Examining the Economic Viability of Corn After Corn Cropping Systems in the United States Corn Belt

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Undergraduate Thesis

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Abstract

Corn cropping systems in the United States have generally involved rotations with soybeans. However, there have been times historically and in recent years that farmers have switched to a corn after corn system. Although a corn/soybean rotation dominates the Eastern Corn Belt, there are still a number of farmers throughout the Midwest that grow corn after corn. There are many variables that affect the decision to execute a corn after corn system, including corn-soybean yield ratios, soybean-corn price ratios, geographic location as it relates to crop yields and markets, soil fertility, tillage practices, pest pressure, and fertilizer requirements.

The objective of this research project is to examine how the variables mentioned above impact crop rotation decisions. When all else is held constant, each variable can be analyzed individually to see its impact to the overall profitability of the system. This is conducted through a Microsoft Excel spreadsheet that itemizes the revenue and expenses for both corn and soybeans, and then solves for net income under each crop budget. This takes into account not only the profit from growing corn after corn, but also the opportunity cost of growing corn instead of soybeans. Once the difference is calculated, the sign of the number will indicate the economic viability, and the size of the number will indicate the strength of certainty for the economic viability. By entering in customized values into the spreadsheet, a farmer/their adviser can view the different scenarios for growing corn after corn, which will assist them in making economically sound decisions on their farm in terms of choosing their cropping system.

Upon analyzing the most recent data from commodity prices, input costs, and average yields for an Eastern Corn Belt scenario, the budget for corn after corn yielded a mean contribution margin of $166.82 per acre, while the corn/soybean rotation budget yielded $267.61. This early 2020 estimation of cropping system profitability resulted in a corn/soybean

rotation being the most viable option, with the corn/soybean rotation being favored by $100.78 for a typical farming operation in the Eastern Corn Belt. The Western Corn Belt scenario estimated the viability of practicing a corn after corn operation typical of Iowa or Eastern Nebraska. Upon entering the custom data for that region into the model, the budget for corn after corn yielded a mean contribution margin of $480.44, while the corn/soybean rotation budget yielded $419.04. This implies that practicing corn after corn in this region of the Corn Belt is favored by $61.40.

Introduction

Corn has been a dominant crop in the U.S. Midwest for many decades. Given the need for corn-based fodder for livestock, along with favorable prices, some farmers grew corn more than other crops, resulting in continuous corn production in some fields and farms instead of rotating with other crops such as wheat, soybeans, or forages. Crop rotations are generally viewed as more favorable for production, yet many farmers view the benefits of more corn to outweigh the limitations of not rotating crops.

Corn is a heavy user of soil nutrients, especially nitrogen, but if production is good corn also produces high amounts of stover that can add considerable organic matter back to the soil. So, the overall effect on soil quality is debated (Dobermann, et. al., 2005). But few debate that a corn crop requires more inputs that other crops such as wheat, soybeans, or forages, thus it can be more expensive to produce.

Along with their ability to naturally fix nitrogen into the soil, soybeans were also valued as a profitable cash crop in the Midwest, given their high oil and protein content. A study in 1993 found that a corn/soybean rotation is the dominant method throughout the Midwest, with corn after corn systems only accounting for 25% of corn acreage (Padgitt, 1993). Although rotations with soybeans are the main choice adopted by farmers, there are still many who will grow corn for many consecutive years. Many variables can have an effect on individual decision making for cropping systems. For example, Figure 1 shows the frequency of corn acres planted throughout the U.S. The dark blue/purple coloration on the map shows a high frequency of corn acres planted, in some cases, up to ten years of corn after corn. The figure displays how geography plays a role in the adoption of corn after corn, where it is largely practiced in Nebraska, Iowa, and Illinois. Economic shifts also contribute to the decision making process. Input prices, most notably fertilizer, as well as the ratio between corn and soybean prices, can impact how profitable the cultivation of one crop is over the other.

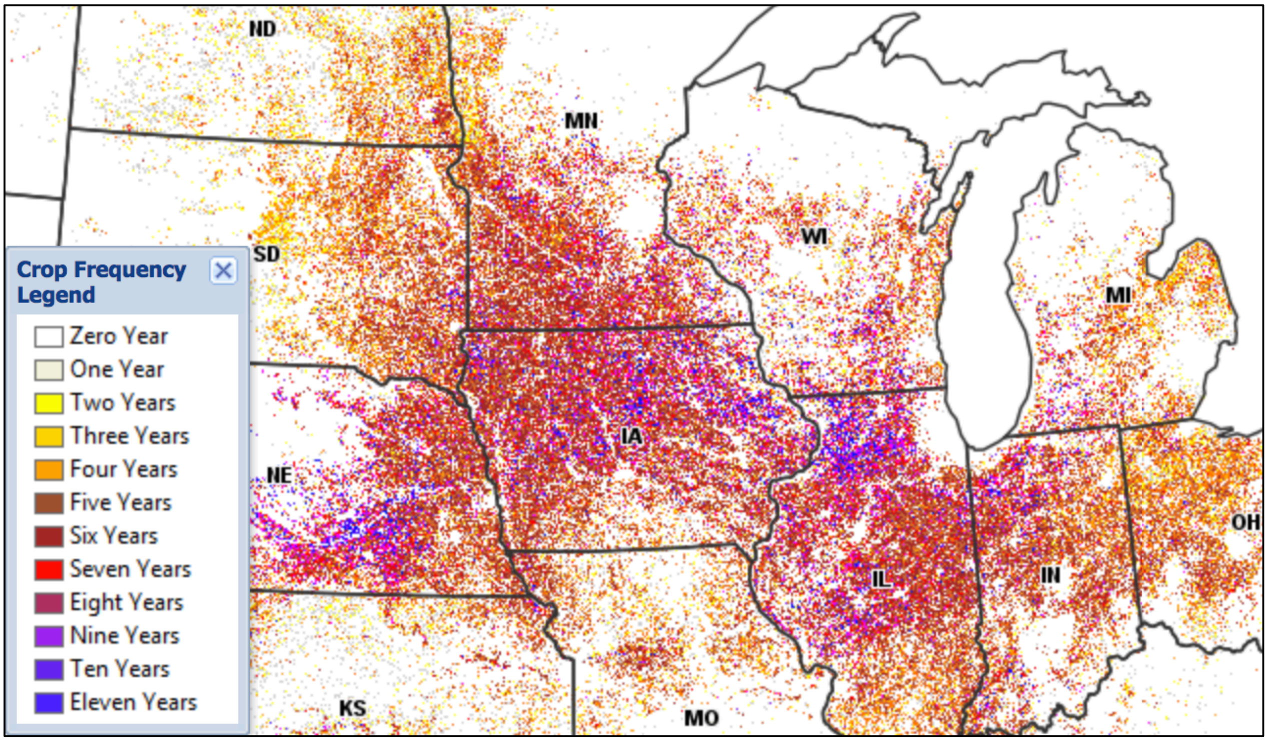

Figure 1: Corn Acreage Frequency (2008-2018)

Source: USDA NASS, 2018.

