The merit of corn biological products used in-furrow

by

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ABSTRACT

Increased corn production to feed and fuel over 7 billion people worldwide over the past few decades has been accomplished by advances in technology and management practices. This thesis focuses on corn fertility management practices, specifically nitrogen management and how the use of corn biological products used in-furrow at planting can be a sustainable practice for the industry while providing net profit gains for the farmer.

Nitrogen is a macronutrient required by corn to produce yields. Providing the right amount of nitrogen is essential in maximizing the plants potential genetic yield. Synthetic nitrogen fertilizer, such as anhydrous ammonia, has been industrialized over the past decade and provides for an affordable nitrogen source for farmers to incorporate into their fertility management practices. These synthetic nitrogen fertilizers have been over-applied to the earth's soils over the last decade as farmers try to push corn yields.

As synthetic nitrogen fertilizers are applied in abundance, nitrogen loss is becoming a growing concern for sustainability. The limiting factors of nitrogen fertilizers are surface run-off and soil erosion, rainwater leaching, gaseous losses by volatilization, and microbial consumption. These factors lead to increased levels of nitrogen fertilizers being applied to counteract fluctuating levels of nitrogen from impacting corn yields. This practice is beginning to have negative impacts on ecosystems and waterways, it has increased dead zones, and reduced air quality.

Biological products have been introduced as an attempt to combat the negative impacts from synthetic Nitrogen fertilizers. Biological products contain living organisms

that, when incorporated into soils, increase soil fertility and productivity. These products also fixate nitrogen naturally through the roots of the corn plant. There are many potential benefits to using these products such as reducing nitrogen costs for the farmer while maintaining or increasing corn yields. This thesis evaluates trials using biological products to determine their merit in providing such benefits to the farmer.

This thesis analyzes 60 trials from three sources to determine the merit of corn biological products applied in-furrow. The results indicate that there is a statistically significant average yield advantage of 7.5 bushels per acre from using biological products in-furrow at planting. Using corn prices and biological product costs, a positive return on investment (ROI) is also demonstrated. Thus, incorporating biological products into fertility management programs can reduce nitrogen costs for the farmer while having the potential to gain yields and increase net profits based on the data provided in this thesis.

Although the data presented in this thesis aids in the merit of corn biological products used in-furrow at planting, additional research trials should be conducted by agricultural retail companies such as Growmark. Following fertilizer labels, conducting and understanding soil tests, and practicing sustainability methods such as the 4R Stewardship is recommended.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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CHAPTER I: INTRODUCTION

Today, the worldwide agriculture industry is tasked with feeding more than 7 billion people (Factbook 2020). Corn, or maize, is one of the major crops produced to accomplish this goal. Over the past 3 decades, corn production has more than doubled, from nearly 500 million tons harvested in 1990 to over 1 billion tons in 2018; Figure 1.1 illustrates this production over time. The increase in production is due to advances in both technology and management practices.

To achieve over 1 billion tons of corn harvested in future years, improvements in fertilizer management practices will be essential. Nitrogen (N) is a macronutrient required by corn to produce yields and is incorporated into fertilizer management practices. Providing the right amount of N to the corn plant can help the plant reach its potential genetic yield. For example, to reach 200-bushel corn yield, it takes about 200 pounds of nitrogen. With the logic of "more nitrogen, more yields", farmers have historically tried to achieve their yield potential by applying more pounds of N to their corn crop.

Farmers apply N in various ways and forms to push yield goals. Anhydrous ammonia is the most used form of N by farmers and retailers. Anhydrous ammonia is 82% actual N which is the highest form of N fertilizer available. Anhydrous ammonia is also the most economical fertilizer option in most cases. Other sources include Urea (45% N) or Urea Ammonium Nitrate (UAN) with an N content of either 28% or 32%.

There are several limiting factors facing nitrogen fertilizers. These factors include surface run-off and soil erosion, rainwater leaching, gaseous losses by volatilization, and microbial consumption. Large amounts of N fertilizer are applied to crops to help prevent fluctuating levels of N from impacting crop yields, however, this leads to wasted N spilling over into the environment. This in turn produces negative environmental impacts on ecosystems and waterways, increases dead zones, and reduces air quality. These loss mechanisms are visualized in Figure 2.1 of the nitrogen cycle. A recent example of these impacts was documented in Hendricks (2014), wherein it was found that higher crop prices increased nutrient losses from the Corn Belt into surface water (Hendricks 2014). This occurred because of two effects. First, higher prices, *per se*, encourage higher nitrogen use; and second, higher prices incentivize farmers to plant corn following corn, which requires greater N fertilizer applied to land, as there is no nitrogen carry-over from a previous soybean crop.

Corn biological products potentially serve as an alternative growth promoter to traditional fertilizers. Biological products are typically living microbial organisms of bacteria or fungi (Sible 2020). Corn biological products contain microbes that attach to the roots and fixate nitrogen for the corn plant. Mycorrhizal fungi are also common in these products, which colonize along the root zone aiding in greater water uptake and immobile nutrients like phosphorus. These biological products offer increased plant health by improving plant tolerance to abiotic stressors and by enhancing uptake of nutrients, enhancing crop quality, improving soil health, and potentially increasing yields (BPIA 2020). Since these products contain living organisms, the products need to be stored in a cool, dry environment as heat and UV exposure can inhibit efficacy (Sible 2020). For best results, biological products need to be applied with or near the seed at planting. For this reason, this thesis focuses on in-furrow applications.

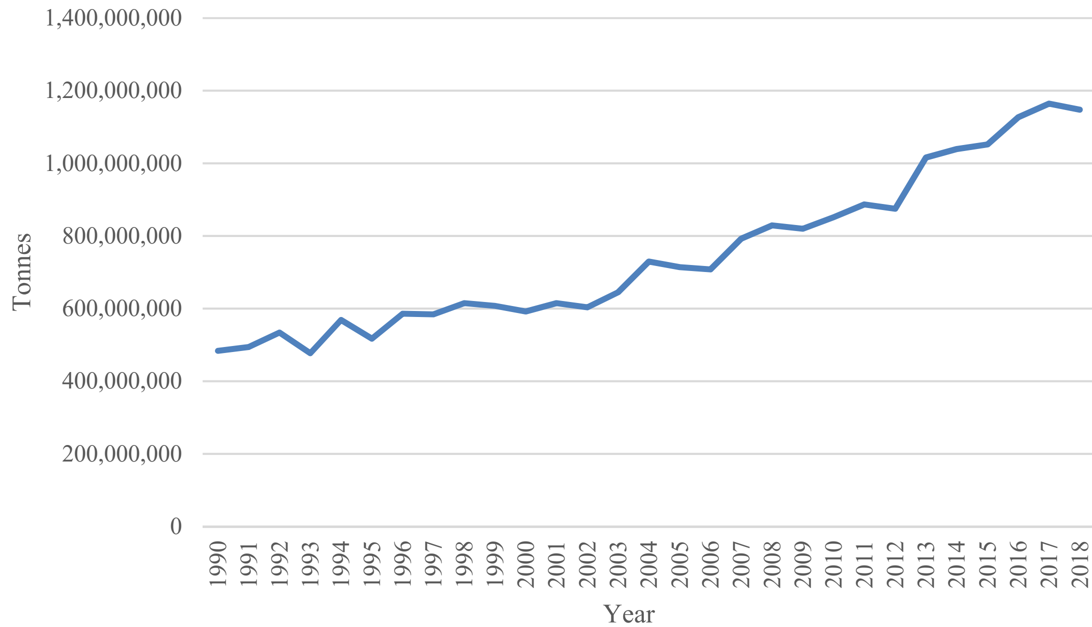
Given this, the objective of this thesis is to determine the efficacy of corn biological products. More specifically, the goal of this study is to determine whether biological products are a profitable alternative or aid to traditional fertilizer systems. Previous research suggests that corn biological products promote seed germination, aid root growth, and most importantly, provide for nitrogen fixation. Enhancing the microbial activity to convert nitrogen from the air to meet the corn crop's nutritional needs can reduce the unsustainable use of synthetic N fertilizer. More generally, the goals of this study are important for finding sustainable solutions in the agricultural industry that reduce the amount of synthetic N fertilizers applied to lands, thereby increasing soil biological health, while still being able to feed the world's increasing population.

