is non-existent. Personal communication with the creator, Dan Pote, indicates the sub-surfer (under current design) would cost the farmer $50,000 (Pote, 2018). The sub-surfer is estimated to have a useful life of eight years, and a salvage value of $5,000. The interest rate is assumed to be 6%. Table 3.2 shows the investment and ownership costs, and the performance rate for the injector method compared to the broadcast method. Even though pricing data is scarce, research has been conducted on machinery and agronomic performance of the sub-surfer technology. Soil specialists indicate that the sub-surfer technology can cover 3.16 acres per hour (McGrath, 2018). This is substantially slower than other fertilizations strategies which impacts operating costs as well as potential delays in planting.

In addition to machinery performance data, agronomic studies have been conducted to determine the impact on crop yields by injecting poultry litter into the soil. Some studies report an increase in yields from 20-36% (Pote et. al., 2011). However, early unpublished studies in Kentucky indicate the injection of poultry litter has the potential to increase corn yields by 7% compared to both surface applied poultry litter and commercial fertilizer (McGrath, 2018). Since both the price of the sub-surfer technology and yield benefits are only estimated at this point, sensitivity analyses are conducted to determine the impact on net returns.

3.4 Results

To establish a baseline comparison, a model looking at 100% commercial fertilization was completed and provided the basis for the poultry litter models. The net return for this model was $771,454 which is substantially lower than any of the poultry litter methods. This net return is lower because the cost of commercial fertilizers is higher relative to poultry litter. This model is omitted from the discussion because the primary focus is on the poultry litter application methods.

Of the four poultry litter fertilization strategies modeled, the economically optimal is spring application of poultry litter using the typical broadcast method with a net return of $844,191. This method is superior because more nutrients are getting to the plant reducing fertilizer costs and the broadcast method allows more ground to be covered reducing operating costs. Optimal production is 1000 acres of corn, 400 acres fertilized with poultry litter and supplemental N and the remaining 600 acres fertilized with 100% commercial fertilizer. Likewise, 1000 acres of soybeans are also produced. Corn is planted in the weeks of April 8th through May 1st while soybeans are planted April 16th through May 1st. Poultry litter is applied in the same week as planting for every week even though it is allowed to occur earlier. Marginal values are reported where for labor in weeks 14-16 and 20, poultry litter acreage limitation, and the acreage devoted to crop production. By adding one hour of labor in week 15 (the most constrained week), the net returns will increase by $204. Similarly, if the acreage for poultry litter application were increased by 1%, net returns would increase by $85.

While the spring broadcast of poultry litter method is economically optimal, spring injection of poultry litter is only $198 less with a net return of $843,993. One of the reasons that this method is comparable to the spring broadcast method is because of the increased yield benefit associated with the injection technology. The increased yield benefit of 7% makes up for the extra time it takes to apply the litter with the slower machinery. The number of acres of corn and soybeans produced, as well as the planting dates, did not change. Unlike the broadcast method, the injection method is in operation four weeks before planting to compensate for the slower performance rate which would delay planting otherwise. If the model were more restrictive, less time prior to planting to inject, spring injection wouldn't be a close alternative to spring broadcast.

The fall fertilization methods resulted in net returns substantially lower than the spring methods. Fall broadcasting was lower because even though it's not conflicting with planting, more supplemental nitrogen is required to meet the yield goals. The resulting net return was $835,953. Likewise, fall injection is lower because even though there is a yield benefit, the added cost of the machine and additional commercial nitrogen required outweighs the increase in yields. The net return for this method was $835,314. All results are presented in Table 3.3.

Since the poultry litter sub-surfer is a prototype technology, sensitivity analyses are required on crucial assumptions in the models. An especially critical assumption is the performance rate of the injection system. This value is varied to determine when fall injection is comparable to the optimal spring broadcasting net returns. Purchase price and yield benefit assumptions are also fundamental to this analysis. Both of those values are also varied to determine the levels in which fall injection competes with spring broadcasting.

Conducting any field operation promptly is critical in grain crop production. The most substantial concern regarding the sub-surfer technology is how slow the machine operates. The sub-surfer has a performance rate of 3.16 acres per hour as compared to the 23.75 acres per hour for the traditional spin spreader. If the sub-surfer is to compete with conventional application methods, the performance rate must be improved. For the fall injection model to have similar net returns as the spring broadcast model, the performance rate of the injector would have to increase to 22 acres per hour, ceteris paribus. For this calculation, the hours required for operating the injector was varied in the fall injection model until net returns match those of the spring broadcast model. Though it proved to be economically viable in the spring, equipment manufacturers and developers will need to focus on increasing the speed of the injector for producers to be convinced that this equipment is the better alternative to traditional application methods.

