An Economic Evaluation of Variable Rate Irrigation for Alabama Corn and Soybean Production

by

Hunter Whatley

A thesis submitted to the Graduate Faculty of
Auburn University
in partial fulfillment of the
requirements for the Degree of
Master of Science

Auburn, Alabama
December 10, 2022

Approved by

Adam N. Rabinowitz, Ph.D., Chair, Assistant Professor, Agricultural Economics & Rural Sociology, Auburn University
Brenda Ortiz, Ph.D., Professor & Extension Specialist, Crop, Soil, & Environmental Sciences, Auburn University
Leah Duzy, Ph.D., Principal Consultant / Agricultural Economist at Compliance Services International
Sunjae Won, Ph.D., Assistant Professor, Agricultural Economics & Rural Sociology, Auburn University

Abstract

The variable rate application of production inputs is a method used by row crop producers to save money and resources. However, this technology comes at a substantial investment cost. This includes the capital investment in the physical equipment and the intellectual investment in managing and operating these advanced technologies. We focus our analysis on precision agriculture for irrigation through the adoption of a variable rate irrigation (VRI) system. We establish the useful life of the equipment, salvage value, and total capital investment necessary for adoption. This allows us to determine a fixed cost of adoption and breakeven yield requirement at various commodity prices to cover investment and annual expenses. We further illustrate through a case study of a farm in north Alabama the potential yield gains from the use of a VRI system during 2018-2021. This analysis provides producers with the framework to evaluate the economic feasibility of adopting these technologies for their row crop operation. It further provides the foundation for future analysis of the economic feasibility of adoption of VRI in Alabama.

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List of Abbreviations

ACES	Alabama Cooperative Extension System
GIS	Geographic Information Systems
TPI	Topographic Positioning Index
TWI	Topographic Wetness Index
VR	Variable Rate
VRI	Variable Rate Irrigation
VRT	Variable Rate Technologies

Chapter One

Introduction

Farmers continue to face challenges in determining how to produce more food for a growing population at less cost. McFadden, Roseburg, and Njuki (2021) explain how farmers have seen an increase in farm size with midsize farms growing largerf in size over the last decade. Also, the farm is getting bigger while fewer people are working on the farm. These two factors make farms much more reliant on technological advancement (McFadden, Roseburg, and Njuki 2021). Without technological advancement, farmers will not be able to produce enough food to feed the entire world.

Sharma and Irmak (2020) back this point up, while adding that farmers are pressured to achieve a maximum yield to feed the growing population. They explain that the hard part is that many states are requiring that farmers use less water. This is because we have seen that natural water has been diminishing in the last couple of decades, so governments are pushing farmers to use less water. To completely understand technological advancement in irrigation starts with the invention of the center pivot in 1950. This invention completely changed the game for farmers and helped them to dramatically increase their yield. This invention allowed farmers to irrigate their crops when the crop needed watering, and the application could be put out at the farmer's will. The water application was put out at a uniform rate across the field. Farmers would no longer have to wait and hope for rain in order to water their crops. Irrigated agriculture stabilized communities and allowed for economic advancement. Today, irrigated cropland covers 20 percent of the world and provides 40 percent of the world's food (Sharma and Irmak 2020). Several research publications at Auburn University also detail the pros and cons of today's center pivot sprinkler system (Ortiz, McClendon, Morata, Bondesan, and Duzy 2020; Bondesan, Ortiz, Morlin, Duzy, Santen, Lena, and Vellidis 2022; Ortiz, Bondesan, Morata, McClendon, and Kumar 2021).

Ortiz et. al. (2020) explains the crucial steps in correctly running the center pivot system. For example, one major disadvantage to the system is that if the system is not run correctly, the field can see a huge loss. Two of the most important things to double-check on your pivot to prevent this loss is to make sure before each season that the operating pressure and the sprinkler nozzles are correct and have not gone bad from the winter. These two things cause the most problems in center pivot failures and cause unequal distribution of water (Ortiz et al. 2020; Ortiz et al. 2021). Another issue addressed is the adoption cost of adding this technology to a farm. The equipment is very expensive, which makes farmers nervous about making enough profit to cover the cost. Furthermore, management time for this equipment can be substantial to set up this equipment and ensure it is running correctly. It also takes time to check the data and make prescription decisions. All these factors must be considered when deciding whether or not the technology would benefit a farmer and help increase the farm's profit (Bondesan et al. 2022).

In another article by Morata, Goodrich, and Ortiz (2019), they explain the investment decision behind the center pivot. It is explained that a center pivot is a large expense, but it takes away one of the largest risks in crop production. That risk is the fact that the crop does not receive enough water and therefore does not produce a maximum yield. Low yields cause the farms to lose money during the year. In this article, they explain that the two biggest factors that affect a farmer's ability to purchase a center pivot are access to natural water and access to an electric grid. If the farmer has to drill to find water, this could cost anywhere from $30,000 to $60,000. The cost of securing electricity for the center pivot also varies because farms are typically in rural areas, so getting connected to the electric grid for a power source can be expensive for a rural farm. The more rural the area where the farm is located, the more expensive it will be. An important point in their research was how much the cost could vary from farm to farm. There is no set cost because of how many factors go into the production of a crop and the technology needed to work with the crop. It is thus important to find out the cost for your individual farm before you make a decision to adopt this technology (Morata, Goodrich, and Ortiz 2019; Bondesan et al. 2022; Ortiz et al. l 2021).

The next major technological advancement in agriculture is precision farming. Precision farming can take many forms but in this research I focus on the use of variable rate Irrigation (VRI). In Maloku (2020) precision farming is referred to as four main elements: GPS, gathering info, decision support, and variable rate technologies. She goes on to explain how agriculture has had to face many changes over the years. The changes come from farm size growth, the growing need for food in growing populations, and natural water reduction. With these changes comes a chance to also have technological advancement. Experts who specialize in food production are trying to develop new products that produce higher revenue and lower cost (Maloku 2020; Ortiz et al. 2021). One variable rate technology that has been created to help producers maximize revenue is a computer system that is added to a center pivot irrigation system. This software is linked to a GPS system, so it knows its exact location in the field in real-time and can irrigate the field according to the field's variability (Sui, Fisher, & Reddy 2015). The software is called Variable Rate Irrigation (VRI). The way the system works is complex. For variable rate irrigation to work, you must start by creating your prescription map. This is made through the GIS software and considers all field characteristics. Once the prescription map is made, it is uploaded to the main panel of the center pivot. This is how the irrigation system knows how much to irrigate at each X, Y coordinate in the field. Almas, Amosson, Marek, and Colette

(2003) explains how precision farming (VRI) can pick up on field variability. With this information, the farmer can adjust irrigation to save water but still produce a maximum yield (Almas, Amosson, Marek, and Colette 2003; Bondesan et al. 2022).

The adoption rate of precision farming differs from state to state across the U.S. Based on a survey of farmers, the adoption rate for precision agriculture in Alabama was 37 percent in 2009, according to the Alabama Cooperative Extension System (ACES). The use of variable rate technology (VRT) was documented not for irrigation but instead for variable rate lime, fertilizer, and seeding. These variable rate technologies (VRTs) helped to save on initial production costs. Another 43 percent of the farmers in Alabama said they are considering using VRT but are nervous due to some barriers to entry. The adoption rate of yield monitors in corn is only 28 percent of all corn harvested in Alabama. For soybeans, the adoption rate of yield monitors is even lower, at 22 percent (Winstead, Norwood, Griffin, Runge, Adrian, Fulton, and Kelton 2014; Maloku 2020). This is important to note because without yield monitors and knowing exactly what yield you are receiving from a certain location in the field; it is hard to determine benefits of variable rate irrigation (VRI). Also, only one in every four farmers uses a Geographic Information System (GIS) system to generate maps to make irrigation decisions. This system is used to create prescription maps for VRTs. The software allows you to stack multiple layers of data on top of each other to see exactly how all the different field characteristics affect yield. Alabama's adoption rates are low compared to several surrounding states (Maloku 2020). This is because some farmers have worries about the economic benefits from VRI. Sui et al (2015) explains that farmers struggle with the high entry cost of technology when they only see a little increase in their yield compared to a uniform rate. Also, in Alabama, farmers do not have to pay for water, so they are not as concerned with the water saving that VRI can provide. (Sui et al 2015; Bondesan et al. 2022).

Almas, Amosson, Marek, and Colette (2003) discuss why the adoption rate differs. VRI is not the same for every farmer. Farms across the state have different characteristics that need to be treated differently so they can produce the best yield. So, for VRI to make an impact, each field must be treated according to its own characteristics. The best impact that VRI can have is on a field with diverse characteristics. VRI is also known to work best with high-value crops such as corn (Almas, Amosson, Marek, and Colette 2003; Bondesan et al. 2022). This is because one needs to have a sufficient yield gain to pay for the expensive technology.

Spati, Huber, & Finger (2021) focuses on another key to adopting VRI, farm size. This research found that the larger the farm size, the more beneficial VRI became. They also state that VRI can only be beneficial under certain conditions and that the amount of technology a farm has should be determined by the size of the farm and its characteristics. The study focused on small farms, so they saw limited benefits but believed if the study had been done on a larger scale, then VRI would have been much more beneficial (Spati, Huber, & Finger 2021). The last factor that has an impact on whether to adopt or not is how the daily rainfall looks. In Sui et al. (2015), there is a noticeable difference in the benefits of VRI during rainy seasons compared to dry seasons. These authors found that the dryer the season was, the more beneficial the VRI became. This technology has much more of an impact when the season is dry because the farmer has more control over the water being applied, and can produce better yields (Sui et al. (2015).

Bobryk, Kitchen, Sudduth and Drummond (2016) research details the importance of prescription maps and their basic functions. They explain that prescription maps are digital maps of your fields and show the different field characteristics. Prescription maps are used to help in the decision-making process of irrigation. The main field characteristic that prescription maps look at is elevation, soil type, and yield. Other factors can also be added, such as rainfall or if the farmer uses other VRTs like fertilizer or seeding rate. These maps are designed to tell the farmer or researcher how the crop responds to the landscape (Bobryk, Kitchen, Sudduth & Drummond 2016). Others back up this point and mention how crucial yield/prescription maps are for a farmer that wants to use variable rate treatments (Almas et al. 2003). Once the prescription map is created, the irrigator creates different management zones based on the selected set of characteristics that the field has (ex., Soil type, hill, valley, dry spot, wet spot, etc.). Each management zone is given an irrigation amount that is a certain percentage of a 1-inch application for the variable rate field. For example, some zones might be 90 percent application, so that zone would receive 0.9 inches of water. For a 60 percent zone, it would receive a 0.6 in water application. After this is completed, the zones communicate with a GPS receiver that is attached to the center pivot. The GPS receiver tells the pivot where it is in real-time, so as it passes through the field, it irrigates the crops at the exact amount each zone needs to reach maximum yield. VRI can deliver water to specific locations causing fields to have a more uniform yield. When the yield becomes more uniform, and you get a higher yield in areas that typically do not produce well, you will see an increase in profit. Sui, Fisher and Reddy (2015) also found that when compared to uniform rate application, VRI saved 25 percent more water in corn and 21 percent more water in soybeans. It is a win-win situation if the farmer can save water and produce higher yields.

Since there is a basic understanding of how VRI can help save water and be beneficial under certain farm conditions to the yield, it is important to know how much this technology will cost you. The VRI package for an existing center pivot consists of four major components: Main panel, power supply, assembly of nozzles, and data packaging. When these components are added to an existing center pivot, the farmer is looking at roughly $37,000 to $55,000 for this technology. These calculations are based on a field size of roughly 130 acres of irrigated land. If you have bigger fields than 130 acres, the cost will go up, and if the field is smaller than 130 acres, it will be cheaper.

Paul and Andy Clark operate a family-run farm located in Huntsville, Alabama. This research project was developed because the farmer has interest in adding VRI to an existing uniform rate pivot. To do this, he needs to understand the economic value of VRI. He is trying to determine if the benefits of VRI outweigh this technology's high cost of adoption. He currently has both VRI and uniform irrigation in a couple of his fields, and he is not sure which method is more economically beneficial for the farm.