This study analyzes 60 trials across multiple states and years that were conducted by three different firms to examine an average impact of corn biological products. This study can therefore be thought of as a meta-analysis of the corn yield and profit impacts of biological products. To summarize the findings of this study, an average net return of $11.85 by using corn biological products in-furrow with an average yield advantage of 7.5 bushels per acre, both of which are statistically significant. Overall, the study shows a positive impact by using biological products.

The importance of this study lies in its contribution to understanding how customers can potentially reduce their synthetic nitrogen fertilizer applications and costs by using biological products of merit. This is achieved by evaluating the return on investment for the end user, in this case corn growers, to assess the profitability of switching to a biological product instead of using the traditional synthetic fertilizer. This is important because, if ROI is higher for biological products, the customer will want to utilize this method of fertility management in corn production, thus also resulting in a reduction in the use of synthetic nitrogen.

The remainder of this thesis proceeds as follows. Additional background and a literature review are presented in Chapter 2. Chapter 3 provides some of the theory and methods relevant to the objective of assessing the efficacy of biological products. Field trial results are presented in Chapter 4. An analysis of the results is provided in Chapter 5 along with recommendations and possible avenues for future research.

Figure 1.1: World Corn Production in Tons from 1990-2018 (FAOSTAT 2020)



CHAPTER II: BACKGROUND AND LITERATURE REVIEW

2.1 Understanding the Nitrogen Cycle

Nitrogen is a component in the chemical structure of chlorophyll, which is required for photosynthesis and manufacturing carbohydrates. Having an adequate supply of nitrogen at critical periods of plant growth and development promotes optimum grain yield. Understanding the nitrogen cycle is fundamental to managing nitrogen. There are six key phases of the nitrogen cycle: Biological Fixation, Industrial Fixation, Immobilization, Mineralization, Nitrification, and Plant Uptake. Figure 2.1 illustrates the nitrogen cycle. Figure 2.1 illustrates some of the limitations to nitrogen such as denitrification, leaching and surface water run-off, volatilization, and reducing air quality through CO_2 emissions.

Biological fixation is how symbiotic bacteria work to naturally fix atmospheric nitrogen and make it available to legume plants such as soybeans. This is possible because nitrogen gas (N_2) comprises 78% of the atmosphere, representing a major source of nitrogen to support plant life.

Nitrogen fertilizers such as anhydrous ammonia or UAN are manufactured by using fossil fuel energy to capture atmospheric nitrogen into forms that can be easily applied to the crop. This process is industrial fixation. The additional nitrogen inputs in this process supplement natural nitrogen cycling and replace nitrogen that is removed as grain.

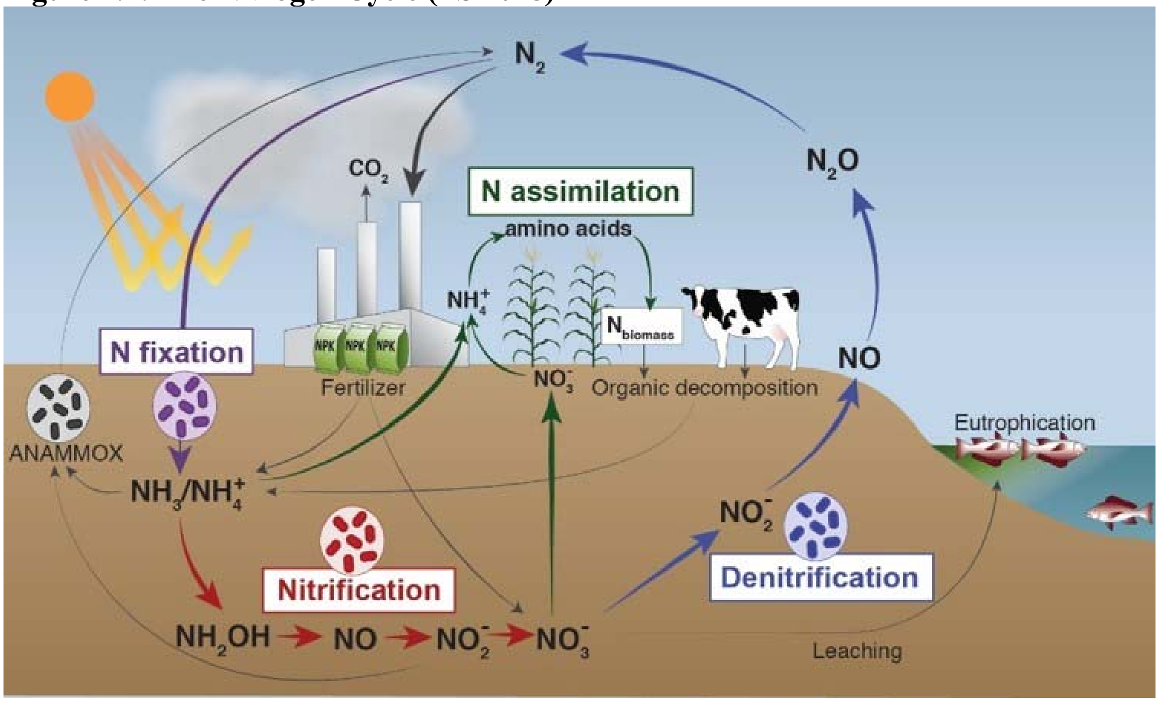
Immobilization is when nitrogen in organic plant materials, such as manure, is immobilized by soil microbes into a stable source of soil nitrogen called organic matter. This form of nitrogen is temporarily unavailable to the plant but is less subject to loss. If high carbon residues are present, fertilizer nitrogen may also be immobilized into microbial biomass.

Mineralization, also known as ammonification, is when nitrogen in organic matter is mineralized and released by soil microbes to make the nitrogen available to the plant. There are several variables that limit the amount of natural nitrogen mineralization. These variables include soil organic matter, soil pH, rainfall, temperature, and other seasonal variables. Conducting a soil test to obtain the estimated soil organic matter and pH helps determine how mineralization contributes to available nitrogen.

The biological transformation of ammonium to nitrites and then nitrates, respectively, is the nitrification process. These transformations occur more rapidly when soil temperatures exceed 50 F. Ammonium ions are readily absorbed by negatively charged soil surfaces. These ions are much less subject to loss when incorporated into soils. Nitrate ions are soluble and repelled by positively charged soil surfaces. This makes nitrates more prone to loss. Nitrification inhibitors can be used with ammonium fertilizers to slow down the nitrification process. The inhibitors improve retention of nitrogen in the soil which prevents loss.

Both ammonium and nitrate ions can be absorbed by the plant in the final process of the nitrogen cycle. Applied nitrogen is taken up by the plant and assimilated into plant biomass. The plant uses its energy to reduce the chemical species back to the ammonium form in the roots or shoots for further assimilation into proteins.

Figure 2.1: The Nitrogen Cycle (FS 2018)



2.2 Negative Effects of Nitrogen Fertilizer

Leaching of nitrogen fertilizer occurs when negatively charged nitrate ions move downward from the soil profile via water movement. In exceedingly wet years, leaching losses can be significant. Leaching is also very prevalent in well-drained soils or artificially drained tile systems. Knowledge of leaching is important because the leached nitrates can end up in drinking water supplies which can negatively affect human health and be detrimental to the environment.

