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Real time variable rate stover collection control system on a single pass dual stream biomass harvester controlling for erosion and organic matter

Daniel Kent Murray
Iowa State University

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Real time variable rate stover collection control system on a single pass dual stream

biomass harvester controlling for erosion and organic matter

by

Daniel Kent Murray

A thesis submitted to the graduate faculty

In partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Major: Agricultural Engineering (Advanced Machinery Engineering)

Program of Study Committee

Stuart J. Birrell, Major Professor

Matt Darr

Matthew Helmers

Iowa State University

Ames, Iowa

2012

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CHAPTER 1 INTRODUCTION

Crop residues, typically left in the field after harvest, could be converted into a renewable fuel for the increasing world population to use. With a fuel source from an annual plant such as corn, dependence on foreign oil would be reduced. Corn stover is an abundant and available crop residue in the Midwestern United States. Graham et al. (2007) estimated that between 1995 and 2000, there were 196 million Mg of corn stover produced annually. As grain yields increase, the amount of corn stover produced also increases.

New harvest equipment will need to be developed in order to collect corn stover as a biomass feedstock. A single pass dual stream harvester collects both grain and corn stover at the same time. This provides a cleaner product to a biomass refinery. However, this harvester would require more power to process the entire corn plant instead of just the ear through the machine. Once corn stover passes through the harvester, a densification process needs to occur in order to make transportation of the material feasible. Then, the logistics of storing and transporting corn stover to a biomass refinery need to be addressed.

Even though millions of metric tonnes of corn stover are available in the United States, not all of it should be collected. A significant amount of crop residue should remain in the field in order to prevent erosion and preserve soil organic carbon. Currently, one way to collect corn stover is to use a second pass baler. A baler usually does not have any precise control on how much material is collected. It simply bales what is available. A single pass dual stream harvester has the potential to include a control system to leave the necessary amount of corn stover in the field for sustainable production. The control system could target areas such as erosion control or organic matter control. In areas where these factors are not a

limiting factor, corn stover could be removed. The control system could also prevent removal in areas where these factors are a concern. For erosion control, the Revised Universal Soil Loss Equation Version 2 (RUSLE2) program in conjunction with site specific information including soil type, slope, and slope length could be used to determine a sustainable corn stover return rate to prevent erosion. In addition, the soil conditioning index (SCI) could be used to determine a minimum corn stover return rate required to prevent depletion of soil organic matter and soil carbon. With this type of a program, fields could be managed on a micro level instead of on a field level or even farm level.

1.1 Literature Review

Over the last twenty years, precision agriculture has progressed rapidly. Precision agriculture uses "spatial information technology applied to agriculture" (Bullock et al., 2002). Different types of precision agriculture tools that are used today include global positioning system (GPS), geographic information systems (GIS), yield monitoring, and variable rate technology. These technologies allow a producer to make site specific zones within a field. For example, a producer can use yield data to determine areas in a field that may need more fertilizer than other areas. Instead of treating a field on a field size or farm size scale, a producer can now use information to manage a field on a site specific basis.

By using precision agriculture, a producer can manage his or her fields on a site specific basis. According to Bongiovanni and Lowenberg-DeBoer (2004), "site-specific management (SSM) is the idea of doing the right thing, at the right place, at the right time." A producer's main objective is to maximize yields while preserving the soil for future generations. Site-specific management can help a producer accomplish this by determining

zones within a field that may need extra fertilizer or areas that shouldn't be tilled to protect that area from erosion.

According to Hatfield (2000), a field has variation from natural variables, random variables, and managed variables. Natural variables include factors that are physically in the field. These include soil type and topography. Random variables are factors that occur randomly such as weather. One part of the field may receive different rainfall amounts than another portion of the field. Managed variables are factors that the producer does to the field. These include tillage practices, fertilizer application, and irrigation. Both natural and random variables are factors that the producer cannot control. However, precision agriculture allows the producer to use managed variables to better account for variation from natural variables. An example of this would be applying more nitrogen to a soil type that lacks nitrogen.

One method of precision farming that has been widely used in fertilizer application is variable rate technology. Traditionally, fertilizer was applied at a single rate across the entire field. According to Babcock and Pautsch (1998), this would usually cause large areas to be oversupplied while other areas were undersupplied. Oversupplying fertilizer does not affect the yield of a crop. However, it is a wasted input and an added expense to the producer. Undersupplying fertilizer causes a decrease in yield. So, that portion of the field would not reach its full potential. With variable rate technology, the producer can now apply different amounts of fertilizer across a field. This results in a lower input cost for the producer while maximizing field productivity.

Similar to fertilizer application, if corn stover was collected from a field in the past, it was collected at a single removal rate. This was accomplished by a second pass baler

collecting material after harvesting grain. One problem with a second pass baler is that it will collect any material that is available to it including rocks and soil. A second pass baler is also not a precision farming tool. As seen in the fertilizer example, field variability requires that different parts of the field require different amounts of the same input. Corn stover is an input to the overall soil quality. It adds organic matter to the soil and covers the soil which prevents soil erosion.

Also, a second pass baler will collect both the bottom portion and the top portion of the plant. According to Johnson et al. (2010), a high quality feedstock comes from the top portion of the plant because it contains fewer nutrients, has a lower moisture content, and has less soil contamination than the bottom portion. Figure 1 (Johnson et al., 2010) shows the amount of carbon and other nutrients that would be harvested at various cut heights. As the cut height increases, the amount of nutrients harvested decreases. With a higher cut height, more of these nutrients will remain in the field for future crops.
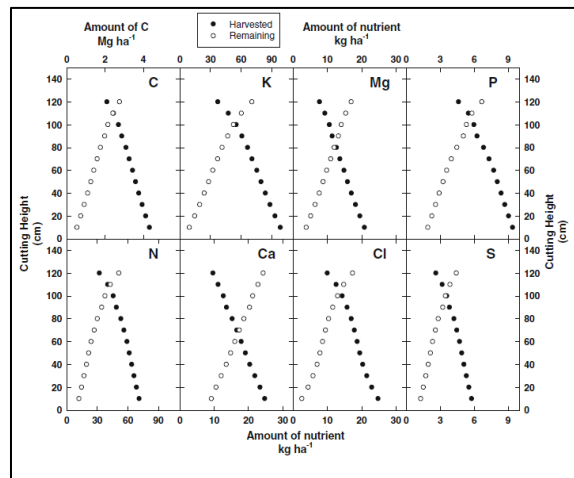
Figure 1: Amount of nutrients harvested and remaining in the field at various cut heights (Johnson et al., 2010).

Another negative aspect of the bottom part of the corn plant is that it has a higher moisture content than the top portion of the corn plant. Water cannot be converted into cellulosic ethanol. According to Hoskinson et al. (2006), "biomass that needs to be collected with greater water content is generally more expensive to harvest, store, and transport than dry biomass."

The base of the stalk also usually has more soil contamination due to raindrop splash and field operations according to Hoskinson et al. (2006). A good quality feedstock would have little soil contamination, or ash. Ash is not good for a biomass refinery because it cannot be converted into ethanol and can potentially damage equipment.