The Clark farm has many fields and several center pivot systems, but the fields we are looking at for this research are the variable rate field and an adjacent uniform application field. They are across the street from each other and have roughly 130 acres of irrigated cropland. For this amount of acres, it would take an irrigation system roughly 3 to 4 days to water completely (one full cycle). The variable rate field uses VRI because so many factors affect the yield in this field. For example, there is serious topography variation in the field. This causes the field to produce varying yields throughout, causing the farmer to lose yield in certain locations. If you lose yield, then you are also losing profit. Another factor that plays a role in this field is soil variation. The field has multiple soil types, and each soil type has a different water-holding capacity. The better the water holding capacity, the more nutrients the crop will receive. So, if some soils have high water-holding capacities while others do not, this would also cause variation in yield. The uniform rate field has much less variation than its neighbor, the variable rate field. The uniform rate field has only two or three different soil types, which helps create a more uniform yield. For their pivot, they use a Valley 365 system that uses diesel gas. They pull their water out of the nearby river for both fields. The pivot they run pumps around 900 gallons per min.

At the Clark farm, they are several field characteristics that cause varying yields. To account for this, they have adopted several variable rate techniques in an attempt to create a more uniform yield throughout their fields. For example, their farm uses variable rate seeding, nitrogen, and irrigation. They also use up-to-date equipment that is installed with GPS location and yield monitors. In addition, they have several types of sensors in their field, so they have a better understanding of when to irrigate. Some of these sensors installed in the field are Trellis, Acclima, and Aqua spy sensors. These sensors can tell what the soil moisture is at three different depths ranging up to 24 inches deep for Acclima but close to 40 inches deep for an AquaSpy. Depending on the soil moisture readings, the farmer knows how wet the soil is under the surface. If the soil is wet, the crop still receives nutrients, but once the soil dries, it is time to irrigate once again. One reason these sensors are so crucial is that the top layer of soil can be deceiving. Even if the top looks wet, what is underneath might be bone dry. So now, with the sensors, the farmer can know the soil's state. This allows for more accurate irrigation, saves water, and helps produce uniform yields.

VRI has added great benefits to the Clark farm. They installed VRI to one of their existing pivots in the field we call the variable rate field. This field has many soil differences and elevation differences throughout the 130 acres. So in this field, VRI has allowed them to produce a more uniform yield. With varying water applications throughout the field, they have indicated seeing stronger yield in areas that had normally not produced well.

Following Boyer, Brorsen, and Raun (2010), we estimate a mixed model to account for different factors for each field, focusing on VRI rather than variable rate nitrogen. We consider the impact on yield from the seed rate, irrigation rate zones (0%, 60%, 70%, 80%, 90%, 100% zones), topography, and if the crop was corn or soybeans.

We then also examine the fixed cost (initial cost of technology, the machine's useful life, and the salvage value) and the operating cost (average interest rate, annual interest payment, maintenance cost, and insurance cost). Using these costs we can calculate a breakeven number of additional bushels that are needed to cover the cost of adoption for a 5-year, 10-year, and 20-year payback period.

In this research, I expect to see that the VRI helps not only save water, but the farmer will also see economic benefits. This will be very dependent on the characteristics of the field. To be suited for VRI treatment, the field must experience diverse characteristics that make it challenging to produce a uniform yield even with structured water application. VRI will help account for variation in the field and produce a more uniform yield even throughout the most diverse elevation points. VRI can account for these factors because of the prescription map and GPS technology. Water will be distributed more efficiently based on the characteristics of the field. If the field does not have many factors affecting it, then VRI is likely not as economically beneficial but could still potentially save water. This would not be as beneficial for those in the state of Alabama because there is no cost for water, but in states that charge for water, the fact that VRI saves water can also help farmers save money. VRI would be more impactful in a state that also restricts irrigation, but farms in Alabama with such diverse characteristics can also reap the new technology's benefits.

Chapter Two

Literature review

Adopting technology has given farmers a fighting chance to produce yields big enough to feed the entire world. Without new and improved technology, farmers do not have the staffing or the time to produce the amount of food demanded of them. Over the years, Agriculture has had to adapt to many changes, but because of the advancement in technology, farming has become more efficient. When farmers receive a higher efficiency rate, they can produce higher yields which equals more profit in their pockets. Farmers have had to adapt to today's environment because the average farm size has increased dramatically. In the United States, most mid-sized farms have grown and are now operating on a large farm-size scale. This creates new problems because the farmers must work more efficiently to complete all the work necessary to have successful yields in their fields. There is added room for technology intervention with larger farm sizes, allowing the farmer to manage a more significant workload with the same skill sets (McFadden et al. 2021). Maloku (2020) explains how adopting the new technology in today's market allows farmers to produce higher yields and achieve a higher efficiency level (Maloku 2020). This relates to McFadden, Roseburg, & Njuki (2021) and backs it up because it addresses the point that technology can help the farmer with his work, allowing him to take on the immense task.

Now with the new technology, farmers do not need to hire as many people for the farms. When the farms have fewer workers, they become more reliant on technology. The technology must run efficiently and last for a good useful life if the farmer is reliant on it (McFadden et al. (2021). Maloku (2020) goes further by explaining the adoption rate of precision agriculture in the United States. In the United States, the adoption rate is relatively high compared to surrounding countries. This is no surprise, as most of the United States is covered in farmland, but the state of Alabama has one of the lowest adoption rates of precision agriculture. This should not be the case in a state known for its farming production. She found that accepting new technology can be hard on farmers because they all struggle with different field variables that affect their yield (Maloku 2020; Winstead et al. 2014).

Since every farmer has a different situation to be dealt with, the new technology must be very advanced to calculate all the different variables it must account for in a field. For example, Sui, Fisher, & Reddy (2015) explain the significance of having different soil types in your field. Depending on the soil type, the crop would require different amounts of irrigation. Each soil has a different water-holding capacity, and that capacity determines how long water stays in the soil. Depending on how long water stays in the soil determines how often irrigation application is needed. Some soils hold water for longer, meaning it needs fewer irrigations because a small amount of water can go a long way. If the soil does not hold water for very long, it needs to be irrigated more frequently so the crop can receive all its nutrients. If you have a soil map of your field, you can see the soil variety throughout your field and control how much water is needed with each variety. You can save water and still receive a max yield if done correctly. Another factor that would change the irrigation amount is the field's topography. Depending on where the hills and valleys are located throughout the field, the crop would need to be irrigated differently for each location. The location of a hill would need more irrigation because the water will run off the hill to the valley. Therefore, the valley will require less irrigation because it receives the runoff water from the hill (Sui et al. 2015; Bondesan et al. 2022).

Maloku (2020) and Winstead, Norwood, Griffin, Runge, Adrian, Fulton, & Kelton (2014) found that farmers hesitated to adopt new technology because of the high initial cost of the technology. Most farmers struggle with the initial price of new technology if they cannot see immediate results. For example, her study found that the adoption rate for variable rate technology was around 40 percent. In Alabama, this number was even lower and was at 37 percent (Maloku 2020; Winstead et al. 2014). Again, Sui, Fisher, & Reddy (2015) backs up Maloku (2020) on why farmers hesitate with new technology. Sui found that the variable rate is not as efficient when there is sufficient rainfall in a growing season. This is simply because the rain was enough water to cover the crops water need. She believes that the farmers do not want to adopt the expensive technology because they do not see the value from an economic standpoint. The fact that states like Alabama offer free natural water hurts the cause of adopting variable rate technology (Sui et al. 2015).

Sharma & Irmak (2020) explains how irrigation methods such as the center pivot have stabilized local communities for economic growth and also helped stabilize outside communities. They explain that the center pivot invention was created around the 1950s and, since then, has made dramatic changes to become more effective (Sharma et al. 2020) (Ortiz, McClendon, Morata, and Duzy 2021). This is where it all originated with a sprinkler system for row crops. This system allowed farmers to have a sprinkler system that would pivot in a circle and water their crops uniformly throughout the field. Even though this stabilized communities there has been a massive amount of diminishing water since this invention. The center pivot comprises of spans that hold roughly fifteen to twenty-five nozzles each. Each span is attached to wheels that allow it to pivot throughout the field. This was huge for farmers, and this invention dramatically increased the yield of crops. Alma, Ammosson, Marek, & Colette (2003) back this up and shows how it plays a considerable role in corn yield increase (Almas et al. 2003).

In the last decade, we have seen that one of the leading issues in agriculture that scientists all over the country are discussing and researching is the diminishing amount of natural water. Water plays a significant role in crop yields, and if the crop is watered correctly, it can dramatically increase the yield compared to only relying on rainfall (Sui et al. 2015). Some states, like Alabama, allow you to use natural water for free, but other states require you to pay per gallon for all water use, even if obtained from a natural source. The reason that states require farmers to pay for each gallon of water used is the high demand for water in agriculture. Natural resources are depleting, so several states are stricter on natural water use. For example, Georgia did not charge farmers for the use of natural water until the year 2000. They created a Drought Act in 2001 that farmers could participate in to pay them for removing irrigation from specific fields. They did this because they saw a massive loss in natural water. They saw creeks get significantly smaller, and some creeks even ran dry (Nijbroek, Hoogenboom, & Jones 2002).

Because corn requires a large amount of water to produce successfully, it needs a constant water source. Due to recent research, scientists have discovered there is a preferred time to water corn. The preferred time is at the beginning stages when the corn is starting to grow fast. Water is essential at this stage, and if the crop lacks water, the crop will have a lower yield. Towards the end of the summer, water is not as important and could be used more sparingly. Ortiz, McClendon, Morata, and Duzy (2021) found a significant increase in yield when a center pivot is involved. The yield increase is shown through a yield map. The map clearly shows where the pivot irrigated because the yield was so much higher than the yield in the parts of the fields that the pivot missed. These parts are called the dryland corners, and their yield is always significantly lower than anywhere else in the field. There are a couple of issues that can cause yield loss. The main issue typically deals with how the pump to the pivot is operated. For example, if the operating pressure is not constant, the field will not be watered uniformly. This would cause some crops not to receive any water, dramatically decreasing the yield. Another issue could come from a nozzle malfunction because they range in size and could be put on incorrectly (Ortiz, McClendon, Morata, and Duzy 2021).

Sharma & Irmak (2020) go much deeper than just the invention of the center pivot. They examine new variable rate technologies and their role in helping produce a more uniform yield. Variable rate irrigation and variable rate nitrogen can be used to help crop productivity and cause increases in yield due to the variable rates used. Their study explains that 20 percent of the world is irrigated farmlands and that 20 percent provides for 40 percent of the world's food. This shows how agriculture production must be accurate and precise because if yields fail, most of the world will go hungry (Sharma & Irmak 2020). With growing populations and the diminishing use of natural water, changes must be made to use the water more efficiently (Nijbroek, Hoogenboom, & Jones 2003). Almas, Amosson, Marek, & Colette (2003) describe how farmers use agricultural technology (VRI specifically) that is eco-friendly to produce high-quality crops (Almas, Amosson, Marek, & Colette 2003). Several researchers have found the answer to water efficiency to be variable rate irrigation. This new irrigation technology can be added as an addition to the existing center pivot. Some studies show how this precision technology works and should be added to increase yield and profits (Sui et al. 2015) (Boyer, Brorsen, & Raun 2010) (Almas et al. l 2003). However, some show how this technology works the same as a uniform application and that the initial entry cost is just too high (Sharma & Irmak 2020) (Maloku 2020). If the crop yield is not maximized, then the importance of variable-rate irrigation diminishes.

To see the best return on investment, the farmer must maximize his yield. Sui, Fisher, & Reddy (2015) mentions that variable rate is most successful in corn crops and during the dry seasons. During wet seasons the rain provides enough irrigation to irrigate your crops, so the irrigation from another source does not need to be site-specific (Sui et al. 2015). Spati, Huber, &Finger (2021) results back up Sui, Fisher, & Reddy (2015). Spati, Huber, &Finger (2021) explains how the variable rate application is efficient if your field produces varying yields under uniform irrigation. VRI technology allows you to apply different rates of application to your low yield so they can produce a better yield; therefore, the farmer earns more profit. Another essential topic is touched on is the farm size aspect. Farm size is critical, as a farm grows more technology is needed to account for more field characteristics that are affecting the yield outcome. Smaller farms do not benefit from variable-rate technologies as much as large-scale farms because they are affected by less factors. So it is recommended that the larger the farm, the more variable rate technology that farm should have to make it run efficiently and produce a max yield (Spati et al. 2021).