Provided the number of different variables that go into choosing a cropping system, there may be instances where farmers may not be making the most profitable decisions. This can be due in part to historical methods being the prime choice for their farm. For example, some farmers may be rotating corn with soybeans because that's the practice most familiar to them. However, what if soybean prices are low in relation to corn prices, or what if the real price of anhydrous ammonia is the lowest it's been in decades? Would these changes be enough the sway the farmer from going against the historical status quo? How much more profitable would they become if they switched the corn after corn? Would only a small monetary advantage be worth the time and energy put into changing their cropping system? The goal of this research study is to answer all of those questions with calculated estimations to arrive at a numerical conclusion.

Doing so would greatly improve farm decision making in terms of profitability by examining the benefits and costs of each method and comparing them against each other.

Methodology

In order to arrive at a numerical answer for the interactive budget, only quantitative variables were used. However, there are qualitative variables that can have an impact on determining whether or not corn after corn is the most viable option. Although the qualitative variables are omitted in monetary terms, there was an attempt to incorporate the costs associated with the qualitative variables into the budget. For example, there are multiple variations of tillage operations that will vary from farmer to farmer. Because corn after corn generally requires more intensive tillage practices, the scenario entered into the budget assumes that heavy tillage operations, such as moldboard plowing and field cultivating, are used. These operations have various potential agronomic impacts, including sidewall compaction, erosion, and mixing of stratified soil nutrients. These variables, while important to consider, are difficult to place a monetary value upon. However, the qualitative variables in this study should not be undermined, even when it is difficult to apply a dollar sign to them. Sidewall compaction and nutrient stratification can limit yield potential. Therefore, analyzing the cited literature is still important to see the costs associated with different cropping systems, even if they may not be accounted for in the numerical data.

Once all quantitative variables are designated, they are entered into an interactive spreadsheet created in Microsoft Excel. The spreadsheet includes three budgets, one for rotational corn, one for rotational soybeans, and one for corn after corn. To analyze the long-term financial differences between corn after corn and a corn/soybean rotation, the mean contribution margin per acre between rotational corn and rotational soybeans is subtracted from mean contribution margin per acre from corn after corn. The ending value is the net economic return difference per acre of practicing corn after corn, taking into account the opportunity cost of growing a corn/soybean rotation. If the net economic return difference comes out to be negative, then it would indicate that the mean contribution margin for a corn/soybean rotation is higher than that of corn after corn, making corn after corn not viable. The opposite is also true, where a positive number indicates that corn after corn would be a viable option given the provided circumstances.

Upon obtaining the mean contribution margin per acre for each method, the data is further interpreted through a breakeven analysis to see how much each variable must change to make the other method more viable. This makes it possible to see to what degree individual variables must change for the net economic return to change. If the degree of the economic return difference is multiple dollars positive or negative, then there is strong evidence that the corn after corn will be either viable or non-viable based on the absolute value of the net economic return. However, if the net economic return difference is nearly zero, then breakeven analysis can be used to see how much each variable must change to change the viability of corn after corn, when all else is held constant.

Through these methods, the two main objectives of this research include:

1) determining the viability of corn after corn with current market prices, and

2) examining the price factors that would make corn after corn viable.

Furthermore, this research paper includes two preset situations that can represent a typical situation for a farmer in the Eastern Corn Belt, as well as in the Western Corn Belt, along with an analysis of the results and applied variable sensitivity to better understand the potential options that corn after corn may present.

Variables

Soybean-Corn Price Ratio

A key factor used to examine the viability of corn after corn is through the soybean-corn price ratio. This ratio looks at how the soybean price compares to the price of corn. The generally accepted soybean to corn ratio is shown below:

$$Soybean\ to\ Corn\ Price\ Ratio = \frac{Soybean\ Price}{Corn\ Price}$$

*Soybean price is calculated using November soybean futures

*Corn price is calculated using December corn futures

*Prices used in the equation are typically determined in mid-March

As the price ratio increases, the price of November soybeans is increasing faster than the price of December corn. Likewise, as the ratio decreases, the price of December corn is rising faster than the price of November soybeans. This ratio is very useful in determining the proportion of the prices for each commodity and which one will generate more revenue.

Depending on the geographic location, one might consider the price ratios of other cash crops dominant in the area. This would include examining price ratios of cotton in the Mississippi Delta and parts of Texas, or the price ratios of winter and spring wheats in the Great Plains. However, this research project will focus on only the soybean-corn price ratio, which applies to a majority of the U.S. Corn Belt. The soybean-corn price ratio has encountered much variation from year to year, which makes it difficult to predict. Therefore, careful attention must be paid to commodity prices to analyze the trend of the ratio.

