VARIABLE CROP RESIDUE MANAGEMENT

by

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ABSTRACT

Production agriculture is constantly evolving to become more efficient and productive. Crop residue serves as a valuable source of nutrients for the soil, but it is increasingly abundant with today’s enhanced crop genetics. If new technology can effectively provide a way to micro-manage crop residue levels within a field, the benefits will go beyond soil health. Surplus crop residue can be collected for secondary income while leaving the optimum amounts in the field to maintain the environment and soil health as well as promote future crop growth. The main objective of this study is to create a budget model that will determine the economic impact of crop residue removal on a controlled basis. The goals are to determine crop residue removal practices that are sustainable for the long-term, while also enhancing soil quality and increasing grain yield in future years. A sub-objective is to build a business case for producers to invest in variable crop residue management. The hypothesis presented in this study is that the increased complexity and price of a variable rate system is offset by more supplemental profits, increased crop yields, and better management of soil health and nutrients.

The negative perceptions of crop residue removal include the fear of soil erosion or loss of soil organic matter. By developing a budget model that is easy to use, takes advantage of existing field data for inputs, and allows producers the ability to look at their operations on a sub-field level, this study aims to provide the necessary motivation to invest in new technology that will increase their productivity. By entering their site-specific crop residue return rate data into a budget model, along with prices and costs related to combine and auxiliary equipment, corn and corn stover, transportation and logistics, and

nutrient replacement, they will come up with a return per acre for both constant rate and variable rate collection.

The budget model determines whether it is economically viable to harvest crop residue from a continuous corn rotation at a variable rate across a field, rather than at a constant rate, using a producer's own specific field data. To validate the concept, data from a joint study between John Deere and Iowa State is entered into the model. Prescriptions for corn stover return rates are provided from the study for pre-defined grid areas. Prescriptions are derived from a combination of data including grain yield, soil loss due to wind and water erosion, climate, topography, and soil sample data at time of planting (Nelson, et al. 2004).

The average corn stover removal percentage was less for variable rate collection than constant rate collection, 26.05% to 31.85%. However, the assumption that grain yield and corn stover yield are positively correlated did not prove to be true in this case study. The variable rate plots had a lower average grain yield of 158.84 bushel/acre, compared to 160.46 for the constant rate plots, but they had more total corn stover available and therefore a higher return rate of 3.70 tons/acre, compared to 3.05 for the constant rate plots. This case study illustrates that less corn stover can be returned to the field through constant or variable rate collection while sustaining higher grain yields than a conventional harvest that would return all of the corn stover to the field. This case study demonstrates that variable rate collection can be more expensive than constant rate, but not in every situation. Every unique field site will require a specific crop residue management recommendation that is determined by both economic and environmental factors.

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CHAPTER I: PROJECT PLAN

1.1 Issue Identification

Those involved in the production agriculture supply chain are looking for means to improve efficiency and/or effectiveness of today’s farming techniques. Producers and input providers alike have a vested interest in growth and sustainability of crop production around the world. Great strides have been made in the areas of seed genetics, farming practices, and precision technology to allow producers to improve their productivity. These developments will lead to another critical value driver for the producer – advanced crop residue management.

Historically, producers have largely ignored crop residue, or even viewed it as more of a hindrance than a benefit. In past decades, the soil was turned over completely with plows to bury the crop residue for decomposition. As cropping practices have evolved, producers have learned that there are benefits to less soil disturbance. Production systems such as no-till and minimum till have gained in popularity over the last two decades, resulting in more crop residue being left on the surface.

Managing crop residue can have many benefits. First and foremost, crop residue serves as a valuable source of nutrients for the soil. However, with the enhanced genetics of today’s crops such as genetically modified corn, the amount of residue remaining after harvest can often be more than what the soil needs (Muth 2012). This can result in negative attributes such as slow soil warmup, disease, and Nitrogen immobilization (Karlen, Birrell, et al. 2014). The most logical solution is to remove what is not needed.

There is an untapped benefit to micro-manage crop residue levels across individual fields. Technology is being developed that allows for harvesting machines to control how much crop residue is left in the field and how much is collected. By tying this farming practice into a system that accounts for variations in topography, grain yield, and soil characteristics, there may be value in optimizing crop residue levels throughout a field.

Another benefit to crop residue management is the secondary income stream that is provided by the collection of the residue. For example, corn stover is a popular feedstock to use in high-quality cattle rations as well as cellulosic ethanol production. Corn stover is made up of the leaves, husks, cobs, and upper stalks of a corn plant. There may be a benefit for the individual producer to collect and sell their corn stover.

Modern farming has less room for error than ever before. As commodity prices fluctuate while input costs stay steady or even rise, producers must get creative to maintain their profitability. The issue of what to do with crop residue after harvest leads to the objective to maximize the benefits of this residue for the environment and future crops. In order to truly optimize crop residue throughout a field, research is under way at Iowa State University (Birrell 2014) to determine the independent variables that affect how much crop residue should be left for a specific set of conditions and how much can be sustainably removed. This research is defining a process for producers to find the appropriate crop residue level targets for a given field to increase their grain yield and sustain the environment.

The goal of this study is to build a simple, intuitive budget model that can be used by producers to evaluate their crop residue removal opportunities. A sub-objective of this paper is to build a business case for producers to invest in variable crop residue management. This supports the strategy of John Deere and Hillco Technologies to create a competitive advantage with a single pass collection system.

1.2 Importance of the Issue

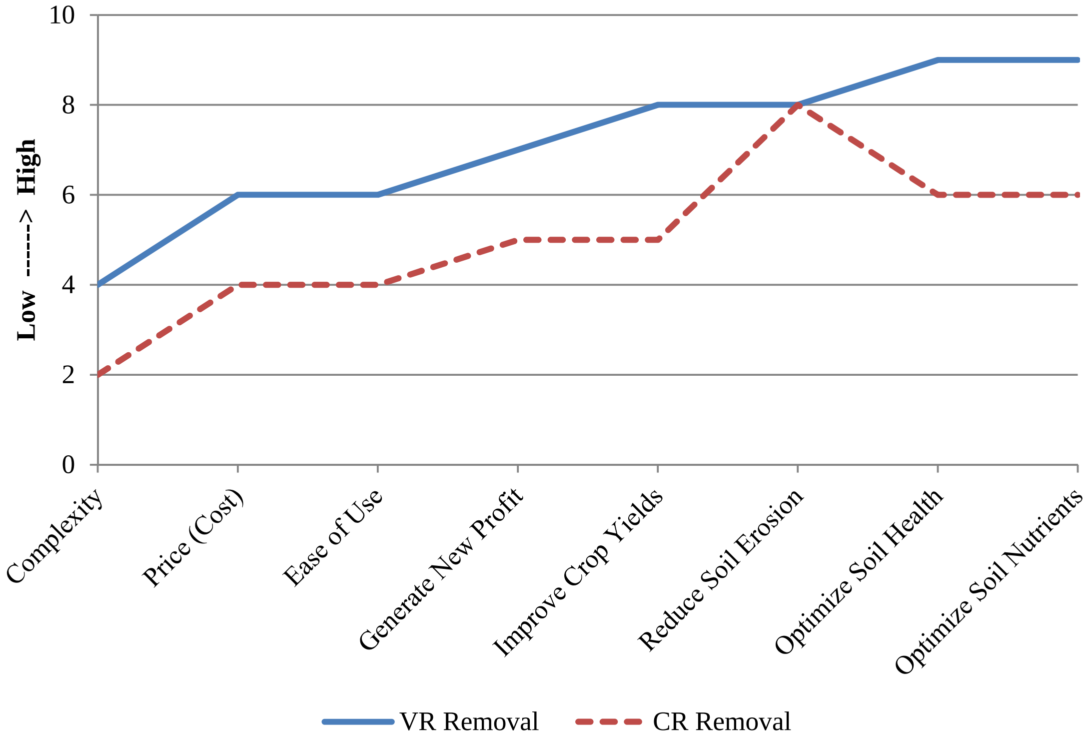
Finding the best solution to crop residue management is both a challenge and an opportunity. With all of the potential variables that could affect this solution, it is difficult to come up with a model that works in all conditions. Furthermore, different producers may have different objectives that they are trying to meet in their own unique operations. It is widely accepted that 1-2 tons/acre of corn stover can be removed from most farm fields without compromising the health of the soil or causing other environmental issues (Muth 2012). However, in high yielding corn of over 200 bushels/acre, as much as 3.5 tons/acre are available to remove if the conditions warrant such a high removal rate (Muth 2012).

Companies such as John Deere, ADM, and Monsanto are collaborating with each other and university researchers to find solutions that will help drive sustainable crop residue removal from farm fields. Each company stands to gain from this research. Monsanto wishes to learn more about the feedstock requirements that should be bred into their future crop varieties. John Deere is interested in the required harvesting and tillage methods to allow a residue management solution to work. ADM is looking at the end-use opportunities for the crop residue that is removed, such as biofuel production and high-quality animal feed.

The key to unlocking the potential of such a solution does not lie within industry, however. It is the producers that grow the crops who must decide whether it is profitable to invest in an infrastructure that will enable them to manage crop residue levels on a micro level. Farm operations today have several characteristics that make them more apt to adopt new solutions than in the past. First, they are larger, so they can take advantage of their economies of scale to make the necessary investments. Second, as younger producers take over their family farms, they are more likely to adopt new technologies. Finally, profit margins are tight and change from year to year. Producers recognize the peaks and valleys that they must endure to have long-term success. One way to do that is to incorporate new revenue opportunities into their current operations. Removing crop residue creates a new revenue stream from existing crops that may help them maintain profits during difficult conditions.

The value drivers of variable rate crop residue management and constant rate removal for a given land area are illustrated in the strategy canvas shown in Figure 1.1. The critical factors were determined by visiting with a variety of people with knowledge of the issue, including subject matter experts within the farm equipment and feed industries, as well as producers who are currently harvesting crop residue in some fashion to either feed to cattle or sell as a by-product. Included in this survey group were engineers at John Deere, the owner of Hillco Technologies, and a producer in central Iowa who is an early adopter of single pass residue collection. Each person was asked to rank the relative importance of each factor, which was then used to produce value curves for both variable rate and constant rate crop residue removal. In summary, the perceived rewards for increased complexity and price of a variable rate system are more profits from selling crop residue, increased crop yields, and better management of soil health and nutrients. Soil erosion will not necessarily change based on variable or constant rate crop residue removal, as long as adequate residue is left on the surface in either scenario.

Figure 1.1: Strategy Canvas for Variable Rate Residue Management



There are competing interests at play when it comes to optimization of crop residue removal. Equipment companies may feel the urge to develop the advanced technology needed to ensure that they stay on the cutting edge, even if the business case does not warrant the investment. It will be a race to see which company delivers their solution concepts to the market first. Companies that are involved in animal feed production will desire only the materials that are high in nutritional value, like corn cobs and leaves, to be removed so that a high-quality feedstock can be created from the crop residue. Furthermore, companies involved in cellulosic biofuel production will desire large quantities of consistent, clean crop residue to be removed for their usage. To create the momentum to propel any solution to mainstream adoption, it will require that all parties associated in the production chain be rewarded for their efforts.

1.3 Deliverables

Developing the solution requires the acquisition of specific field data. Since crop residue levels have a distinct effect on wind and water erosion as well as soil organic matter, data for those variables must be available. Soil loss from water erosion is often defined by the Revised Universal Soil Loss Equation (RUSLE2) (Muth 2012). The results of such an analysis could become one input into a prescription for how much crop residue to leave in certain areas of a field. Soil organic matter is also an important variable that must be considered. It must be maintained at healthy levels to promote growth of new plants and provide high crop yields. This is a variable that is also highly dependent on the type of tillage practices being used. Data from soil samples throughout a given field are necessary to gauge the current levels of organic matter in the soil and where the most immediate needs for building organic matter are. Soil sample data also indicates the nutrient levels in the soil and the relative temperature, which are strong indicators of successful crop emergence. Analysis of all the data should give an accurate portrayal of how much crop residue is necessary throughout a field to maintain soil health and increase productivity (Dalzell, et al. 2013).

Current grain yields for a producer's fields are also a required input. They not only help determine where the soil nutrients are the highest, but also help determine the crop residue available after harvest. By subtracting the minimum level of crop residue needed by the soil, the budget model will calculate the amount of crop residue available for removal. The model should allow the producer to select the necessary granularity for the data that they enter based on the severity of the variations found in the field.