Denitrification is the primary mechanism of nitrogen loss, especially in the Midwest. Most soil microbes are aerobic and require oxygen to respire. Under saturated soil conditions, combined with warm temperatures, bacteria called facultative anaerobes can alternately use the oxygen in nitrate to respire. The bacteria convert the nitrate to nitrous oxide gas which can escape the soil system into the atmosphere. This process is denitrification.

Fertilizers such as anhydrous ammonia or those containing urea are subject to nitrogen loss via volatilization. Free ammonia gas volatizes from the soil surface to the atmosphere. Losses are greater with wet, moist soil and high soil pH that are combined with high soil temps and high surface residue. Without proper management, volatilization losses from urea can exceed 50%, making incorporation or the use of urease inhibitors beneficial.

Runoff and erosion can occur through the physical loss of ammonium ions absorbed into soil particles or other surface-applied fertilizers. These losses can be prevented through soil conservation practices and incorporation of fertilizer materials.

The industrialization of synthetic fertilizer in the 20th century helped evolve the industry to boost yields to feed the increasing world population. As farmers and agricultural retailers continue to raise high yielding corn with synthetic N fertilizers, however, this often led to over-fertilization. This occurrence means that the corn plant is not up taking all the available N fertilizer being applied, resulting in an excess of N. The excess of N is beginning to cause environmental problems due to leaching and runoff. Problems include air and water pollution, negative impacts on human health, and other environmental issues from the manufacturing process using fossil fuels.

Overuse of synthetic fertilizers is causing excess nutrients to be washed down streams and rivers into the ocean. The added N causes aquatic plants such as algae, phytoplanktonic, and seaweed to feed and grow rapidly on the water surface. This growth contributes to a loss of oxygen within the water and thus organisms beneath the surface water cannot absorb oxygen and die. Dead zones are the result of this immense mortality of aquatic life. Dead zones occur along coastal lines where the fertilizer runoff is occurring. Figure 2.2 illustrates how a dead zone is created. The Baltic Sea is home to 10 of the world's largest marine dead zones (Geographic n.d.). The Chesapeake Bay and the Gulf of Mexico are dead zones related to the United States. See Figure 2.3 for a depiction of the Gulf of Mexico dead zone.

Figure 2.2: How Dead Zones Are Created (Geographic n.d.)

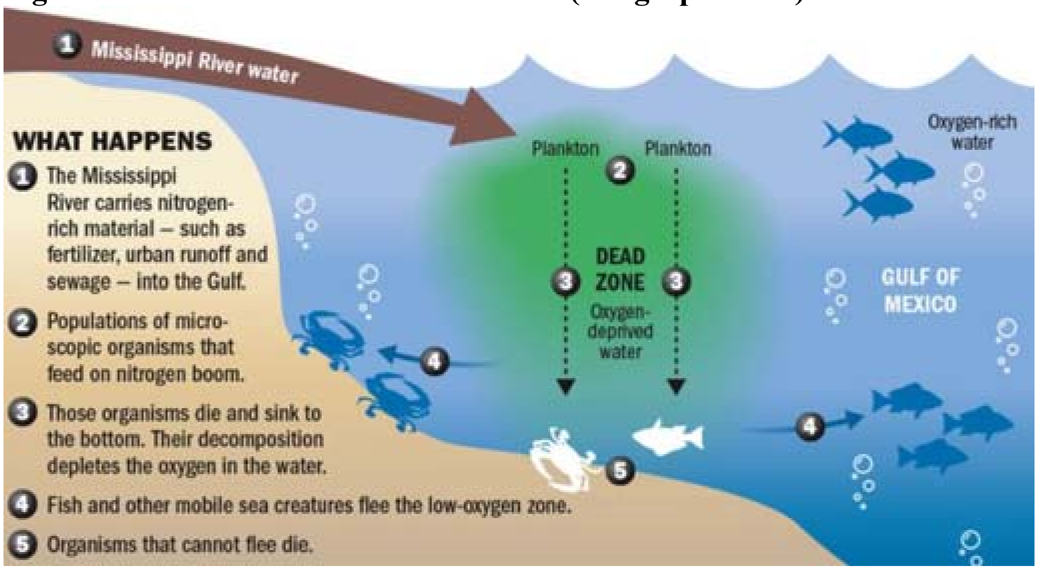


Figure 2.3: Gulf of Mexico Dead Zone Image (Geographic n.d.)

2.3 4Rs

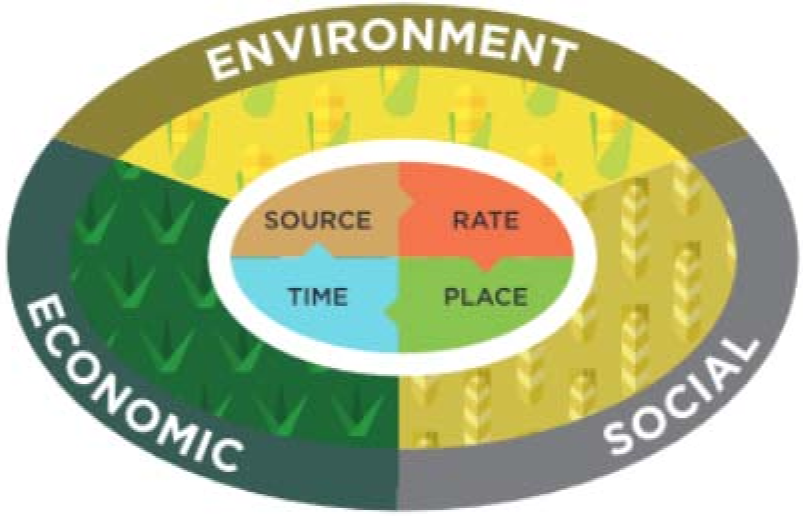
The 4R Nutrient Stewardship is a framework used to achieve yield goals while providing environmental protection and improved sustainability. The 4R nutrient stewardship requires the implementation of best management practices that optimize the efficiency of fertilizer use, according to The Fertilizer Institute. The goal of the 4Rs is to minimize nutrient losses from fields. The 4R concept involves applying the "Right" fertilizer source at the "Right" rate at the "Right" time and in the "Right" place. The Fertilizer Institute outlines the principles of the 4Rs (Institute 2017):

> Right Source – Provide a balanced supply of essential nutrients. Consider both naturally available sources and the characteristics of specific products available to plants.
>
> Right Rate – Assess and make fertilizer choices based on soil nutrient supply and plant demand.
>
> Right Time – Assess and make fertilizer conclusions based on the dynamics of crop uptake, soil supply, nutrient loss risks, and filed operation logistics.
>
> Right Place – Address root-soil dynamics and nutrient movement. Manage spatial variability within the field to meet site-specific crop needs to limit potential losses.

The 4R nutrient stewardship is an attempt by the agriculture industry to respond to the pressures of an increasing world population and additional regulations. The 4Rs can benefit by improving agricultural productivity and by minimizing negative impacts to the environment. Economic goals such as improving net farm income can also be achieved.

The stewardship improves the quality of farm family housing, diet, and education through social goals. The environmental goals of the 4Rs will provide lasting sustainability by reducing soil erosion of nutrients, reducing volatilization of ammonia emissions, and reducing nitrification losses of nitrous oxide.

Figure 2.3: The 4R Stewardship Concept (Institute 2017)



2.4 Biological Products

Scientists employed by large global agricultural corporations, along with environmental agencies, are working to develop alternatives to meet the nitrogen needs of the corn plant and maintain high yields. Biological Nitrogen Fixation (BNF), the first process mentioned in the nitrogen cycle, has been a focal point in finding these alternatives. As stated, BNF is a process in which Nitrogen gas (N_2) from the atmosphere is incorporated into the tissue of certain plants (National Forage and Grasslands Curriculum n.d.). Legumes, such as soybeans, can naturally take in N from the air because of the legumes' symbiotic relationship with soil microbes and bacteria. This symbiotic reaction forms nodules on the roots of the plant which is where BNF takes place. The importance of focusing on BNF is that it can reduce fertilizer costs while maintaining soil fertility and high yields.