For the Variable rate to work, it needs control zones, a GPS receiver, a prescription map, and evapotranspiration amounts (Sui et al. 2015) (Sharma & Irmak 2020) (Maloku 2020). Most fields in Alabama have variety in soil, topography, water availability, and environmental impacts. According to Almas, Amosson, Marek, & Colette (2003) all these characteristics can be dealt with using variable-rate applications. Each field area needs to have the correct irrigation and nitrogen application rate so the crop can reach a maximum yield even when it is affected by different variables throughout the field. They mention that variable rates can help to maximize crops when the field has several variables affecting the yield. The variable rate application will not be practical if the field has a uniform yield. Another field variable that significantly impacts the field is the elevation throughout the field. The elevation creates water runoff and plays a huge role in crop productivity. With water runoff, the crops at the top of the hills require more water, while the valley requires less water because they receive the runoff from the higher elevation. If a field with elevation variability irrigates uniformly, the farmer will see varying yields throughout his farm (Almas et al. 2003) (Bondesan et al. 2022).

In some cases, farms are unsuitable for variable-rate irrigation and might have a payback time of 27 years. The farms that work well with uniform irrigation do not need to apply variable rates to low-yielding points in the field. If the field is suitable and works well with variable-rate irrigation, some farmers can make their money back in less than ten years. For the farm to work well with VRI, it must have several variables that affect the yield totals (Sharma & Irmak 2020). What makes this study so hard is that all fields have various soil types, topography, water availability, and environmental impacts. This that no two farms will use the same exact method to produce a higher yield. Each field needs to be treated individually.

Because this technology is so new, there is not much research on its cost-effectiveness. Sharma & Irmak (2020) explains the difficulty of calculating the cost-benefit because of all the different variables for field characteristics (Sharma & Irmak 2020). The big question is what is the economic value of this new technology. In Boyer, Brorsen, & Raun (2010) it examines how variable rate nitrogen affects the crop. They found that the yield increases if you use variable rate nitrogen according to your field characteristics. The mixed model attempts to put an economic value on the variable rate of nitrogen application. They run a mixed model that uses fixed effects. The yield model considers the seed rate, soil variety, crop variety, nitrogen rate, and irrigation characteristics. After it considers all the field characteristics, it tells you how the crop responds to each variable rate and whether it receives a max yield. The second model that is run is a return-on-investment model. This model considers all the fixed costs and operating costs that occur on the farm. It then describes the number of additional bushels needed to cover the cost of adoption and turn a profit (Boyer, Brorsen, & Raun 2010).

Prescription maps are the instruction manual for the variable rate irrigation system and should be uploaded at the beginning of the growing system. This instruction manual delivers instructions to a sprinkler system that tells the system exactly how much water to distribute in a specific location. Because of the precision involved, this uses multiple field variables to generate the prescription for the field. Variable rate irrigation requires a base station that works as an embedded computer. Its goal is to communicate with the GPS receiver and the prescription map and to distribute water where the crops need it. It tries to prescribe the exact amount needed to restore all the crops to 100 percent field water capacity. The use of soil sensors helps to ensure that the crops are receiving the correct amount of water. If the crops are perfectly watered, they should reach a max yield and use less water than a uniform application rate. The system uses digital map data from previous years, field canopy temperature readings, and evapotranspiration readings. When these different calculations are evaluated, it can give you an excellent recommendation on when to irrigate. O'Shaughnessy, Evett & Colaizzi (2015) explains that prescription maps increase farm efficiency and yields (O’Shaughnessy, Evett & Colaizzi 2015).

Prescription maps are generated using a geographic information system (GIS) that is used to stack multiple layers of data on top of each other. This allows you to see how each factor affects your yield. You then use these stacked layers to help create a prescription of irrigation for your field. For example, the GIS would show you the varying yields through your field, and according to the yields, you change your VR prescription amounts to help increase the yield in your low-yielding areas. In the high-yielding areas, you attempt to reduce the VR prescriptions to the least amount possible while still receiving a max yield. As the center pivot goes throughout the field, the GPS receiver reads the prescription map. The map is linked with a specific irrigation amount that is linked to a specific zone. The zones are created depending on the characteristics that are affecting the field's yields. The prescription maps take all these variables into account and water the crop to the exact amount it needs. The way that it waters the crops at different rates is by using pulsing nozzles. In zones that do not need as much water, the nozzles shut off for a span of a couple of seconds. If the zone needs a full amount of water, then the nozzles do not pulse (Mcfadden et al. 2021) (Sui et al. 2015) (O'Shaughnessy et al. 2015) (Sharma & Irmak 2020). Sui, Fisher, & Reddy (2015) found that by using variable rate nitrogen and variable rate irrigation the farmer could save 25 percent of irrigated water in soybeans and 21 percent of irrigated water in corn. These results occurred because there was not much rainfall during the season. In a season with more rainfall, the variable rate efficiency would be diminished (Sui et al. 2015).

Bobryk, Myers, Kitchen, Shanahan, Sudduth, Drummond, Gunzenhauser, & Raboteaux (2016) explains how prescription maps are essential in agriculture today. The results of this study show how you can have a more accurate understanding of the landscape of your field with the use of digital maps. Prescription maps consider the field's elevation, soil variability, and land use change. This allows the map to explain how the crops react to the different variables in the field. Depending on the variability in the field, the management zones are generally given an irrigation rate of 0, 25, 50, 75, or 100 percent, but you can set it to any rate you need. The rate is determined by how much water is needed to restore the crop to 100 percent water-holding capacity. After the zones are given a percentage rate, the farmer uses supplemental irrigation, which tells the pivot how many inches to apply to the crop. This irrigation recommendation can come from several things, but most are based on evapotranspiration (ET) estimates. This study also explains how he believes digital maps are the future of making precision agriculture decisions. Without them, it would be tough to have the precision needed to reach max utility. He also mentions how digital maps can be used to create your management zones. Because the maps use such detail, it helps to create your management zones based on the soil variety and field characteristics. He found that the fields had greater utility when the prescription maps were based on soil variety (Bobryk et al. 2016).

McFadden, Roseburg, & Njuki (2021) investigates deeper details of specific digital maps. The maps that he investigated were soil maps and yield maps rather than the broad description of digital maps. They explain that soil maps are developing slower because soil samples are still predominately used, but soil maps are extremely useful when making precision agriculture decisions. His data showed that when a farmer efficiently uses these maps to make decisions, the farm's inefficiency goes down 8.5 percent when using yield maps and goes down another 7.2 percent for using soil map data. This is huge because when a farm becomes roughly 15 percent more efficient, it will save costs and make more profit (Mcfadden et al. 2021). Almas, Amosson, Marek, & Colette (2003) backs up the importance of yield maps. His research found that yield maps significantly increase efficiency and should be used in farm management decisions (Almas et al. 2003).

Chapter 3

Field Characteristics

The fields for this project are located in Huntsville, Alabama. Paul and Andy Clark run the farm and have accepted many new technologies, including multiple variable rate technologies. They use the Valley 365 center pivot system to irrigate their crops at their farm. The center pivot uses a diesel engine to pull water from a nearby river. They operate a large farm, but we are only looking at two of their fields. The variable rate field and the uniform rate field are the two we are targeting. We chose these two fields because they are similar in size and are across the street from each other. The variable rate field is set at a 1in water application. The uniform rate field is set at a 0.7in water application. The variable rate field uses VRI because the field characteristics cause it to produce a varying yield. The variable rate field also has varying topography causing crops to receive different amounts of water because of water runoff. In one spot of the field, there is even standing water in the field. Another note is that the variable rate field has multiple soil varieties throughout the field. The different soils have different water-holding capacities, which causes the crops to receive different amounts of water. The uniform field is a flatter field that does not have much change in topography, but it does have varying soils.

The elevation plays a huge role in the outcome of the yield. The variable rate field has varying elevation throughout the field that causes water and nutrient runoff. Because of this, we see that the valleys produce a much higher yield than the top of the hills. One way to account for this is by using the Topographic Positioning Index (TPI) and Topographic Wetness Index (TWI). These indexes are ways to attempt to see the role elevation plays. Also, these two indexes work together. While the TPI shows the slope of the field, it does not exactly describe which areas accumulate more water. TPI is used to show us which way the slope is going, but TWI describes which areas are accumulating water and how much water the soil is holding. It shows us where the wettest part of the field is located and how wet that portion can be when the water is applied. For TWI to work, it uses the TPI slopes in its algorithm (Kopecký, M., Macek, M., and Wild, J. 2020).

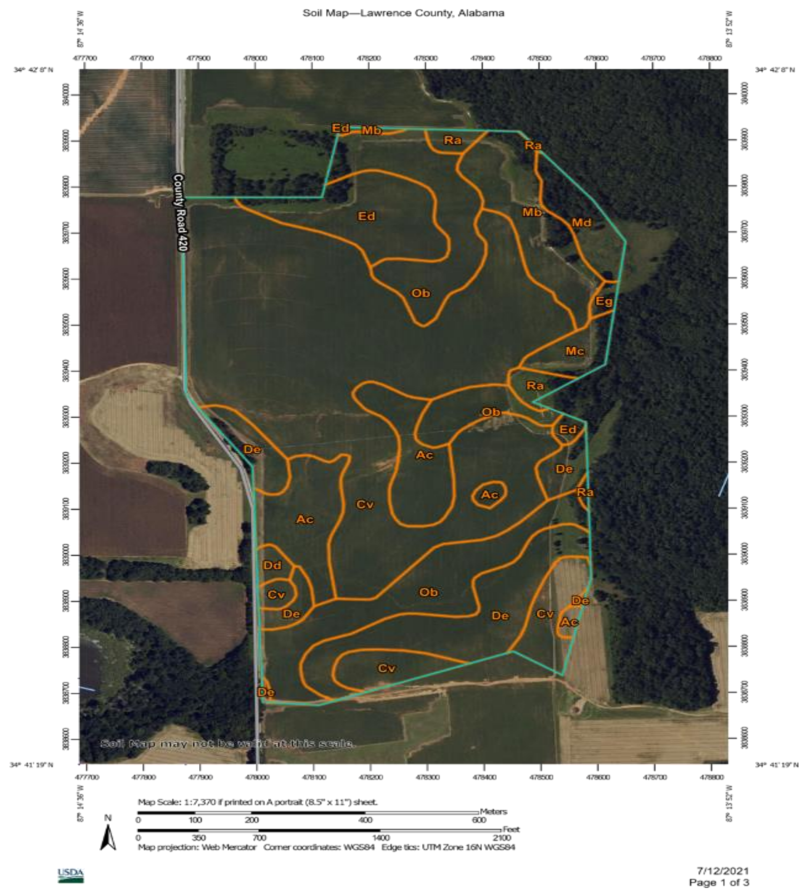
The TPI focuses on the elevation points in the field and compares them to the nearest elevation point. For example, if the elevation is five at one point and the nearest point has an elevation of six, then the slope is -1. The -1 symbols that portion of the field is slightly sloping downward. It either adds or subtracts that number depending on which is larger. If the number is negative, that symbolizes that the field slopes downward; if it is a positive number, then the field rises in elevation. This allows us to compare the yield data to elevation and see what the exact yield is at in the rising and declining portions of the field (Reu, Bourgeois, Bats, Zwertvaegher, Gelorini, Smedt, Chu, Antrop, Maeyer, Finke, Meirvenne, Verniers, and Crombé 2012).

The TWI shows what areas of the field are more likely to accumulate water. A negative TWI number means that area is at the top of a hill and is less likely to accumulate water, while positive numbers are areas that are more likely to accumulate water. This means the higher the number is, the lower that area is in the field. Using these two indexes together shows us where water tends to run off and where it accumulates. With this information compared to the yield data, we can see how the yield is affected by the water in the field, which helps to give us a better understanding of the factors that influence the varying yields. The way that TWI is calculated is by using three major components. It uses the catchment area, flow width, and slope gradient. The slope gradient is the TPI number. In the TWI, the slope gradient approximates the downward slope and then takes the catchment area and divides that by the flow width. So, the number that comes from that formula tells us whether the water is running down the slope or if it is an area that accumulates water and has high soil moisture levels (Kopecký, Macek and Wild 2020).

In Figure 1, we can see how the variable rate field is made up of 11 different soil types in roughly 184 acres of the field. Only 130 acres are irrigated. Five of the soil types are less than 3 percent of the field, so we exclude those because they do not make up enough of the field to make a difference. Of the six remaining soil types, the largest is Cumberland loam (Cv) which covers 42 percent of the field. The next largest is Ooltewah silt loam (Ob), which covers 16.5 percent of the field. The following soil type is Decatur silty clay (Dd, De), which covers 11 percent of the field. Abernathy- Emory silt loam (Ac) is the next soil, covering 8.5 percent of the field. The last two soil types that make an impact are Etowah loam (Ed, Eg) and Tyler/Monongahela sandy loam (Mb, Mc, Md,) and they both cover 6 percent of the field. The remaining five soils comprise the last 10 percent of the field. As we can see, several major soils impact the field, and each soil impacts how the crops need to be watered so that they can achieve maximum utility. Figure 1 also represents the uniform rate field's soil characteristics. The uniform rate field size is roughly 153.4 acres but only 125 acres of irrigated crops. The field has three soil varieties. Decatur silty clay (Dc, Db, De) is the largest soil variety and is 65 percent of the field. The second largest is the Abernathy-Emory silt loam (Ac), which covers 29.5 percent of the field. The third contributor is the Cumberland loam (Cv), which covers 5.5 percent of the field. This field has much less variability in the soil characteristics and could receive a more uniform application.