Acquiring the necessary data to develop a budget model will require close collaboration with engineering groups within John Deere, university researchers who are already working with John Deere, and other companies who are willing to share their field trial data. Much of the necessary data has been collected and analyzed for associated research. For example, John Deere is working with Iowa State University to study the soil fertility impact when using alternative tillage methods and removing specific levels of crop residue. This is important to understand so that the necessary tillage tools can be provided as well as nutrient application equipment to add nutrients like nitrogen, phosphorous, and potassium (NP&K) back into the soil. A dissertation written by David Muth (2012) looks at the sustainability of removing variable amounts of agricultural residues for bioenergy production. There are many parallels between his research and this study.

Since this study approaches the solution from the viewpoint of an equipment manufacturer, the solution must be one that can be supported by current and developing technology related to machinery interfaces. Much advancement has been made in this area in recent years, with machines that can communicate through telematics with each other as well as farm managers located in command centers. While John Deere does not control all of the Intellectual Property in this space, they do have a distinct advantage in how broad their product offering is. The John Deere strategy focuses on offering the producer a complete suite of products, including hard iron, GPS, telematics, and management software, so that they can be more efficient and productive than ever before. Once producers invest in this integrated solution, they will desire to add onto it and make it even more powerful. Offering common user interfaces with all of these products, similar to how

Apple has designed the iPad, iPhone, iMac, etc. to function the same, is of utmost importance.

Incorporating a solution for variable crop residue management into this strategy makes it stronger and even more unique in the industry by adding another level of differentiation. Creating a solution of exceptional utility that is a win-win-win for John Deere, their suppliers, and their customers will first require a strategic price that customers are willing to pay. Target costs must then be determined that will provide the necessary profit margins to the various members of the supply chain. If this can be successfully accomplished, then value innovation will exist and the business case for adopting variable crop residue management will be strong.

1.4 Implementation Plan

The hurdles to implementing this solution are multiple and complex. There are many negative perceptions around crop residue removal, such as the fear of soil erosion or loss of organic matter, which may dissuade producers from even considering implementing a crop residue management system on their farm. These perceptions must be overcome with education based on fact. These facts need to be presented in a format that is easy to understand and compelling to the audience. They must speak to the long-term sustainability of the land and the short-term economic benefits. Just like any drastic change in cultural practice, it will likely take time to build the momentum from first adopters to mainstream farming practice.

To convince those that believe any type of crop residue removal is bad for the environment, reference should be made to the findings from multiple research studies that show how crop residue maintenance, done with the proper levels of removal, can actually increase soil fertility over time, reduce disease, and maintain optimum soil temperatures for plant growth (Muth 2012) (Karlen, Birrell, et al. 2014) (Dalzell, et al. 2013). Removing crop residue is not just about creating another revenue stream. When combined with the proper conservation program, it will help producers sustain their soil health into the future. This then enables them to continue making the productivity leaps necessary to feed the world population, which is estimated to reach 8.1 billion people by 2025 (AP 2013).

Operator training is another challenge that must be addressed. Users who are intimidated by new technology or find it to be burdensome are less likely to adopt it. The first step should be to publish clear instruction guides and training modules that dealers can use to educate their customers. Next, the user interfaces should be easy to understand, intuitive, and instructional. Consistency is a key attribute. The applications for crop residue management should look and feel like current applications that our customers are already using, such as AutoTrac™ and the Greenstar™ yield monitor.

Finally, once customers are convinced that they need to implement advanced crop residue management on their farms, industry must be prepared and motivated to provide them with the right tools. John Deere has been at the forefront when participating in research and development projects, but not many of the special products that have been co-developed with other companies or universities have actually been put into production. To make some of them a reality, a compelling business case must be developed that gives leadership the courage to invest money and reputation on such a concept.

One example that John Deere was able to deliver to the market through a partnership with Hillco Technologies is a single pass collection system, which collects corn stover directly out of the combine and feeds it into a round baler. This eliminates multiple passes across the field to rake and bale the material after harvest of the grain. By collaborating on the development of this product, John Deere and Hillco were able to position themselves in the market with a unique product not available by competitors. As customer acceptance and demand increase, these companies are not just capturing market share, but defining a new needs-based market position. This as an example of how new market spaces can be created by combining new technology with the proper education to build the business case for the customer.

1.5 Conclusions

Production agriculture is constantly evolving to improve efficiency and/or effectiveness of today’s food production. The growth and sustainability of food production is critical with the global population rapidly approaching 8.1 billion people by 2025 (AP 2013). Great strides have been made in the areas of seed genetics, farming practices, and precision technology to allow producers to improve their productivity. However, this will not be enough to sustain those producers over time with the growing financial pressures they face. Additional value innovations must be discovered and rapidly accepted in mainstream agricultural. One such value innovation that any producer could adopt, given the right technology and motivation, is variable rate crop residue management. By developing a budget model that is easy to use, takes advantage of existing data for inputs, and allows producers the ability to look at their operations on a sub-field level, this study aims to provide the necessary motivation for them to invest in new technology that will increase their productivity over time.

CHAPTER II: LITERATURE REVIEW

2.1 Overview

There have been many research projects completed that focus on crop residue removal for use in creating energy. Based on guidelines set by the Energy Independence and Security Act of 2007 to reach 136 billion liters annually by 2022, agricultural residues will be a necessary source for bioenergy production. To meet these ever-increasing needs, it is estimated that over 150 million tons of agricultural residues could be sustainably removed today from fields in the United States (Muth 2012). The following papers all demonstrate strong evidence that crop residue can be removed in a sustainable manner to help meet this need in the United States for energy independence.

2.2 "An Investigation of Sustainable Agricultural Residue Availability for Energy Applications" by David Muth

The dissertation by Muth (2012) provides an in-depth look at sustainable crop residue availability for use in bioenergy production in the United States, focusing on crop residues found in the state of Iowa. Muth proposes a decision support framework that ensures producers have the necessary tools to evaluate their individual field environments and be able to remove residue while still meeting USDA conservation guidelines.

A comprehensive background on the history of residue removal is provided in the Muth dissertation, starting with a study by Larson (1979), who was one of the first to look at the effects of crop residue removal on soil erosion. His research led to the development of the first Universal Soil Loss Equation that took into account tillage practices, rainfall, erosion, runoff, and nutrient removal and their effects on residue management (Larson 1979). Renard (1997) continued this research, which resulted in refinements being made to the Soil Loss Equation as well as other methodologies. Nelson (2002) used the Revised

Universal Soil Loss Equation (RUSLE) in the early 2000s to begin measuring sustainable removal rates based on soil type and cropping rotations. Further studies by Karlen (2003) and Nelson (2004) were conducted to further define the amount of residue available for alternative uses such as bioenergy production. They began adding more agronomic and environmental factors to the studies such as greenhouse gas impacts, carbon sequestration, and water quality. As the result of higher crop yields, better farm management practices, and a better understanding of sustainable removal, the amount of available residues has increased significantly (Nelson, et al. 2004). From 1979 to 2012, the amount of agricultural residues available for sustainable removal has increased from 49 to 150 million tons (Muth 2012).

Residue removal must be considered carefully, since it can affect up to six environmental factors related to the soil. Soil organic carbon, wind and water erosion, plant nutrient balances, soil water and temperature dynamics, soil compaction, and off-site environmental impacts must all be considered (Wilhelm, et al. 2010). The key to sustainability is to accurately model these individual characteristics for a producer's field so that they can make the proper removal decisions. There are four different papers within Muth's dissertation that go into great detail about different aspects of residue collection.

First, an integrated modeling strategy is proposed by Muth (2012) and compared to other modeling frameworks. Other models commonly used include the Revised Universal Soil Loss Equation (RUSLE2), the Wind Erosion Prediction System (WEPS) (USDA-NRCS 2012), and the Soil Conditioning Index (USDA-NRCS 2003). The proposed integrated approach combines aspects of these three models to more accurately estimate residue availability.

Second, the proposed modeling strategy is put to the test by Muth in an application using data from across the United States. The results were impressive, showing over 150 million metric tons of agricultural residues being available to remove sustainably in 2011 and nearly 208 million metric tons in 2030 (Muth 2012). However, Muth (2012) notes that nearly 240 million metric tons will be needed to meet the mandate set forth in the Energy Independence and Security Act of 2007 that 56 billion liters (15 billion gallons) of biofuel in the US be derived from cellulosic feedstocks by 2022 (Muth 2012).

Third, the factors within a given field are analyzed by Muth (2012) to reveal the challenges created by variability in soil, topography, and grain yield. It is shown that each of these factors may limit how much residue can be removed sustainably and will show a compounding effect. The average amount of crop residue recommended for removal by conservation management guidelines is typically 2.68 Mg/ha (1.2 ton/acre), but the Muth (2012) study shows that sustainable removal rates can vary significantly within a single field. In most of their trials when residue is removed at a constant rate, there is too much residue removed from certain areas of the field while there is excess left on the surface in other areas.

Fourth, Muth (2012) investigates the challenges and need for variable rate residue removal. His research builds on the evidence gained in previous studies that suggests opportunities exist for optimizing residue removal in a single field. For the three Iowa corn fields that were studied, one field had large variations in soil properties that drove the need for variable rate residue removal, while the other two showed a correlation between residue removal and grain yield. In all cases, there were locations in the fields where no residue could be sustainably removed, but other areas where large amounts could safely be taken off. In all three fields, Muth (2012) found that more overall crop residue could be removed sustainably by using variable collection than the Natural Resource Conservation Service (NRCS) guidelines for raking and baling (constant rate collection). This method of addressing sub-field variability shows promise but requires advancements to be made in harvesting methods, according to Muth (2012).

2.3 "Simulated Impacts of Crop Residue Removal and Tillage on Soil Organic Matter Maintenance" by Brent Dalzell

Dalzell (2013) looks at the effects of crop residue removal on soil erosion and soil organic matter (SOM) loss. These are two very important variables when determining the amount of crop residue to remove from a field. They can be greatly affected by the type of tillage practices that the producer uses as well. Conventional tillage, for example, depletes soil organic matter (SOM) regardless of whether any residue was removed prior to the operation. Residue levels play a much larger part in no-till operations, where it has been found that SOM levels can actually increase over time with the proper residue management program. Dalzell (2013) goes on to point out that any research to measure SOM needs to consider different depths, at least up to 30 cm, because the levels can vary throughout the soil horizon.

With the anticipation of crop residues, particularly from corn, being used more in the future as a feedstock to produce cellulosic ethanol, it is even more important that proper residue management techniques are used. There are concerns that the improper removal of residue over time will increase the chances for soil erosion and reduced SOM, which will in turn reduce crop yields and create environmental concerns. Dalzell (2013) stresses the importance of reaching a balance of necessary crop residue left on the field to maintain high agronomic productivity and environmental sustainability.

According to Dalzell (2013), there are challenges to measuring the effects that crop residue removal may have over time. For one, it usually takes years for SOM to change considerably. Dalzell (2013) found that it takes up to 2.5 years for the SOM to change enough to be statistically significant. There are also vast variations in soil type and conditions across a single field. Two models are referenced that have been used to simulate the dynamics of SOM. They are the Century model created by Parton (1987) and the ROTH-C model developed by Jenkinson (1990). Because of the challenges with collecting the necessary field data for these models, the CQESTR model was created by Rickman (2001). This model contains improvements that allow data for variables such as soil type, climate, tillage practices, and organic matter removal (residue) or addition (manure) to be considered.

The study conducted by Dalzell (2013) aimed to model the long-term effects on SOM of varying tillage and crop residue removal practices using the CQESTR model. In addition, he wanted to quantify how much residue could be removed without sacrificing the levels of SOM in the field. The results of the model were compared to soil samples taken throughout the experiment in two fields in west-central Minnesota to determine the accuracy of the model.

One important conclusion that was drawn by Dalzell (2013) was a distinction between the two tillage methods used. While conventional tillage would deplete the SOM in the upper 30 cm of soil, it was shown that in no-till practices the SOM in that range of soil depth would actually increase at a rate that was proportional to the amount of crop residue left on the field. These residue levels will vary depending on whether the producer plants a corn-soybean rotation or continuous corn. The results of the study indicated that crop rotations, tillage practices, and crop residue removal all have significant effects on the sustainability of SOM in the soil. It was also pointed out that maintaining crop residue on the surface has the greatest benefits to the soil within the upper 30 cm of the profile. Below that, the SOM will generally decline over time unless effective no-till farming practices are used continuously for many years.