Based on this concept, scientists and researchers have developed biological products for corn. Pivot Bio is one company that has launched a biological product that delivers nitrogen via microbes that attach to corn roots. The microbes can naturally take in N_2 from the atmosphere and fixate it into ammonia for the corn plant to utilize through the root. The products are to be used in furrow with a starter fertilizer at the time of planting. As noted, the potential benefit of these biological products is that they reduce nitrogen costs for the farmer while maintaining or increasing corn yields.

Corn biological products offer many benefits. These products can increase plant health and improve plant tolerance to abiotic stressors such as drought or wet feet. The living microbial organisms within the biological products colonize along the root zone aiding in greater water and nutrient uptake. This can lead to overall enhanced crop quality. The products improve soil health and soil fertility. All these benefits provide the potential for a farmer to see an increase in yields. With that, corn biological products could be a potential alternative to synthetic nitrogen fertilizer that can provide sustainability if yield demands are still being met.

Corn biological products have some limitations that may not be favorable to some consumers. Since these products contain living organisms, they need to be stored in cool, dry environments with minimal exposure to heat and UV rays. If exposed to these conditions, the living organisms have the potential to die and inhibit efficacy of the product. The products have a 1-year shelf life; thus, the farmer must not only have proper storage but also make sure to order appropriate amounts of product so there is no carry-over. The farmer must also have the appropriate equipment to apply the corn biological product in-furrow as these products must be applied with/near the seed at planting. Upgrading equipment is a costly expense if the farmer is not already fitted out with in-furrow capabilities. Another cost associated is the starter fertilizer that must be used in combination with corn biological products in-furrow.

CHAPTER III: THEORY AND METHODS

3.1 Economic Theory

In economics, the objective of the decision maker is to maximize net benefits (profits). This theory is applicable here because Growmark's decision to offer biological products depends on whether: i.) The products prove beneficial to Growmark's customers with reduced Nitrogen costs and/or constant/increased corn yields, and ii.) If the products can be a profitable offering for Growmark.

Consumer behavior is relevant to this thesis. In the market economy, the demands of consumers, in this case agricultural producers, drive profitability. Thus, learning what to produce and how to sell it is why consumers are studied. Knowing what to produce for the consumer is based on their preferences. Farmers have preferences for some inputs over others. In this thesis, for example, synthetic fertilizer has been the preferred fertilizer because of its price point and the net benefit that synthetic fertilizer has historically provided.

"More is better" is often an assumption about consumer behavior. This is true in the agriculture industry for corn yields. The assumption that more nitrogen fertilizer leads to more/higher yields is evident after examining figure 3.1 (FAOSTAT 2020). Figure 3.1 demonstrates an increase in synthetic N fertilizer use in the United States over a 10-year span. In comparison, the amount of corn yields harvested in the United States over the same 10-year span also shows an increase; Figure 3.2 illustrates increasing corn yields over time (FAOSTAT 2020). The two figures provide for an assumption of more Nitrogen fertilizer generally equals more yields harvested (up to some limit).

The increase in fertilizer use relates to the Law of Diminishing Marginal Returns where productivity will eventually decline. At what point is too much nitrogen being applied that the corn plant is not utilizing it, leading to wasted product and, more importantly for the customer, money? The "4R Nutrient Stewardship" helps distinguish this law. Figure 3.3 demonstrates how timing of nitrogen to the corn plant at the appropriate plant growth stage is important to maximize utility and reduce risk. At growth stage V9, there is a point of equilibrium between nitrogen uptake and potential risk of nitrogen leaching. Timing of nitrogen fertilizer is a key concept for maximizing plant potential and marginal cost benefit for the consumer to ensure profit. The goal is to provide soundproof evidence that biological products can provide the consumer more yields when applied at the right time to comply with the "more is better" theory of consumer behavior.

Economics demonstrates how human behavior can be modeled; the supply and demand model is an example. The objective of producers is to maximize profits, where profit is revenue minus cost. Economics evaluates profit maximization by finding the optimal level of input. For this thesis, the input of interest is nitrogen fertilizer, and the output is corn yield. Biological products potentially act as an input substitute in the corn production process for synthetic nitrogen fertilizer. Substitutes in production are inputs used in place of each other in the production process. The research conducted in this thesis reveals that using the right input (nitrogen product), at the right rate and time, leads to a minimization of production costs. The Marginal Rate of Technical Substitution (MRTS) between two or more inputs (nitrogen products) is used to determine the rate at which one input can be decreased as the use of another input increases to take its place; in this thesis, the objective is to evaluate whether a decrease in the rate of synthetic nitrogen fertilizer can be compensated for with an increase in biological products while at the same time reducing costs.

We can write the profit associated with a traditional synthetic fertilizer system as:

$$\pi^s = py^s - c^s$$

where p is the price of corn, y^s is the yield associated with a traditional fertilizer, and c^s is the cost associated with a traditional system. The profit function for biological products, in combination with a starter fertilizer, can be written as follows:

$$\pi^b = py^b - c^b$$

Where p is the price of corn, y^b is the yield associated with a biological product, and c^b is the cost associated with the biological product. A farmer is incentivized choose a CBP system if the associated profit exceeds the profit from a traditional system; i.e., if

$$\pi^b - \pi^a = p(y^b - y^s) - (c^b - c^s) > 0$$

This simple equation demonstrates that a biological system can be a profitable alternative if there is yield advantage, cost advantage, or a combination in which any disadvantage is outweighed by the advantage. For example, even if biological product system costs more, as long the yield advantage is large enough, there will be a profit advantage. Alternatively, if there is yield disadvantage to the biological system, if cost savings are large enough, then it will also be more profitable.

Figure 3.1: United States UAN Agricultural Use from 2008-2018 (FAOSTAT 2020)

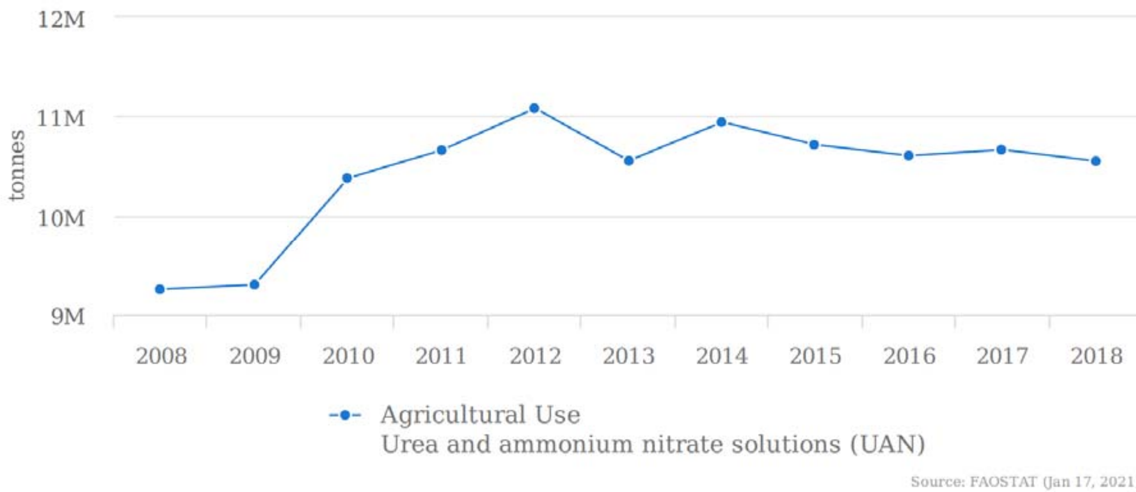


Figure 3.2: U.S. Corn Production/Yield Quantities 2008-2018 (FAOSTAT 2020)