Two factors in determining a sustainable corn stover return rate to the field are erosion control and organic matter control. According to Wilhelm et al. (2004), only a small portion of the carbon in corn stover is converted into soil organic matter. This requires a large input of carbon in order to maintain soil organic matter levels. Graham et al. (2007) performed a county level analysis for the entire United States on the amount of corn stover that could be sustainably collected. Constraints used in this study included soil moisture and erosion. An estimated 54 million Mg of corn stover could be collected sustainably under 1995-2000 tillage practices. This represents about 30% of the total corn stover produced in the United States. Also, over 60% of this collectable corn stover came from Iowa, Minnesota, and Illinois as can be seen in Figure 2. These states are mostly flat. Therefore, controlling for erosion is not a major limiting factor. Also, these states are among the top corn grain producing states in the nation. This means that corn stover is very abundant in these areas. According to Wilhelm et al. (2010), central Iowa had a corn stover yield of

about 13 Mg*ha^{-1} in 2007. Of this, he recommends a return rate of 5.5 Mg*ha^{-1}*year^{-1} for central Iowa in order to prevent erosion and sustain soil organic matter. For a single pass dual stream harvester, a cutting height just below the ear with 100% collection of corn stover entering the combine would leave enough corn stover in the field to meet this recommendation. In other locations, a greater percentage of the total corn stover would need to be returned to the ground to control these two factors. This could result in a cut height with a single pass dual stream harvester that is above the ear if the producer is collecting 100% of the corn stover that enters the combine. Therefore, predicting a sustainable corn stover return rate is very regionally dependent.
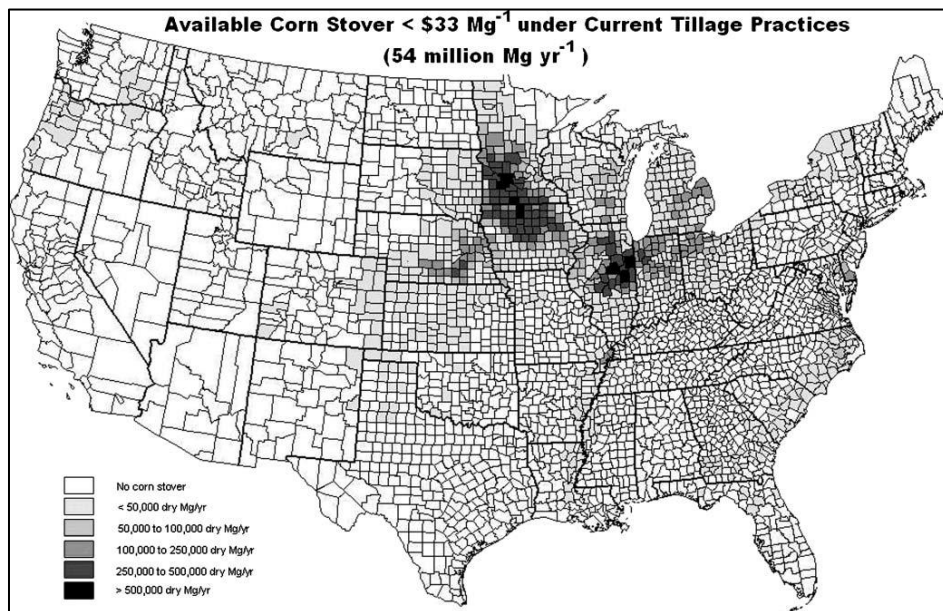
Figure 2: Available corn stover under 1995-2000 tillage practices (Graham et al., 2007).

One method that the United States Department of Agriculture-Natural Resource Conservation Service (USDA-NRCS) uses to estimate soil loss is the RUSLE2 program. The RUSLE2 program uses inputs such as soil type, slope, slope length, climate, and

management practices to estimate soil loss during one year. The soil loss tolerance (T) value is the amount of soil that can be eroded without degrading soil quality and ranges from 2.24 to 11.21 Mg*ha^{-1}*year^{-1} (1 to 5 ton*acre^{-1}*year^{-1}). If estimated soil loss is below the soil loss tolerance value, then the soil is in compliance with erosion factors. Removing biomass from a field increases the estimated soil loss parameter in the RUSLE2 program. Another factor in the RUSLE2 program is the soil conditioning index (SCI). According to Hubbs et al. (2002), SCI is broken down into three components: organic matter (OM), field operations (FO), and erosion (ER). If these values are greater than zero, then the management practices performed by the producer are improving the soil quality. A value below zero indicates that the specified management practices are degrading soil quality. Removing biomass from a field will cause the SCI-OM subfactor to decline. However, if the SCI-OM subfactor can remain greater than zero, then the soil quality is still improving.

In order to control a corn stover return rate, the total amount of corn stover needs to be determined. Then, the amount of corn stover to be harvested and the amount of corn stover to be returned to the ground can be determined. The Harvest Index (HI) is a ratio of the amount of grain to the amount of aboveground plant material including grain (Equation 1). Linden et al. *(2000)* reported HI values ranging from 0.4 to 0.6 with an average of 0.56 over a 13 year study. Year average HI values ranged from 0.50 to 0.57. Johnson et al. (2006) also reported an average HI value of 0.53 for 2000. Both of these sources indicate that a 1:1 ratio of grain to corn stover could be used to estimate total stover with caution. Factors affecting the HI include time, weather, grain yield, and hybrid type.

$$HI = \frac{M_{grain}}{M_{grain} + M_{stover}} \tag{1}$$

HI = Harvest Index

M_{grain} = Grain yield, dry matter ($Mg*ha^{-1}$)

M_{stover} = Total stover available, dry matter ($Mg*ha^{-1}$)

Wilhelm et al. (2010) reported another way to estimate total corn stover. His method uses grain yield as shown in Figure 3. This model shows that stover biomass increases as grain yield increases.
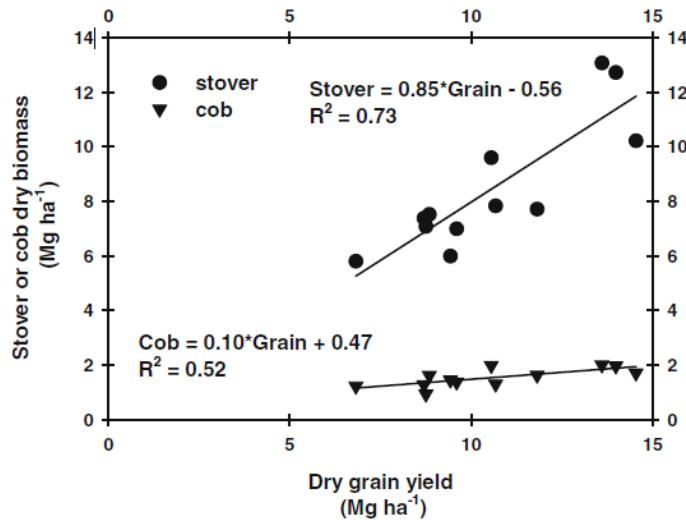
Figure 3: Stover dry biomass vs. dry grain yield (Wilhelm et al., 2010).