The recommendation by Dalzell (2013) was to only remove crop residue when in a continuous corn production cycle coupled with no-till in order to maintain SOM. Under these conditions, at least 3.6 Mg/ha (1.6 ton/acre) of crop residue should be left on the surface to maintain agronomic productivity and environmental sustainability.

2.4 "Multi-location Corn Stover Harvest Effects on Crop Yields and Nutrient Removal" by Douglas Karlen, Stuart Birrell, et. al.

Because of the large potential for corn stover in the US to become the preferred feedstock for cellulosic ethanol, it is critical that producers understand the production cycle of biomass. Most importantly, Karlen, Birrell, et. al. (2014) sets out to define how corn stover is not just a waste material that can be removed without consequence, but rather an important component to the environment that helps protect against soil erosion, maintains soil carbon, and provides many of the necessary nutrients for the next generation of plants. To strike the right balance between the economic benefits of removal and the environmental requirements to leave some stover on the field, a firm understanding of all consequences of its removal is necessary (Karlen, Birrell, et al. 2014).

To meet the 15 billion gallon requirement set forth by the Renewable Fuel Standard (RFS2) for cellulosic biofuels by 2022, it is estimated by the EPA that at least 7.8 billion gallons will need to come from corn stover. It will take 82 million tons of corn stover to accomplish this feat (Karlen, Birrell, et al. 2014). There are many reasons why corn stover may be preferred over other cellulosic materials. It is grown over a large percentage of the farmland in the United States and is easily removable after harvest of the grain. It is also a secondary source of profit for the producer, so there is an economic benefit that shouldn't disrupt the market supply of corn. In addition, it is located in an area of the country that has already developed the infrastructure to be able to handle harvesting and transporting the material. Also, with the development of genetically modified corn varieties, it is possible to increase the amount of stover produced without sacrificing grain yield.

Karlen, Birrell, et. al. (2014) warns, however, that there are both environmental and productivity risks associated with improper removal of corn stover. If not managed properly, crop residues can lead to increased wind and water erosion, reduced water retention and soil aggregation, issues with nitrogen immobilization, and reduced soil temperatures. It can also have a pronounced effect on the nutrients available for the next crop. Any nitrogen, potassium, or phosphorus that is removed with the crop residue will likely need to be replaced by future nutrient application. The objective of the Karlen, Birrell, et. al. (2014) study was to document the effects on grain yield and soil nutrients by analyzing field research data from 36 sites over 239 site-years where corn stover was removed at zero, medium, and high rates. The variables also include two different tillage practices, conventional and no-till, as well as two crop rotations, corn-soybeans and continuous corn. Corn stover yield was calculated and then compared to actual machine removal rates.

Results show that grain yield actually averaged five bushel/acre higher when corn stover was removed at the medium or high rates than when no stover was removed at all (Karlen, Birrell, et al. 2014). This was more prevalent in no-till situations than when conventional tillage practices were used. The average removal rates were 1.7 tons/acre for the medium case and 3.2 tons/acre for the high case, leaving 54% and 15% of the total biomass, respectively, in the field. Soil nutrient removal was also noted for each treatment. One interesting observation was that the type of crop rotation did not have a significant effect on grain or corn stover yields (Karlen, Birrell, et al. 2014).

An important conclusion drawn from this research is that it is not adequate to use generalized data from a cross-section of fields to make site-specific management decisions for an individual location. Each field site should be analyzed for its unique soil types, weather patterns, tillage practices, hybrid selections, cover crops, etc. (Karlen, Birrell, et al. 2014). However, there were lessons learned when this data was analyzed. For instance, it appears that removal of a portion of the corn residue may be worthwhile from a yield perspective and be more cost-effective than tilling the residue into the ground. The quality of the corn stover also varied by when it was harvested, making individual site-specific decisions even more critical to be able to maximize the value of the material being removed. Soil nutrient removal was proportional to the stover yield and varied based on when the crop residue was removed from the fields. This is another factor that should be monitored closely in each unique situation so that the proper amount of nutrients can be maintained in the soil (Karlen, Birrell, et al. 2014).

2.5 Conclusions

The three papers reviewed here all demonstrate a common theme – crop residue removal is sustainable if done correctly. While Muth (2012) and Karlen, Birrell, et. al. (2014) focused on how much residue could be sustainably removed, Dalzell (2013) focused on how much should be left on the field. From either viewpoint, there are many independent variables to take into account when analyzing a particular field. Any model that is going to accurately portray the crop residue requirements of the soil, and thus how much can be sustainably removed, must take into account soil organic matter, wind and water erosion, plant nutrient balances, soil water and temperature dynamics, soil compaction, and off-site environmental impacts. All three papers also point out the variability within a given field due to soil types, topography, and grain yield, which gives merit to further investigation into the feasibility of removing variable amounts of crop residue to maximize productivity and sustainable removal.

CHAPTER III: THEORY

3.1 Objectives

The main objective of this study is to create a budget model that will determine the economic impact of crop residue removal on a controlled basis so that the environment is preserved and future crops thrive. The goals are to determine crop residue removal practices that are sustainable for the long-term, while also enhancing soil quality and increasing grain yield in future years. A sub-objective of this research is to build a business case to invest in variable crop residue management. By developing a budget model that is easy to use, takes advantage of easily accessible data for inputs, and allows producers the ability to look at their operations on a sub-field level, this study aims to examine the economics of investing in new technology that will increase productivity over time.

3.2 Economic Theory

A financial analysis is necessary to determine and test the relationships between multiple variables that can have an impact on grain yield and crop residue. The importance of grain yield and crop residue will become evident with a budget model that compares constant rate to variable rate residue collection. Changes in grain yield will obviously affect profitability. Changes in the amount of crop residue collected across a field may also show a significant effect on profits. Locations that are susceptible to wind and water erosion, generally produce lower grain yields and less crop residue but have a greater need for surface residue to control erosion. These areas will generate less profit from both grain and crop residue harvesting than areas that are immune to erosion. Furthermore, there are economic benefits in leaving enough crop residue to ensure that the next crop has all of the essential nutrients to thrive, while harvesting the surplus crop residue so that it can be sold as a secondary income source.

3.3 Trends in Precision Agriculture

Precision agriculture is a growing trend in most developed countries. In the Midwestern United States, 75% of producers use some type of precision agriculture on their farmland, primarily in the forms of yield monitors, GPS, and soil sampling (The Context Network 2013). In addition, over 50% of these producers plan to increase their use of precision agriculture technology as it becomes available (The Context Network 2013). This demonstrates that a large percentage of producers today invest in new technology if they can receive economic benefits through increased efficiency, reduced costs, or increased profitability. Most growers see an incremental return of at least $6/acre from the precision applications they use today (The Context Network 2013). As more applications become available, there will be more opportunity to “bundle” them to gain even more benefits. According to a 2011 USDA survey, the logical 3-step adoption process is 1) yield monitors, 2) soil maps, and 3) variable rate technology that takes advantage of the data collected in the two prior steps (The Context Network 2013). This study, along with research underway at Iowa State University (Birrell 2014), uses data from grain yield monitors and soil maps to vary crop residue levels within a field based on a prescription for optimum crop residue.

3.4 Prescription Farming

The budget model developed in this study will provide producers with a tool to calculate the revenue potential for leaving variable amounts of crop residue within a field. However, they will first need to determine a variable return rate prescription with the help of an agronomic services firm or university extension. Prescription farming, or variable rate application, is becoming more popular in the areas of chemical application and seeding. It allows inputs to be varied across fields based on the field variability. This not only reduces input usage, it also increases efficiency and provides positive environmental and economic benefits. Research is underway to determine the potential for controlling other operations in this variable manner, such as tillage and crop residue collection (Birrell 2014). The prescription for crop residue collection gives the producer a recommended return rate for how much crop residue to return to the field. It can be divided into pre-determined field plot sizes based on how much variability exists in a particular field. These recommendations for how much crop residue to return to the field depend on variations in grain yield, soil loss due to wind and water erosion, climate, topography, and soil sample data at the time of planting (Nelson, et al. 2004).

The most commonly used method to estimate the crop residue needs of the soil utilizes the Revised Universal Soil Loss Equation model (RUSLE2). It can be used to estimate removal rates while ensuring that soil erosion does not exceed the soil loss thresholds (T values) set by the USDA Natural Resource Conservation Service (NRCS) (Karkee 2012). The RUSLE2 model is driven by a basic equation that estimates average annual soil loss.

$$\mathbf{A = R \times K \times L \times S \times C \times P}$$

A = average annual soil loss (tons/year)
R = climate erosivity factor (location/county specific)
K = soil erodibility factor (soil type specific)
L = slope length factor
S = slope steepness factor (soil type specific)
C = cover management factor (based on residue levels, crop rotations, yields, and tillage practices)
P = supporting practices factor (silt barriers, terraces, etc.)

The objective when creating a prescription for crop residue collection is to ensure that soil loss (A) is less than the soil loss threshold (T) throughout a field. An iterative approach is necessary to determine site-specific tolerable crop residue removal levels that maintain this relationship. Soil loss (A) is first calculated for the situation where all crop residue is returned to the surface. As the amount of crop residue returned is decreased, the cover management (C) factor increases until the soil loss (A) for a given area is very close to the threshold level (T). In highly erodible areas, (A) may already be greater than (T), even when all crop residue is returned to the surface. In these instances, no crop residue should be removed. The climate erosivity (R) and soil erodibility (K) factors used by RUSLE2 can be found in the county-level soil databases managed by the USDA-NRCS. The slope length (L) and slope steepness (S) factors can be determined through digital elevation models (DEMs) provided by the U.S. Geological Survey (USGS) for most fields in the United States (Karkee 2012).

It is important to point out that the RUSLE2 model does not take into account wind erosion and the possible long-term effects that crop residue removal may have on soil organic matter. These variables must also be carefully considered before deciding how much crop residue can be removed within a field. If wind erosion and soil organic matter concerns are significant in the area being analyzed, then the WEPS model (for wind) and CQESTR model (for organic matter) would be more appropriate to use.

3.5 Conclusions

There have been many studies completed that look at how much crop residue is needed for environmental reasons so that the excess can be removed for other important uses, like biofuel production. The motivations behind most of these studies have been to determine whether there is enough crop residue supply available in certain states or across the United States to meet the future demands of the biofuel industry. This study is differentiated by focusing on the producer's perspective. Most producers would welcome the additional income from selling their crop residue. However, if it is not done correctly, they may unintentionally be reducing future profit opportunities from their primary cash crop. They may already have the data to make the best decisions, but the management tools for a thorough analysis are missing.

By entering their site-specific return rate data into a budget model, along with prices and costs related to combine and auxiliary equipment, corn and corn stover, transportation and logistics, and nutrient replacement, they will come up with a return per acre for both constant rate and variable rate collection. By comparing these potential profits, they can then make an informed decision about whether or not to invest in either means of collection.

CHAPTER IV: METHODS

4.1 Methodology

A budget model is used to determine whether it is economically viable to harvest crop residue at a variable rate across a field, rather than at a constant rate. This model is designed so that a producer can enter their own specific field data. To validate the concept, data from a joint study between John Deere and Iowa State University is entered into the model. This data is from a 4-year field study looking at variable rate crop residue collection based on a sustainability prescription of optimum levels of crop residue from corn stover needed by the environment and future crops. The level of crop residue returned to the field was varied in grids of 25 m^2 based on the prescription method outlined in section 3.4, so that the remaining crop residue could be removed from the field for supplementary income. This information, along with additional economic inputs, is then inserted into the budget model that producers can use to estimate whether their fields have enough variation in key areas to make variable crop residue collection an economically viable alternative.

4.2 Data

The data used in this analysis is from a 175 acre field site in Boone County, Iowa that is growing continuous corn and has significant variation in the following areas:

- Grain yield (bushel/acre)
- Soil loss due to water erosion (RUSLE2 output)
- Topography (elevation maps)
- Soil sample data at time of planting (% organic matter, nutrient levels, soil temperature)

Other factors taken into account by the joint study, but do not vary for the given farm site, include rainfall and average ambient air temperature. Wind erosion was not considered to be a significant factor in this joint study.

Figure 4.1: Topography, Uthe Farm, Boone County, Iowa

Source: (Birrell 2014)

The variations, illustrated in Figure 4.1, create a desire to determine differences in the need for crop residue across the field. They are used by Birrell (2014) to prescribe the optimum amounts of corn stover to return to the field. Grain and corn stover yields, along with the prescribed return rates, provide the necessary data to calculate how much corn stover can be collected.