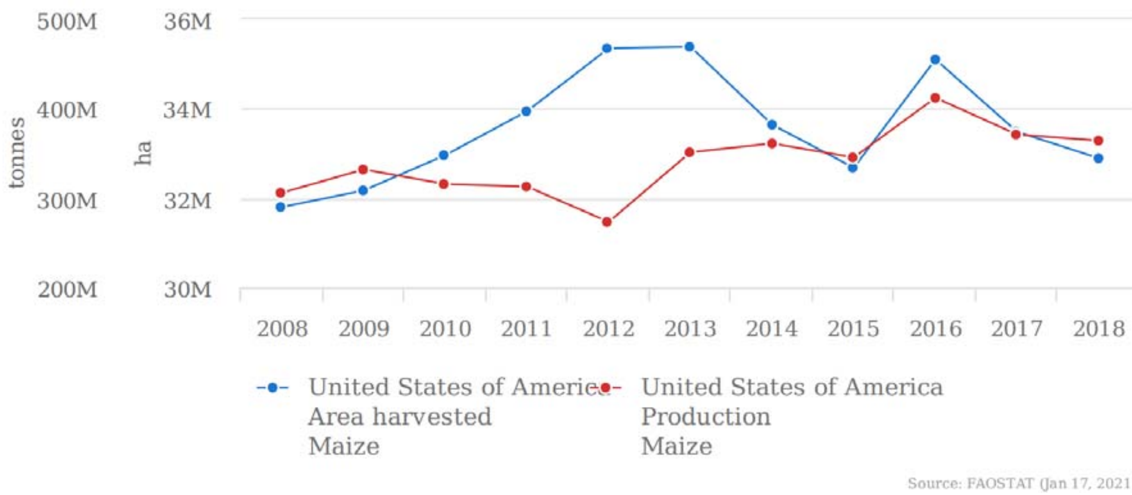
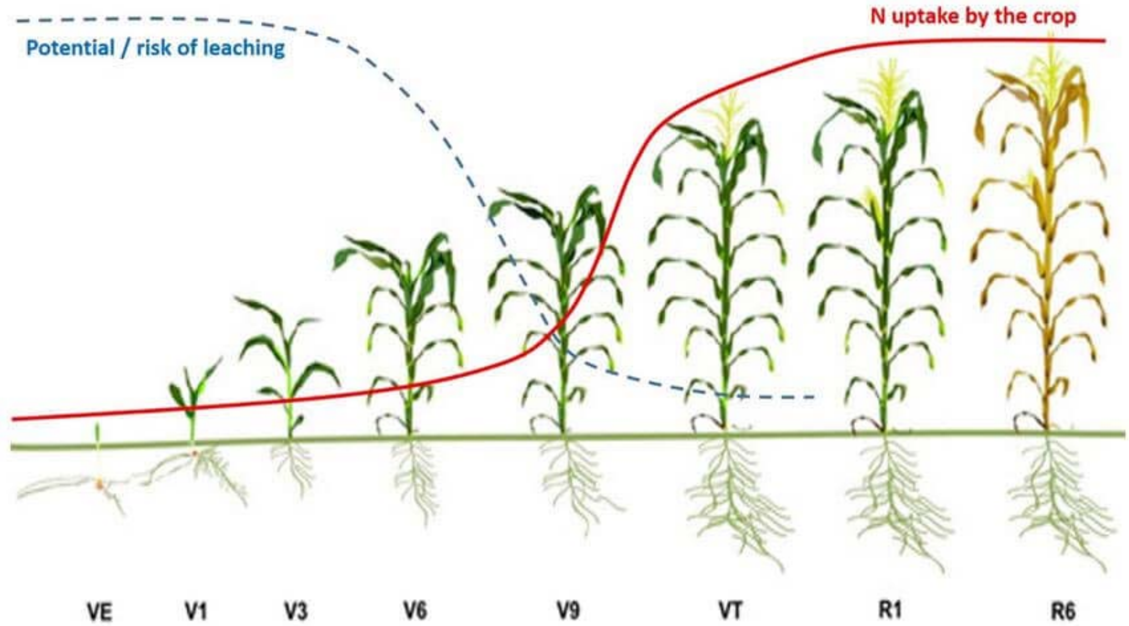


Figure 3.3: Nitrogen uptake of corn plant growth stages (FS 2018)



3.2 Methods

To meet the objectives of determining whether corn biological products are effective, third party trials were researched. These trials were conducted in multiple states in multiple years and tested several corn biological products applied in-furrow at the time of planting. The products were tested against a control group of traditional fertilizer to determine positive or negative yield comparisons.

Traditional nitrogen fertilizer trials using anhydrous ammonia were also researched. These trials came from the Prairieland FS database from 2018- 2020. Prairieland FS uses the Maximum Return to N (MRTN) method for choosing the correct N rate that provides the highest ROI. This method utilizes economics of cost per unit of N and commodity prices to maximize the ROI of N. The MRTN calculator can be found and utilized at http://cnrc.agron.iastate.edu/. The equation used to determine the total pound of N needed per acres is:

#N/bu x Yield Goal

The result is then adjusted for N credits from alternative nitrogen sources such as legumes from the previous year or other fertilizer sources such as N from phosphates. The equation used is:

(#N/bu x Yield Goal) – (Alternative N Credits) = #N/acre to apply

For example, a farmer expects 190 bu/ac yield goal. The #N/bu equals 1.2. The phosphate N credit is 36# with a legume credit of 30#. Plugging into the equation to solve for the #N/acre to apply looks like this:

(1.2 x 190) – (36+30) = 162# of nitrogen to apply.

The MRTN method is used in the Prairieland FS nitrogen trials that have been researched and presented in the next chapter of this thesis to compare against the biological product trials.

CHAPTER IV: DATA AND RESULTS

4.1 Summary of Trials Studied

For this thesis, a meta-analysis was conducted where an average effect from multiple data sources was analyzed. Studies used for this thesis are summarized in Table 4.1. The table shows a total of 60 trials analyzed across three studies. All products were applied in-furrow at the time of planting in the Midwest region. The trials done by Beck's and Pivot Bio were during a time span of 2018-2019 while the Trovec trials were conducted during the time of 2006-2010. The next three sections discuss each study in detail.

Table 4.1: Summary of Studies.

Study	Trials	Product Type	Time Period	Region
Beck's Biological In-Furrow	16	Multi Product*	2018-2019	Multi State
Trovec In-Furrow	35	Trovec	2006-2010	Multi State
Pivot Bio	9	PROVEN	2019	Multi State

*Beck's Multi Product study includes SabrEx for Corn IF, Myco Apply Endo Prime, Brandt EnzUp ZN, SB4400
**Multi State trials in Wisconsin, Minnesota, Illinois, Kentucky, Iowa, Arkansas, Nebraska, Kansas

4.2 Beck's Biological In-Furrow Results

Beck's Hybrids conducted In-Furrow Biological studies for public use. These studies are considered 3rd party because the company only sells seed and conducted the trials as research for farmers to use. The trials were conducted in Wisconsin over a 2-year span (2018-2019), in Minnesota in 2019, and a multi-state aggregate trial in 2019 from test sites in Illinois, Iowa, Kentucky, Minnesota, and Wisconsin. Each trial in the study tested 3-4 biological products applied with a starter fertilizer and included a control with only starter fertilizer. When evaluating the ROI of each trial, the cost associated with the starter fertilizer is included in the data.

Table 4.2 provides the data from the Beck's Hybrids 2018 Wisconsin study. When determining ROI, the assumed corn market price was \$3.92/Bu. This trial studied 4 biological products, with 2 products resulting in a positive ROI. This is a 50%-win rate for biological products. (Hybrids 2018)

In the second year (2019) of Beck's Hybrids research on biological products, they used in-furrow applications in Wisconsin (Table 4.3). The market price for corn had increased to $4.04. The results show only 1 out of 4 products studied had a positive ROI, although two of the products showed positive yield results. The objective of this thesis is to conclude higher yields with higher profitability rates for the farmer, thus the data presented in Table 4.3 leads to a 25%-win rate for biological products. The product that provided for the 25%-win rate also contains 9 different biological bacteria to boost early plant growth. This knowledge could lead to future recommendations.