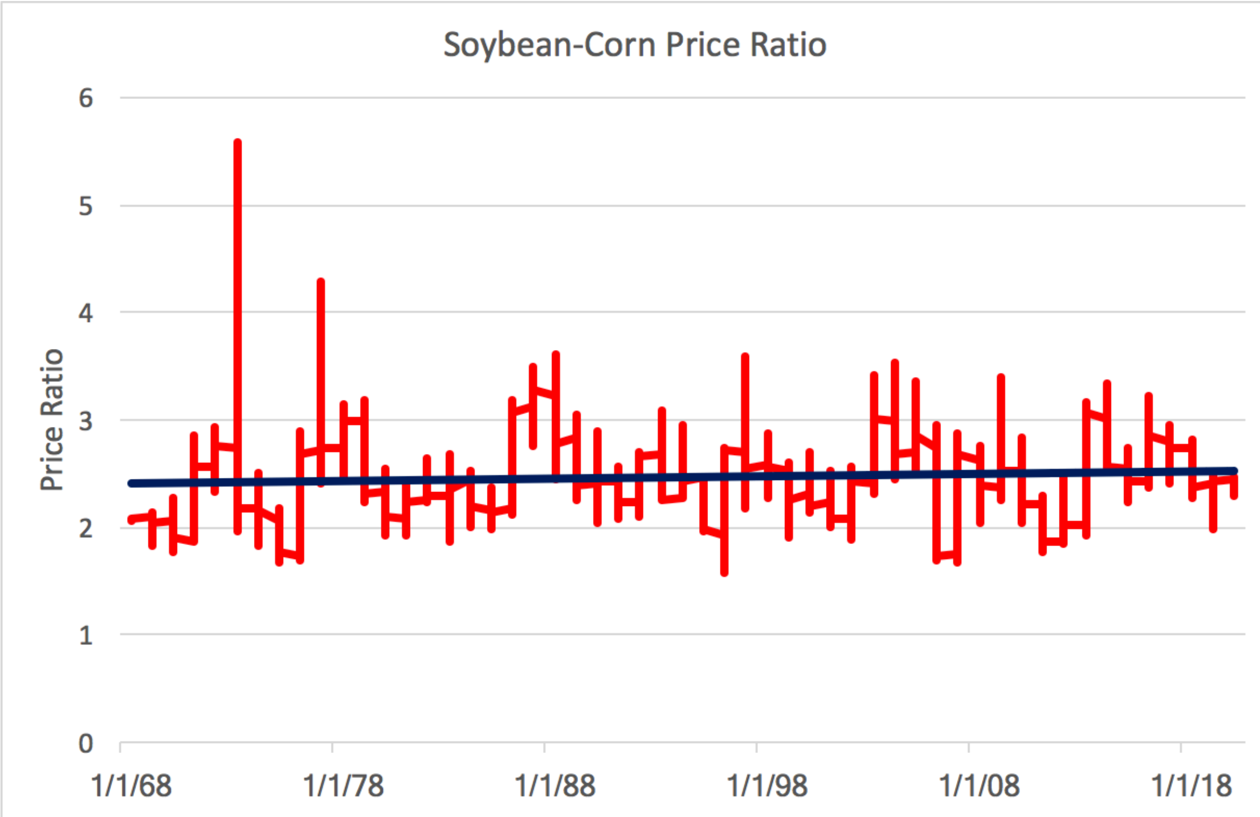

Figure 2: Soybean-Corn Price Ratio Since 1968

Source: Macrotrends, 2020.

The average ratio between soybean prices and corn prices in Figure 2 is roughly 2.5:1, lower than the generally accepted 3:1 price ratio. The flat slope historically exhibited by the soybean-corn price ratio might indicate that there is no significant long run difference between commodity prices. However, short term prices for corn and soybeans may be more volatile, as shown in the price spike in the 1970's in Figure 2. When prices are more volatile, it is very possible that prices may favor corn after corn in one year and rotational corn in the next year.

The soybean-corn price ratio is a major determinant for the relative profitability of corn and soybeans. It can also have geographic ties, depending on where the crops are grown. For example, the ratio may become narrower in areas where corn production is favored, such as near an ethanol plant or cattle feedlot operation. Due the higher number of feedlots present in parts of the Western Corn Belt, it is common to see a narrower soybean-corn price ratio.

Corn-Soybean Yield Ratio

The corn-soybean yield ratio looks at the average yield of corn and compares it to soybean yields. Historically, a commonly accepted ratio has been roughly 3:1, where corn generally has yielded 3 times the bushels per acre of soybeans in the same year. Figure 3 illustrates how the upward sloping corn-soybean yield ratio in Nebraska may be a significant factor in corn after corn profitability.

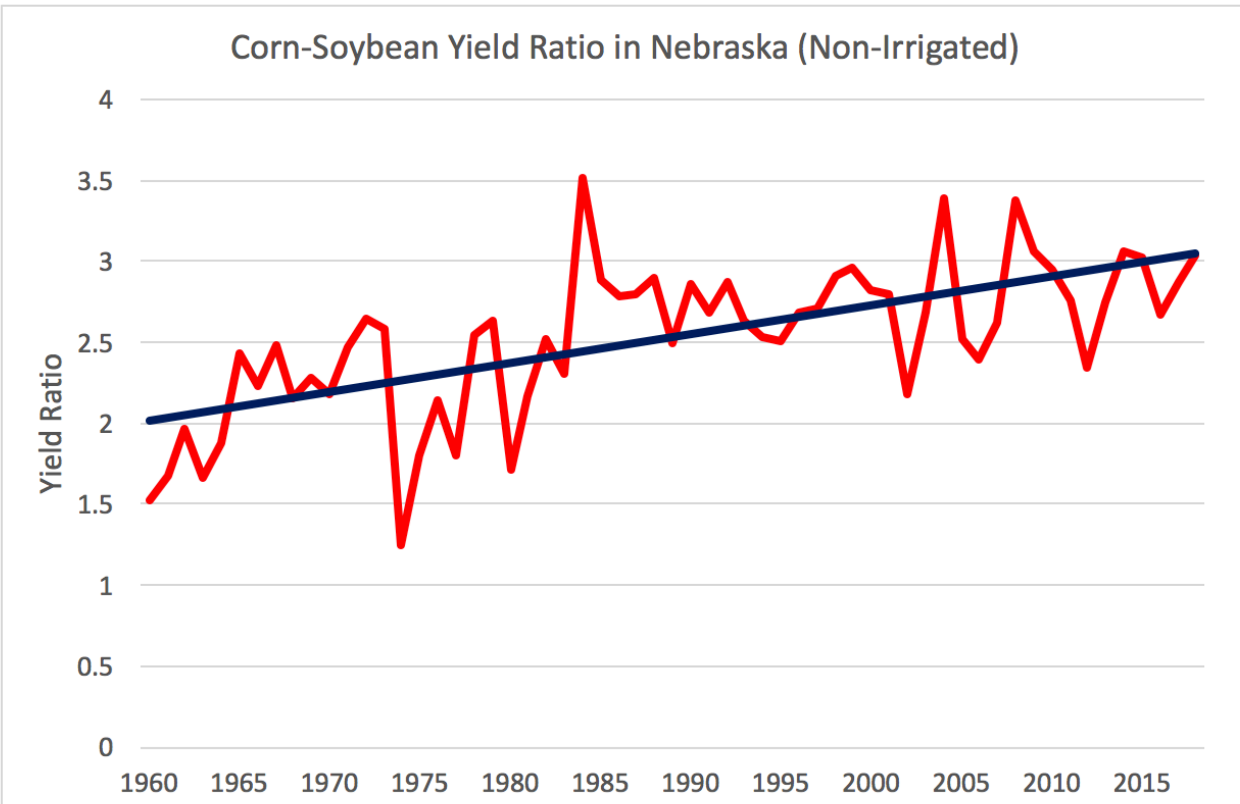

Figure 3: Non-Irrigated Corn-Soybean Yield Ratio in Nebraska Since 1960

Source: USDA NASS, 2020.