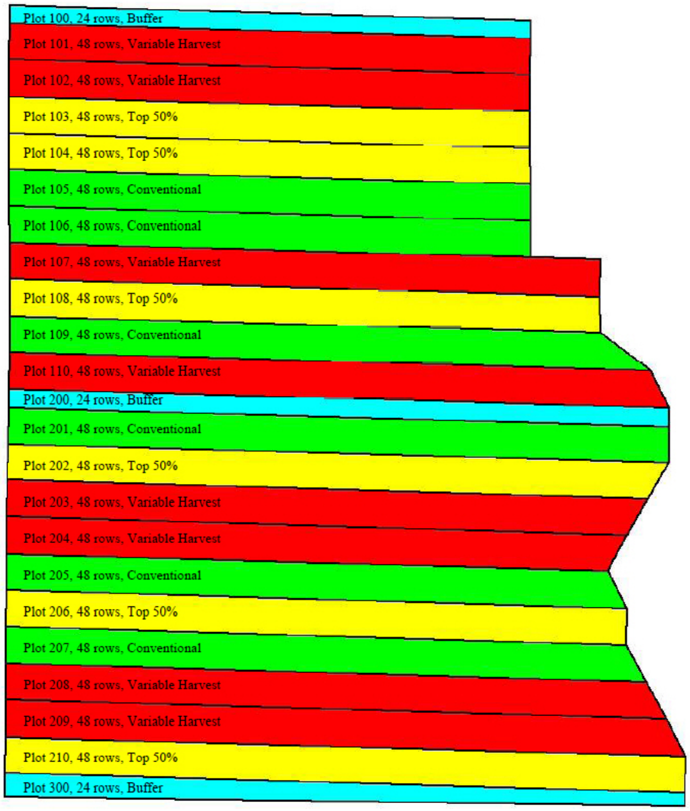
The joint study was conducted on two separate fields of the Uthe farm, shown in Figure 4.2. These field sites were selected due to their extreme variations in topography and soil types. Each field site was divided into plots, 20 at North Reynoldson and 10 at the Uthe site. Each plot ranges in size from 4.5 – 7 acres. Harvest data has been collected for the last four years using consistent treatments for crop rotation, harvest operations, and tillage operations. Data from the 2014 harvest will be used in the budget analysis to determine whether variable rate residue collection is more or less expense than constant rate collection for these specific field sites and the factors associated with them.

Figure 4.2: Field Layout, Uthe Farm, Boone County, Iowa

Source: (Birrell 2014)

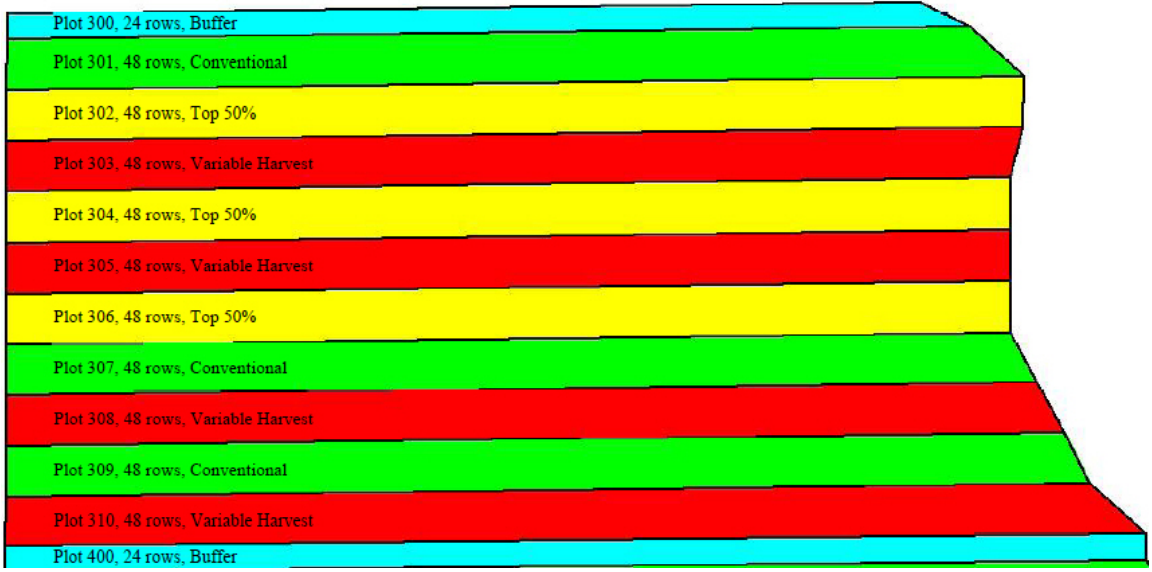
The design of the joint study includes three different harvesting methods and three different tillage practices. The harvesting methods include conventional harvesting, where all corn stover is returned to the field, constant rate crop residue collection, where the top 50% of the corn plant is collected, and variable rate residue collection, where a prescription is used to determine how much corn stover to return to the field in each 25 m^2 grid. The variable return rate across all plots is a prescription determined by variations in soil loss, elevation, rainfall, ambient air temperature, soil organic matter, and soil temperature. The tillage practices include conventional tillage, variable depth tillage, and no-till. Figures 4.3 and 4.4 illustrate the plot layouts for both fields.

Figure 4.3: Field Plots, North Reynoldson Field



Source: (Birrell 2014)

Figure 4.4: Field Plots, Uthe Field



Source: (Birrell 2014)

The reason to consider multiple tillage and crop residue removal treatments is to determine if they are directly related to the amount of crop residue that should be left on the surface. If certain treatments show a strong correlation to increased grain yield, they will be important factors in determining how much crop residue to leave on the surface. More crop residue on the surface generally results in less soil erosion, more soil organic matter, and slower soil warm-up in the spring when the crop is planted. According to related research, the organic matter in the soil is a significant factor when determining how much crop residue can be removed (Karlen, Varvel, et al. 2011).

Data from the joint study is compiled in a format that can be used to generate summaries for the data shown in tables 4.1, 4.2, and 4.3. Grain yield for each plot was calculated by dividing actual grain weights removed from each plot by the number of acres planted on each plot. In reality, a producer would use the grain yield values provided by their combine yield monitor, but for this study, actual grain weights were used to increase the accuracy of the results. Because the focus of this study is to compare variable rate to constant rate collection, the plots where no collection took place (table 4.3) serve only as a benchmark for calculating the potential grain yield increase or decrease (eq. 4.4). That leaves 12 plots where variable rate collection was employed and 9 plots where constant rate collection occurred. Those plots are summarized below (tables 4.1 and 4.2).

Table 4.1: Variable Rate Collection Plots, Joint Study Summary, 2014 Harvest

	Acres	Grain Yield (bu/acre)	Stover Yield (tons/acre)	Return Rate (tons/acre)	Total Stover (tons/acre)	Stover Harvested (%)	Yield Change (%) (eq. 4.4)
	4.551	152.14	1.46	3.66	5.12	28.52%	-3.63%
	4.717	132.54	1.18	2.53	3.71	31.81%	-16.05%
	5.18	169.40	1.53	4.43	5.96	25.67%	7.30%
	5.779	156.35	1.29	4.64	5.93	21.75%	-0.96%
	4.698	163.48	1.39	3.24	4.63	30.02%	3.55%
	4.591	153.81	1.03	2.93	3.96	26.01%	-2.57%
	5.276	154.47	1.15	3.82	4.97	23.14%	-2.15%
	5.399	148.42	1.05	2.8	3.85	27.27%	-5.98%
	5.942	181.79	0.91	2.98	3.89	23.39%	15.15%
	5.866	150.37	1.07	2.74	3.81	28.08%	-4.75%
	6.508	175.09	1.59	5.13	6.72	23.66%	10.90%
	6.988	159.16	1.65	4.75	6.4	25.78%	0.82%
Total	65.500						
Wt. Avg.	5.460	158.84	1.28	3.70	4.99	26.05%	0.61%
Std Dev	0.780	13.09	0.25	0.9	1.11	3.00%	8.00%
Min	4.551	132.54	0.91	2.53	3.71	21.75%	-16.05%
Max	6.988	181.79	1.65	5.13	6.72	31.81%	15.15%

Table 4.2: Constant Rate Collection Plots, Joint Study Summary, 2014 Harvest

	Acres	Grain Yield (bu/acre)	Stover Yield (tons/acre)	Return Rate (tons/acre)	Total Stover (tons/acre)	Stover Harvested (%)	Yield Change (%) (eq. 4.4)
	4.571	155.19	1.25	2.31	3.56	35.11%	-1.70%
	4.658	142.02	1.23	2.2	3.43	35.86%	-10.04%
	5.278	160.16	1.14	2.71	3.85	29.61%	1.45%
	5.099	162.60	1.33	4.18	5.51	24.14%	3.00%
	4.969	158.01	0.93	4.03	4.96	18.75%	0.09%
	5.288	150.56	0.98	2.62	3.6	27.22%	-4.63%
	6.399	175.46	1.72	3.81	5.53	31.10%	11.14%
	5.903	184.09	2.5	2.76	5.26	47.53%	16.61%
	6.189	149.10	1.42	2.64	4.06	34.98%	-5.56%
Total	48.350						
Wt. Avg.	5.370	160.46	1.42	3.05	4.47	31.85%	1.64%
Std Dev	0.650	13.15	0.48	0.76	0.88	8.00%	8.00%
Min	4.571	142.02	0.93	2.2	3.43	18.75%	-10.04%
Max	6.399	184.09	2.5	4.18	5.53	47.53%	16.61%

Table 4.3: Conventional Harvest Plots, Joint Study Summary, 2014 Harvest

	Acres	Grain Yield (bu/acre)	Stover Yield (tons/acre)	Return Rate (tons/acre)	Total Stover (tons/acre)	Stover Harvested (%)	Yield Change (%) (eq. 4.4)
	4.585	171.05		3.82	3.82		8.35%
	4.636	158.38		4.87	4.87		0.32%
	5.522	165.97		3.24	3.24		5.13%
	5.803	138.55		3.73	3.73		-12.24%
	4.701	138.96		2.8	2.8		-11.98%
	5.170	132.46		3.86	3.86		-16.10%
	6.039	178.49		5.35	5.35		13.06%
	6.353	160.92		2.91	2.91		1.93%
	6.746	169.88		2.98	2.98		7.61%
Total	49.560						
Wt. Avg.	5.510	157.87	0	3.71	3.71	0	0.00%
Std Dev	0.790	16.55	0	0.89	0.89	0	10.00%
Min	4.585	132.46	0	2.8	2.8	0	-16.10%
Max	6.746	178.49	0	5.35	5.35	0	13.06%

The weight of the corn stover removed from each plot was provided from the joint study, in addition to grain yields and corn stover return rates for each plot. The corn stover yield (eq. 4.1), total corn stover produced (eq. 4.2), percentage of corn stover harvested (eq. 4.3), and potential grain yield increase or decrease (eq. 4.4) are calculated for each plot and summarized in tables 4.1, 4.2, and 4.3.

(4.1) Corn stover yield (tons/acre) = corn stover weight (lbs) / 2000 / acres

(4.2) Total corn stover (tons/acre) =

corn stover yield (tons/acre) + return rate (tons/acre)

(4.3) Stover harvested (%) =

corn stover yield (tons/acre) / total corn stover (tons/acre)

(4.4) Potential grain yield increase or decrease (%) =

(grain yield – benchmark grain yield) / benchmark grain yield

If all areas of the field required the same amount of crop residue to be fully optimized, this study would be concluded with a simple assertion that constant rate collection is the best solution. However, the field variations discussed so far in this study will cause the crop residue requirements to vary throughout the field. Tables 4.1 and 4.2 show the corn stover removal for variable rate collection averaged 26.05%, compared to constant rate collection, which averaged 31.85%. However, the hypothesis that grain yield and corn stover yield are positively correlated did not prove to be true in this case study. The variable rate plots had a lower average grain yield of 158.84 bushel/acre, compared to 160.46 for the constant rate plots, but they had more total corn stover available and therefore a higher return rate of 3.70 tons/acre, compared to 3.05 for the constant rate plots.

Since the prescriptions made for the variable rate return of crop residue to the surface required that soil loss due to water erosion did not exceed the soil loss thresholds set by the USDA-NRCS, variable rate collection resulted in a smaller percentage of corn stover collected. For instance, steep slopes in the field are more susceptible to erosion, so they require more crop residue to remain on the surface. These areas may also have less total crop residue available due to lower grain (and corn stover) yields.