Likewise, the eventual purchase price of the sub-surfer is currently unknown. A break-even analysis showed that, under current assumptions, the injector would have to be purchased at a price of $10,000 or lower for net returns of the fall injection method to be comparable to that of the spring broadcast method. The likelihood of this equipment selling for this price is very slim, especially during the initial commercial release. Furthermore, since there are limited yield studies, which will vary by location, the yield benefit is varied. The fall injection method requires a yield benefit of 10.25% to be comparable to the spring broadcast method. All of the above break-even analyses are summarized in Table 3.4.

In addition to the breakeven analysis, suitable field day risk was also assessed in this study. Suitable field day risk analysis is an important part of this study because many of the field operations in question are imperative in determining the optimal strategy. For the base models, the median level or 50% likelihood is assumed for each week's days suitable for fieldwork. This case presented an average of 4.9 days per week available for field work. Following that, two additional assumptions were used: (1) 15^{th} percentile represents the fewest days available for field work (extremely risk averse); and (2) 35^{th} percentile represents fewer days available for field work than the median case (risk averse). For the 35^{th} percentile there was an average of 4.3 days suitable fieldwork, and for the 15th percentile, there were 3.4 days suitable. See Table 3.5 for descriptive statistics on suitable field days.

The results of the two risk averse field work probability levels are presented in Tables 3.6 and 3.7. As expected the optimal net return in all scenarios decreased with the risk-averse cases. Farmers typically tend to be more risk-averse, in other words, they plan for fewer days available. The results of the 35th percentile were very similar to the median case with the main difference being an additional planting week (April 1st) for planting corn and an additional week (April 8th) for planting soybeans in the spring broadcast scenario yielded a net return of $839,701. Fall broadcast became the second optimal while spring injection fell became the least optimal of the four options. This is likely because the number of days required to run the injector exceeded those of the days available resulting in a delay in planting and reducing yields. For the extremely risk-averse case, the spring broadcast method had a net return of $815,943. Corn planting remained the same, but soybean planting is even more spread out with it starting April 1st continuing until June 1st with some weeks not having any planting. Also, in this scenario, spring broadcast was superior to all methods even though poultry litter fertilization interfered with planting and forced soybean planting to be scattered out over a nine-week time frame. As suitable field day risk increased, the difference of net returns between fall injection and spring broadcasting decreased. This result was expected given the nature of the injector and the limited time available to do other spring operations.

3.5 Conclusions

The goal of this analysis was to provide insight and evidence of the economic impacts of poultry litter as a fertilizer source and more specifically compare the sub-surface injector to the more traditional application methods. A resource allocation, linear programming model was used to determine the optimal fertilization strategy for a typical farm in Henderson County, Kentucky. Results suggest that the spring broadcast of poultry litter method was the optimal fertilization strategy compared to the new technology of injection. This result provides further evidence that this method should be the recommended one for Kentucky farmers.

Another result that provides excellent insight is that the spring injection method is just slightly less optimal than spring broadcast. The sub-surface injector has the potential to become an economically viable option for Kentucky farmers in the future. However, if fall injection is to be competitive with the spin spreader in spring application, the performance rates would have to increase significantly. Being able to cover the most ground as quickly as possible while maintaining accuracy is very important to farmers who are often dealing with suitable field day issues. Also, if the yield increase associated with the injector were to improve, then the additional cost to the farmers would be outweighed by the additional revenue in yield gains they would receive.

This study does have limitations. The biggest issue faced was information regarding the sub-surface injector. The majority of this data had to be estimated due to lack of current published data because of the technology being in the prototype stage. The economic model itself is deterministic rather than stochastic. Future modeling could include stochastic modeling to reflect the uncertainty in the base assumptions. Also, future research might consist of more field trials in Kentucky to determine a definite yield increase for the injector. Likewise, the impact this equipment has on the environment has been discussed but not yet quantified.

This analysis is useful to many people in the agriculture industry. On the farm level, farm managers can use this information to decide if their current fertilization practices are optimal. As it currently stands, the sub-surface injection technology does not provide enough benefit to the farmers for them to switch from the more traditional broadcasting method. In the current state of the technology, these results are perhaps even more important to the manufacturers of the sub-surface injector. They can use this information to improve equipment specifications to enhance the profitability of commercializing this technology.