Once the total amount of corn stover is determined, the amount of corn stover remaining on the ground due to the cut height must be determined. Wilhelm et al. (2010) reported that the fraction of biomass remaining in the field could be determined based on a relative plant cut height. Relative cut height is determined by dividing cut height by the total plant height. Figure 4 shows the results of this study. The relationship shows an increasing fraction of biomass remaining in the field with increasing relative cutting height. An R^2 value of 0.93 suggests a strong linear correlation between these two factors.
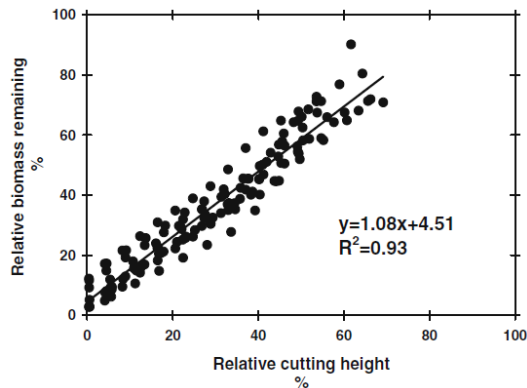
Figure 4: Relative biomass remaining in the field vs. relative cutting height (Wilhelm et al., 2010).

Karkee et al. (2011) developed a computer program to determine a sustainable corn stover removal rate based on erosion. This program utilized the RUSLE2 program. Through an iterative process, the amount of corn stover that could be removed under a certain set of inputs could be determined. Simulations were completed for a flat field in Winnebago County, Iowa, and a hilly field in Crawford County, Iowa. To control for erosion, most of the biomass could be removed from the Winnebago County field while most of the biomass needed to remain in the field on steep slopes in the Crawford County field (Karkee et al., 2011).

McNaull et al., 2010, developed a control system on a single pass dual stream biomass harvester to return a target corn stover return rate. In this system, a user specified corn stover return rate was input into a computer control program. Based on crop conditions, the program would adjust to meet the target return rate.

1.2 Objectives

The purpose of this research was to determine a corn stover return rate on a site specific basis for a single pass dual stream harvester. Soil erosion and organic matter management were the determining factors for a corn stover prescription return rate. The direct objective and subobjectives are specified below:

- Develop a process to determine the optimal corn stover prescription return rate based on erosion management and organic matter management.

    - Develop a database of soil types and elevation data for the Midwestern United States.

    - Evaluate the performance of the material other than grain (MOG) split vanes.

    - Integrate prescription return rate with previously developed control system. This required integration of the sustainable corn stover removal rate computer program using the RUSLE2 algorithms and the control system developed to return a user specified corn stover return rate into a turn-key integrated real-time variable rate stover collection system.

CHAPTER 2 CONTROL DEVELOPMENT

The RUSLE2 program was used in order to determine a sustainable corn stover return rate. RUSLE2 is a computer program developed by the USDA-NRCS to predict soil loss. Inputs to the RUSLE2 program are soil type, slope, slope length, grain yield, and management practices. RUSLE2 uses these factors to determine an annual soil loss on each ith day as shown in Equation 2 below (Renard et al., 1997).

$$a_i = r_i k_i l_i S c_i p_i \tag{2}$$

a_i = Average annual soil loss

r_i = Erosivity factor

l_i = Soil erodibility factor

S = Slope steepness factor

c_i = Cover management factor

p_i = Supporting practices factor

The slope steepness factor does not change throughout the year, so the subscript is omitted. Corn stover is part of the cover management factor. When corn stover is removed from a field, this factor will increase, causing the average annual soil loss to also increase.

2.1 Soil Data Conversion

Soil type is a spatial variable that can be determined by GPS position. From the USDA-NRCS website (http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx), soil data was downloaded for each county in the United States. When this data was downloaded, it was available in a shapefile. A conversion of the shapefile was made in order to make this data more useful for a computer program to interpret. The conversion process for Boone

County, Iowa, is shown in Figure 5 and was completed using ArcMap. The first map on the

left is the shapefile downloaded from the USDA-NRCS website. A small portion of the map

is enlarged to show map attributes. The shapefile was then converted to a raster map with the

line number that corresponds to the map attributes as the map feature. The raster map was

completed on a 10 meter grid. A raster map is shown in the middle of Figure 5 with a small

portion enlarged. Line numbers increase from the top to the bottom of the map causing the

map to decrease in darkness from top to bottom. Darker colors represent smaller line

numbers. Then, the raster map was exported on a 10 meter grid to a text file lookup table.

Reference information is located at the top of the text file. The lookup table for a small

portion of the enlarged portion of the raster map is shown in the table on the right in Figure 5.

A soil data database was developed based on state and county for all counties in the United

States. Each county folder contains two text files. One file contains the 10 meter grid soil

data lookup table. Each data point in this file refers to a line number in the second text file in

the same folder. The line number contains the soil type associated with that particular point.

This process will be addressed later in this chapter.
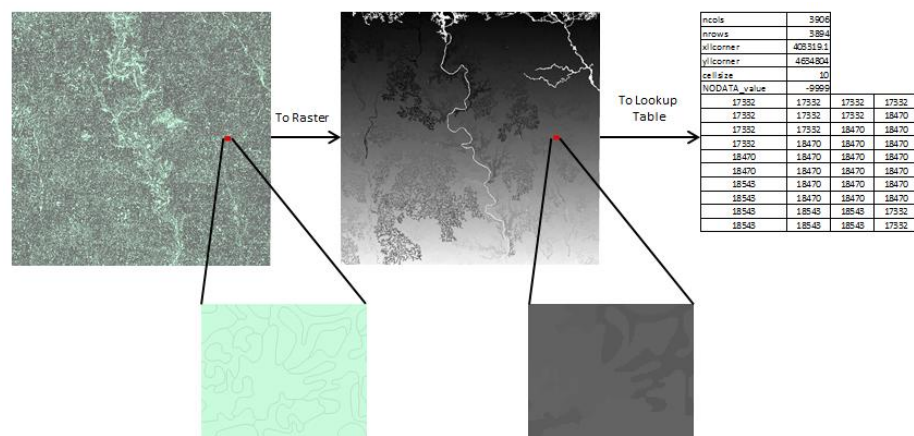
Figure 5: Conversion of shapefile to lookup table for Boone County, Iowa.