Figure 1. Lawrence County Soil Maps from SSURGO Soil Survey

Map A



Map B

Note: Soil map data came from the NRCS. Map A: Variable Rate Field. Map B: Uniform Rate Field. Variable Rate and Uniform rate refer to the water applied to the field. Variable rate puts out percentages of a 1-inch application. Uniform Rate put outs a Uniform water application of .7 inches. The data was retrieved from https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm.

These two fields use a crop rotation of corn and soybeans. For example, starting in 2018, both fields were planted with corn. Then in 2019, they planted the variable rate field with soybeans and the uniform field with cotton. For 2020, they planted both fields with corn. In 2021 they planted both fields with soybeans. Also, both fields are irrigated at the same time every time. If one field needs to be irrigated, then they both get water. The irrigation for the variable rate field is set at 1 inch of water. The irrigation rate does not apply a uniform 1 inch across the field. As the pivot goes through the field, it applies a variable rate that is prescribed by the prescription map. Certain zones get varying amounts of water, but all of the zone's irrigation amounts are calculated by a percent of the 1-inch application. For example, if a zone is prescribed to receive 80% percent of the application, then that area receives 0.8 inches of irrigation. The uniform field is irrigated at a uniform application of 0.7 in of water. So, the entire field will receive 0.7 inches of irrigation across the entire field uniformly.

Chapter 4

VRI Equipment

Many farmers in today's world use the invention of the center pivot to irrigate their crops. With the addition of new VRTs, many farmers can control the exact amount of water and chemical application in their field (Ortiz et al. 2020; Bondesan et al. 2022; Ortiz et al. 2021; Lal Almas et al. 2003; Sui et al. 2015). VRI helps to decrease water use, power use, runoff, and nutrient leaching. Also, VRI can help save on fertilization costs (Boyer et al. 2010). With new, expensive technology, farmers want to understand how much it will cost and what components are needed to install this system on an existing center pivot. VRI allows the farmer to put an exact amount of irrigation or nitrogen in certain parts of the field. When considering the installation of VRTs, several key components must be added to your existing center pivot to ensure that the variable rate is working properly. If the system is not used correctly, then you can see yield loss and will not gain any benefit from using the new technology. There are four main components to adding variable rates to a pivot. The components consist of the main control panel (VRI Generation), power supply, assembly of nozzles, and data packaging.

The main control panel is the unit that controls everything that is happening on the pivot. It turns the pivot on and off. Also, the control panel can control aspects like pump pressure, shutdown alert, and which direction you want the pivot to move. Most irrigation companies create apps that allow you to control all of this from a distance, but it is linked to the control panel. You can also see all the details about the pivot you need to know from this panel. Also, the panel is where you upload the prescription map, so the pivot knows where to put the water and how much to apply.

The next component is the power supply. The power supply on the Clark farm is a diesel engine. A diesel engine runs the center pivot, but some farms use an electric power source. The power source is determined by where the farm is located. The farm would choose whichever option is cheaper, so for the Clark Farm, this is diesel because they are not close to an electric power source. Depending on how rural the location of the farm is, this price can vary. The more rural the farm, the more expensive it will be to run a power source at the location.

The next part you need to add for VRI is the assembly of nozzles. VRI uses different nozzles than the center pivot because they perform different functions. For a center pivot with no VRI, you just need the basic nozzles that release the same amount of water throughout the field. The VRI system needs nozzles that put out different amounts in different areas. The way the nozzles open and close determines where the water is put. The basic functions on the nozzles are the same but the VRI has an adjustable piece that sits on the end of the nozzle. This piece moves up and down according to the water pressure coming through the hose. The uniform application nozzles are left open on the end with no adjustable piece. In parts of the field where less water is needed, the nozzles pulse, causing them to shut off and not allowing the full amount of water to get on the field. In parts of the field where more water is needed, they remain open, and the full amount of water is put on the field. Also, how many inches you want to apply determines the size of the nozzle you want to install.

The last but most important component is the data package. This package is how the pivot can communicate with GPS, cell phones, and any other technology. This package lets the system communicate with a GPS in real-time and lets the pivot know where it is in the field. It also lets the farmer control their pivot from home on their phone. It allows the farmer to monitor pivot movements, schedule irrigation events, and analyze data to ensure it runs correctly. The panel has smart technology that analyzes rainfall data, crop growth models, and crop water usage data. The system puts those three major components together and suggests when to irrigate. Some irrigation providers even give you access to customize the app with things that specifically benefit their farm. This allows personalization and helps to create better efficiency on the farm.

The price of the VRI package varies across companies. Several companies try to add additional technology or packages to make the customer want to purchase theirs over a competitor. However, the above components are the standard parts to add VRI to an existing pivot. The price range for adding VRI varies from $37,000 to $55,000 depending on which package and what quality technology you decide to purchase for your conditions on the farm. This cost would cover roughly 130 acres of irrigated land. Every farmer would see a little variation in price because you are installing certain components for specific needs within the field.

We analyze three different price ranges for this technology for cost analysis. In table 1, we see that the low cost will be a price of $37,000, the medium cost will be $46,000, and the high cost will be $55,000. For a 130-acre field, this would make the per acre cost around $284.62 on the low side and $423.08 on the high end. This technology is assumed to have a useful life of 20 years. If the salvage value is 10%, then we would see a per-acre depreciation cost ranging from $28.46 to $42.31. This would make our per acre total capital cost to be $256.16, $318.46, and $380.77, respectfully for Low, Medium and High cost systems.

Table 1. Capital investment for Variable Rate Irrigation

Capital Costs	Low	Medium	High
Initial Cost (VRI)	$37,000.00	$46,000.00	$55,000.00
Initial Cost/acre (VRI)	$284.62	$353.85	$423.08
Life of Machine	20 years	20 years	20 years
Salvage Value	10%	10%	10%
End of Life Salvage Value/acre	$28.46	$35.39	$42.31
Annualized Total Capital Cost/acre	$256.16	$318.46	$380.77

In table 2, we compute other fixed expenses for the loan payment and ownership of the system. We assume that we are financing the entire equipment package, and our interest rate is 6%. This would make our annual interest payment ranging from $211.67 to $314.61 for the life of the assumed 20-year loan. On a per-acre basis this ranges from $10.58 to $15.73. We also assume an insurance rate of 2.5 percent. To determine the annual insurance cost, we multiply the capital cost by the insurance rate, and obtain a per-year cost of $6.40 to $9.52. The next step is to add the maintenance cost to the operating expense. We use an estimate of $400 per year for annual maintenance, recognizing that this expense may not occur every year but it is necessary to budget for the expense as items such as computer boards could run $2,000 at one time. The per acre annual maintenance allocation would be ($400/130 acres) $3.08. With the maintenance cost added to the annual interest payment and the annual insurance cost, we get a per acre total annual ownership cost of $20.06 for the Low Cost estimate, $24.20 for the Medium Cost estimate, and $28.33 for the High Cost estimate. We then multiply these three amounts by the useful life of 20 years, and we can have a total ownership cost ranging from $401.28 to $566.59.

Table 2. Other Fixed Costs for 20-year payback period

Other Fixed Costs for 20-years	Low	Medium	High
Average Interest Rate	6%	6%	6%
Annual Interest Payment/acre	$10.58	$13.16	$15.73
Maintenance Cost Allocation/acre	$3.08	$3.08	$3.08
Insurance Rate	2.50%	2.50%	2.50%
Annual Insurance Cost	$6.40	$7.96	$9.52
Total Annual Cost	$20.06	$24.20	$28.33
Total of Other Fixed Cost (Life of Machine)	$401.28	$484.03	$566.59
Total Fixed Cost	$657.44	$802.49	$947.36
Annualized Total Cost	$32.87	$40.12	$47.37

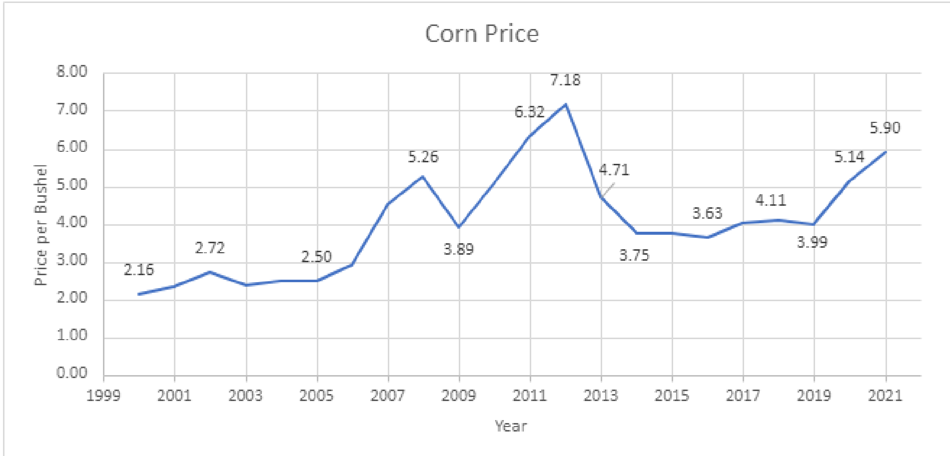
Since we have found the capital and other fixed costs for the life of the equipment, we add those together and get a per acre total cost of $657.44 on the low end and $947.36 on the high end. We then take the per acre total fixed cost and divide it by the useful life of the machine, which is 20 years, and we see the annual cost per acre ranging from $32.87 to $47.37. We also ran the same method on a 5-year payback time seen in table 3, which is what the farmer specifically wanted to examine. When we changed the payment time from 20 years to 5 years, we see each annual cost increase by 4 times the amount. For the Low Cost, the annual expense per acre was $131.69, while for the High Cost it was $189.83. These are the yearly cost per acre that the farmer would expect to pay if he wanted to cover the cost of adoption over a 5-year period.

Table 3. Other fixed costs for a 5-year payback period

Other Fixed Cost for 5-years	Low	Medium	High
Average Interest Rate	6%	6%	6%
Annual Interest Payment/acre	$10.64	$13.23	$15.82
Maintenance Cost Allocation/acre	$3.08	$3.08	$3.08
Insurance Rate	2.50%	2.50%	2.50%
Annual Insurance Cost	$6.40	$7.96	$9.52
Total Annual Cost	$20.12	$24.27	$28.42
Total of Other Fixed Cost (Life of Machine)	$402.40	$485.40	$568.40
Total Fixed Cost	$658.56	$803.86	$949.17
Annualized Total Cost	$131.69	$160.77	$189.83

As seen in figure 2, over the last 20 years, the price of corn has varied from $2.16 to $7.18 per bushel. We took the average price and found it to be $4.03 per bushel. To determine the number of additional bushels of yield needed to cover the per-acre cost of the technology, we would take the total fixed cost per acre and divide it by the average price of $4.03 per bushel. This would be a breakeven scenario. Thus to cover the annualized total cost of the technology in table 2; there would need to be a per-acre yield increase of 8.16 additional bushels of corn for the low priced system, 9.96 bushels for a medium priced system, and 11.75 bushels for the high price system.

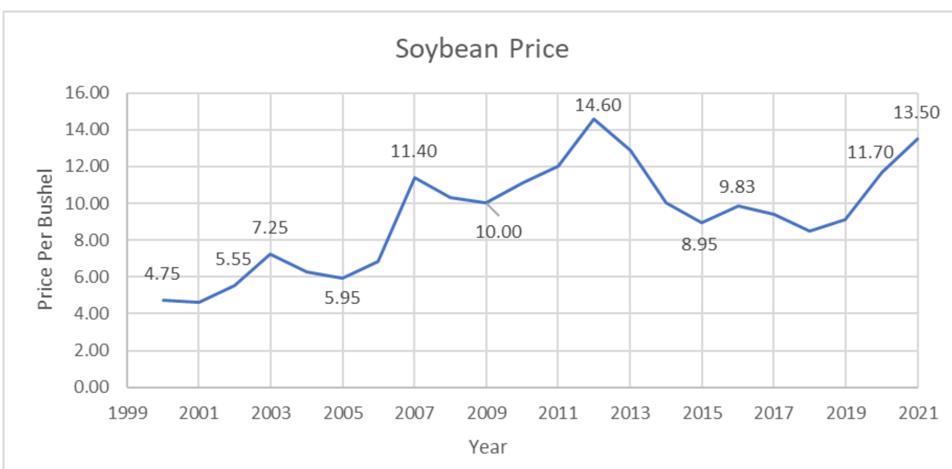
Figure 2. Alabama 20-year Average Corn Price



Note: Data retrieved from USDA NASS Quickstats data for Alabama corn price.