3.6 Tables and Figures

Table 3.1: Nutrient uptake by fertilizer source (actual pounds/acre)

	Spring Broadcast	**Fall Broadcast**	**Spring Injection**	**Fall Injection**
Nitrogen				
Poultry Litter	60	0	60	0
Commercial	120	180	120	180
Phosphorus				
Poultry Litter	80	80	80	80
Commercial	-	-	-	-
Potassium				
Poultry Litter	100	100	100	100
Commercial	-	-	-	-

Table 3.2: Investment cost, ownership cost, and performance rate for poultry litter application methods

	Broadcast	**Injection**
Investment Cost	$17,900	$50,000
Annual Ownership Cost:		
Depreciation	$915	$5,625
Interest	$512.40	$1,650
Total	$1,427.40	$7,275
Performance Rate (ac/hr)	23.75	3.16

Note: Ownership calculations are based on a 10% salvage value, useful life of 8 years, and a 6% interest rate of each piece of equipment (MSBG)

Table 3.3: Planting dates and amount of acres planted by fertilization method

		Fertilizer Method			
		Spring Broadcast	Fall Broadcast	Spring Injection	Fall Injection
	Net Returns	$844,191	$835,953	$843,993	$835,458
Corn Planting: Poultry Litter Fertilization	*April 8th*	249	-	-	-
	April 16th	-	396	396	396
	April 23rd	99	4	-	4
	May 1st	52	-	4	-
Corn Planting: 100% Commercial Fertilization	*April 8th*	51	452	232	452
	April 16th	549	148	144	148
	April 23rd	-	-	224	-
Soybean Planting	*April 16th*	120	124	61	124
	April 23rd	480	611	425	611
	May 1st	400	265	514	265

Table 3.4: Break-even values for fall injection to compete with spring broadcasting

	Break-Even Values
Performance Rate	22 (ac/hr)
Purchase Price	$10,000
Yield Benefit	10.25%

Table 3.5: Summary statistics for suitable field day data (per week)

Suitable Field Day Percentile	Average	Minimum	Maximum
50th	4.9	3.3	6.2
35th	4.3	2.7	5.9
15th	3.4	1.4	5.7

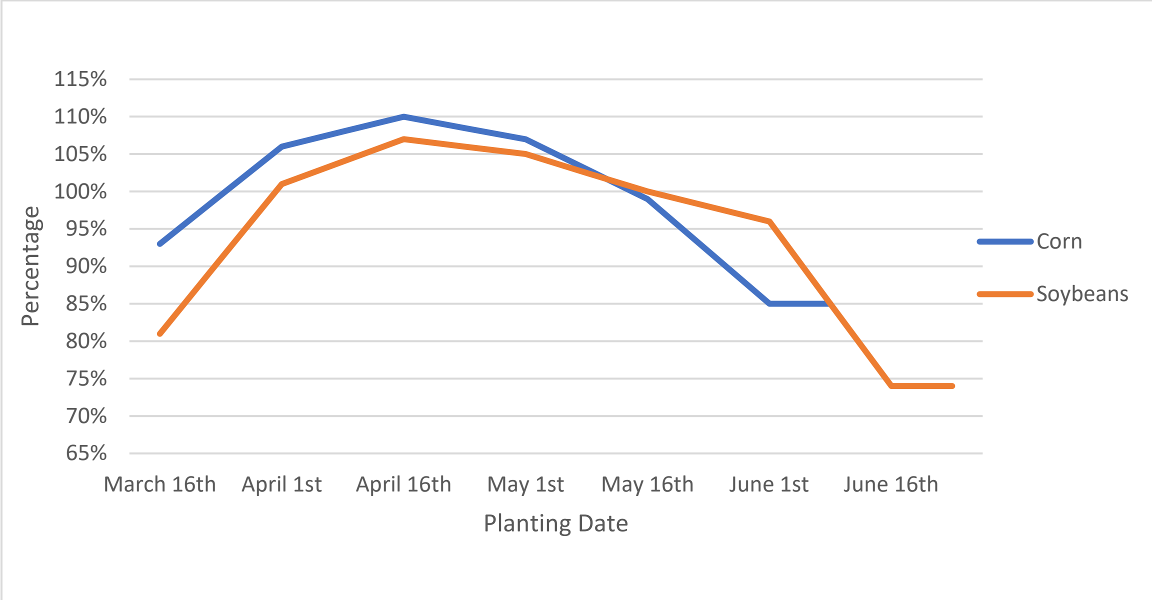
Table 3.6: Suitable field day risk – 35th percentile (risk averse)