Two fields located southwest of Ames, Iowa, were used for variable corn stover return rate testing. These two fields are called the Uthe Southwest Field and the Uthe Northeast Field. The soil symbols for these two fields are shown in Figure 6. Soil types are shown in Figure 7. Each plot has a variety of soil types associated with it, which will cause different soil type inputs for the RUSLE2 program.
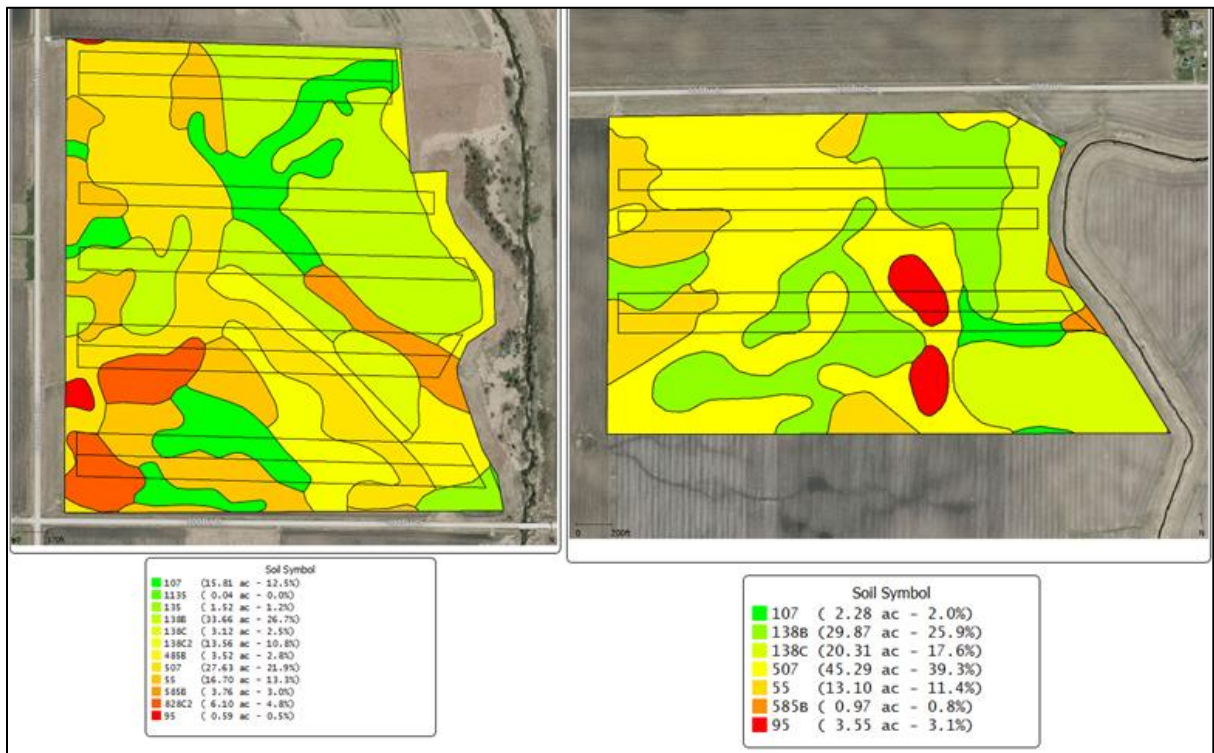
Figure 6: Soil symbol maps for the Uthe Southwest Field (left) and Uthe Northeast Field (right). The variable corn stover return rate plots are outlined in black.
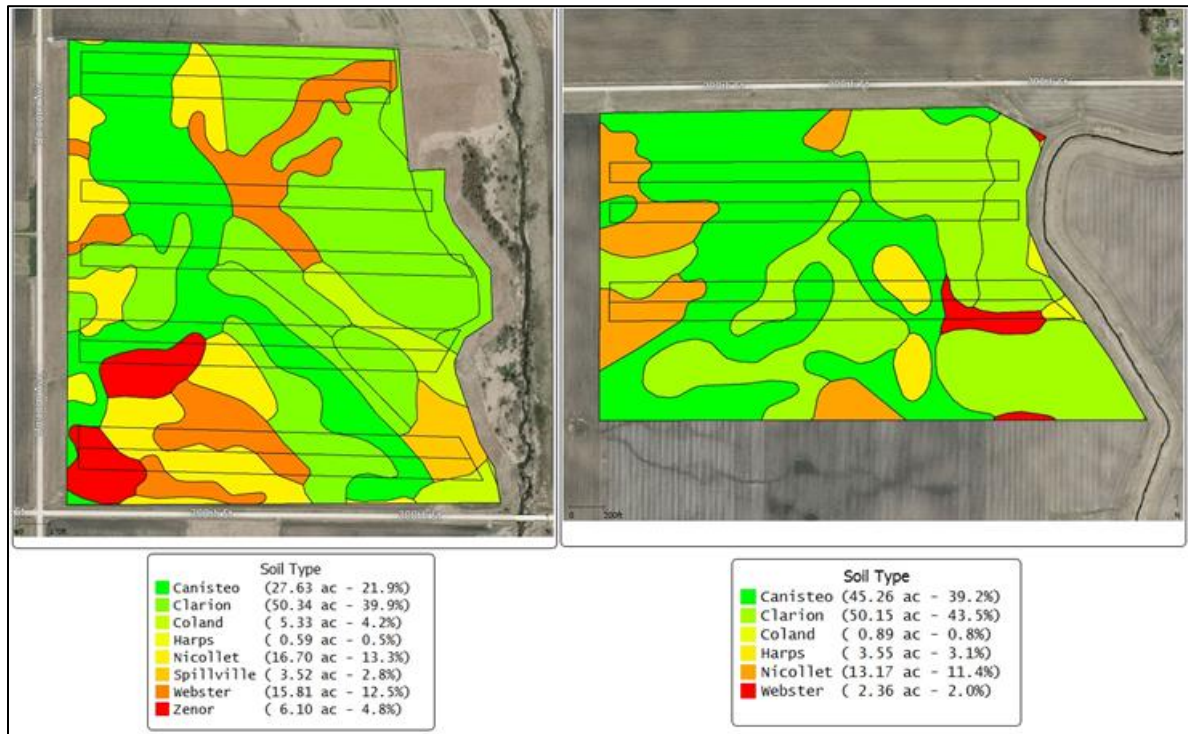
Figure 7: Soil types for the Uthe Southwest Field (left) and the Uthe Northeast Field (right).

2.2 Slope Steepness and Slope Length

Two other major input factors of the RUSLE2 program are slope steepness and slope length. National Digital Elevation Models (DEM) were previously acquired from the United States Geological Survey (USGS) on a 1/3 arc second resolution (approximately 10 meter grid). For the Uthe Farm, LIDAR (Light Detection And Ranging) elevation data was used. LIDAR provides higher resolution elevation data than National DEMs. Determination of slope steepness and uphill slope length utilized algorithms developed by Karkee et al. (2010). The slope steepness and slope length of the two Uthe Fields are shown in Figure 8 and Figure 9, respectively. In the Uthe Southwest Field (map on left), a slope exists along the eastern edge of the north half of the field. For the southern half of this field, a slope exists in the

middle of the field.   A terrace is located just to the west of this location.   In the Uthe