4.3 Model

A budget model is developed to aid producers in determining whether variable rate crop residue collection based on a prescription return rate is best for their fields. The model is tailored to corn stover, but it could be adapted to other forms of crop residue if necessary. This economic analysis looks at the net returns to collect the amounts of corn stover which maximize grain yield and soil fertility. There are many alternative methods for collecting corn stover, which can affect the net returns of collecting crop residue. The collection method evaluated in this analysis is single-pass baling. This method requires a mechanical system that collects the corn stover directly out of the combine and feeds it into a baler. The advantages of using such a system are that it does not remove the lower stalk sections, which contain the majority of the nutrients that the next crop will need, it does not allow the corn stover to touch the ground, eliminating dirt and debris from getting into the bales, and it is the easiest to control with software to adjust collection rates on the go.

For variable rate collection, the system would likely be controlled to return finite levels of corn stover to the field (low, medium, and high settings, for example). There are also shredding, raking, and baling techniques, called second and third pass baling that can be considered with this budget model. There are economic trade-offs to the various collection methods, which would make for an interesting follow-up study.

4.4 Model Inputs

The budget model requires the producer to enter data for crop-specific inputs, incremental operating costs associated with their combine, and operating costs for auxiliary equipment that they must purchase and maintain in order to harvest corn stover. Additional transportation cost data are also required if they plan to load and truck the bales using their own equipment or a contracted hauler. Other factors taken into account in the budget model include nutrient replacement costs, the amount of total corn stover available, the amount that can be sustainably harvested, and any potential yield increases or decreases that may actually occur from removing corn stover from the field. The budget model specifically requires the following key economic data:

- Price per ton of harvested corn stover.
- Average bale weight.
- Price of corn.
- Combine price, financing period, fuel use, fuel cost, total working hours, and operator labor cost.
- Decrease in harvest productivity as a result of simultaneous residue collection.
- Auxiliary equipment operating costs.
    - List price, financing period, annual interest rate, and parameters related to Netwrap expenses.
- Transportation method, either contract trucking or hauling on own trailer.

    - If contracting, trucking rate, trailer size, transport distance, loading & unloading time, and loader tractor fuel use.
    - If hauling, trailer size, transport distance, loading & unloading time, loader tractor fuel use, fuel mileage, fuel cost, average hauling speed, and operator labor cost.
- Nutrient replacement – cost of Nitrogen, Phosphorus, and Potassium.
- Potential yield increases or decreases from partial removal of corn residue.

4.5 Model Equations

The budget model first calculates how much corn stover is harvested for both constant rate and variable rate collection scenarios (eq. 4.5), as well as corn stover yield (eq. 4.6) for both scenarios. Total corn stover available from each plot is also calculated using site-specific data (eq. 4.7). The corn stover data used in this study is based on the joint study field plots and may not be representative of all situations.

(4.5) Total corn stover (tons/acre) =

corn stover return rate (tons/acre) / (1 - % of corn stover harvested)

(4.6) Corn stover yield (tons/acre) =

total corn stover (tons/acre) x % of corn stover harvested

(4.7) Total corn stover harvested (ton) =

corn stover yield (tons/acres) x plot size (acres)

The number of bales harvested per year (eq. 4.8) and per acre (eq. 4.9) are then calculated.

(4.8) Number of bales/year = corn stover harvested (tons) x 2000 / bale weight (lbs)

(4.9) Number of bales/acre = bales per year / plot size (acres)

The model then calculates the factors associated with the following operations:

Incremental Operating Costs – Combine

(4.10) Harvesting rate (acres/hour) =

plot size (acres) / separator hours run on combine / number of plots

(4.11) Residual value (combine) =

(C1- (C2 x Years Financed^-.05) - (C3 x hours used/year^-0.5))^2

C1, C2, & C3 determined by ASABE Standard D497.7

This case study assumes a finance period of 5 years.

Operating Costs – Auxiliary Equipment

(4.12) Residual value (equipment) =

(C1- (C2 x Years Financed^-.05) - (C3 x hours used/year^-0.5))^2

C1, C2, & C3 determined by ASABE Standard D497.7

This case study assumes a finance period of 5 years.

(4.13) Maintenance costs ($/bale) = total equipment costs x 0.02 / bales per year

The model assumes 2% maintenance costs, which is an estimate by Hillco Technologies.

Transportation Costs – Trucking and Logistics

(4.14) Number of bales per Netwrap roll =

Netwrap length (ft) / (2 x 3.14 x bale diameter (ft)/2 x 4.5)

The model assumes 4.5 wraps of Netwrap are used per bale, which is recommended by Hillco Technologies.

Calculations are made for two trucking scenarios – one in which the hauling is contracted out to an independent trucker, and one in which the producer hauls the bales with their own truck and trailer. The factors used are determined by whether the producer selects “contract” or “own” in the budget model.

(4.15) Number of bales per trailer =

(trailer size (ft) / bale diameter (ft) x 2) + (trailer size (ft) / bale diameter (ft) – 1)

This assumes two bales are placed across the width of trailer for the first level and one bale width for the second level.

(4.16) Net transport weight (lbs/trailer) =

number of bales per trailer x bale weight (lbs)

(4.17) Number of loads per year = bales per year / bales per trailer

(4.18) Contract trucking cost per loaded mile =

trucking rate ($/bale/loaded mile) x number of bales per trailer

(4.19) Total hauling cost (contract) =

number of loads x transport distance (miles, one way) x trucking cost per loaded mile

(4.20) Total hauling cost (own) =

$$\frac{\textbf{number of loads x 2 x transport distance (miles, one way)}}{\textbf{fuel mileage (miles/gallon) x fuel cost (\$/gallon)}} + \frac{\textbf{number of loads x 2 x transport distance (miles, one way)}}{\textbf{average speed (miles/hour) x operator labor cost (\$/hour)}}$$

(4.21) Loading & unloading time (hours) =

bales per year x 2 x loading & unloading time (minutes/bale) / 60

Other Factors

(4.22) Equivalent corn stover to be replaced (tons) =

(corn stover yield – 1 (tons/acre)) x plot size (acres)

It is recommended that for removal rates below 1 ton/acre, no additional nutrient applications are needed (Karlen, Kovar and Birrell 2014).

(4.23) Equivalent Nitrogen (N, lbs) = equivalent corn stover (tons) x 14 (lbs/ton)

(4.24) Equivalent Phosphorus (P, lbs) = equivalent corn stover (tons) x 1.4 (lbs/ton)

(4.25) Equivalent Potassium (K, lbs) = equivalent corn stover (tons) x 16 (lbs/ton)

Harvesting corn stover results in 14 lbs/ton of N, 1.4 lbs/ton of P, and 16 lbs/ton of K to be removed (Karlen, Kovar and Birrell 2014).

Finally, profit and return per acre are calculated by subtracting all costs from the revenue generated by selling corn stover. The model provides a direct comparison of profitability with constant rate and variable rate collection.

(4.26) Revenue from corn stover =

corn stover yield (tons/acre) x corn stover price ($/ton) x plot size (acres)

- *Incremental Operating Costs – Combine*

(4.27) Increased fuel consumption =

$$\frac{\textbf{combine fuel use (gallons/hour)}}{\textbf{harvesting rate (acres/hour)}}$$

x fuel cost ($/gallon) x plot size (acres) x decreased harvest productivity (%)

(4.28) Increased combine depreciation =

$$\frac{\textbf{[current value – future value]}}{\textbf{financing periods (years)}}$$

x decreased harvest productivity (%)

(4.29) Increased labor costs =

$$\frac{\textbf{operator labor cost (\$/hour)}}{\textbf{harvest rate (acres/hour)}}$$

x plot size (acres) x decreased harvest productivity (%)

- *Operating Costs – Auxiliary Equipment*

(4.30) Depreciation = [equipment costs – residual value] / financing periods

(4.31) Interest costs =

$$\frac{\textbf{CUMIPMT(annual interest rate, financing periods, equipment costs, 1, 3, 0)}}{\textbf{Financing periods}}$$

(4.32) Maintenance costs =

maintenance costs (\$/bale) x bales per acre x plot size (acres)

(4.33) Netwrap costs = cost of Netwrap (\$/roll) / bales per roll x bales per year

- *Transportation Costs – Trucking and Logistics*

(4.34) Moving bales to storage (shown above)

(4.35) Loading & unloading costs =

(loading & unloading time (hours) x operator labor cost (\$/hour))

+ (loading & unloading time (hours) x tractor fuel use (gallons/hour)

x fuel cost (\$/gallon))

- *Other Factors*

(4.36) Nutrient replacement costs (\$) =

equivalent Nitrogen (lbs) x Nitrogen cost (\$/lb)

+ equivalent Phosphorus (lbs) x Phosphorus cost (\$/lb)

+ equivalent Potassium (lbs) x Potassium cost (\$/lb)

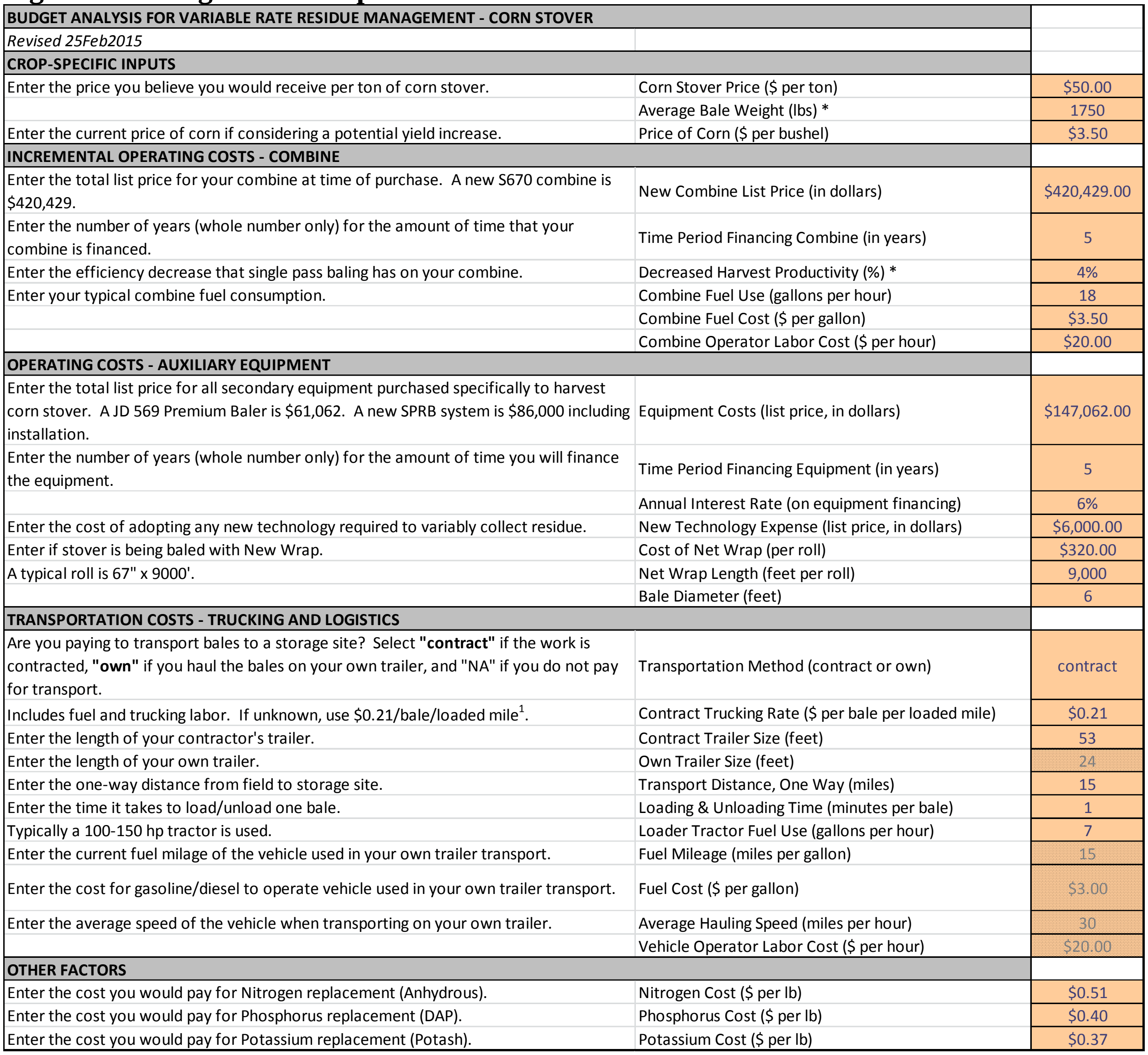
(4.37) Potential yield increase or decrease =

potential yield increase or decrease (%) x price of corn ($/bushel)

x grain yield (bushel/acre) x plot size (acres)

The budget model (figures 4.5, 4.6, 4.7, and 4.8) represents site-specific data from the joint study field sites. Assumptions were made regarding the input costs (figure 4.5) based on representative data provided by Hillco Technologies and John Deere. This data will vary based on a producer’s unique situation. For example, in this case study it is assumed that all equipment will be financed over five years. That can be adjusted down if the producer has a larger scale operation to spread costs over. The model has the functionality to be able to enter actual field plot acres and then utilize the goal seek function to scale the entire operation up or down to determine the size of farm necessary to break even with either constant or variable rate collection. This has been done with the joint field studies to help draw conclusions between the collection methods. For a simple comparison, the data in the following figures has been scaled up to represent a 500 acre farm for both constant rate and variable rate collection.