Another consideration is a possible yield penalty for corn after corn. Penalties may stem from increased pest pressure and a lack of plant available nitrogen in the soil for the corn crop to uptake since there was no previous legume to fix nitrogen into the soil. Yield penalties should be customized for each individual farm, but a good benchmark for corn after corn is 6%, taken from the 2020 Purdue Crop Budget (Langemeier et. al., 2019). While most fields are assumed to incur a corn after corn penalty for each year, there are a great number of farmers that still find corn after corn to be profitable. Over the course of a 10-year study, farmers who practiced corn after corn saw a significant drop in yields after the first year of practicing it. However, after the second year, the yields of corn after corn began to steadily rise each year, breaking even with rotational corn in the seventh year, then exceeding rotational corn up to the last year of the study. The suggested reasoning for this includes increased soil organic matter, higher soil quality, and available nitrogen (Erickson & Lowenberg-DeBoer, 2005). Further consideration will be needed for yield penalties of long-term corn after corn. Although a majority of farmers in the previously mentioned study found long-run corn after corn to be even more economical than a corn/soybean rotation, an individual analysis of the situation would be needed to correctly assess the relative yield penalty of corn after corn for multiple years.

Interpretation of the yield penalty for corn after corn must be left up to the individual farmer. Like all variables analyzed in this study, it will ultimately be up to the individual farmer to find the numbers that best represent their unique situation. For this specific study, a 6% yield penalty is assumed for the corn after corn budget.

Fertilizer

One of the major drawbacks associated with corn after corn systems is cost of the nitrogen (N) fertilizers required. Nitrogen uptake in corn is generally higher than soybeans, corn cannot fix nitrogen like soybeans can in their association with *Rhizobia* bacteria, and there can be N immobilization due to the high amount of residue, where nitrogen is tied up in the soil. Therefore, a rotated cropping system can provide more available soil nitrogen than corn after corn. Overall, corn after corn systems will require more fertilizer than rotated corn, which in turn makes growing corn after corn more expensive.

According to Purdue University's 2020 crop year estimates in the November 2019 Crop Budget Report, a corn after corn system will require an extra $11 for fertilizer expenses per acre compared to a corn/soybean rotation (Langemeier et. al., 2019). Using an average productivity soil, corn after corn required 240 lbs. N per acre compared to rotated corn's 200 lbs. per acre and rotated soybeans 0 lbs. per acre. Although more nitrogen is required for corn after corn, less phosphate and potash are required compared to rotated corn, 59 lbs. per acre of phosphate for corn after corn compared to rotated corn's 63 lbs. Corn after corn also requires 63 lbs. per acre of potash, whereas rotated requires 66 lbs. Estimates for fertilizer costs for 2020 were $0.30 per pound for nitrogen, $0.41 per pound for phosphate, and $0.31 per pound for muriate of potash (Langemeier et. al., 2019). To determine the recommended rates of fertilizer for each cropping system, the Tri-State Fertilizer Recommendations were applied to the budget.

Variables that impact the amount of fertilizer required to apply to each cropping system include anticipated yields, soil test levels, critical levels for phosphate and potash, soil CEC, and prices of each fertilizer. These variables were entered into various equations from the Tri-State

Fertilizer Recommendations to determine the expenditures of nitrogen, phosphorous, and potassium fertilizers. The equations are as follows:

$$Applied\ N\ {}^{lb.}/_{ac.} = (1.36 \times YG) - 27$$

$$Applied\ P_2O_5\ {}^{lb.}/_{ac.} = [(CL - STL) \times 5] + (YG \times CR)$$

$$Applied\ K_2O\ {}^{lb.}/_{ac.} = \begin{bmatrix} ([75 + (2.5 \times CEC)] - STL) \times \\ (1 + (0.05 \times CEC)) \end{bmatrix} + (YG \times CR) + 20$$

where YG=Yield Goal, CL=Critical Level, STL=Soil Test Level, CR=Crop Removal, and CEC=Cation Exchange Capacity.

These equations are entered into the spreadsheet to provide estimates for the amount of fertilizer needed for each cropping system. The largest differences in determining fertilizer recommendations for corn after corn and rotational corn include soybeans lacking a need for nitrogen, higher yield goals for corn, and different nutrient removals for phosphate and potash between corn and soybeans.

Limestone

Corn grows best around a pH of 6.2. Use of ammonium-containing fertilizers can make the soil more acidic and make it less optimal for corn growth. As a result, soil acidification through corn after corn systems may require more lime application and thus higher expenses. To estimate lime applications, the Tri-State Fertilizer Recommendations suggests a linear relationship between the SMP buffer pH and the targeted pH level. The equation for lime applications is as follows:

$$Applied\ Lime\ {}^{tons}/_{ac.} = 60.4 - 0.87 \times LTI$$

where Lime Test Index (LTI) = SMP buffer pH multiplied by a factor of 10.

*Assuming a target pH of 6.5 on a mineral soil

For the 2020 crop year, the price of ag lime was estimated to be $19.00 per ton (Langemeier et. al., 2019), but this can vary considerably as it is nearly always locally sourced. Purdue's November 2019 estimates also include, on average, an additional 120 lbs./ac. of lime needed for continuous corn acres (Langemeier et. al., 2019). Due to the additional nitrogen fertilizer applied to corn following corn fields, it is assumed that those fields will have a slightly lower pH level. Note that this will vary across many different fields. Different target pH levels, fertilizer practices, and soil organic matter content are among the many variables that can influence the amount of lime needed.

Tillage

One of the biggest considerations when deciding whether or not to practice corn after corn is the amount of residue to be managed. This is not only a cost issue, but potential issues can arise from not properly managing residue. A corn crop can produce tremendous amounts of residue. For a corn yield between 150 and 225, approximately 4.5 to 6.75 dry tons of corn stover remain per acre after grain harvest (Nielsen, 1995). It is evident that corn cropping systems produce tremendous amounts of residue.