Northeast Field (map on right), a slope exists along the eastern edge of the field.
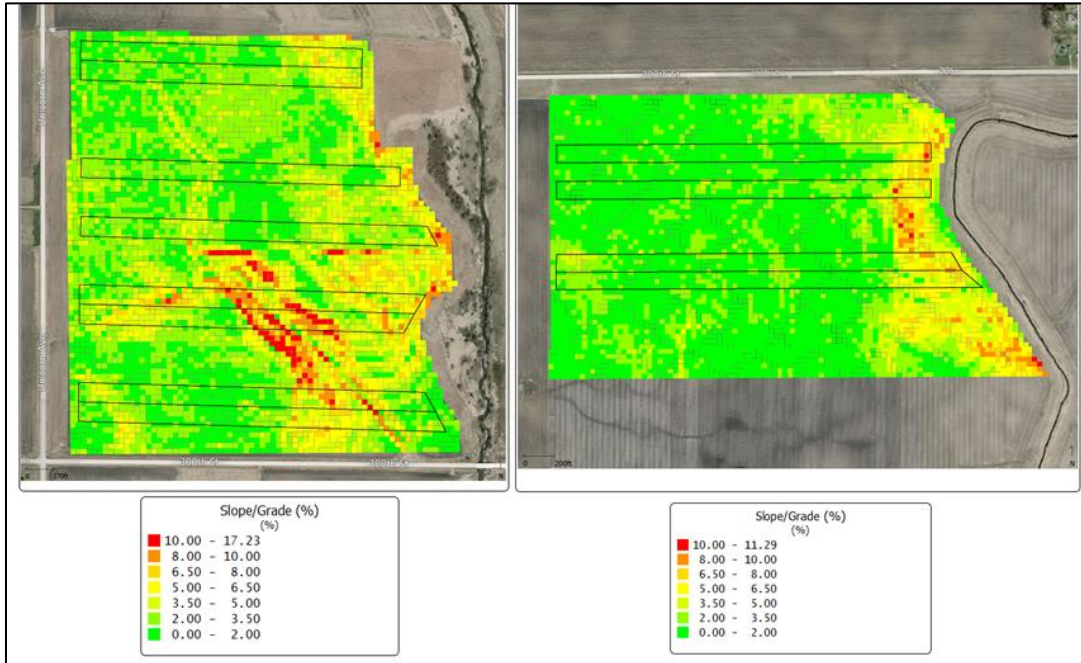
Figure 8: Slope steepness for the Uthe Southwest Field (left) and the Uthe Northeast Field
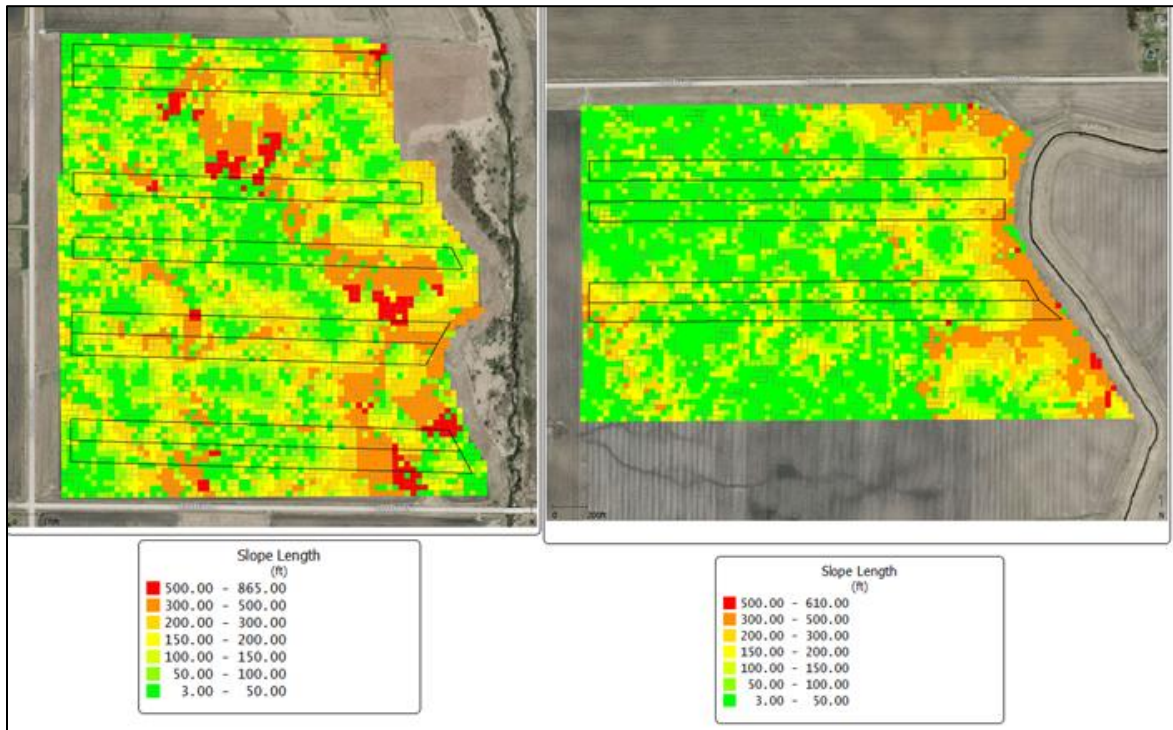
(right).

Figure 9: Slope lengths for the Uthe Southwest Field (left) and the Uthe Northeast Field
(right).

2.3 User Interface

A computer program was developed that uses the RUSLE2 in order to determine a sustainable corn stover return rate. This program will be referenced as the Variable Corn Stover Return Rate Program. The user interface for this is shown in Figure 10. This user interface shows all inputs for the RUSLE2 program including management practices, soil type, slope, slope length, and yield. On the left side of the user interface, the user selects the management practices performed on the field. In the center, the user selects the corn stover harvest method that will be performed on the field. The different corn stover harvest methods are as follows:

1. "Harvest % of Recommended" Method: The RUSLE2 program determines a sustainable corn stover return rate on a site specific basis. The final prescribed return rate can be adjusted by increasing or decreasing the percentage of the RUSLE2 recommended return rate. 100% means that the final prescribed return rate will equal the RUSLE2 recommended return rate.

2. "Harvest 100%" Method: For this method, all corn stover that enters into the combine will be collected and removed from the field.

3. "Harvest (ton/ac)" Method: The user can set a constant corn stover harvest rate on a ton per acre basis.

4. "Stover Return (ton/ac)" Method: A constant corn stover return rate can also be selected on a ton per acre basis.

5. "No Harvest/Return All" Method: Under this method, all corn stover that enters the combine will be returned to the ground. This is similar to a conventional combine.

6. "MOG Split Position Harvest" Method: A constant MOG split position can be set. The MOG split position is a diverter located at the back of the combine that splits the biomass stream into a collected fraction and a returned fraction. The MOG split position will be discussed in the Equipment and Materials chapter.

Figure 10: User interface for the Variable Corn Stover Return Rate Program.

A GPS receiver was attached to the combine. GPS position was transmitted serially to the computer program in order to determine the exact location of the combine. Latitude and longitude values are displayed on the Variable Corn Stover Return Rate Program user interface in the "Lat" and "Lon" boxes. Latitude and longitude were converted to a Universal Transverse Mercator (UTM) projection and displayed next to the "Lat" and "Lon" boxes. North American Datum of 1983 (NAD83) UTM Zone 15 North was the reference datum for soil type and elevation data for central Iowa. Therefore, this datum was also used to convert latitude and longitude into a UTM projection. Using GPS position, both soil type and elevation data could be referenced.