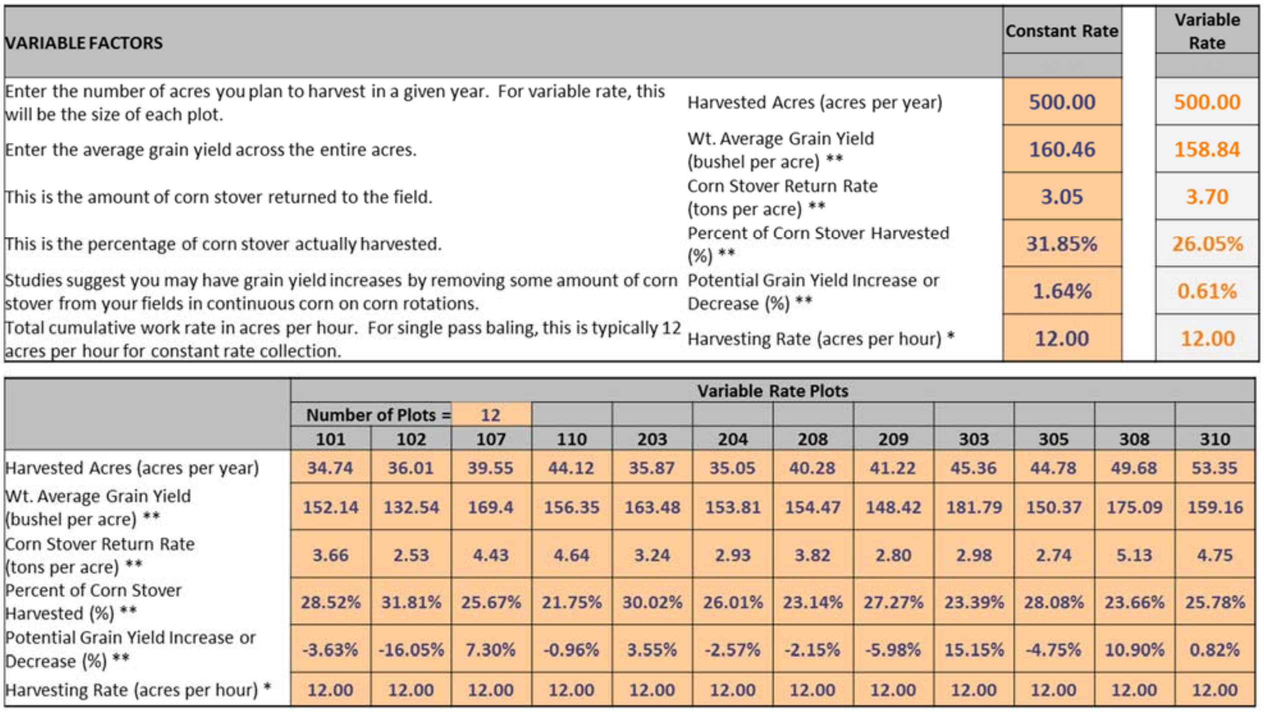
Figure 4.5: Budget Model Inputs



BUDGET ANALYSIS FOR VARIABLE RATE RESIDUE MANAGEMENT - CORN STOVER		
Revised 25Feb2015		
CROP-SPECIFIC INPUTS		
Enter the price you believe you would receive per ton of corn stover.	Corn Stover Price ($ per ton)	$50.00
	Average Bale Weight (lbs) *	1750
Enter the current price of corn if considering a potential yield increase.	Price of Corn ($ per bushel)	$3.50
INCREMENTAL OPERATING COSTS - COMBINE		
Enter the total list price for your combine at time of purchase. A new S670 combine is $420,429.	New Combine List Price (in dollars)	$420,429.00
Enter the number of years (whole number only) for the amount of time that your combine is financed.	Time Period Financing Combine (in years)	5
Enter the efficiency decrease that single pass baling has on your combine.	Decreased Harvest Productivity (%) *	4%
Enter your typical combine fuel consumption.	Combine Fuel Use (gallons per hour)	18
	Combine Fuel Cost ($ per gallon)	$3.50
	Combine Operator Labor Cost ($ per hour)	$20.00
OPERATING COSTS - AUXILIARY EQUIPMENT		
Enter the total list price for all secondary equipment purchased specifically to harvest corn stover. A JD 569 Premium Baler is $61,062. A new SPRB system is $86,000 including installation.	Equipment Costs (list price, in dollars)	$147,062.00
Enter the number of years (whole number only) for the amount of time you will finance the equipment.	Time Period Financing Equipment (in years)	5
	Annual Interest Rate (on equipment financing)	6%
Enter the cost of adopting any new technology required to variably collect residue.	New Technology Expense (list price, in dollars)	$6,000.00
Enter if stover is being baled with New Wrap.	Cost of Net Wrap (per roll)	$320.00
A typical roll is 67" x 9000'.	Net Wrap Length (feet per roll)	9,000
	Bale Diameter (feet)	6
TRANSPORTATION COSTS - TRUCKING AND LOGISTICS		
Are you paying to transport bales to a storage site? Select **"contract"** if the work is contracted, **"own"** if you haul the bales on your own trailer, and "NA" if you do not pay for transport.	Transportation Method (contract or own)	contract
Includes fuel and trucking labor. If unknown, use $0.21/bale/loaded mile[1].	Contract Trucking Rate ($ per bale per loaded mile)	$0.21
Enter the length of your contractor's trailer.	Contract Trailer Size (feet)	53
Enter the length of your own trailer.	Own Trailer Size (feet)	24
Enter the one-way distance from field to storage site.	Transport Distance, One Way (miles)	15
Enter the time it takes to load/unload one bale.	Loading & Unloading Time (minutes per bale)	1
Typically a 100-150 hp tractor is used.	Loader Tractor Fuel Use (gallons per hour)	7
Enter the current fuel milage of the vehicle used in your own trailer transport.	Fuel Mileage (miles per gallon)	15
Enter the cost for gasoline/diesel to operate vehicle used in your own trailer transport.	Fuel Cost ($ per gallon)	$3.00
Enter the average speed of the vehicle when transporting on your own trailer.	Average Hauling Speed (miles per hour)	30
	Vehicle Operator Labor Cost ($ per hour)	$20.00
OTHER FACTORS		
Enter the cost you would pay for Nitrogen replacement (Anhydrous).	Nitrogen Cost ($ per lb)	$0.51
Enter the cost you would pay for Phosphorus replacement (DAP).	Phosphorus Cost ($ per lb)	$0.40
Enter the cost you would pay for Potassium replacement (Potash).	Potassium Cost ($ per lb)	$0.37

It is important to note that the variable factors (figure 4.6) are specific to the actual field sites and will vary for every producer’s unique field data. The effects of these variations will be studied further in a subsequent sensitivity analysis. The results shown in the variable rate column are either a weighted average or summation of all 12 plots. The weighting is necessary because each plot is a slightly different size. The data entered for the 12 individual plots for variable rate collection are also shown in figure 4.6.

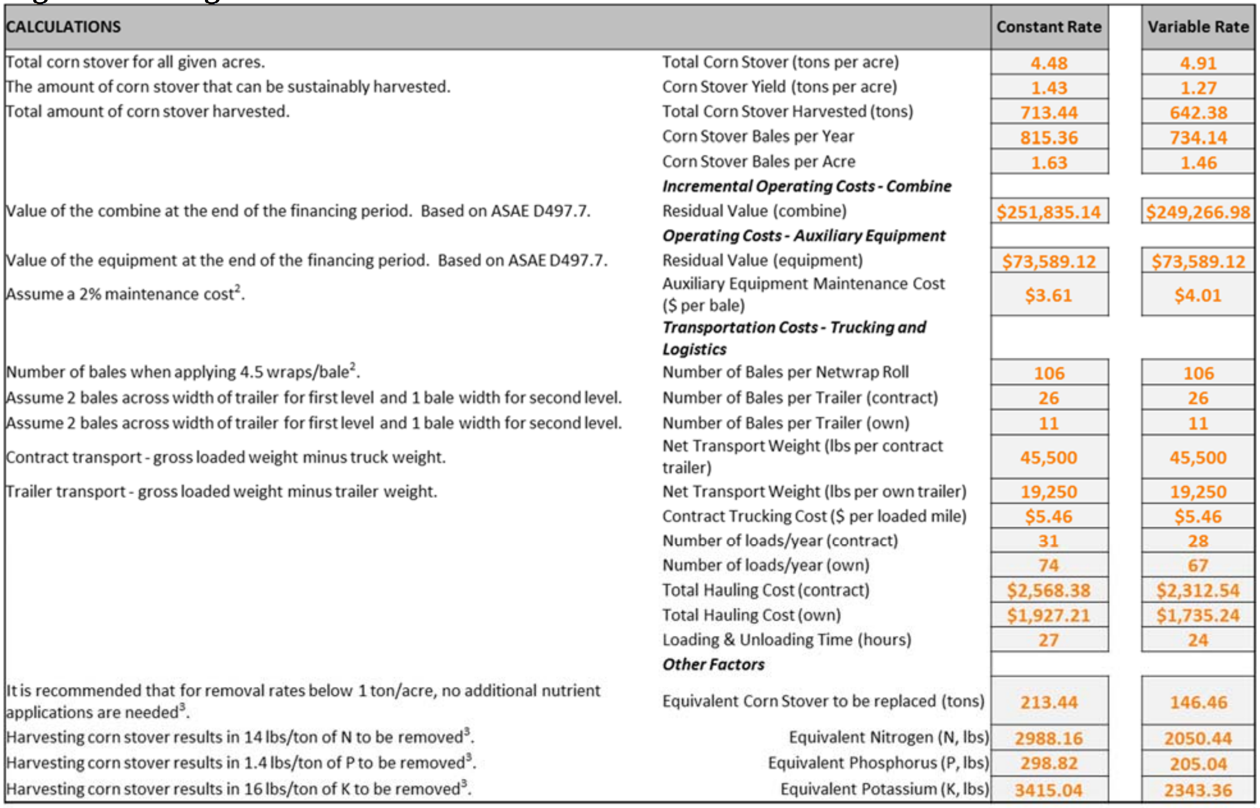
Figure 4.6: Budget Model Variable Factors



VARIABLE FACTORS		Constant Rate	Variable Rate
Enter the number of acres you plan to harvest in a given year. For variable rate, this will be the size of each plot.	Harvested Acres (acres per year)	500.00	500.00
Enter the average grain yield across the entire acres.	Wt. Average Grain Yield (bushel per acre) **	160.46	158.84
This is the amount of corn stover returned to the field.	Corn Stover Return Rate (tons per acre) **	3.05	3.70
This is the percentage of corn stover actually harvested.	Percent of Corn Stover Harvested (%) **	31.85%	26.05%
Studies suggest you may have grain yield increases by removing some amount of corn stover from your fields in continuous corn on corn rotations.	Potential Grain Yield Increase or Decrease (%) **	1.64%	0.61%
Total cumulative work rate in acres per hour. For single pass baling, this is typically 12 acres per hour for constant rate collection.	Harvesting Rate (acres per hour) *	12.00	12.00