Tillage is the most common and effective practice in managing residue. There are a variety of different farm implements that can be used to break down residue. Some are designed specifically to bury, break down, or pulverize crop residue, including field cultivators, tandem disks, and moldboard plows. Other implements can manage crop residue in addition to their main tasks. That would include the double-disc openers on a planter, or the knives on an anhydrous toolbar. Both of these examples assist with residue management, even though that is not the main purpose of the implement.

The amount of residue that remains on the field is ultimately up to the grower, but it is generally accepted that less corn residue is better if corn will be planted again during the next growing season. Although not very common, some will plant corn in a non-tilled environment. Special attention and care must be applied to have the seed germinate and grow through all the residue. Double-disc seed furrow openers must be adjusted properly and sharpened, and can be more effective than coulters in chopping residue (Jasa, 2007). Additionally, the grower is encouraged to offset their planter a few inches off the previous year’s rows. This will reduce bouncing off old row stumps, which could lead to less uniform seed depth (Jasa, 2007). There are a variety of implements that can effectively manage residue (Table 1), each leaving different amounts after a field pass.

Table 1: Effectiveness of Residue Management for Various Implements

Implement Type	% Corn Residue Remaining	% Soybean Residue Remaining
Moldboard Plow	0-10	0-5
Chisel Plow with Sweeps	70-85	50-60
Coulter Chisel Plow with Sweeps	60-80	40-50
Disk Chisel Plow with Sweeps	60-70	30-50
Tandem Disk Harrow with >10" blade spacing	25-50	10-25
Field Cultivator with 12-20" Sweeps	60-80	55-70
Combination Finisher	50-70	30-50
Anhydrous Toolbar with Closing Discs	60-75	30-50
Conventional Drill with Double-Disc Openers	85-95	75-85
Rotary Hoe	85-90	80-90
Conventional Planter with Staggered Double Disk Openers	90-95	85-95

Source: Eck, et. al., 2001.

These approximate corn residue figures are up for interpretation on what would most benefit the individual field. Generally, less residue is preferred, especially when considering corn after corn. Residue can interfere with field passes (planting, side-dressing, etc.), and residue is associated with pest issues, such as anthracnose stalk rot in corn. However, minimal or no tillage on corn has been proven to increase long term effects on soil fertility. Tillage can also have its own drawbacks. Incorporating tillage, as opposed to no till, means more field passes, and potentially compaction from heavy machinery. Excessive soil disturbance may also lead to erosion concerns in the long-run. It is ultimately up to the individual farmer to find the right tillage practice for their field, as every field is different. Some fields may require heavy tillage practices, while others may be managed without any tillage. Strip tillage is also an option for some farmers. For one farm operation, strip tillage works great for their fields. To manage their tillage practice, they set their corn head to chop stalks less than 12 inches. Additionally, unless there is deep compaction present, they run aerator over the residue to speed up the process of rotting the stalks (Bernick, 2007).

Beyond the agronomic impacts of tillage, there are also costs associated with incorporating tillage into a cropping system. While machinery costs and depreciation are assumed to be similar across all cropping systems in our analysis, there are significant differences in operational expenses for different cropping systems. These costs are associated with fuel expenses, as different cropping systems require different forms of tillage operations, and different forms of tillage operations have different fuel costs. The cost of incorporating tillage can be significantly more expensive in a corn after corn system than a rotational corn or soybean system. For example, if a farmer is preparing to plant corn after corn in the upcoming season, then they might use a disk/chisel plow for primary tillage and a field cultivator or tandem disk as secondary tillage. On the contrary, if rotational soybeans will be planted, then the farmer may potential incorporate less tillage, or even none at all. In this case, a corn after corn system would have a much higher fuel expense. But what if soybeans are omitted from the equation, and just corn systems are analyzed? In this case, it possible that corn after corn and rotational corn would require similar tillage operations prior to planting, yet there are still monetary differences between each tillage operation. If corn after corn and rotational corn each require one tillage pass, but corn after corn requires a moldboard plow while rotational corn requires a field cultivator, then the fuel expenses per acre will be higher for corn after corn. This is because the moldboard would require more horsepower and fuel to completely invert the top 8 inches of the soil profile, whereas a field cultivator is only breaking up residue and soil clods on the surface and subsurface of the soil profile. A complete list of various field operations, including tillage, planting, fertilizer application, pesticide spraying, and harvesting, can be found in Table 2.

Table 2: Estimated Fuel Consumption from Field Operations

Field Operation	Fuel Consumption in Corn System (gal./ac.)	Fuel Consumption in Soybean System (gal./ac.)
12’ Moldboard Plow	1.32	1.32
37’ Chisel Plow	1.25	1.25
Tandem Disk 30’ Fold	0.74	0.74
47’ Field Cultivator	0.31	0.31
18’ V Ripper 25”	1.10	1.10
Side-dressing	0.46	0.46
Sprayer/Dry Fertilizer Spreader	0.15	0.15
16 Row Planter	0.07	0.07
12 Row 375 HP Combine	2.0	2.0

Source: Lazarus, 2019.

Because of the generally more intensive tillage operations in corn after corn, there are higher fuel costs associated with practicing corn after corn. These costs are reflected in the budget used to calculate profitability of corn after corn. Although the estimated fuel cost of each field operation is the key component of the interactive spreadsheet, all of the impacts mentioned should be carefully considered when planning for the next cropping system.

Soil Impacts

Intensive corn after corn cropping systems have shown significant long-term build-up of organic matter in the soil and increased nitrogen use efficiency (Dobermann, et. al., 2005), which is a potential benefit of adopting corn after corn. In their study, intensive corn after corn systems had a significant accumulation of soil carbon and nitrogen over a long-term period. But when dealing with the large amounts of residue left over from corn, one must take into consideration how the carbon to nitrogen ratio can affect nutrient availability. Naturally occurring soil bacteria can temporarily immobilize and tie up soil nitrogen. While leaving residue behind after harvest can combat soil erosion and retain soil moisture, microbial activity could have a negative effect on the fertility of the soil. After harvesting corn, the remaining corn debris will slowly decompose due to soil microbes feeding on the stover. The C:N ratio in corn residue is generally 70:1, while soil microbes require a diet consisting of a 24:1 ratio. Since the C:N ratio is higher in corn, the microbes will decompose the corn debris slowly, and the microbes will need to consume any available nitrogen in the soil in order to consume the high carbon content corn debris (USDA NRCS, 2011). This process is commonly known as immobilization in the nitrogen cycle. The end result of process is that microbial activity could deplete the amount of available nitrogen in the soil unless the residue finishes decomposing after a corn harvest. Understanding the C:N ratio and soil carbon build-up from intensive corn after corn farming is necessary when deciding if corn after corn is worth the costs associated with it.