Upon initializing the Variable Corn Stover Return Rate Program, data from the county soil lookup table is extracted for an area of about 1035 ha. This area is a square with the current combine position in the center. All soil types for the entire county are loaded into the program when initializing. Elevation data is also extracted from the DEM files for this same area. Then, slope steepness and slope length values are calculated.

2.4 RUSLE2 Inputs

The RUSLE2 program has statistics determined for several components that determine soil erosion including climate, soil, and management practices. Climate is based on county monthly average rainfall amounts and rainfall intensity. The soil component contains soil texture and percent composition. Some soils are more susceptible to water erosion than others due to their composition. Different management practices also have an effect on soil erosion.

To use these predetermined statistics, the user needs to download localized database components from the RUSLE2 website, and then import each component into a RUSLE2 database that can be used by the RUSLE2 program. The RUSLE2 website is located at http://fargo.nserl.purdue.edu/rusle2_dataweb/RUSLE2_Program.htm. A list of all the files within a RUSLE2 database can be generated into a text file so that all files associated with that database can be viewed in one place. This offers a good search tool to be used with a computer program. A database and associated text file were generated for each state in the United States.

2.4.1 RUSLE2 Initialization

The RUSLE2 program is started when the "Initialize" button is pressed in the Variable Corn Stover Return Rate Program. This loads the RUSLE2 program database for the state that the combine is located and opens a "Profile" worksheet. The RUSLE2 program does not actually appear on the screen when this is done, but the parameters are available for the Variable Corn Stover Return Rate Program to utilize. The "Profile" worksheet is shown in Figure 11. Basic information in the "Profile" worksheet can be adjusted and interpreted using a computer program like the Variable Corn Stover Return Rate Program for a site specific area. In the "Profile" worksheet, the climate information for the county is loaded upon initialization and is put into the "Location" box in Figure 11. Several of the tabs located in the section with a black box around it will be emphasized later in this chapter. The "Yields" and "Soil Conditioning Index" folders in the red box will be expanded later, too.
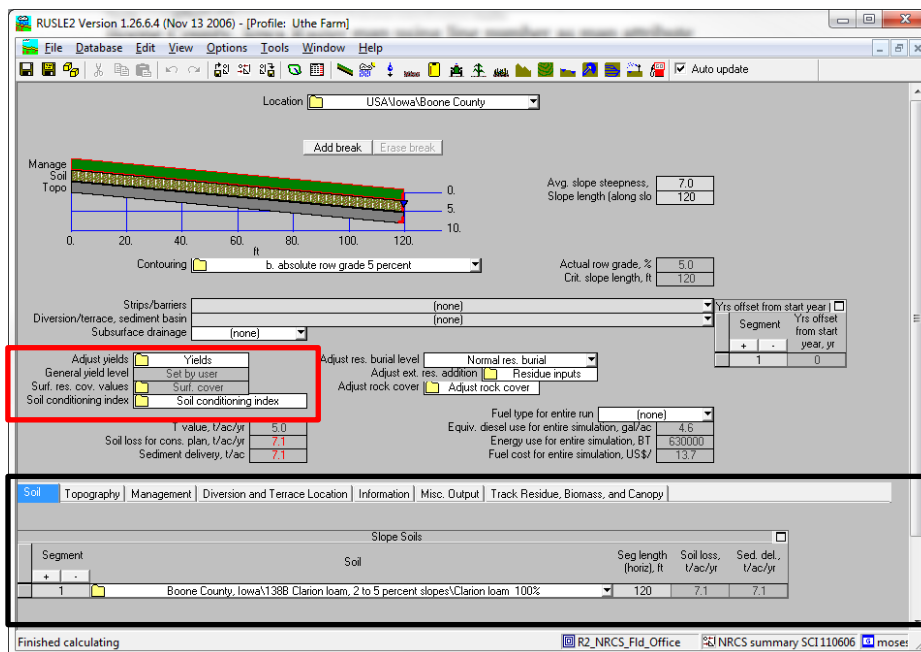
Figure 11: Profile worksheet in RUSLE2.

2.4.2 RUSLE2 Soil Type Determination

When the "Start" button is pressed in the Variable Corn Stover Return Rate Program, soil information for the current location is extracted from the soil lookup table. The data point in the lookup table refers to a line number in a second table that contains the soil symbol. Once the soil symbol for the current location is identified, the soil type is then located in the RUSLE2 program database. This process is shown in Figure 12 for the data point highlighted in yellow. The table on the left is the table that was generated from the conversion process that was shown in Figure 5. The top left corner in the lookup table (highlighted in yellow) refers to line number 17332 in the second table. This line number corresponds to soil symbol 107. Soil symbol 107 is then found in the RUSLE2 database for Boone County, Iowa, as shown in the table on the right of Figure 12. This database line is then loaded into the "Soil" tab in the RUSLE2 program (Figure 11) and into the "Soil Type" box in the Variable Corn Stover Return Rate Program (Figure 10).
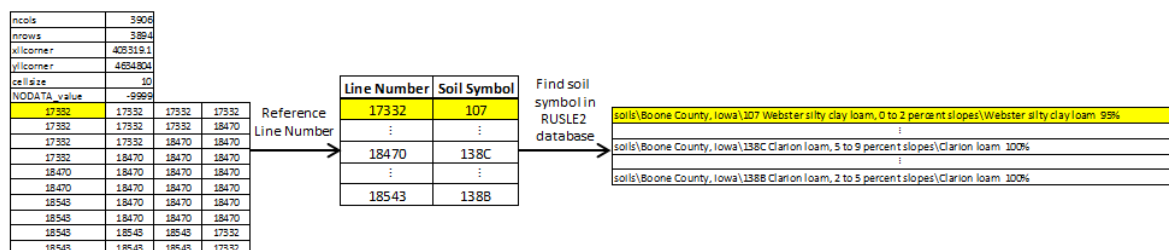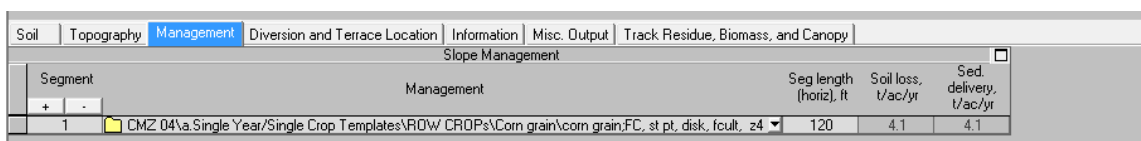
Figure 12: Each data point in the soil data lookup table refers to a line number in the reference table containing all soil symbols for a particular county. The soil symbol is then located in the RUSLE2 database.