	Variable Rate Plots											
	Number of Plots =	12										
	101	102	107	110	203	204	208	209	303	305	308	310
Harvested Acres (acres per year)	34.74	36.01	39.55	44.12	35.87	35.05	40.28	41.22	45.36	44.78	49.68	53.35
Wt. Average Grain Yield (bushel per acre) **	152.14	132.54	169.4	156.35	163.48	153.81	154.47	148.42	181.79	150.37	175.09	159.16
Corn Stover Return Rate (tons per acre) **	3.66	2.53	4.43	4.64	3.24	2.93	3.82	2.80	2.98	2.74	5.13	4.75
Percent of Corn Stover Harvested (%) **	28.52%	31.81%	25.67%	21.75%	30.02%	26.01%	23.14%	27.27%	23.39%	28.08%	23.66%	25.78%
Potential Grain Yield Increase or Decrease (%) **	-3.63%	-16.05%	7.30%	-0.96%	3.55%	-2.57%	-2.15%	-5.98%	15.15%	-4.75%	10.90%	0.82%
Harvesting Rate (acres per hour) *	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00

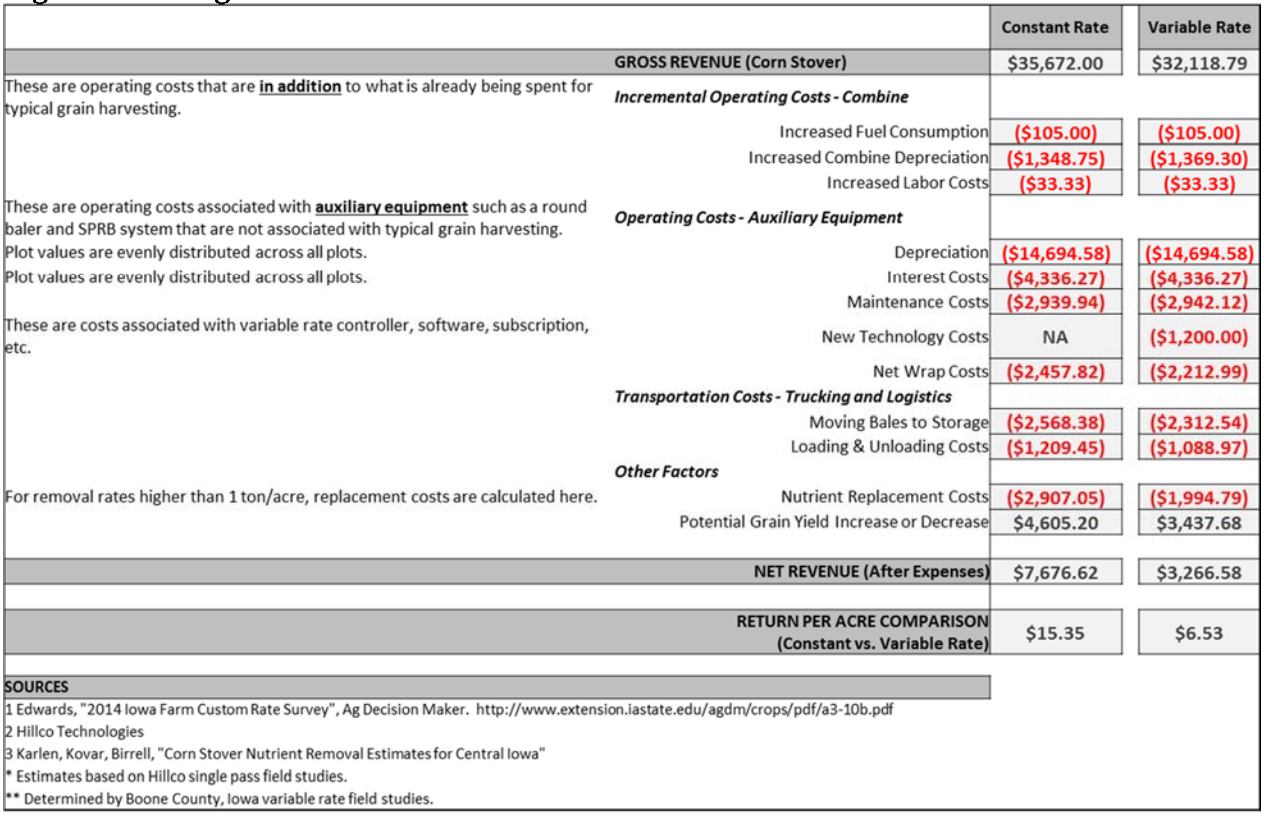
Figure 4.7 Budget Model Calculations



CALCULATIONS		Constant Rate	Variable Rate
Total corn stover for all given acres.	Total Corn Stover (tons per acre)	4.48	4.91
The amount of corn stover that can be sustainably harvested.	Corn Stover Yield (tons per acre)	1.43	1.27
Total amount of corn stover harvested.	Total Corn Stover Harvested (tons)	713.44	642.38
	Corn Stover Bales per Year	815.36	734.14
	Corn Stover Bales per Acre	1.63	1.46
	Incremental Operating Costs - Combine		
Value of the combine at the end of the financing period. Based on ASAE D497.7.	Residual Value (combine)	$251,835.14	$249,266.98
	Operating Costs - Auxiliary Equipment		
Value of the equipment at the end of the financing period. Based on ASAE D497.7.	Residual Value (equipment)	$73,589.12	$73,589.12
Assume a 2% maintenance cost[2].	Auxiliary Equipment Maintenance Cost ($ per bale)	$3.61	$4.01
	Transportation Costs - Trucking and Logistics		
Number of bales when applying 4.5 wraps/bale[2].	Number of Bales per Netwrap Roll	106	106
Assume 2 bales across width of trailer for first level and 1 bale width for second level.	Number of Bales per Trailer (contract)	26	26
Assume 2 bales across width of trailer for first level and 1 bale width for second level.	Number of Bales per Trailer (own)	11	11
Contract transport - gross loaded weight minus truck weight.	Net Transport Weight (lbs per contract trailer)	45,500	45,500
Trailer transport - gross loaded weight minus trailer weight.	Net Transport Weight (lbs per own trailer)	19,250	19,250
	Contract Trucking Cost ($ per loaded mile)	$5.46	$5.46
	Number of loads/year (contract)	31	28
	Number of loads/year (own)	74	67
	Total Hauling Cost (contract)	$2,568.38	$2,312.54
	Total Hauling Cost (own)	$1,927.21	$1,735.24
	Loading & Unloading Time (hours)	27	24
	Other Factors		
It is recommended that for removal rates below 1 ton/acre, no additional nutrient applications are needed[3].	Equivalent Corn Stover to be replaced (tons)	213.44	146.46
Harvesting corn stover results in 14 lbs/ton of N to be removed[3].	Equivalent Nitrogen (N, lbs)	2988.16	2050.44
Harvesting corn stover results in 1.4 lbs/ton of P to be removed[3].	Equivalent Phosphorus (P, lbs)	298.82	205.04
Harvesting corn stover results in 16 lbs/ton of K to be removed[3].	Equivalent Potassium (K, lbs)	3415.04	2343.36

Various calculations that are used in the final revenue formulas are depicted in figure 4.7. It should be noted that the residual value of the combine is slightly lower for variable rate collection because of the 4% decreased harvest productivity, which results in more hours being put on the combine. This also leads to slightly more combine depreciation, as shown in figure 4.8. Figure 4.8 also shows the calculations made for gross revenue, net revenue, and return per acre. The scenarios shown represent the revenue generated on 500 total harvested acres when using the joint study data. A producer would want to use their actual acres to calculate a positive or negative return.

Figure 4.8: Budget Model Revenue Calculations



		Constant Rate	Variable Rate
	GROSS REVENUE (Corn Stover)	$35,672.00	$32,118.79
These are operating costs that are **in addition** to what is already being spent for typical grain harvesting.	***Incremental Operating Costs - Combine***		
	Increased Fuel Consumption	($105.00)	($105.00)
	Increased Combine Depreciation	($1,348.75)	($1,369.30)
	Increased Labor Costs	($33.33)	($33.33)
These are operating costs associated with **auxiliary equipment** such as a round baler and SPRB system that are not associated with typical grain harvesting.	***Operating Costs - Auxiliary Equipment***		
Plot values are evenly distributed across all plots.	Depreciation	($14,694.58)	($14,694.58)
Plot values are evenly distributed across all plots.	Interest Costs	($4,336.27)	($4,336.27)
	Maintenance Costs	($2,939.94)	($2,942.12)
These are costs associated with variable rate controller, software, subscription, etc.	New Technology Costs	NA	($1,200.00)
	Net Wrap Costs	($2,457.82)	($2,212.99)
	Transportation Costs - Trucking and Logistics		
	Moving Bales to Storage	($2,568.38)	($2,312.54)
	Loading & Unloading Costs	($1,209.45)	($1,088.97)
	Other Factors		
For removal rates higher than 1 ton/acre, replacement costs are calculated here.	Nutrient Replacement Costs	($2,907.05)	($1,994.79)
	Potential Grain Yield Increase or Decrease	$4,605.20	$3,437.68
	NET REVENUE (After Expenses)	$7,676.62	$3,266.58
	RETURN PER ACRE COMPARISON (Constant vs. Variable Rate)	$15.35	$6.53

SOURCES

1 Edwards, "2014 Iowa Farm Custom Rate Survey", Ag Decision Maker. http://www.extension.iastate.edu/agdm/crops/pdf/a3-10b.pdf
2 Hillco Technologies
3 Karlen, Kovar, Birrell, "Corn Stover Nutrient Removal Estimates for Central Iowa"
* Estimates based on Hillco single pass field studies.
** Determined by Boone County, Iowa variable rate field studies.

CHAPTER V: RESULTS

5.1 Uthe Farms Data Summary

The joint study provides the necessary data to evaluate whether variable rate collection pays off for a specific field site. One output of the joint study is corn stover return rates, which are determined across a grid network based on several key variables. To employ variable rate collection, a producer must first come up with a prescription for pre-defined grid areas. This prescription should be derived from a combination of data on grain yield, soil loss due to wind and water erosion, topography (elevation), and soil sample data at time of planting (% organic matter, nutrient levels, soil temperature) (Nelson, et al. 2004).

It is shown in Table 5.1 that grain yields were higher for instances where some level of corn stover was removed. Plots where constant rate collection was used actually had the highest overall grain yields, while plots with variable rate collection had the second highest grain yields. Plots where conventional harvesting was used (no collection) showed the lowest grain yields. The prescription approach resulted in a lower percentage of corn stover being collected than the constant rate approach and therefore more being returned to the field to help manage the soil health.

Table 5.1: Comparisons of Grain Yield and Corn Stover

	Wt. Average Grain Yield (bu/acre)	% of Stover Collected	Stover Return Rate (tons/acre)
Conventional Harvest	157.87	0%	3.71
Constant Rate Collection	160.46	31.85%	3.05
Variable Rate Collection	158.84	26.05%	3.70

An important output of this prescription approach is the corn stover return rates throughout the field. This case study illustrates that less corn stover can be returned to the field through constant or variable rate collection while sustaining higher grain yields than a conventional harvest that would return all of the corn stover to the field. This is a key discovery in determining whether any corn stover should be removed, and should be confirmed for each unique field site.

Using what is learned from the joint study, a budget model is developed to determine whether it is economical to remove corn stover variably from different areas within a given field. To validate the model, data from the actual field plots harvested in the joint study is used, which includes prescriptions for the optimum level of corn stover that should remain in each plot in order to maintain soil health and sustain the environment, as well as how much can be removed. The budget model also uses data that is readily available to a producer, as well as assumptions derived from related research, to determine whether variable rate collection provides more profit potential than constant rate collection.

In the case of the joint study field sites, the budget model predicts that constant rate collection would be slightly more profitable than harvesting at a variable rate. In this case, constant rate collection does not become profitable until a minimum of 376 total acres are harvested due primarily to the large investments in harvesting equipment. Table 5.2 shows that at this size of operation, variable rate collection would cost an extra \$3,620.61, or \$9.62 per acre, considering all investments and expenses related to harvesting the corn stover using a single pass system. Variable rate collection is also impacted by the lower grain yields seen in those plots compared to the constant rate collection plots.

Table 5.2: Financial Summary at Break-Even Point for Constant Rate Collection

376 acres	Gross Revenue	Total Costs	Grain Yield Change	Net Revenue
Constant Rate Collection	$26,837.34	($30,302.01)	$3,464.66	$0.00
Variable Rate Collection	$24,164.25	($30,371.16)	$2,586.30	($3,620.61)

Table 5.3 summarizes the same data at the break-even point for variable rate collection. In this scenario, the producer does not become profitable until at least 441 total acres are harvested. With this size of operation, constant rate collection would generate an extra $4,035.80 in net revenue, or $9.15 per acre, considering all investments and expenses related to harvesting the corn stover using a single pass system.