		Fertilizer Method			
		Spring Broadcast	**Fall Broadcast**	**Spring Injection**	**Fall Injection**
	Net Returns	***$839,701***	***$832,689***	***$828,476***	***$832,193***
Corn Planting: Poultry Litter Fertilization	*April 1st*	132	-	-	-
	April 8th	77	-	-	-
	April 16th	-	124	396	124
	April 23rd	92	196	-	196
	May 1st	99	80	-	80
	May 8th	-	-	-	-
	May 16th	-	-	4	-
Corn Planting: 100% Commercial Fertilization	*April 1st*	-	-	98	-
	April 8th	248	324	-	324
	April 16th	352	276	31	276
	April 23rd	-	-	352	-
	May 1st	-	-	119	-
Soybean Planting	*April 8th*	5	81	-	81
	April 16th	193	166	39	166
	April 23rd	402	353	-	353
	May 1st	400	400	345	400
	May 8th	-	-	444	-
	May 16th	-	-	172	-

Table 3.7: Suitable field day risk – 15th percentile (extremely risk averse)

		Fertilizer Method			
		Spring Broadcast	**Fall Broadcast**	**Spring Injection**	**Fall Injection**
	Net Returns	**$815,943**	**$810,702**	**$772,288**	**$810,207**
Corn Planting: Poultry Litter Fertilization	*April 8th*	90	-	-	-
	April 16th	303	228	-	-
	April 23rd	207	64	104	151
	May 1st	-	249	-	249
	May 8th	-	-	-	-
	May 16th	-	-	-	-
	May 23rd	-	-	10	-
	June 1st	-	-	-	-
	June 8th	-	-	33	-
Corn Planting: 100% Commercial Fertilization	*April 1st*	277	-	-	-
	April 8th	-	72	-	72
	April 16th	-	290	228	290
	April 23rd	2	114	64	114
	May 1st	121	117	206	117
	May 8th	-	7	304	7
	May 16th	-	-	51	-
Soybean Planting	*April 1st*	233	232	275	232
	April 8th	249	275	377	275
	April 16th	14	-	-	-
	April 23rd	153	95	25	95
	May 1st	188	-	316	-
	May 8th	-	291	-	291
	May 16th	-	14	-	14
	May 23rd	-	-	7	-
	June 1st	163	93	-	93

Figure 3.1: Yield percentage by planting date



Source: Beck Hybrids Practical Farm Research 2017

Note: Data is based on Western Kentucky numbers over a 13 year period

CHAPTER 4. SUMMARY

This thesis presents an intriguing combination of econometric modelling and math programming techniques. Analyses include: the relationship between nitrogen fertilizer usage and weather patterns and a whole farm examination of the economic viability of the poultry litter sub-surface injector. Both studies have farm management implications for farmers as they make short and long-term production decisions. Likewise, the information presented in both analyses can be used by agribusinesses for future decision making.

In chapter two, an econometric analysis investigated the relationship between nitrogen fertilizer usage and weather patterns on a national level. The regression results indicated that total nitrogen usage across all sources was driven by the 1996 Farm Bill, January El Niño, March El Niño, and July La Niña weather patterns. Likewise, anhydrous ammonia usage, was driven by corn acreage and July Niña weather pattern. Urea and nitrogen solutions usage could not be explained with the national variables considered in this analysis.

It is important to note that no formal conclusions can be made from the results of this study due to the aggregate nature of the data. However, the results are intriguing and could potentially spur more research in the future. Nonetheless, these findings suggest that weather patterns may perhaps play an important role in nitrogen usage. Farmers may use predictive weather technology to determine when to apply fertilizer and what application strategy works best. In addition, farmers could decide how much fertilizer they need to purchase in advance to reduce costs. For example, if the forecasts are calling for a dry March (El Niño) in a given region, farmers should purchase and apply 13%

more fertilizers. Fertilizer retailers can use this information to determine the amounts of fertilizer they need to keep on hand and can capitalize on the farmers who need to apply more nitrogen late in the season. Likewise, custom applicators may use this information to better market their service and determine which application strategy to use each year.

Chapter three discusses a linear programming model used to determine if the poultry litter sub-surface injection method is an economically viable alternative to traditional broadcast methods. In addition to application method, optimal application timing was also determined. Results indicate that spring broadcasting is economically optimal, though spring injection yields a net return similar to spring broadcasting. This study provides evidence that sub-surface injection has the potential to become more economically feasible than the typical broadcast method of poultry litter.