2.4.3 RUSLE2 Slope Steepness and Slope Length Determination

Slope steepness and slope length are also located for the current location in two tables similar to the table on the left of Figure 12. Instead of containing line numbers, the slope steepness and slope length values are in these two tables. These factors are loaded into the "Avg. slope steepness" and "Slope length (along slope), ft" boxes in the RUSLE2 program as shown in Figure 11. These values are also loaded into the "Slope (%)" and "Slope Length (ft)" boxes in the Variable Corn Stover Return Rate Program for the user to view.

2.4.4 RUSLE2 Management Practices

The management practices that the producer performs on the field are inserted into the RUSLE2 program under the "Management" tab as shown in Figure 13. This management folder can be expanded to show each field operation (Figure 14). Operations can be added to this management folder to include other operations that the producer might perform. For the Variable Corn Stover Return Rate Program, baling operations are inserted into this management folder to remove various amounts of corn stover. The date for the baling operations is the same as the harvest date.

Segment	Management	Seg length (horiz), ft	Soil loss, t/ac/yr	Sed. delivery, t/ac/yr
1	CMZ 04\a.Single Year/Single Crop Templates\ROW CROPs\Corn grain\corn grain;FC, st pt, disk, fcult, z4 ▾	120	4.1	4.1

Figure 13: "Management" tab of the RUSLE2 program.
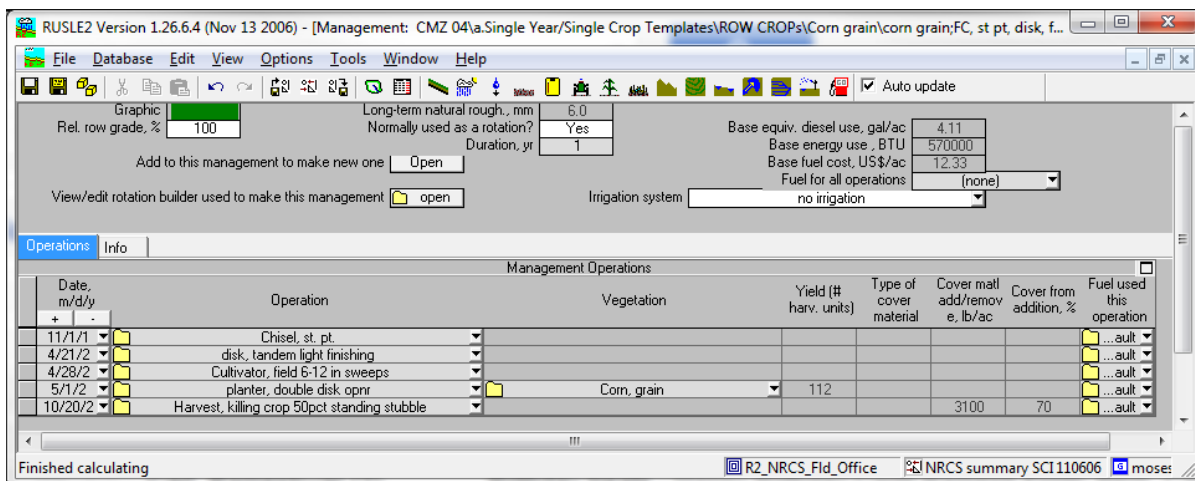
Figure 14: Management folder expanded to show all operations associated with this

management practice.

2.4.5 RUSLE2 Grain Yield

From the "Profile" worksheet in Figure 11, the "Yields" folder is expanded to show the grain yield. The grain yield from the grain mass flow sensor on the combine is transmitted over Controller Area Network (CAN) in kg*s⁻¹. Mass flow is converted into Mg*ha⁻¹ as shown in Equation 3. This value is converted to bushels per acre (Equation 4) and inserted into the "Yield (# of units)" box in Figure 15 and displayed in the "Yield (bu/ac)" box on the user interface of the Variable Corn Stover Return Rate Program (Figure 10). Yield data in the RUSLE2 program is rounded to the nearest 10 bushels per acre.

$$M_{grain} = \dot{m}_{grain} \left(\frac{1}{speed*width} \right) \left(\frac{10000 \text{ m}^2}{\text{ha}} \right) \left(\frac{1 \text{ Mg}}{1000 \text{ kg}} \right) \tag{3}$$
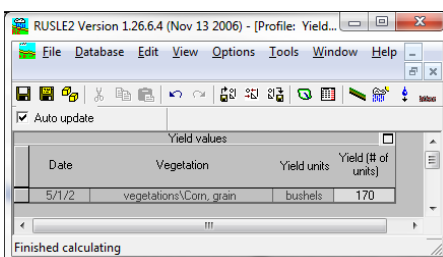
$\dot{m}_{grain}$ = Grain mass flow (kg*sec⁻¹)

$speed$ = Combine ground speed (m*sec⁻¹)

$width$ = Corn head width (m)

$$Y_{grain} = M_{grain} \left(\frac{2204.62 \text{ lbs}}{\text{Mg}}\right)\left(\frac{2.47 \text{ ha}}{\text{acre}}\right)\left(\frac{1 \text{ bushel}}{56 \text{ lbs}}\right) \qquad (4)$$

Y_{grain} $\qquad$ = Grain mass yield (bushels*acre^{-1})
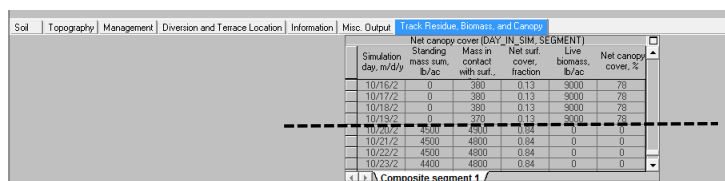
Figure 15: Yield information for the RUSLE2 program.

2.4.5 RUSLE2 Residue

Another tab that is utilized from the "Profile" worksheet is the "Track Residue, Biomass, and Canopy" tab (Figure 16). This tab contains a table that associates the amount of biomass for each day in the simulation. In this table, biomass is divided into a standing amount, amount on the ground, and live biomass. When harvest occurs, the live biomass amount is converted into standing and ground biomass as shown by a dramatic change above and below the dashed line in Figure 16. Standing, ground, and live biomass values are read by the Variable Corn Stover Return Rate Program for the day before harvest and the day after harvest. The difference between these two values is the amount of corn stover that was removed by baling operations in the RUSLE2 simulation.

Figure 16: "Track Residue, Biomass, and Canopy" tab in the RUSLE2 program.

2.5 RUSLE2 Outputs

Two different control methods were used for determining the amount of corn stover that could be removed in a sustainable manner. The first control method is erosion control. This helps to prevent soil erosion from removing too much corn stover. The T value is read from the "T value, t/ac/yr" box in Figure 11. Then, corn stover is removed by inserting baling operations until the soil loss value is greater than the T value. The soil loss value is found in the "Soil loss cons. plan, t/ac/yr" box in Figure 11.