When deciding to plant corn after corn, one must pay attention to the type of soil that it would be planted on. Due to the high amounts of nutrients that corn needs to uptake, nutrient availability and retention are very important factors. A soil factor related to soil nutrients is cation exchange capacity (CEC). CEC is used to measure the capacity of a soil to hold exchangeable cations (Brown & Lemon, 2018). Sandy soils such sandy loams or loamy sands will have lower CEC, and thus are more susceptible to nutrient leaching. Since corn is a heavy nutrient consumer, planting corn after corn in a sandy soil, as opposed to a silty or clay soil, could require even more nutrient application. Although soil type and conditions can affect any crop, it is important to note that as corn after corn requires more fertilizer application, there is more fertilizer available for leaching depending on the soil type.

Drainage is another key soil factor that is important for maximum corn after corn yields. While high CEC soils tend to also have high organic matter content and higher water holding capacity, they can conversely create drainage issues. If drainage tiles are not incorporated into the field, then soils with poor drainage will take longer to get rid of any excess water. This issue tends to be more significant in the Eastern Corn Belt. Ponding water on any cornfield is a cause for alarm, especially in early season development. In addition to the other challenges faced by corn after corn systems, ponding water or saturated soils can lead to surface crusting, seedling rots, nitrogen deficiencies, and disease growth encouragement.

To maximize the effectiveness of a corn after corn cropping system, ideal soil conditions are needed. Generally, these would include soils high in organic matter and CEC. Very sandy soils would potentially require irrigation and stabilizers applied with fertilizers, and muck soils would require drainage. However, every farm has unique characteristics and needs, which this research study tries to address to the best ability.

Grain Drying

There is a combination of factors that lead to corn having a higher moisture content when harvested in a corn following corn system. Weather conditions, hybrid maturity, and time constraints are a few examples of why corn after corn systems may have a higher moisture content at harvest. When rotating corn with soybeans, there is less time and money spent on drying soybeans compared to continuous years of corn cultivation. Therefore, the costs associated with drying corn are included in this estimation.

It is estimated that drying corn requires approximately 0.022 gallons of liquefied petroleum fuel (LP) to lower the moisture of a bushel of corn by 1%. The following equation is utilized to estimate the cost per acre of drying corn:

$$LP\ {}^{gal.}/_{ac.} = (\%ML - \%TL) \times 0.022 \times Yield$$

where ML=Moisture Level and TL=Target Level.

Incorporating this equation into the general estimation for corn after corn viability allows the farmer to determine whether or not the additional drying expenses will alter the profitability of growing corn after corn.

Pest Issues

Corn after corn cropping systems have historically shown increased pest pressure, including diseases, weeds, and, most notably, insects. While insect pressure can still be troublesome in corn after corn, most corn hybrids available today have protections against such pests, such as genetically modified resistance from *Bacillus thuringiensis* genes. Diseases and weeds are also capable of posing a threat to overall yields, but crop rotation is one of the most fundamental forms of disease control practices, as rotating crops can deprive various pathogens of their food source (Vincelli et. al. 2008). Herbicide options are reduced when only one crop is grown, as rotational crops offer additional/different herbicide options to control persistent weeds. This lack of rotation between crops is what gives corn after corn a disadvantage from a pest management standpoint.

One of the most notable of diseases found in corn after corn is Anthracnose Stalk Rot, caused by the fungus *Colletotrichum graminicola*. Anthracnose inoculum overwinters in corn residue. Corn after corn, especially no-till or conservation tillage, is very susceptible to infection. Other foliar diseases that overwinter in corn residue include Gray Leaf Spot (*Cercospora zeae-maydis*) and Goss's Bacterial Wilt and Leaf Blight (caused by the bacterium *Clavibacter michiganensis subsp. Nebraskensis*) (Wise, 2010). Ear rotting pathogens like Diplodia (*Stenocarpella maydis*) and Gibberella (*Fusarium graminearum*) thrive in corn residue and can significantly reduce grain quality. This is especially true for Gibberella Ear Rot, as it the fungus can infect kernels with two mycotoxins and pose a health threat to swine and other livestock (Wise & Woloshuk, 2010).

The increased disease pressure in corn after corn could pose various economic drawbacks, including reduced grain quality and elevator discounts, yield losses, and increased consumption of fungicides. However, many farmers, including those that practice corn after corn, may not find it economically suitable to utilize fungicides on their operation. Much like the previous variables discussed, pest management practices will vary across each individual farm.

Implementation

A Microsoft Excel spreadsheet was used to systematically evaluate the revenues and costs of each cropping system. The key variables include total revenue and expenses from nitrogen, phosphate, and potash fertilizers, seed, pesticide, and fuel from field operations and corn drying. These are considered to be the biggest factors in determining the profitability of a cropping system. As previously stated, some variables, such as interest and depreciation on machinery, are assumed to be roughly equal for each cropping system. Therefore, they are omitted from the spreadsheet. The main variables presented in this research project include sub-variables. These sub-variables are the variables that are actually entered into the spreadsheet by the farmer, and they are what impact the main variables listed above. The complete list of revenue and expense variables (bold), and their respective sub-variables, can be found below.