Figure 3 shows the price of soybeans over the last 20 years. The prices range from $4.60 to $14.60 per bushel, with an average price of $9.30 per bushel. To find the number of additional bushels to cover the cost of technology, we take the total fixed cost found in table 2 and divide it by the average price of $9.30 per bushel. The additional bushels needed per acre to cover the price would be 3.53 bushels on the low end, 4.31 for medium, and 5.09 for the high end.

Figure 3. Alabama 20-year Soybean Pice



Note: Data retrieved from USDA NASS Quickstats data for Alabama soybean price.

Those are just the breakeven prices of a 20-year time frame. The farmer also wanted to see a 5-year payback time. Tables 4 and 5 show the additional bushels that would be needed to cover the cost of technology over 5 years, 10 years, and 20 years, for corn and soybeans, respectively. The most likely time frame that the machine would be paid off is sometime between the 10-to-20-year time frame. It is difficult to say with confidence when exactly this technology would be paid off because of the varying yield we see in the years of data that we have. The additional number of bushels vary but seen below is the amount of additional bushels per acre that the farm would need to see to cover the adoption cost.

Table 4. Breakeven Analysis for Corn

Corn Bushels ($4.03)	Low	Medium	High
5 years	32.7	39.9	47.1
10 years	16.1	19.7	23.2
20 years	8.2	10.0	11.8

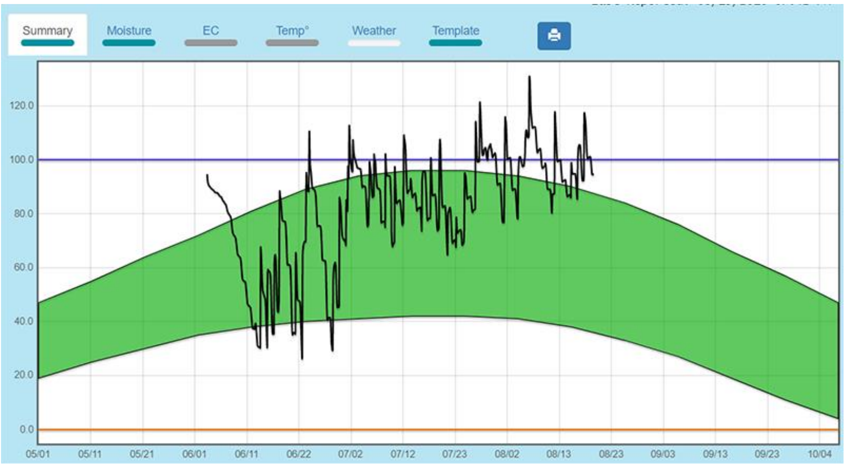
Table 5. Breakeven Analysis for Soybean

Soybean Bushels ($9.30)	Low	Medium	High
5 years	14.1	17.3	20.4
10 years	7.0	8.5	10.1
20 years	3.5	4.3	5.0

Other equipment needed to ensure that VRI is working efficiently is soil sensors. The farmer uses soil sensors to make his irrigation decisions. The sensors have sensors at 4 in intervals where they read the soil moisture and tell the farmer how wet the soil is at those depths. Depending on the moisture level, the farmer knows if his crop is too wet or if it needs irrigation. The sensor sends the data to an app installed on your phone, so you can see them anytime and anywhere. There are many soil sensors on the market, but the one used to make the irrigation decisions on the Clark Farm is the AquaSpy sensor.

The aqua spy has three main parts. The base station, the drive, and the sensor. The base station is a solar panel that gives the sensor power. Also, the base station has a drive attached to the back, which allows the base station to have the internet to connect to the aqua spy servers. As the sensor reports data, the data gets uploaded to the server. The farmer can access this data, which looks like figure 4.

Figure 4. Representative Data Graph from AquaSpy Sensor



Note: The data from this graph came from the AquaSpy website. This graph does not show data from the Lawrence County Field but shows what the data would resemble. AquaSpy is a sensor that measures volumetric water content. The company represents this data using a scale that, according to the company, corresponds to the percent of available water.

In figure 4, the black line shows you the soil moisture. If the line goes above the top line, the soil is too dry, and you need to irrigate. If the line goes below the bottom line, the soil is too wet, and you should turn the irrigation off or wait to run it. If you keep the black line between the two lines, your crop receives the exact water it needs, and you will achieve a maximum yield for the crop. The cost for the aqua spy soil sensors varies depending on what you need. We are looking at the AquaSpy sensor that has the three-sensor integrated probe. This is the specific sensors used on the Clark farm. This costs roughly $360 per sensor annually, but they also have cheaper options if you prefer to pay for it monthly. I do not include the sensor cost in the breakeven analysis for the VRI system because the technology is not specific to VRI and could be used with a uniform rate system as well.

Chapter 5

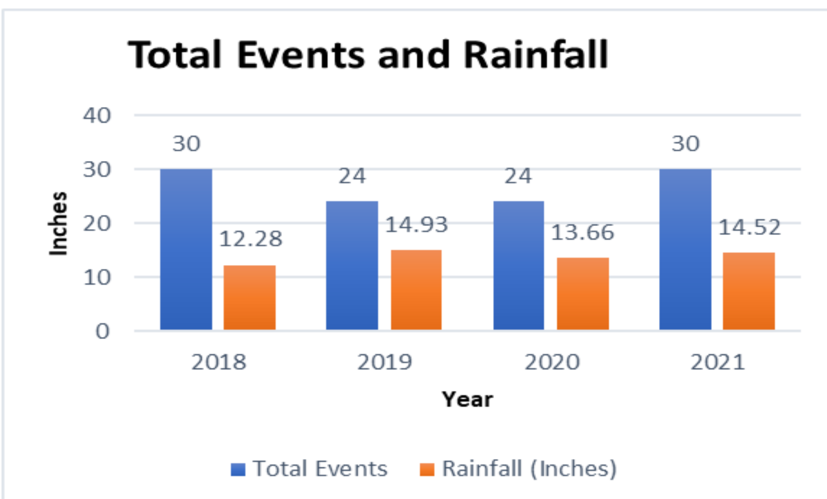
Data

The data for this project were collected from several sources from 2018 to 2021. The four years of rainfall data came from the Prism climate group. This website allows you to directly enter an X, Y coordinate, and it pulls up the amount of rainfall that region received throughout the year. The way it does this is by collecting all the data from nearby weather stations and running it through their model. Once the data is run through the model, the irrigation is given for a specific location. The rainfall data from the Prism climate group is not as accurate as the farmer's rainfall because the given location extends past the geographical location of the farm. And we know that even over the distance of a mile, rainfall can differ.

In Figure 5, we can see the rainfall of all four years compared to each other. This allows us to see which seasons had the most inches applied throughout the growing season and which were the driest. It is important to note that the most water intake for corn is during the R1 to R5 growing stage. This would take place at the beginning of the season. This is when the farmer would need to irrigate the most unless there is sufficient rainfall.

Figure 5

Total Rainfall Data from Lawrence County Field

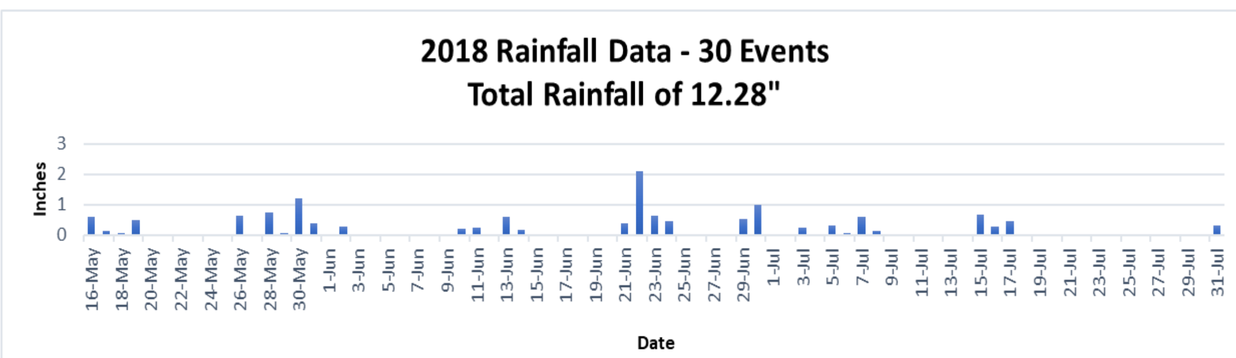


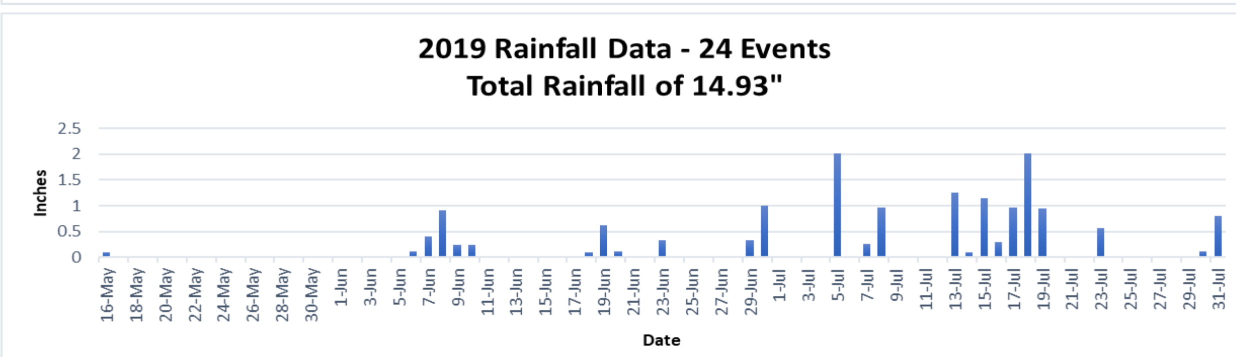
Note: The data was retrieved from the Prism Climate Group. The data spans from May 16th to July 31st.

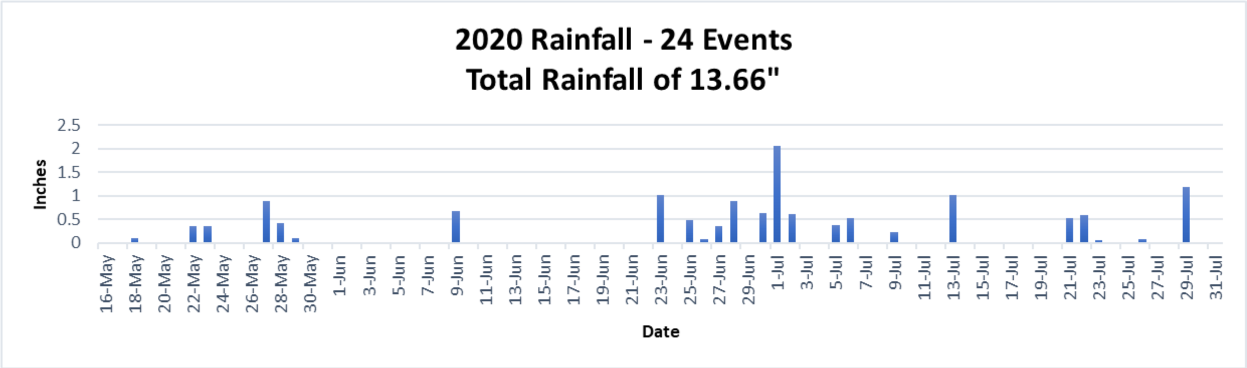
In figure 6, we separate the rainfall event by each individual year. By doing this, we can compare which portion of the season received the most rainfall and which part of the season needed to use the irrigation system the most. We can see from figure 6 that in 2018, most of the rainfall occurred at the beginning of the season (June) compared to the end (July). This is impactful because this is when the crop needs the most water. In 2019, we saw that there was almost no irrigation in June, but in July, there was a lot of rainfall. In 2020, most of the rain occurred towards the end of the growing season. This is when the crop needs the least amount of water, so water from an irrigation system would be essential for the year 2020. It is very important to examine the timing of rainfall events because it is important for the production of a crop.