The 2019 Minnesota trial conducted by Beck's Hybrids resulted in a 0%-win rate for biological products. Table 4.4 shows the results from the study. Note that 3 out of the 4 products shows a positive bushel advantage over the control. After calculating ROI with a corn market price of $4.04/Bu, none of the products provided a positive ROI resulting in a 0%-win rate.

The multi-state study conducted in 2019 by Beck's Hybrids tested 4 biological products. Table 4.5 reveals the results of this study. Biological products provided a 50%-win rate after calculating ROI with a corn price of $4.04/Bu. Note, however, that all biological products resulted in a positive increase in yield. Notice that the same biological product, SB4400, from the 2019 Wisconsin study that had the only positive ROI is also in the multi-state study with a positive ROI for the grower.

Table 4.2: 2018 Wisconsin Beck's Hybrids Biological In-Furrow Study

In-Furrow Treatment	% moisture	Bu./A.	Bu./A Difference	ROI
Control: Starter	21.3	230.7		
Starter + 4 grams McycoApply EndoPrime	21.9	235.7	5	9.6
Starter + 12.8oz AgZyme	21.8	234.4	3.7	3.51
Starter + 1 oz SaberEx for Corn IF	21.8	229.2	-1.5	-11.73
Starter + 1qt iNvigorate	22	229.4	-1.3	-14.59

Corn $3.92/Bu. AgZyme $110/gal. iNvigorate $38/gal. SabrEx for Corn IF $748.80/gal. Myco Apply Endor Prime $10/A.

Table 4.3: 2019 Wisconsin Beck's Hybrids Biological In-Furrow Study

In-Furrow Treatment	% moisture	Bu./A.	Bu./A Difference	ROI
Control: Starter	21.8	257.4		
Starter + 1pt SB4400	21.6	260.9	3.5	4.73
Starter + 1qt. Brandt EnzUp Zn	21.5	257.6	-0.2	-6.7
Starter + 1oz SaberEx for Corn IF	21.9	255	-2.4	-15.55
Starter + 2oz MycoApply EndoPrime	21.6	255.6	-1.8	-18.28

Corn $4.04/Bu. SabrEx for Corn IF $748.80/gal. Myco Apply Endo Prime $740/gal. BRANDT EnzUp ZN $30/gal. SB4400 $75.28/gal.

Table 4.4: 2019 Minnesota Beck's Hybrids Biological In-Furrow Study

In-Furrow Treatment	% moisture	Bu./A.	Bu./A Difference	ROI
Control: Starter	24.3	217.5		
Starter + 1qt. Brandt EnzUp Zn	24.9	219.3	1.8	-0.23
Starter + 1oz SaberEx for Corn IF	24.8	218.4	0.9	-2.21
Starter + 1pt SB4400	24.6	217.9	0.4	-7.79
Starter + 2oz MycoApply EndoPrime	25.1	216.9	-0.6	-13.42

Corn $4.04/Bu. SabrEx for Corn IF $748.80/gal. Myco Apply Endo Prime $740/gal. BRANDT EnzUp ZN $30/gal. SB4400 $75.28/gal.

Table 4.5: 2019 Beck's Hybrids Multi-State (IL, IA, KY, MN, WI) Biological In-Furrow Study

In-Furrow Treatment	% moisture	Bu./A.	Bu./A Difference	ROI
Control: Starter	24.1	230.7		
Starter + 1pt SB4400	24.2	233.5	2.8	1.9
Starter + 1qt. Brandt EnzUp Zn	24.3	232.5	1.8	-0.23
Starter + 1oz SaberEx for Corn IF	24.3	232.4	1.7	1.02
Starter + 2oz MycoApply EndoPrime	24.3	232.9	2.2	-2.11

4.3 Trovec In-Furrow Results

Another third-party study researched for this thesis is the biological Trovec. Trovec is a liquid biological that can be applied in-furrow or as a foliar to corn. The study on Trovec included 35 replicated research trials for in-furrow application with a starter fertilizer. The trails were conducted between the years 2006-2010, providing for several years of research on the product. Of the trials, 80% provided a positive net return. The average advantage for using Trovec is 10.9 bushels per acres. Trovec data for this trial is presented in Appendix A. By using our profit formula from Chapter 3 of this thesis, and the averages from Table 4.7, we can calculate the Trovec advantage. For this purpose, assume the price of corn is \$4.04/Bu, the current 2021 cost of a standard nitrogen system using anhydrous ammonia is \$45.90/ac (\$510/ton of product), and the current 2021 cost of Trovec is \$6.16/ac. Now plug into the profit formula for the traditional system and the biological system:

$$\pi^s = 4.04 * 156.3^s - 45.90^s$$

$$\pi^s = \$585.55$$

$$\pi^b = 4.04 * 167.2^b - (45.90^s + 6.16^b)$$

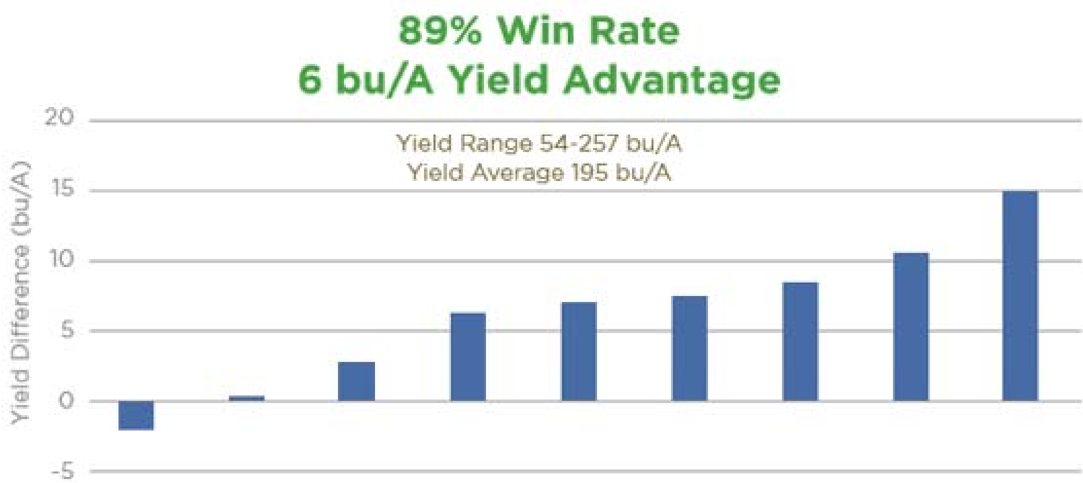
$$\pi^b = \$623.43$$

By using the Trovec biological system, the famer could expect a net gain of \$37.88 over the traditional system.

4.4 Pivot Bio Results

Pivot Bio is a company focusing on the development of corn biological products. Their product, PROVEN, is applied in-furrow with a starter fertilizer. In 2019, 6 universities (University of Nebraska, University of Illinois, University of Arkansas, University of Minnesota, Kansas State University, and Iowa State University) conducted on-farm trials resulting in an 89%-win rate and a 6 bu/acre yield advantage. Yields across trials ranged from 54 to 257 bu/acre with an average of 195 bu/acre. Figure 4.1 represents the combined university trials (Proven 2019).