Table 3: Variables and Sub-Variables

Total Revenue
Anticipated Yield, Adjusted Yield, Yield Penalty, and Commodity Prices @ Date of Delivery
Nitrogen Expense
Anticipated Yield, Adjusted Yield, and Nitrogen Price
P_2O_5 Expense
Soil Test Level, Anticipated Yield, Adjusted Yield, and P_2O_5 Price
K_2O Expense
Soil Cation Exchange Capacity, Soil Test Level, Anticipated Yield, Adjusted Yield, and K_2O Price
Limestone Expense
SMP Buffer pH and Price of Lime
Seed Expense
Seeding Rate and Seed Price
Fuel Expense (Field Operations)
Field Operations (Planting, Harvesting, Tillage, Etc.), Number of Passes, and Price of Diesel
Fuel Expense (Drying)
Moisture Level, Target Moisture Level, Anticipated Yield, Adjusted Yield, and Price of LP Gas
Pesticide Expense
Rate, Number of Applications, and Price of Pesticide

To estimate an average scenario for this simulation, there were many assumptions that had to be made. To accurately project the prices received at harvest in the spreadsheet, a $0.25 basis was subtracted from the December 2020 corn futures price, and a $0.35 basis was subtracted from the November 2020 soybean futures price. A 6% yield penalty was entered for the corn after corn budget, which is based on the 2020 Purdue Crop Budget Estimates (Langemeier, et. al., 2019). Anhydrous ammonia was used for corn, along with diammonium phosphate and muriate of potash for both corn and soybeans. Rotational corn received a 30 lb./ac. nitrogen credit. Soil tests for both budgets accounted for a buildup and maintenance for P and K on medium textured soils. Seed expenses assume 80,000 kernels per unit for corn and 140,000 seeds per unit for soybeans. Price for seed corn was derived from a 2018 average retail price across multiple DEKALB® hybrids with SmartStax® traits and glyphosate tolerance. Price for soybean seed was derived from an average retail price across multiple Asgrow® Roundup Ready 2 Xtend® varieties (Worden, 2018). The corn after corn system used a 37' chisel plow as primary tillage and a 47' field cultivator as secondary tillage, while the rotational corn system used a 30' tandem disk and an 18' V Ripper 25". The soybean system used only a 47' field cultivator to illustrate the lower need for tillage. Both rotational corn and corn after corn assumed drying expenses with a target moisture of 15%, but the corn after corn system assumed an initial moisture of 20% compared to 18% in the rotational corn system. Fuel expenses were assumed to be $2.00 per gallon for LP gas and $3.00 per gallon for diesel. Herbicides used for both corn after corn and rotational corn were the same, as well as the same rates used. Corvus® was used as a pre-emergence herbicide and Halex® GT was used as a post-emergence herbicide in both corn budgets. The soybean budget used XtendiMax® as both a pre-emergence and post-emergence herbicide. Trivapro® was used as a fungicide only for the corn after corn system. All pesticides were single field passes at the maximum rate allowed based on each crop.

Table 4: Variable Inputs for Eastern Corn Belt Scenario

Variables	Corn after Corn Values Entered	Rotational Corn Values Entered	Rotational Soybean Values Entered
Anticipated Yield	176 bu./ac.	176 bu./ac.	54 bu./ac.
Yield Penalty	6%	N/A	N/A
Adjusted Yield	165.44 bu./ac.	N/A	N/A
Anticipated Price @ Date of Delivery	$3.70/bu.	$3.70/bu.	$9.20/bu.
Analysis of N Product	82%	82%	N/A
Price of N Product	$0.30/lb.	$0.30/lb.	N/A
P Soil Test Level	12 ppm	12 ppm	12 ppm
Analysis of P_2O_5 Product	46%	46%	46%
Price of P_2O_5 Product	$0.41/lb.	$0.41/lb.	$0.41/lb.
Soil CEC	10 meq/100g	10 meq/100g	10 meq/100g
K Soil Test Level	85 ppm	85 ppm	85 ppm
Analysis of K_2O Product	60%	60%	60%
Price of K_2O Product	$0.31/lb.	$0.31/lb.	$0.31/lb.
SMP Buffer pH	6.75	6.8	6.8
Price of Lime	$19.00/ton	$19.00/ton	$19.00/ton
Seeding Rate	33,000 seeds/ac.	32,000 seeds/ac.	169,000 seeds/ac.
Price of Seed	$257/unit	$257/unit	$72/unit
Price of Diesel	$3.00/gal.	$3.00/gal.	$3.00/gal.
37’ Chisel Plow	1 pass	N/A	N/A
47’ Field Cultivator	1 pass	N/A	1 pass
30’ Tandem Disk	N/A	1 pass	N/A
18’ V Ripper 25”	N/A	1 pass	N/A
NH_3 Side-dressing	1 pass	1 pass	N/A
Dry-Spreading P & K and Liquid Pesticide Spraying	4 passes	3 passes	3 passes
Moisture at Harvest	20%	18%	N/A
Target Moisture Level	15%	15%	N/A
Price of LP Gas	$2.00/gal.	$2.00/gal.	N/A
Pre-Emergence Herbicide Rate	5.6 fl. oz./ac.	5.6 fl. oz./ac.	44 fl. oz./ac.
Price of Pre-Emergence Herbicide	$7.80/fl. oz.	$7.80/fl. oz.	$0.40/fl. oz.
Post-Emergence Herbicide Rate	64 fl. oz./ ac.	64 fl. oz./ ac.	22 fl. oz./ac.
Price of Post-Emergence Herbicide	$0.51/fl. oz.	$0.51/fl. oz.	$0.40/fl. oz.
Fungicide Rate	13 fl. oz./ac.	N/A	N/A
Price of Fungicide	$1.02/fl. oz.	N/A	N/A

Table 5: Variable Inputs for Western Corn Belt Scenario

Variables	**Corn after Corn Values Entered**	**Rotational Corn Values Entered**	**Rotational Soybean Values Entered**
Anticipated Yield	250 bu./ac.	250 bu./ac.	50 bu./ac.
Yield Penalty	2%	N/A	N/A
Adjusted Yield	245 bu./ac.	N/A	N/A
Anticipated Price @ Date of Delivery	\$4.00/bu.	\$4.00/bu.	\$9.00/bu.
Analysis of N Product	82%	82%	N/A
Price of N Product	\$0.27/lb.	\$0.27/lb.	N/A
P Soil Test Level	15 ppm	15 ppm	15 ppm
Analysis of P_2O_5 Product	46%	46%	46%
Price of P_2O_5 Product	\$0.40/lb.	\$0.40/lb.	\$0.40/lb.
Soil CEC	15 meq/100g	15 meq/100g	15 meq/100g
K Soil Test Level	115 ppm	115 ppm	115 ppm
Analysis of K_2O Product	60%	60%	60%
Price of K_2O Product	\$0.31/lb.	\$0.31/lb.	\$0.31/lb.
SMP Buffer pH	6.8	6.9	6.9
Price of Lime	\$19.00/ton	\$19.00/ton	\$19.00/ton
Seeding Rate	36,000 seeds/ac.	36,000 seeds/ac.	169,000 seeds/ac.
Price of Seed	\$257/unit	\$257/unit	\$72/unit
Price of Diesel	\$2.80/gal.	\$2.80/gal.	\$2.80/gal.
37’ Chisel Plow	N/A	N/A	N/A
47’ Field Cultivator	N/A	1 pass	1 pass
30’ Tandem Disk	N/A	N/A	N/A
18’ V Ripper 25”	1 pass	N/A	N/A
NH_3 Side-dressing	1 pass	1 pass	N/A
Dry-Spreading P & K and Liquid Pesticide Spraying	4 passes	3 passes	3 passes
Moisture at Harvest	20%	18%	N/A
Target Moisture Level	15%	15%	N/A
Price of LP Gas	\$2.00/gal.	\$2.00/gal.	N/A
Pre-Emergence Herbicide Rate	5.6 fl. oz./ac.	5.6 fl. oz./ac.	44 fl. oz./ac.
Price of Pre-Emergence Herbicide	\$7.80/fl. oz.	\$7.80/fl. oz.	\$0.40/fl. oz.
Post-Emergence Herbicide Rate	64 fl. oz./ ac.	64 fl. oz./ ac.	22 fl. oz./ac.
Price of Post-Emergence Herbicide	\$0.51/fl. oz.	\$0.51/fl. oz.	\$0.40/fl. oz.
Fungicide Rate	13 fl. oz./ac.	N/A	N/A
Price of Fungicide	\$1.02/fl. oz.	N/A	N/A