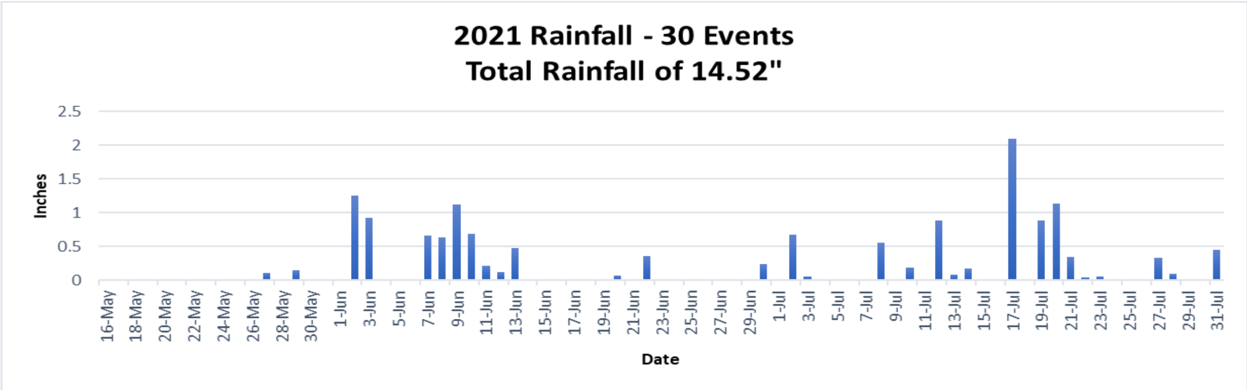
Figure 6

4-Year Rainfall Data in Lawrence County Field









Note: The data was retrieved from the Prism Climate Group. The data spans from May 16th to July 31st.

The irrigation data came from the Valley 365 website. A list of the data is seen in table 6. This website is linked to the pivot through a GPS computer, so all the data gets saved to the server. Some of the data we originally received were inches applied, gallons applied, hours pumped, days of water application, days irrigation lasted, and acres applied. We faced two issues with these data at the start. The first issue was with how long the days of water application lasted. The days were not constant. This was because an irrigation event could start at 10 pm and run for 48 hours, but the system counted it as three days because of the two hours registered at the end of the first day. The rainfall created another issue as well. When rain occurred, the pivot was stopped, and when the pivot resumed after the rain, it did not start from the beginning of the field. The starting point of all the cycles was not in the same location. This created a few irrigation events to be partial events spread over several days. So, the irrigation data we targeted to be used in the model was the acres applied. We know that the pivots full circle is roughly 128 acres. So, compare that to the inches applied, and we get an estimate of the farm's total irrigation applied throughout the field, but it becomes difficult to determine the exact irrigation amount for each zone on the field. In table 6, we can also see how limited the irrigation was for 2019. The reason was because of the amount of rainfall received, so irrigation was not run very much.

Table 6. Irrigation Data from Lawrence County Field

Irrigation Data						
2018 (Corn)	Inches Applied	Gallons Applied	Hours Pumped	Days of water application	Days irrigation lasted	Acres applied
June	1.75	3,835,095	78.59	June 7th-June 12th	5	429.816
	0.32	595,707	12.43	June 15th	1	69.09
	2.07	3,350,274	68.33	June 18th-June 21st	4	236.499
	1.74	1,125,184	22.96	June 27th-June 28th	2	47.831
	2.64	3,336,173	69.04	June 30th-July 3rd	4	200.625
July	1.54	1,531,189	31.55	July 5th-July 6th	2	73.076
	3.27	2,965,307	61.76	July 24th-July 27th	4	129.544
Total	13.33	16,738,929	344.66		22	1186.481
2019 (Soybean)	Inches Applied	Gallons Applied	Hours Pumped	Days of water application	Days irrigation lasted	Acres applied
August	2.67	2900175	59.49	Aug 2 - Aug 4	3	119.578
	1.75	1566712	32.7	Aug 12- Aug 13	2	65.768

	0.53	684848	14.36	Aug 20- Aug 21	2	63.111
total	4.95	5151735	106.55		7	248.457
2020 (Corn)	Inches Applied	Gallons Applied	Hours Pumped	Days of water application	Days irrigation lasted	Acres applied
June	1.35	4,545,204	93.22	June 19-June 23rd	4	
July	1.75	2,037,203	46.71	July 10 to July 12	3	134.85
		3,250,427	74.58	Jul 20 to 23	4	254.435
Total	3.1	9,832,834	121.29		11	389.285
2021 (Soybean)	Inches Applied	Gallons Applied	Hours Pumped	Days of water application	Days irrigation lasted	Acres applied
May	0.13	94,565	2.21	31-May	1	25.909
June	1.93	2,280,408	46.86	June 28-June 30	3	128.878
July	2.02	2,300,084	46.96	July 5 - July 7	3	128.214
	1.35	539,887	13.67	July 31- Aug 1	2	37.202
August	1.3	1,013,938	23.22	Aug 5 - Aug 6	2	64.44
	1.94	2,287,824	47.2	Aug 11 - Aug 13	3	127.549
Total	8.67	8,516,706	180.12		14	512.192

It is important to understand how many inches were applied and when these inches were applied because they affect the production of a crop. By comparing the rainfall to the amount of water applied through irrigation, we can calculate the total amount of water applied to the field. This is one of the top factors in the outcome of the yield for corn. In our research, this was a difficult factor to account for because of the partial irrigation that occurred from the rainfall stopping the pivot and the pivot not being returned to the same starting point every time.

The yield data was received from the yield monitors equipped on the farm's tractors. Once we received the yield data, it was processed through the GIS platform so we could stack multiple layers of variables to see how they affect each other. For example, some stacked layers are yield, seed rate, topographic wetness index, and topographic positioning index. All of these variables have an impact on what the final yield is going to be. Through GIS we obtain the X, Y coordinates for these data to understand how the varying application rate affects yield at an exact location. In Figure 7, we see the yield captured in the variable rate field during the four years. In Figure 8, we can see the yield for the uniform rate field in three years. The reason there is not a fourth year is because 2019 was cotton and we do not have these data as it was only on one field and only for one year of cotton production. In both fields, we notice a good amount of variability in the yield of these fields. Using these maps, we can see the yield differences and target those areas with different irrigation amounts so the crops can reach maximum yield. To do this, we must analyze how varying irrigation, nitrogen, and seeding rates affect a crop's yield in one exact location and how that differs from all the other locations in the field.

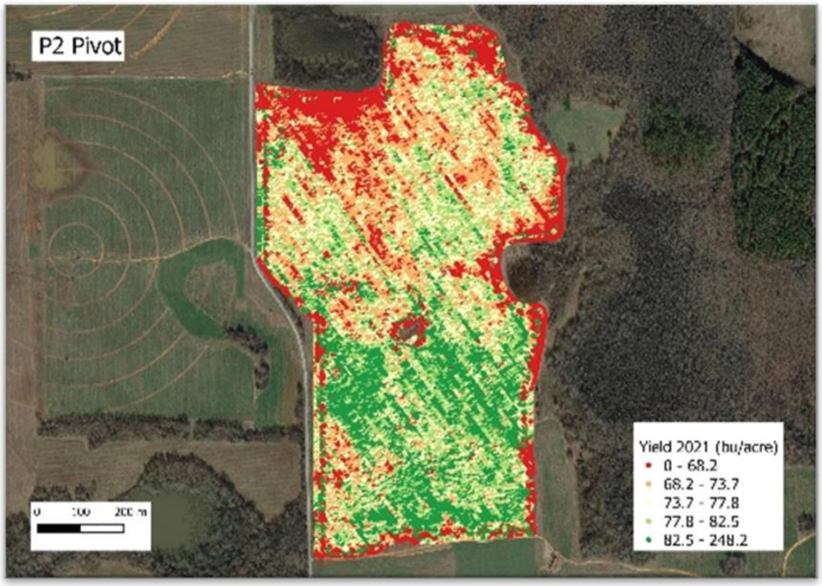
Figure 7. Yield Map from Lawrence County Variable Rate Application Field

Map A: Corn (2018)

Map B: Corn (2020)

Map C: Soybean (2019)

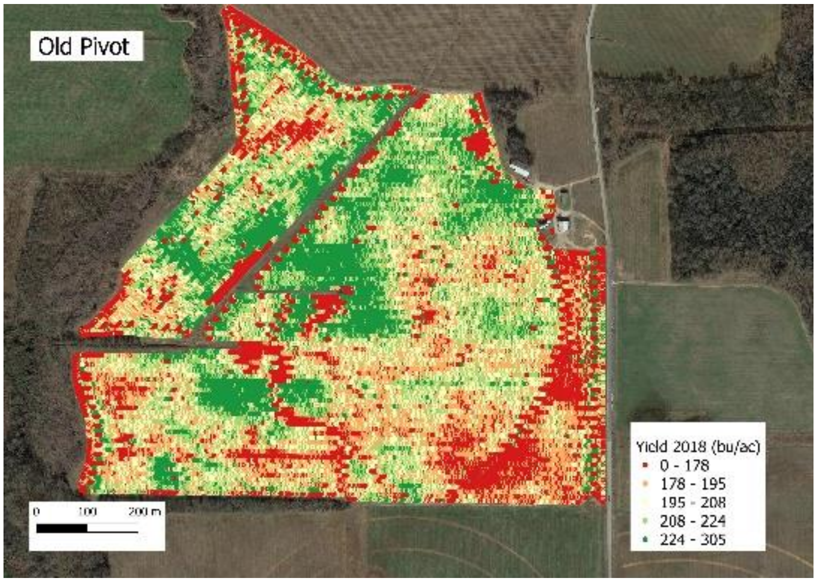
Map D: Soybean (2021)



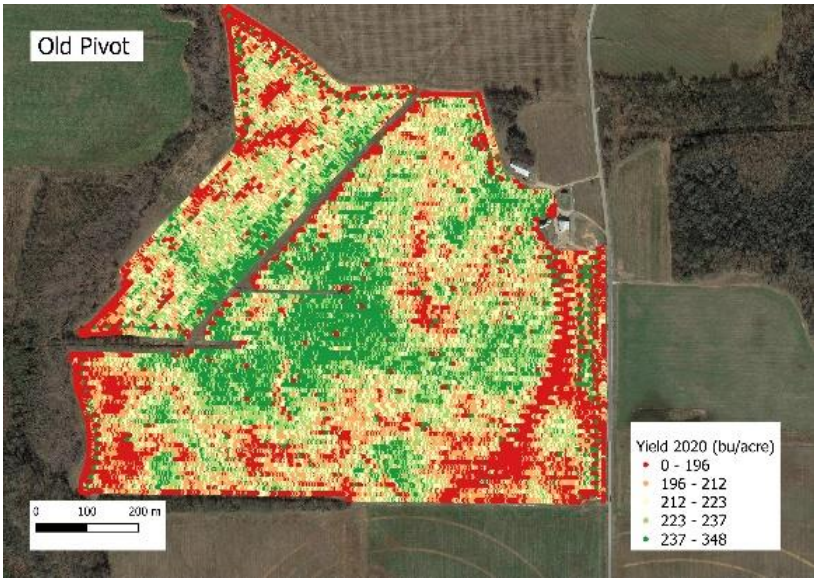
Note: Yield map data came from the farmer and then was processed through GIS. Maps A and B refer to the corn years 2018 and 2020, while Maps C and D refer to the soybean years 2019 and 2021. Variable rate and Uniform rate refer to the water applied to the field. Variable rate puts out percentages of a 1-inch application. Uniform Rate put outs a Uniform water application of .7 inches. Variable Rate Irrigation was used. Zones where 0%= no irrigation 60%= .6 inches, 70%= .7 inches, 80%= .8 inches, 90%= .9 inches, and 100%= 1 inch application.