Table 5.3: Financial Summary at Break-Even Point for Variable Rate Collection

441 acres	Gross Revenue	Total Costs	Grain Yield Change	Net Revenue
Constant Rate Collection	$31,481.97	($31,510.45)	$4,064.27	$4,035.80
Variable Rate Collection	$28,345.85	($31,379.71)	$3,033.86	$0.00

This case study does not infer that variable rate collection will always generate less revenue. A couple key factors are hidden in the costs. Nutrient replacement costs are a key determinant, especially when collection rates get over 30%. Due to the lower average collection rates in the variable rate plots, $427 is saved at breakeven in this case study through less nutrient replacement requirements. This would become more substantial if the constant collection rate grew higher. There is also a cost of adoption that goes along with variable rate collection that should decrease over time as it becomes a more accepted farming practice. It is estimated at $6,000 in this model, but the technology is not yet fully developed and a price in the market has not been set.

5.2 Sensitivity Analysis

Since constant rate collection is more profitable in this case study, it is desirable to determine when that changes due to more extreme variations in the field data. The following sensitivity analysis is derived from a baseline of when both collection methods are at their break-even point for revenue. The factors considered include total harvested acres, weighted average grain yield, corn stover return rate, percent of corn stover harvested, and potential grain yield increase or decrease. Table 5.4 depicts the sensitivity to the total harvested acres in this case study. This data shows that as the number of acres increases, the difference in return between constant and variable rate collection decreases. This difference appears to be decreasing at a decreasing rate, and the equipment used will have limitations on how many acres it can harvest, so going over 2000 acres would be of limited value.

Table 5.4: Sensitivity to Total Acres

	Change in Return/Acre		
Acres	**Constant Rate**	**Variable Rate**	**Difference**
200	($54.61)	($67.09)	($12.49)
300	($15.74)	($26.19)	($10.45)
376.17	$0.00	($9.62)	($9.62)
441.27	$9.15	$0.00	($9.15)
500	$15.35	$6.53	($8.82)
600	$23.13	$14.71	($8.41)
700	$28.68	$20.56	($8.12)
800	$32.84	$24.94	($7.90)
2000	$50.33	$43.35	($6.99)

One reason that the model predicted a revenue advantage to constant rate collection is because it exhibited a greater grain yield. It cannot be statistically proven that this grain yield differential is due to the method of corn stover collection (Birrell 2014). Table 5.5 shows that if grain yields were equal and all other variables held constant, variable rate collection would actually have a greater return/acre at lower yields until you reach a common grain yield of 170 bushel/acre. At that point, constant rate collection becomes more profitable. However, the differences in return/acre are negligible.

Table 5.5: Sensitivity to Grain Yield

	Change in Return/Acre		
Grain Yield (bu/acre)	**Constant Rate**	**Variable Rate**	**Difference**
140	(\$1.17)	(\$0.82)	\$0.36
150	(\$0.60)	(\$0.38)	\$0.22
158.84	(\$0.09)	\$0.00	\$0.09
160.46	\$0.00	\$0.07	\$0.07
170	\$0.55	\$0.48	(\$0.06)
180	\$1.12	\$0.92	(\$0.21)
190	\$1.70	\$1.35	(\$0.35)
200	\$2.27	\$1.78	(\$0.49)
250	\$5.14	\$3.95	(\$1.19)

The amount of corn stover returned to the field can also vary, depending on how the prescription is set up. In this case study, the return rate in each variably collected plot was determined for 25 m^2 grids and then averaged for the purpose of this analysis. Table 5.6 shows that variable rate collection is profitable when the return rate is above 3.70 tons/acre, all other variables held constant, but still not as profitable as constant rate. This occurs because the total corn stover produced, and therefore collected, also goes up when all other variable factors are held constant.

Table 5.6: Sensitivity to Return Rate

	Change in Return/Acre		
Return Rate (ton/acre)	**Constant Rate**	**Variable Rate**	**Difference**
2.5	($7.16)	($13.55)	($6.39)
3.05	$0.00	($7.01)	($7.01)
3.2	$1.94	($5.30)	($7.24)
3.4	$4.47	($3.13)	($7.60)
3.6	$7.05	($1.03)	($8.08)
3.70	$8.35	$0.00	($8.35)
3.8	$9.68	$0.94	($8.74)
4.0	$12.22	$2.93	($9.30)

The sensitivity to the percentage of corn stover harvested tells a different story. With all other variables held constant, if this percentage is equal for both collection methods, then variable rate is more profitable than constant rate. This occurs because increasing the percentage of corn stover harvested increases the total amount harvested using variable rate, which increases gross revenue. The breakeven point for variable rate (26.05%) is also lower than constant rate (31.85%).

Table 5.7: Sensitivity to Corn Stover Harvested

	Change in Return/Acre		
% Stover Harvested	**Constant Rate**	**Variable Rate**	**Difference**
20%	($21.61)	($11.96)	$9.65
22%	($17.55)	($7.98)	$9.57
24%	($13.35)	($3.98)	$9.38
26.05%	($9.80)	$0.00	$9.80
28%	($6.65)	$3.81	$10.45
30%	($3.26)	$7.81	$11.08
31.85%	$0.00	$11.75	$11.75

The relative differences in grain yield between variable rate and constant rate plots are perhaps the most surprising results from this case study. The hypothesis was that variable rate collection would optimize the amount of crop residue left in the field and therefore boost grain yields in areas where more crop residue was needed by the soil. In this case study, however, grain yields in the variable rate plots were less than the constant rate plots. However, table 5.8 illustrates that if the change in grain yields had been the same, with all other variables held constant, then variable rate collection would have shown much higher profits when above the baseline yield of a conventional harvest. This is primarily due to the increased profits from the additional grain.

Table 5.8: Sensitivity to Grain Yield Increase/Decrease

	Change in Return/Acre		
% Yield Change	**Constant Rate**	**Variable Rate**	**Difference**
-5%	($37.29)	($63.00)	($25.71)
-4%	($31.67)	($51.78)	($20.10)
-3%	($26.06)	($40.55)	($14.49)
-2%	($20.44)	($29.33)	($8.88)
-1%	($14.83)	($18.10)	($3.27)
0%	($9.21)	($6.88)	$2.34
0.61%	($5.78)	$0.00	$5.78
1.64%	$0.00	$11.54	$11.54
2%	$2.02	$15.58	$13.55
3%	$7.64	$26.80	$19.16
4%	$13.25	$38.03	$24.77
5%	$18.87	$49.25	$30.38

Comparing investment costs between variable rate and constant rate collection provides an indicator of how much must be spent to breakeven in both cases. For constant rate, table 5.9 shows that $30,302.04 of investment and 376.17 acres is required to break even on return. It takes a larger investment of $31,379.71 and 441.27 acres to accomplish the same goal with variable rate, as shown in table 5.10. These two tables also illustrate the number of acres and return/acre at common investment levels. The conclusion for this unique case study is that greater returns can be generated from fewer acres with constant rate collection due to the higher revenue from grain and corn stover sales and the avoidance of paying the new technology costs associated with variable rate collection.

Table 5.9: Sensitivity to Investment Costs, Constant Rate

Constant Rate Collection			
Cost Increment	Investment Costs	Acres	Return/Acre
-	($30,302.04)	376.17	$0.00
3.6%	($31,379.71)	434.23	$8.29
5.0%	($32,948.46)	518.74	$17.04
5.0%	($34,595.44)	607.47	$23.60
5.0%	($36,325.51)	700.68	$28.71

Table 5.10: Sensitivity to Investment Costs, Variable Rate

Variable Rate Collection			
Cost Increment	Investment Costs	Acres	Return/Acre
-5.0%	($29,810.49)	339.99	($16.57)
-	($31,379.71)	441.27	$0.00
5.0%	($32,948.46)	542.50	$10.38
5.0%	($34,595.44)	648.79	$17.79
5.0%	($36,325.53)	760.42	$23.34

Nutrient replacement costs are dependent on how much crop residue is removed. For removal rates greater than one ton/acre, the model calculates a cost to replace the nitrogen, phosphorus, and potassium that is removed with the residue above that threshold. Table 5.11 illustrates the sensitivity to these replacement costs. At equivalent replacement costs, with all other variables held constant, variable rate is still more expensive. The nutrient replacement costs could be reduced by decreasing the collection rate on each variable rate plot. However, that does not improve overall profitability because it also reduces the gross revenue generated from corn stover.

Table 5.11: Sensitivity to Nutrient Replacement Costs

	Change in Return/Acre		
Nutrient Replacement Costs	**Constant Rate**	**Variable Rate**	**Difference**
($500.00)	$4.48	$2.86	($1.63)
($1,000.00)	$3.16	$1.72	($1.44)
($1,760.39)	$1.13	$0.00	($1.13)
($2,000.00)	$0.50	($0.54)	($1.04)
($2,187.10)	$0.00	($0.97)	($0.97)
($3,000.00)	($2.16)	($2.81)	($0.65)
($3,500.00)	($3.49)	($3.94)	($0.45)

CHAPTER VI: SUMMARY AND CONCLUSIONS

6.1 Summary

The results derived from the joint study data were surprising in the fact that variable rate collection didn't provide an economic incentive over constant rate collection for these particular field plots. It is expected in most instances that variable rate collection will result in less crop residue being removed from the field, which results in less secondary income. However, the lower average grain yield in those plots (158.84 bushel/acre, compared to 160.46) was also a driver for the budget model showing a greater return for constant rate collection. Furthermore, the new technology cost for variable rate collection is a hurdle to adoption. It is important to note that this is just one data sample from one year of crops. There are many environmental variables related to weather, planting conditions, chemical applications, disease, etc. that could have non-uniform effects on the grain yields throughout a field. Furthermore, any grain yield advantages of variable rate collection may not show up for several years. For example, it takes several years to repair and build up soil organic matter if it has been depleted by poor farming practices in the past. This would be comparable to the delayed effects on grain yield that are often seen when producers convert from conventional tillage to no-till.

The main objective of this study to create a budget model that will determine the economic impact of crop residue removal has been met. The model was tested with case study data and proved to be effective in comparing variable rate collection to constant rate, which was another objective of this study. This model should allow producers to meet their goal of determining crop residue removal practices that are sustainable for the long-term, while also enhancing soil quality and increasing grain yield in future years. In cases where variable rate proves to have an economic advantage, the model will also enable producers to build a business case for investing in variable crop residue management.

The hypothesis presented in this study, which stated that the additional costs of a variable rate system could be offset with greater profits, did not prove to be true for the case study that was analyzed. However, as the price of variable rate technology decreases, it will become easier for producers to implement such a system. A logical first step would be to invest in constant rate collection, which already exhibits the benefits of supplemental income, increased crop yields, and better management of soil health and nutrients. Then, by using this budget model year after year, the producer's unique field data will indicate when it is time to make the additional investment to convert their collection system to variable rate technology.

6.2 Future Directions

This is only the beginning of the research necessary to quantify the economic potential of variable crop residue management. There are alternative collection methods, such as second and third pass baling, which should be modeled. In many regions, continuous corn is not a viable option because of soil fertility, weed, or pest issues. Therefore, other crop residue types need to be evaluated, in addition to crop rotations. A corn-soybean rotation is a popular choice among many Midwest producers. The John Deere-Iowa State joint study also has multiple years of data from the Iowa field site, which should be analyzed and compared to determine if any economic trends are apparent. It will likely take more years of data collection before anything definitive can be proven, however. Finally, there are other means of managing crop residue that should be evaluated. The most obvious are the many different types of tillage practices. The joint study is already collecting data on no-till, conventional tillage, and variable depth tillage to begin understanding their effects on soil health and environmental sustainability.

6.3 Conclusions

The final recommendation for crop residue management needs to include more than just the method of collection. Variable rate collection may soon become a viable alternative, but it requires new technology that will evolve. The significant factors that resulted in variable rate collection being more expensive than constant rate include decreased collection rates, the new technology cost, and relative differences in grain yield. All of the environmental factors discussed in this study have significant effects on grain and corn stover yield and will vary from field to field. When deciding how to manage crop residue levels, a producer must consider these unique factors together in a crop residue management system. It is hoped that the budget model created in this study will assist in evaluating the economics of their unique system. One must also consider the environmental benefits of returning the necessary amounts of crop residue to the earth to sustain the soil, even if it costs a little more to do so.

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