Though Kentucky farmers currently apply poultry litter in the fall due to suitable field day concerns, based on the results of this study, they should consider altering their application timing and apply poultry litter in the spring. Switching application timing will increase the farmer's net returns by nearly 1% for the conditions analyzed. The information presented in this study is also beneficial to equipment manufacturers because even though the injector currently has a slow performance rate, the net returns were very close to that of the traditional methods. Multiple sensitivity analyses were completed which show manufacturers how they need to improve the sub-surface injector for it to be an economical option for farmers in Kentucky and likely across the nation. For fall injection to compete with spring broadcasting performance rate of the sub-surface injector will need to increase by 10.25%. Suitable field day risk was also assessed by looking at three levels of risk neutral, risk averse, and extremely risk averse. For all risk levels, spring broadcasting was the superior method though planting dates were adjusted as the number of days available decreased.

Both analyses provide a basis for future research. For the first essay (chapter two), research should include obtaining propriety data sets which are more disaggregated. Hopefully these data sets will allow a state or regional approach to the model which will give more beneficial results. This mode currently focuses on nitrogen however it can be modified to look at usage of other nutrients as well. Likewise, for the second essay (chapter three), more research needs to be done regarding the sub-surface injector performance rate and yield benefits. This model focuses on poultry litter, but it can also be used to compare all types of manure fertilizer application methods. Similarly, it can be modified to represent other parts of the state or country.

APPENDIX

APPENDIX 1. MODEL SPECIFICATION

Model specification (for a given *f* and *p)*:

(1) $Max\ Y$

$Subject\ to$:

(2) $\Sigma_e\, \Sigma_d\, \Sigma_h\, \mathrm{X}_{e,f,d,h} - ACRES \leq 0$

(3) $\Sigma_d\, \Sigma_h\, \mathrm{X}_{e,f,d,h} - .5\ ACRES \leq 0\ \forall\ e$

(4) $\Sigma_e\, \Sigma_d\, \Sigma_h\, \mathrm{LAB}_{e,f,d,h,w}\, \mathrm{X}_{e,f,d,h} \leq FLDDAY_{w,p}\ \forall\ w$

(5) $\Sigma_e\, \Sigma_d\, \Sigma_h\, \mathrm{EXPYLD}_{e,f,d}\ \mathrm{X}_{e,f,d,h} - \mathrm{SELL}_e \geq 0$

(6) $\Sigma_{e,d,h} X_{e,f,d,h}\ \mathrm{COST}_{e,f} - \Sigma_e\, \mathrm{PRICE}_e\ \mathrm{SELL}_e + \mathrm{FERTOWNERSHIP}_f + Y = 0$

Equations (objective function and constraints) include:

(1) Annual net return
(2) Acreage limitation
(3) Crop rotation requirement
(4) Suitable field day limitation by week and percentile
(5) Sales balance
(6) Net return balance

Variables include:

Y = Annual net return ($)
$\mathrm{X}_{e,f,d,h}$ = Production of crop *e* using fertilizer source and application timing *f* planting date *d* and harvest period *h* (acres)
SELL_e = Number of bushels sold by crop *e*

Parameters include:

$\mathrm{LAB}_{e,f,d,h,w}$ = Labor requirements for production (hours)
$\mathrm{FLDDAY}_{w,p}$ = Field days available across each week and percentile
$\mathrm{EXPYLD}_{e,f,d}$ = Expected yield (bushels) based on crop, planting date, and fertilizer source
$\mathrm{REQ}_{e,f,d,h,i}$ =Requirement of input *i* for production of crop *e*
$\mathrm{FERTOWNERSHIP}_{f}$ = Annual ownership costs of the implements used for fertilization f
$\mathrm{COST}_{e,f}$ = Variable cost of production for enterprise *e* by fertilizer source *f*
$ACRES$= limited to 2000 acres
PRICE_{e} = Price per bushel received for crop *e*

Indices include:

(1) e = Crop enterprise (corn, full season soybeans)
(2) f = Fertilizer source and application timing (spring broadcast of poultry litter, fall broadcast of poultry litter, spring injection of poultry litter, fall injection of poultry litter)
(3) d = Planting date (March 16th, March 23rd, April 1st, April 8th, April 16th, April 23rd, May 1st, May 8th, May 16th, May 23rd, June 1st, June 8th, June 16th, June 23rd)
(4) h = Harvest period (harvest 1, harvest 2)
(5) w = Weeks (week 1-52)
(6) p = Suitable field day percentiles (15th, 35th, 50th)

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