Figure 4.1: Pivot Bio PROVEN University Results From 9 Locations (Proven 2019)



4.5 Overall Impact of Corn Biologicals

To understand the overall impact of corn biologicals on yields, the results from all study trials were collected and summarized. These results are provided in Table 4.6. Mean yield impacts were computed for each study, as well the mean impact across all studies. To determine whether these impacts were statistically different from zero, standard errors and t-statistics were computed under the null hypothesis that there was no yield impact(Studenmund 2017). Specifically, the following was calculated:

$$\mathrm{tstat} = \frac{\bar{\mathrm{y}}}{\mathrm{se}(\bar{\mathrm{y}})}$$

where $\bar{\mathrm{y}}$ is the mean yield impact of a biological system and $\mathrm{se}(\bar{\mathrm{y}})$ is the standard error associated with that impact, which is calculated as: $\mathrm{se}(\bar{\mathrm{y}}) = \mathrm{sd}(\mathrm{y})/\sqrt{n}$, where $\mathrm{sd}(\mathrm{y})$ is the standard deviation of the yield impacts and $\sqrt{n}$ is the square root of the number of trials (denoted by n). T-statistics were also calculated for the average net returns. Statistical significance was determined using $n - 1$ degrees of freedom.

The mean yield effects are summarized in Table 4.6. The table shows a total of 60 trials that were analyzed. Diving into the yield aspect, the average yield across all trials was 7.5 bushels per acre using a biological product in-furrow, which was statistically significant at the 5% level (the corresponding t-stat). Assuming the price of corn is $4.04/bushel, an average yield effect of 7.5 bushel/acre, and an average biological cost of $12.06/acre (Table 4.7), the net gain in profit from using the biological products is $21.07 per acre, which is statistically significant at the 1% level. The net gain in profit of $21.07 per acre is highly depended on the Trovec trial results. The Beck's trials have significant negative impact suggesting there is still some risk depending on product selection. The equation used to determine the net gain in profit is as follows:

Profit Gain = Price * Yield Advantage - Cost

The result of a net profit gain of $21.07/acre from the trials summarized in this thesis signifies a positive ROI for the farmer by using the biological products in-furrow. This suggests there would be demand for biological products that an agricultural retail outlet could provide. Thus, the merit of corn biological products has been shown in this scenario.

The standard deviation was also analyzed for each trial observed in this thesis. It is valuable in utilizing the standard deviation to understand risk involved. For this thesis, the risk is whether to use biological products in-furrow not knowing the merit of the product. Table 4.6 depicts the standard deviation for each trial. Having points further from the mean will have a higher deviation within the data set making the data more spread out creating a larger standard deviation (Hargrave 2021). The sample set of 60 trials, after summarizing, has a standard deviation of 4.5 (Table 4.6). Given the assumption of a normal curve, 68% of the data points will fall within one standard deviation above or below the mean (Hargrave 2021); thus, 68% of the data points will fall within one standard deviation above or below 7.5 bushel. For this data set, 25% of the data points fall below 4.49 bushel, 25% of the data points be above 10.51 bushel, and 50% of the data points lay between 4.49 and 10.51 bushel. This range of 6.02 (the distance between 4.49 bushel and 10.51 bushel) is the positive risk observed for this data set. The standard deviation for this data set is observed to have risk associated to a positive outcome for the grower choosing to use corn biological products in-furrow. Each quartile of the normal distribution curve results in a positive net yield advantage. The summary in Table 4.6 is comprised of averages from each trial analyzed in the meta study. This is impactful because it shows an average net return of $11.85 by using the biological products. This return is calculated by subtracting the average cost of the biological products in the trials from the average revenue earned by the yield gain of using the biological products. The net return for the farmer is attractive based off Table 4.7 and leads to assumption that corn biological products should be an adopted practice.

Table 4.6: Biological Product Trial Yield Impacts

		Yield Impacts			
Study	Trials	Mean Impact	Standard Deviation	Standard Error	t-stat
Beck's	16	0.94*	2.180	0.54	1.73
Trovec	35	10.89***	11.204	1.89	5.75
Pivot Bio	9	5.92***	5.271	1.75	3.37
Summary	60	7.5***	9.8	1.26	5.93

**$p<0.10$; ***$p<0.01$*

Table 4.7: Corn Biological Product Costs and Returns

Study	Avg. Cost	Avg. Revenue	Avg. Net Return	Net Return t-stat
Beck's Biological In-Furrow	$ 10.01	$ 4.04	$ (5.97)***	-2.71
Trovec In-Furrow	$ 6.16	$ 43.99	$ 37.83***	4.95
Pivot Bio	$ 20.00	$ 23.93	$ 3.93	0.55
Averages	$ 12.06	$30.33	$ 21.07***	3.99

Assuming $4.04/bu corn price. Averages are computed over all 60 trials.
****$p<0.01$*

CHAPTER V: CONCLUSION AND RECOMMENDATIONS

The research for this thesis concludes that sustainability is of high importance due to excessive applications of synthetic fertilizers that are beginning to harm the environment. To assist with the limitations of nitrogen, corn biological products applied in-furrow at the time of planting potentially provides solutions to the harmful impacts of synthetic fertilizers. These biological products provide benefits to all aspects of the plant's life cycle from seed germination and root development to plant maturity (Agricen n.d.) Biological products also help plants tolerate abiotic stresses like heat, cold, drought, or too much water (wet feet). These products are an added benefit to soil fertility when applied due to developing micro-organisms. With these benefits in mind, the data from this thesis concludes that, more times than not, the farmer will see a yield and net return advantage by using biological products in-furrow at planting with a starter fertilizer.

The theories presented in this thesis conclude that a positive gain in profits is attractive and should incentivize the farmer to adopt biological products. As discussed in Chapter 4, positive ROIs were seen by using the biological products. Using the profit formula, a higher profit was also seen using the biological system.

Not all biological products tested in the trails researched for this thesis had yield advantages or an increase in ROI. The findings from the data suggesting net profit gain is heavily dependable on the Trovec trial results. Therefore, it is recommended to read product labels and search for biological products with additional modes of action. These are the products that had positive results in the trials considered in this thesis.

Soil types are different across all regions. It is recommended to do a soil test before deciding to use a corn biological product. The amount of organic matter within the soil will make a difference on how a biological product performs. Biological applications to soils with high organic matter content will have little effect on the corn plant because the soil already possesses a high number of micro-organisms. Soils will low organic matter will show the largest yield advantages after applying biological products due to added soil nutrition from the biological product. A soil test is also recommended in making fertilizer management practices after evaluating phosphate and potassium levels. This will assist in determining any nitrogen credit from other fertilizer sources.

It is recommended that a nitrogen fertilizer plan is made by the farmer for the entire plant life cycle. Utilizing the MRTN method and practicing the 4R Stewardship will assist in applying correct amounts of nitrogen. Using the information from Chapter 4, a fertilizer program that reduces farm costs can be made. An agricultural retailer conducted a study showing a trend of yield drag beginning at 150 pounds of nitrogen applied; Figure 5.1 illustrates this trend-line. At 150 pounds of nitrogen applied via NH3, a minimum yield of 209.3 is observed. It costs \$45.90/acre for 150lbs of N at an NH3 price of \$510/ton. Taking the average from the yield advantages in the biological trials, the average yield advantage is 7.5bu/acre. The average cost per acre of the products \$12.06/acre. Assuming a corn price of \$4.04/bu, the profit formula is as follows:

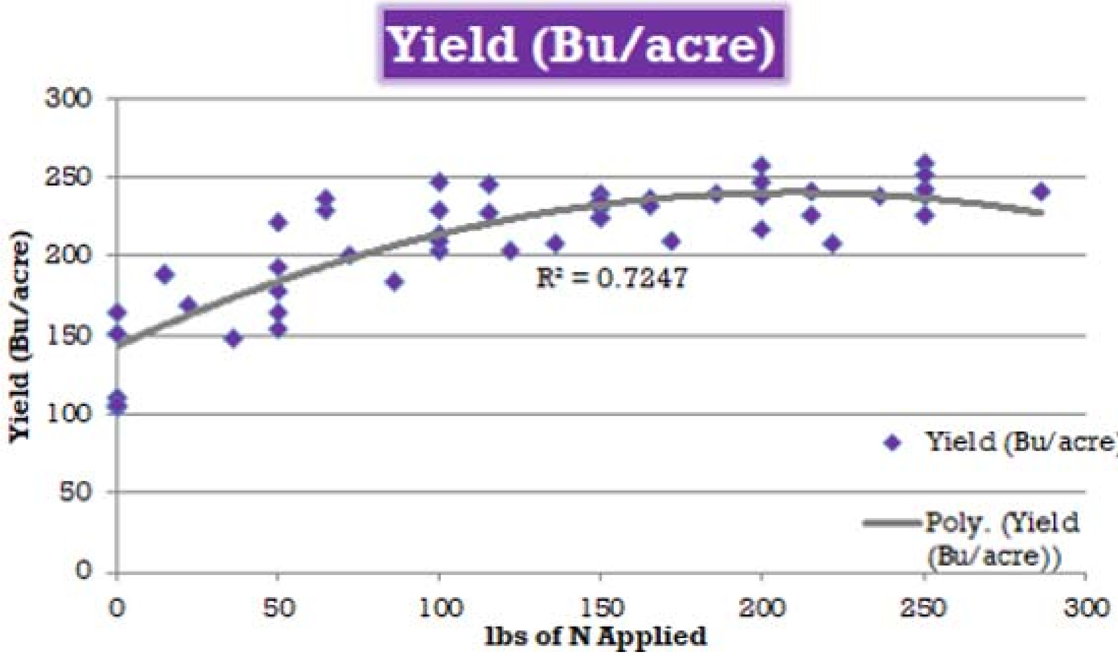
$$\text{Traditional} = (209.3*\$4.04) - \$45.90 = \$799.67$$

$$\text{Biological} = (7.5*\$4.04) - \$12.06= \$18.24$$

Combined nitrogen fertilizer program generates an expected revenue of \$817.91. This fertilizer program utilizes the trend line seen from the agricultural retailer's nitrogen study at 150lbs of nitrogen applied. A yield increase from the added plant health throughout the growing season from the added biological product in this plan helps to minimize the fertilizer cost, resulting in a higher ROI. This recommended program meets the objective of this thesis in using a biological product to reduce the amount of synthetic fertilizer applied while reducing farm input costs.

It is also recommended that further research around biological products are conducted. Further trials should be set in place as biological products are still new and developing. Additional types of biologicals should also be studied along with the way they can be applied. This thesis focuses on in-furrow applications. Not all farmers in the Midwest have equipment with the ability to apply in-furrow. It is very costly to upgrade to newer equipment with in-furrow capability so adopting the practices would be unlikely. It could be more favorable for these farmers to use “over the top” foliar products or planter box options. Biological products that can fit into these categories should be evaluated. Other limitations to consider is the addition of starter fertilizer to biological products used in-furrow at planting. The starter fertilizers can vary in nutrient analysis as well as cost per acre when evaluating net profit. With corn biological products applied with starter fertilizers in-furrow, it could be desirable to study the effect on yields when synthetic fertilizer is reduced.

Figure 5.1: Nitrogen Rate Data Scatter Plot (FS 2018)



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APPENDIX A

Year	City	State	Region	Treated	Standard	Diff	Diff	Method	Rate	Coop Company
2006	Marysville	OH	Midwest	151.5	113.2	38.3	33.9%	In Furrow	8oz	S/S Ag Research
2007	Marysville	OH	Midwest	148.5	113.2	35.4	31.2%	In Furrow	8oz	S/S Ag Research
2006	Hoytville	OH	Midwest	117.0	86.9	30.1	34.7%	In Furrow	8oz	S/S Ag Research
2007	Hoytville	OH	Midwest	112.8	86.9	25.9	29.8%	In Furrow	8oz	S/S Ag Research
2009	Fergus Falls	MN	Midwest	205.2	179.9	25.3	14.1%	In Furrow	8oz	Viger Ag Research
2008	Hoytville	OH	Midwest	148.3	125.5	22.8	18.2%	In Furrow	8oz	Andersons
2010	Jackson	TN	South	209.2	190.4	18.8	9.9%	In Furrow	6 oz	D&D Research
2009	Lamberton	MN	Midwest	227.0	209.0	18.0	8.6%	In Furrow	8oz	Univ of Minnesota
2007	Fergus Falls	MN	Midwest	165.1	147.1	18.0	12.2%	In Furrow	6oz	Viger Ag Research
2008	Hoytville	OH	Midwest	154.7	137.1	17.6	12.8%	In Furrow	8oz	Andersons
2008	Jackson	TN	South	154.7	137.1	17.6	12.8%	In Furrow	6oz	D&D Research
2007	Fergus Falls	MN	Midwest	163.9	147.1	16.8	11.4%	In Furrow	6oz	Viger Ag Research
2008	Jackson	TN	South	156.4	140.7	15.7	11.2%	In Furrow	6oz	D&D Research
2007	Verona	WI	Midwest	229.4	216.9	12.5	5.8%	In Furrow	6oz	Agstat
2010	Jackson	TN	South	196.6	186.4	10.2	5.5%	In Furrow	6 oz	D&D Research
2010	Memphis	TN	South	69.3	60.4	9.0	14.8%	In Furrow	6 oz	AgriCenter
2008	Richland	IA	Midwest	101.9	93.2	8.7	9.3%	In Furrow	6oz	Bennett Ag Research
2007	Richland	IA	Midwest	171.5	163.7	7.8	4.8%	In Furrow	8oz	Bennett Ag Research
2008	Rockdale	WI	Midwest	157.2	150.4	6.8	4.5%	In Furrow	6oz	HEPTA-S Research
2008	Hoytville	OH	Midwest	166.2	159.6	6.6	4.1%	In Furrow	8oz	Andersons
2008	Jackson	TN	South	166.2	159.6	6.6	4.1%	In Furrow	8oz	D&D Research
2008	Campbell	MN	Midwest	229.0	222.5	6.5	2.9%	In Furrow	8oz	Viger Ag Research
2008	East Lansing	OH	Midwest	217.7	212.4	5.3	2.5%	In Furrow	8oz	Andersons
2008	Campbell	MN	Midwest	223.1	218.6	4.5	2.1%	In Furrow	8oz	Viger Ag Research
2008	Richland	IA	Midwest	141.5	137.7	3.8	2.8%	In Furrow	6oz	Bennett Ag Research
2008	Rockdale	WI	Midwest	127.6	125.1	2.5	2.0%	In Furrow	8oz	HEPTA-S Research
2008	Memphis	TN	South	123.4	121.2	2.2	1.8%	In Furrow	6oz	AgriCenter
2009	Lamberton	MN	Midwest	213.0	211.0	2.0	0.9%	In Furrow	6oz	Univ of Minnesota
2008	Campbell	MN	Midwest	230.5	229.0	1.5	0.7%	In Furrow	6oz	Viger Ag Research
2010	Belleville	IL	Midwest	187.0	186.0	1.0	0.5%	In Furrow	6oz	Southern Illinois Univ
2008	Richland	IA	Midwest	130.5	131.0	-0.5	-0.4%	In Furrow	6oz	Bennett Ag Research
2009	Clinton	NC	South	141.6	142.1	-0.5	-0.4%	In Furrow	3oz	AgriTechnologies
2007	Richland	IA	Midwest	159.1	163.7	-4.6	-2.8%	In Furrow	6oz	Bennett Ag Research
2007	Verona	WI	Midwest	211.6	216.9	-5.3	-2.4%	In Furrow	6oz	Agstat
2008	Rockdale	WI	Midwest	143.5	149.1	-5.6	-3.8%	In Furrow	3oz	HEPTA-S Research
				167.2	**156.3**	**10.9**	**7.0%**			
Cost of Trovec Paid Back				AVG TRT	AVG GSP	AVG BU	AVG %			
Cost of Trovec Not Paid Back				Yield	Yield	Difference	Difference			