Figure 8 Yield Maps from Lawrence County Control Field

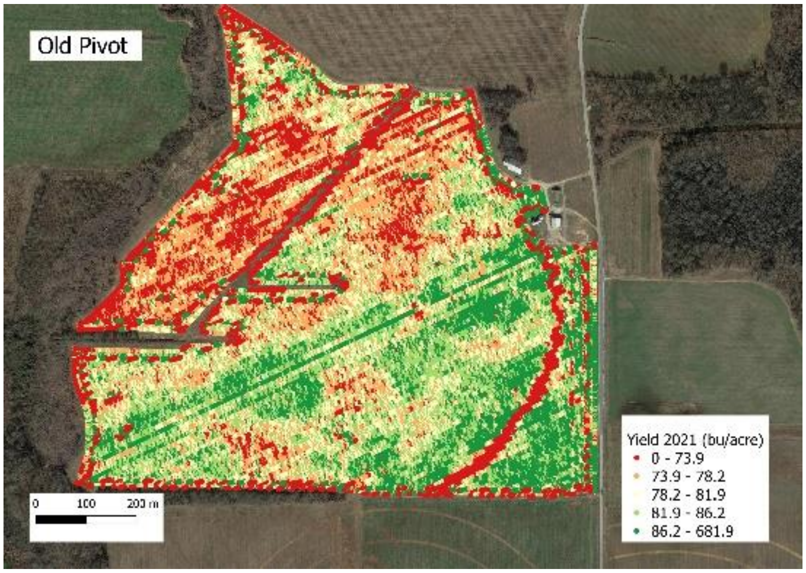
Map A: Corn (2018)



Map B: Corn (2020)



Map C: Soybeans (2021)



Note: Map A refers to the Corn year 2018, Map B refers to the Corn year 2020, and Map C refers to the Soybean year 2021. There is no yield map for 2019 because it was planted with cotton. Uniform irrigation was applied to this field.

After we stacked the layers in GIS, it allowed us to process the data in Stata, so we could compare the variables and estimate a yield model to assess the potential for a return on the VRI investment. The data were given an X and Y coordinate depending on where that point is located in the field. That X and Y coordinate was also assigned to a zone. Each zone has a different irrigation rate depending on what the crops in the region needed, as depicted by the prescription map.

A data cleaning process was undertaken because yield monitors are less reliable on the edges of the field. To account for this and potential speed changes in harvesting we removed all observations that were more than three standard deviations from the mean yield. This removes outliers from the data. This process was done for both corn and soybean data on both fields.

We create binary variables for three different variables: crop, field, and year. For the fields, we have the variable rate field and the uniform rate field. For the year, we used 2018 to 2021. We use these binary variables to give all the variables a 0 or 1. The zero indicates that the variable is not present, while the one shows that the variable is present. This allows us to segment the data and control for these different factors that affect the production yields.

Chapter 6

Methods

We use a mixed model approach of fixed and random effects to find how the different field characteristics play a role in affecting the yield of corn and soybean.[1] Some of the factors that we want to control are the seed rate, irrigation rate, topographic position index, and topographic wetness index. When these factors are controlled, we can see what impact irrigation has on crop yield. Once the increase or decrease of yield is found, we then compare the yield to the cost of adoption of the new variable rate irrigation technology (VRI) to see if the increase in yield from VRI can cover the cost of adoption of the new technology. We expect that our null hypothesis would be that variable rate irrigation and uniform rate irrigation would produce the same yield.

The mixed model using fixed and random effects is specified as follows.

$$Y_{tlz} = \alpha + \Sigma_{(n=1\text{ to }6)}\, \beta_n I_{nz} + \gamma S_z + \delta S^2_z + \theta W_z + \lambda P_z + \zeta Yr_z + u_{tz} + e_{tlz}$$

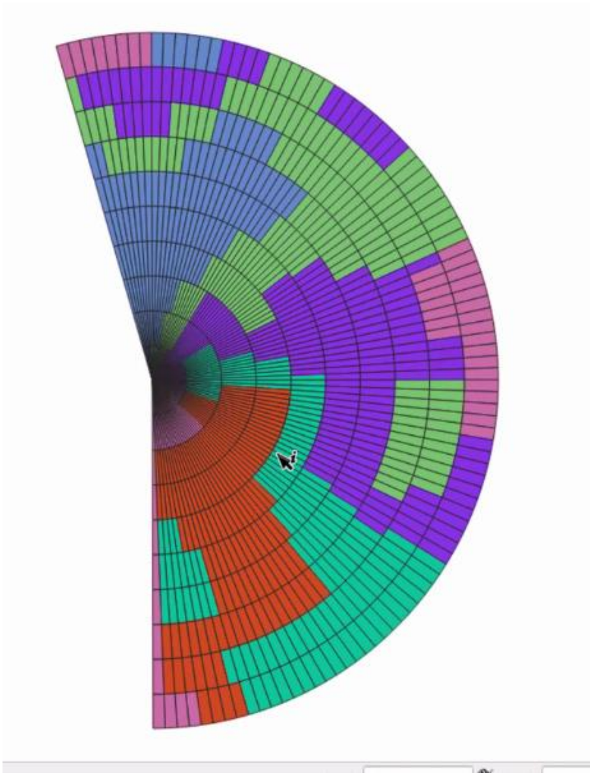
The Y_{tli} is the yield, which is associated with a *t* time, *l* field, and *z* irrigation zone. The yield intercept (α) is your constant. The next part of the model β_r is the coefficient for each of the six different irrigation rates (*I*) used. There are several other major factors that we are looking at that affect yield: seed rate (S) and squared seed rate (S^2), topographic position index (P), topographic wetness index (W), and year fixed effect (Yr), each with their own respective coefficient. The u_{tl} is the zone-year random effect with a mean zero and variance σ^2_u and the e_{tli} is the random error term with a mean zero and variance σ^2_e.

The irrigation rate has six different rates based on a one inch water application. For the variable rate field, the rates are 0%, 60%, 70%, 80%, 90%, and 100% irrigation. Irrigation in the

[1] See Boyer et al. (2010) for a similar approach on variable rate nitrogen trials.

two fields are different because, in the variable rate field, most of the field receives a percentage of the 1 in application. The variable rate field uses variable rate irrigation with the six different rates, while the uniform field uses a uniform application of 0.7 in of water. Also, the irrigation rate in the variable rate field is associated with roughly 79 different management zones that consist of different irrigation rates. Most of the zones have the same rate but are located at different areas of the field, depending on the characteristics that are affecting them. We can see the prescription map located in figure 9.

Figure 9 Prescription Map for Variable Rate Irrigation in Lawrence County Field



Note: Data for the prescription map was provided by the farmer and then recreated by Dr. Ortiz's research group. The irrigation rate application zones are 0%= Pink, 60%= Red, 70%= Teal, 80%= Purple, 90%= Lime Green, and 100%= Blue.

The second model deals with the economic feasibility of the VRI system. The factors that affect economic feasibility are the capital cost and annual fixed expenses of owning the system. The primary capital considerations associated with this model is the initial cost, the machine's useful life, and the salvage value (See Table 1). The other fixed costs would consist of the average interest rate, the annual interest payment, the maintenance cost allocation, and the insurance cost (See table 1).

This is the correct model and approach that should be used when looking at the benefits of VRI, but several issues came into play as using this model as an approach. The first issue was that we only had two years of corn data and two years of soybean data in the variable rate field. In the uniform field, we were missing the 2019 yield data for soybeans because it was planted with cotton instead of soybeans. The other three years copied the pattern of the variable rate field. With limited years it was hard to determine what factors were truly playing a role because there was not much to compare the years with. Thus with only one year of soybean data on the uniform field, it provides only a limited control for comparison.

Another issue is that the X, Y coordinates points do not align correctly for roughly 90 percent of our dataset. A fixed effects model that relies on balancing a point with multiple data points over time would not estimate correctly in this situation. Thus it becomes necessary to aggregate the data to average values within each of the irrigation management zones.

Another factor that was difficult to control was the water applied to the field. The irrigation rate applied to the field was not accurate because of partial irrigation events due to stopping the pivot during rainfall and then starting the pivot again at the same point. This caused there to be partial irrigation events at various unknown points in the field. When the pivot was started back after the rain, it started where it was shut off, or might have been walked back to a starting point while applying a small amount of water. This location could have been anywhere in the field, sometimes in the middle and sometimes at the ¼ mark in the field. This caused some areas to receive more water than other areas, even when in the same irrigation rate. This can cause further variation in yield for which we cannot control. For example, if the pivot was stopped in the middle of the field due to rain, then when the rain stopped and the pivot started back up, only half of the field received the irrigation prescription. Then when the next cycle started, it went back over the half that was just irrigated. So, the first half received two irrigation prescriptions while the portion on the other side of the field was only irrigated by the pivot before the rainfall event. The pivot in our study goes 190 degrees. It does not make a full cycle.

Finding a suitable control for comparison to the VRI field was also a challenge. The VRI field has obvious yield impact from topography and water runoff that occurs. One way to control for this in our model is to control for the topographic position index (TPI) and topographic wetness index (TWI), but we only have this data for the VRI field. We do not have these data for the uniform rate field, although we know that field is relatively flat.

Chapter 7

Summary Statistics

Table 7 below shows our summary statistics from each field's corn and soybean data. In the corn data from the variable rate field, we see the number of observations is 144. This was computed after removing the tails of the data, dropping dryland corners, and averaging all points within each irrigation zone. We also found one zone that had two different irrigation rates and so that was too was dropped. The summary statistics show that the minimum and maximum yields ranged from 73 bushels to 265 bushels, with an average yield of 222. Thus even with aggregating data we still find considerable amount of yield variation in the field. When we examine the irrigation rates, we see that the 80% and 90% zones covered most of the field.

Table 7. Summary Statistics for Variable Rate Field Corn

Corn	Variable Rate Field			
Variable	Mean	Std. Deviation	Min	Max
Yield	222.16	28.17	73.22	265.34
Seed rate	33,226.47	1,510.57	27,496.47	36,765.89
Nitrogen rate	47.79	4.54	31.83	64.22
Topographic Wetness Index	4.12	1.07	1.78	7.01
Topographic Positioning Index	0.06	0.90	-1.65	2.86
0% Irrigation	0.11	0.32	0	1
60% Irrigation	0.13	0.33	0	1
70% Irrigation	0.15	0.36	0	1

80% Irrigation	0.24	0.43	0	1
90% Irrigation	0.24	0.43	0	1
100% Irrigation	0.14	0.35	0	1
Observations	144			

For the corn data in the Uniform field, we have only 2 observations, one from each of the two years representing an average yield for the entire field after all outlying data are removed in a similar fashion to the VRI field. This process effectively smooths the data to come up with a baseline comparison. Here we saw the yield's minimum to be 206 bushels and the maximum to be 221 bushels with an average of 214 bushels. We did not have as much variation in the yield, but the average yield across the two years was smaller than the yield in the variable rate field.

Summary Statistics of Uniform Field Corn

Corn	Uniform Field			
Variable	Mean	Std. Deviation	Min	Max
Yield	214.20	10.89	206.50	221.90
Seed rate	33,748.72	79.68	33,692.38	33,805.07
Nitrogen rate	55.84	10.08	48.72	62.97
Topographic Wetness Index	0	0	0	0
Topographic Positioning Index	0	0	0	0
Observations	2			

In the soybean data for the variable rate field, we saw an observation number of 142. Data was processed in the same fashion as the corn data. In the soybean yield, we saw a minimum of 33 bushels and a maximum of 8 bushels with an average of 67 bushels. Again, we had a good amount of variation in the field. The irrigation events that took up most of the field in this field were the 80% and 90% zones. We only had one year of data in the uniform field for soybeans, so we did not have anything to compare it to over time. The average yield for that field was 79 bushels of soybeans.

Summary Statistics of Variable Rate field and Uniform Rate Field Soybeans

Soybeans	**Variable Rate**			
Variable	Mean	Std. Deviation	Min	Max
Yield	67.68	10.76	33.83	88.49
Seed rate	119,543.50	4,796.92	109,607.70	135,682.00
Topographic Wetness Index	4.03	1.10	0.79	6.97
Topographic Positioning Index	0.07	0.90	-1.54	3.00
0% Irrigation	0.10	0.30	0	1
60% Irrigation	0.13	0.33	0	1
70% Irrigation	0.15	0.36	0	1
80% Irrigation	0.24	0.43	0	1
90% Irrigation	0.24	0.43	0	1
100% Irrigation	0.14	0.35	0	1
Observations	142			

Soybeans	Uniform Field			
Variable	Mean	Std. Deviation	Min	Max
Yield	79.53	-	79.53	79.53
Seeding rate	122,200.00	-	122,200.00	122,200.00
Topographic Wetness Index	0	-	0	0
Topographic Positioning Index	0	-	0	0
Observations		1		

We then estimated the mixed model regression to determine the impact of our independent variables on yield. This is shown in Table 8. We compare the irrigation rates relative to 100 percent in this model. So, from the chart, we can see the increase or decrease in yield in the zones 0%, 60%, 70%, 80%, and 90% compared to the 100% application. In the case of the uniform field, since irrigation occurs at 0.7 inches, this would be the 70% rate. If the statistic is insignificant, there is no difference between water at that specific zone compared to the 100% zone. In the irrigation 0% zone, we saw that you would lose roughly 18 bushels of yield if you did not water compared to the 100 percent zone. In the corn regression, we saw that the 60% and the 70% were both significant and that if we watered less, then we would receive a better yield close to 17 to 25 bushels of corn. We can see that the seeding rate was significant. Also we saw that the TWI and TPI were significant as well, meaning they had a positive impact on yield. This means that the yield was increased in areas that were more likely to accumulate water. Another significant statistic was that in the year 2018 compared to 2020, we saw that 2018 produced a better yield of 14 bushels compared to 2020. This increase and decrease in bushels came from factors that were not controlled.