Results and Discussion

Table 6: Results for Eastern Corn Belt Scenario

	Corn After Corn	Corn/Soybean Rotation
Mean Contribution Margin Per Acre	$166.82	$267.61
Net Economic Return Difference Per Acre	-$100.78	

Table 7: Results for Western Corn Belt Scenario

	Corn After Corn	Corn/Soybean Rotation
Mean Contribution Margin Per Acre	$480.44	$419.04
Net Economic Return Difference Per Acre	+$61.40	

Tables 6 and 7 above display the resulting data calculated from each cropping system. The scenario for the Eastern Corn Belt resulted in the corn after corn system contributing $166.82 per acre, while the mean average contribution margin for the corn/soybean rotation was $267.61. The difference calculated between both budgets resulted in a net economic return of -$100.87. Under the conditions listed above, rotating between corn and soybeans would be the most economical choice. Note that these are estimates. The numbers calculated may not be what is actually accrued by practicing these systems, rather the magnitude of the numbers is what is meaningful. For example, practicing corn after corn based on these variables may not yield the farmer $166.82, but it is more likely that under these conditions, the difference between each cropping system may be $100.78.

For the Western Corn Belt scenario, practicing corn after corn is a much more viable option compared to a corn/soybean rotation. In fact, our model estimated a $61.40 higher return for a corn after corn system given the circumstances listed in Table 5. These results seem to align with the practices of farmers in the Western Corn Belt. When the conditions are favorable, farmers in that region of the Corn Belt can and will practice a corn after corn cropping system. A major factor could be an increased number of local feedlots that will cause an increase in corn demand, which will ultimately promote corn production in those areas. Additionally, various soil attributes may favor corn production over soybean production. If other factors including fertilizer and fuel expenses are low, it may cause a corn after corn system to be more profitable than a corn/soybean rotation.

The final objective of this research project is to evaluate which variables must change, and to what extent, to make corn after corn a more viable option for farmers in the Eastern Corn Belt. This was done using Goal Seek in Microsoft Excel, where a sample of different variables were analyzed to see how much they should change, while all else held constant, to bring the net economic return to +\$0.01. This allows for the grower to see which variables need to change for them to switch cropping systems, that is, performing a breakeven analysis. Table 8 shows selected variables and their respective percent changes required to make corn after corn profitable by \$0.01, thus marginally showing the point where corn after corn becomes more viable than rotational corn.

Table 8: Breakeven Analysis for Eastern Corn Belt Scenario

Variable	**Goal Seek Value**	**Original Value**	**%Δ from Original Value**
Adjusted Corn Yield (bu./ac.)	205	165	+24%
Anticipated Soybean Yield (bu./ac.)	30	54	-44%
Anticipated Corn price ($/bu.)	5.01	3.70	+35%
Anticipated Soybean Price ($/bu.)	5.47	9.20	-41%

While all else is held constant, in order to hit the breakeven value that would constitute a corn after corn system, either corn prices need to rise by 35%, or corn yields would have to increase by 24%. Likewise, either soybean prices would need to drop by 41%, or soybean yields would have to drop by 44%. According to these values, the most probable scenario to occur that would make corn after corn viable would be for corn yields to increase. This is likely due to the fact that the yield, whether it be corn or soybeans, can be managed by the farmer. The farmer has no control over commodity prices, therefore market shocks would have to be the cause for commodity prices to favor the farmer. Perhaps this is another reason for extensive corn after corn in parts of the Western Corn Belt, as corn cropping systems utilize a large amount of soil nutrition.

While these results may appear daunting at first, note that this only accounts for changes in a single variable while all else is held constant. In reality, there may be multiple variables changing at smaller rates that influence profitability decisions. For example, it would be uncommon for only the price of corn to rise up to a level where corn after corn is the most viable option. However, it would be more likely that the price of corn and estimated corn yield increase by a small margin, while the price soybeans, nitrogen fertilizer, and diesel fuel drop.

Conclusions

The initial estimation for a typical farmer in the Eastern Corn Belt concludes that using a corn after corn cropping system would be very uneconomical. The following sensitivity analysis concludes that either corn yields or prices would need to substantially increase beyond current levels, or soybeans yields or prices would need to substantially decrease to make corn after corn more profitable than a corn/soybean system. The purpose of the second estimation is to illustrate a variety of factors that contribute to a higher profitability in a corn after corn system. Modeled after a typical farmer in the Western Corn Belt, commodity prices, input expenses, and agronomic decisions are adjusted to demonstrate how profitable a corn after corn system could potentially be.

The spreadsheet created for this study is intended to be a resource to growers in determining which cropping system they should execute. Furthermore, the previously mentioned qualitative variables must also be accounted for to determine the agronomic benefits and costs of each cropping system. Because every farmer faces a unique situation every year, decisions must be constantly adjusted and monitored to capture the most profit available. This research thesis, supplemented by the interactive spreadsheet model, is intended to assist farmers across the entire U.S. Corn Belt with analyzing the costs and benefits of different cropping systems and determining the most profitable options for future growing seasons.

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