Table 8. Regression for Corn and Soybeans

Regressions	Corn		Soybeans	
Yield	Coef.		Coef.	
0% Irrigation	-18.80		2.36	
	(10.21)		(2.49)	
60% Irrigation	25.90	**	7.35	***
	(11.78)		(2.62)	
70% Irrigation	17.83	*	5.90	***
	(9.87)		(2.22)	
80% Irrigation	11.63		2.56	
	(9.31)		(2.14)	
90% Irrigation	9.34		1.19	
	(8.23)		(1.99)	
Seeding Rate	0.095	**	-0.016	***
	(0.042)		(.0037)	
Seeding Rate Squared	-1.41e-06	**	6.63e-08	***
	(6.57e-07)		(1.53e-08)	
Topographic Wetness Index	7.60	*	2.60	***
	(3.91)		(0.94)	
Topographic Positioning Index	14.76	***	2.99	***
	(4.04)		(1.00)	
Year 2018 for Corn	14.30	***	-15.15	***

Year 2019 for Soybeans	(2.66)		(0.99)	
Uniform Field	11.91		13.09	*
	(27.77)		(7.56)	
_cons	-1425.75	**	1006.49	***
	(663.33)		(220.86)	
(Std. Err.)				
***P value (3 stars less than 1%, 2 stars less than 5%, 1 star less than 10%)				

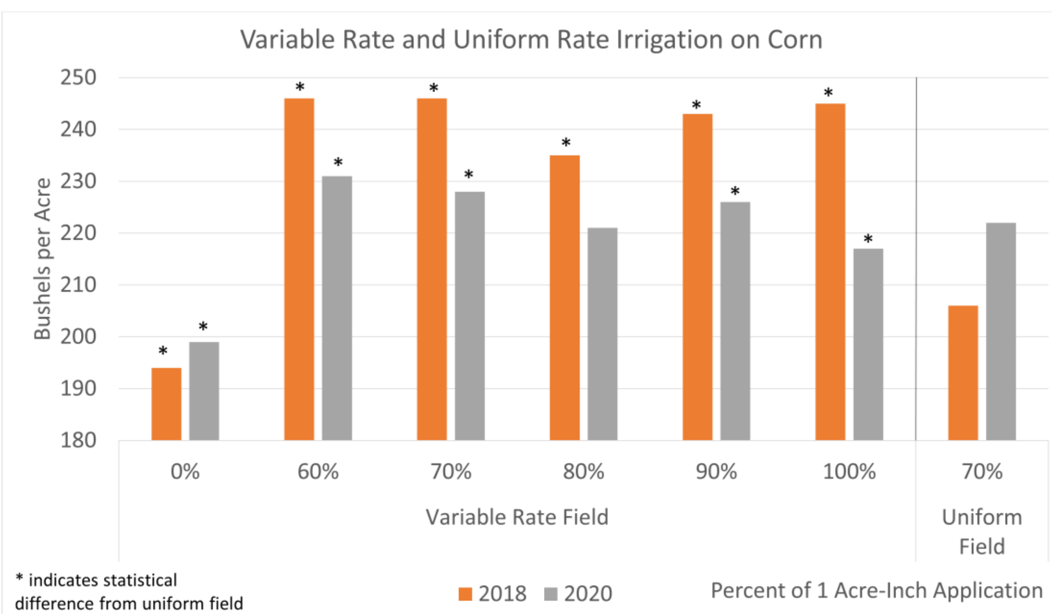
The soybean analysis showed that the 60% and 70% zones were significant and we gained 5 to 8 bushels of soybeans in each zone. This shows us that compared to the 100% zone, the crop would receive a better yield if watered less. The soybean looks to have been overwatered, causing the yields in the higher zones to decrease. The seeding rates here were significant. For TWI and TPI, we saw that the yield would increase slightly in areas where water accumulates. In 2019, we saw that it had 15 fewer bushels of soybeans compared to the year 2021. Again these fewer bushels came from factors in the field that were not controlled for in our model.

Chapter 8

Discussion/Future Research

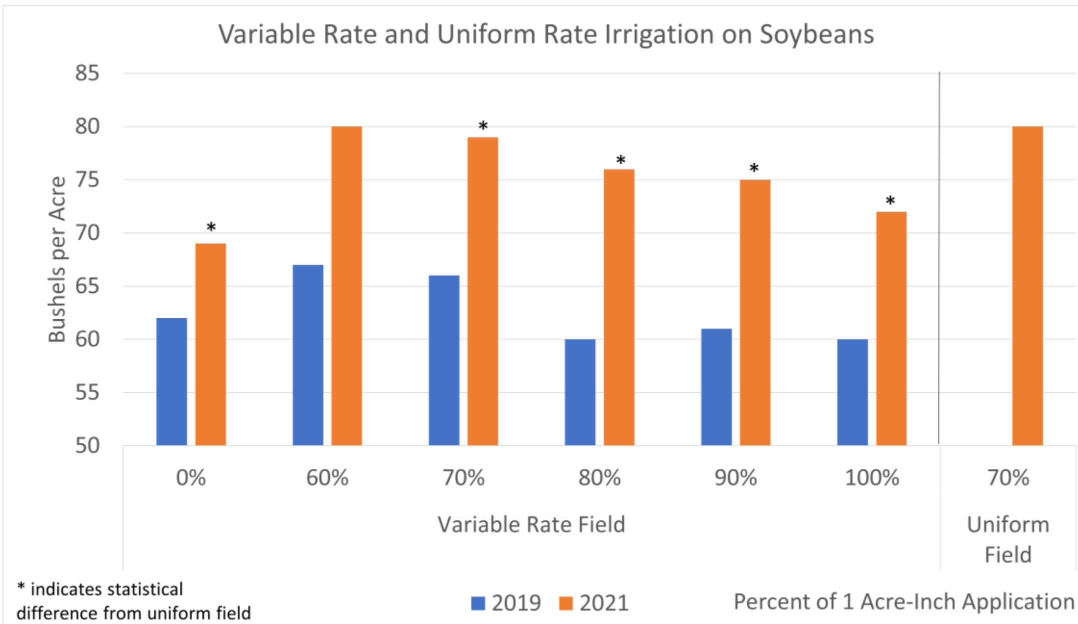
The results of this research show that, in some cases, variable rate irrigation is beneficial and can provide added value in zones with less irrigation. We can see this in figure 10. This figure shows us which irrigation amounts in the variable rate field, dealing with corn, are statistically significant compared to the uniform rate field. We see in 2018 that all the irrigation rates outperformed the uniform rate field and are statistically significant. This means with reduced irrigation, we would receive a better yield. In 2020 we saw that the 60%, 70%, and 90% zones received a higher yield than the uniform rate field, but the increase in yield was not as significant in 2020 as it was in 2018. In figure 11, we see how the variable rate field is compared to the uniform rate field with soybean production. In this field, we saw that the uniform field outperformed the VR field. We saw that as we increased irrigation, we lost yield. The only way to change the irrigation application in a field is through variable-rate irrigation, and with figures 10 and 11, we can see how important it is to use variable-rate application of water.

Figure 10. Corn Yield from Lawrence County Field



Note: The yield is bushels per acre. In this field variable rate application is used. Zones where 0%= no irrigation 60%= .6 inches, 70%= .7 inches, 80%= .8 inches, 90%= .9 inches, and 100%= 1 inch application. The variable rate field is compared to the Uniform application field (.7 inch application of water). The * indicates where the irrigation zone has a statistically significant difference from the uniform field yield.

Figure 11. Soybean Yield from Lawrence County Field



Note: The yield is bushels per acre. In this field variable rate application is used. Zones where 0%= no irrigation 60%= .6 inches, 70%= .7 inches, 80%= .8 inches, 90%= .9 inches, and 100%= 1 inch application. The variable rate field is compared to the Uniform application field (.7 inch application of water). The * indicates where the irrigation zone has a statistically significant difference from the uniform field yield.

The question of whether the cost of adoption can be paid back is still unclear. We saw in the regression results that some irrigation zones do produce a better yield with less irrigation, but the payback time has a lot of varying factors. For example, in 2018, compared to 2020, we saw a yield difference of 14.3 bushels of corn. In 2019 compared to 2021, we saw a loss of 15 bushels of soybeans. These yield variations came from factors during those years that were not controlled for in the model. This might include rainfall amounts or the total amount of water applied to the crop during the year. We need more years of data to see which yields are more likely to occur. With more years, we can find a better average to compare to the adoption cost over a specific time frame. If the yields are closer to the 2018 or 2021 results, we would have a quicker payback period than the 2019 and 2020 results. The 5-year payback time would be very difficult to achieve because it needs 32 to 47 additional bushels of corn per acre to pay for the cost of adoption. It is likely the payback period would fall sometime between the 10 to 20-year time frame, but that is still uncertain. The uncertainty comes from the variation in yield produced over a short time frame. Further complicating our results is the lack of a true control for the field. The uniform field is not an ideal control because it has different factors that affect the yield than the variable rate field. We were not able to control all of these variations. Without a uniform field comparison, we cannot see exactly how many additional bushels of corn or soybeans that we are truly receiving as a result of only the VRI and not other factors. We know that some irrigation zones in the variable rate field produce a better yield, but we are not confident in the exact number of additional bushels received due to VRI.

We also experienced variations in rainfall events over our study period. For example, most of the rainfall in 2018 occurred at the beginning of the season, while most of the rainfall in 2020 occurred at the end of the season. This plays a role because the crop needs more water at the beginning of the season, which could be why 2018 had better yields than 2020. These rainfall events also caused partial irrigation events. By having partial irrigation events, some areas received more water than other areas, but we did not have this information and thus could not develop an adequate control.

Another important note to make dealing with rainfall amounts is how variable rate irrigation technology can be used as a protection method against dry years. In dry years when we do not have early rainfall, then the variable rate irrigation can be used to water the crop and help produce higher yields. In years like 2019, where we see that there is plenty of rain to cover the crop's water use, the technology might not be used as much. In wet years, we would assume that the increase in yield from the dry years can cover the cost of adoption for both years. This is important because if a span of several dry years occurs, then the farmer would not have to worry about losing yield during this time because he would have the VRI protection. There is value to this protection that is dependent upon the farmers risk aversion, where those that are more risk averse will yield a greater utility from having VRI protection that may not produce as much return on the investment.

A lot of future research would be fascinating and beneficial for the adoption rate of VR applications. One thing that would be beneficial to my research to look at in the future would be linking the soil variety coordinates to the GIS layers to see how each variety impacts the yield. In my study, I found soil variety is essential when creating a prescription map. The different soil holds water for different lengths of time, so if the field has diverse soil, it could create varying yields. If water is appropriately added according to the soil type and how long they hold water, the yields could be increased, and the farmer would see more returns.

Another crucial factor for future research is to track exactly what is being done in each field. One issue we came up with during our research is missing and limited years of data. We were missing some nitrogen and fertilizer treatments during the 4-year data set. Also, we only had one year of soybean data to work within the uniform field. With only one year of data, it is hard to see exactly what factors play a role in the yield outcome. Also, with only one year, we could not use it as a control for the soybean data. It would also have been better to have more than four years of data for this project. With the number of factors that play a role in the production of a crop, the more years of data, the better the results will be. With more years of data, you can see better what factors are truly affecting the yield. For example, two years have much better rainfall than the other two years, and just by that factor, we see a large difference in yield. The production of both fields was also not the same, making it very hard to find a control for both fields. It was difficult to find indicators for both fields because they used variable nitrogen, water, soil description, and seeding rates. TWI and TPI could have been a great control for examining both fields, but due to limited time, we only had this data for one field (variable-rate field). It did play a factor, and we saw positive results from adding TWI and TPI but to be a control, we needed it for both fields. Future projects should consider developing the study design in advance of the research, rather than performing research on farmer provided data from actual production not intended for research.

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