The second control method is organic matter control. For this control method, the "Soil conditioning index" folder (Figure 11) is expanded to show the SCI value and subfactors for a particular location under certain management practices, soil type, slope steepness, and slope length conditions (Figure 17). Corn stover is removed by inserting baling operations until the SCI-OM subfactor is equal to zero. All SCI values are read for the organic matter control return rate and erosion control return rate and displayed on the Variable Corn Stover Return Rate Program under the SCI and RUSLE2 headings, respectively. Prescribed return rates in tons*acre^{-1} are displayed under the same headings.
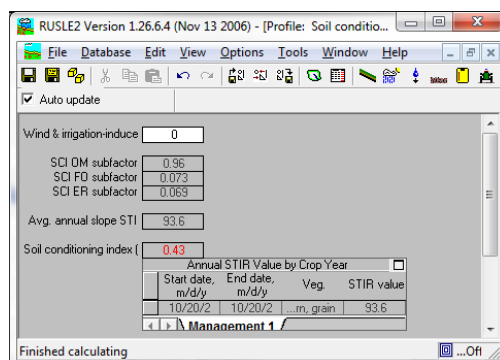
Figure 17: Soil conditioning index window in the RUSLE2 program.

2.6 Combine Return Rate Controller

The RUSLE2 control method with the higher prescribed return rate is the return rate that is used by the combine. Currently, a second computer running a control program sets the MOG split position in order to achieve the prescribed return rate. Figure 18 shows a flowchart of how the prescribed return rate was used and how the control system adjusted to meet the prescribed return rate.
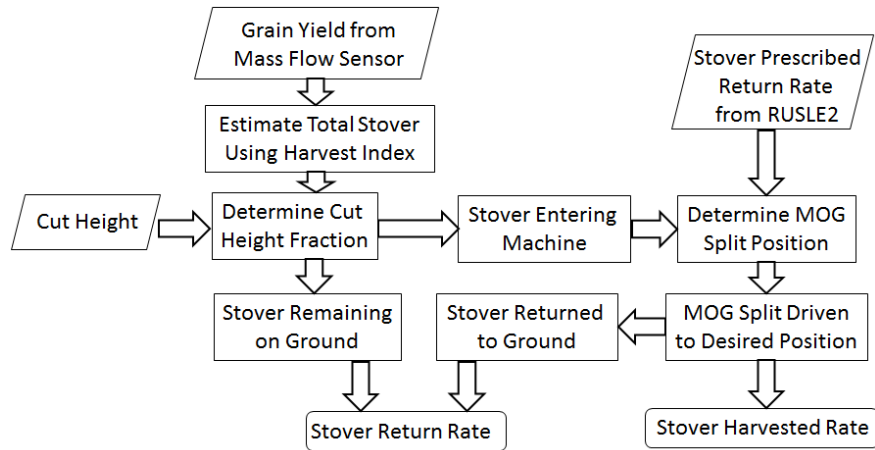
Figure 18: Flowchart illustrating how stover return rate was determined and how the prescribed return rate was implemented into the control system.

2.6.1 Total Stover Estimation

The first step of the control system was to determine the grain yield from the mass flow sensor. Converting the grain mass flow value of kg*sec^{-1} to Mg*ha^{-1} was previously shown in Equation 3. By using the Harvest Index, the amount of total stover available for an area can be determined. By rearranging this ratio, the total stover available can be determined as shown in Equation 5.

$$M_{stover} = M_{grain}\left(\frac{1}{HI} - 1\right) \tag{5}$$

2.6.2 Stover Fractions by Cut Height

The cut height of the biomass collection corn head is another input into the combine return rate control system. Plant material below the cut height will remain on the ground while plant material above the cut height will enter the machine (combine). For variable rate testing, a cut height of just below the ear shank was used. The fraction of corn stover remaining on the ground due to the cut height is a function of cut height that will be determined during field testing (Equation 6). The amount of corn stover entering the machine on a Mg*ha^{-1} basis is shown in Equation 7.

$$X_{Cut\ Height} = f(Header\_height) \tag{6}$$

$X_{Cut\ Height}$ = Corn stover fraction returned to the ground by cut height

$Header\_height$ = Cut height (cm)

$$M_{machine} = M_{stover}\left(1 - X_{Cut\ Height}\right) \tag{7}$$

$M_{machine}$ = Corn stover entering combine (Mg*ha^{-1})

2.6.3 Stover Fractions by MOG Split Position

At this point, the amount of corn stover in the machine and the amount of corn stover left by the cut height are determined. In order to achieve the prescribed corn stover return rate from the RUSLE2 program, part of the corn stover in the machine may need to return to the ground. The amount of corn stover in the machine that needs to return to the ground to achieve the prescribed return rate is shown in Equation 8. If this value is less than zero, the amount of corn stover left by the cut height is greater than the prescribed return rate, so all of the corn stover in the machine can be collected or harvested.

$$Rx_{machine\ return} = Rx_{stover} - M_{stover} * X_{Cut\ Height} \tag{8}$$

$Rx_{machine\ return}$ = Corn stover in machine needed to return to the ground (Mg*ha^{-1})

Rx_{stover} = Prescribed corn stover return rate from RUSLE2 program (Mg*ha^{-1})

In order to normalize the amount of corn stover in the machine needed to be returned to the ground, a relationship between the amount of corn stover in the machine needed to be returned to the ground and the amount of corn stover in the machine can be determined. This relationship makes a return rate into a fraction of corn stover in the machine to be returned to the ground as shown in Equation 9.

$$X_{MOG\ split} = \frac{Rx_{machine\ return}}{M_{machine}} \tag{9}$$

$X_{MOG\ split}$ = Fraction of corn stover in machine returned to the ground

For a control system to set the MOG split position based on the machine fraction of corn stover to be returned to the ground, a relationship between the two needs to be determined. Equation 10 shows that the MOG split position is a function of the fraction of corn stover in the machine returned to the ground that will be determined during field testing.

$$MOG\ Split\ Position = fn(X_{MOG\ split}) \tag{10}$$

$MOG\ Split\ Position$ = MOG Split Position (%);   0% = closed (0% collection)

                                              100% = open (100% collection

                                              of corn stover in machine)

The total corn stover return rate is then estimated by adding the amount of corn stover left by the cut height and the amount of corn stover returned by the MOG split position as shown in Equation 11.

$$M_{return\ rate} = X_{MOG\ split} * M_{machine} + M_{stover} * X_{Cut\ Height} \tag{11}$$

$M_{return\ rate}$ = Estimated corn stover return rate $(Mg*ha^{-1})$

CHAPTER 3 EQUIPMENT AND MATERIALS

3.1 Single Pass Dual Stream Harvester

A single pass dual stream harvester previously developed in conjunction with John Deere Harvester Works in Moline, Illinois, was used for this project. This harvester is a John Deere 9860 STS combine that has been modified to collect both corn grain and corn stover at the same time.

At the rotor, grain is separated from the corn stover. The corn stover then enters the discharge beater. The rotor, concaves, sieves, and discharge beater were not modified from a standard combine. After the discharge beater, a modification was made to the combine in order to improve material flow. A mass flow sensor was installed to estimate the amount of corn stover passing through the machine. Then, a flat slide was installed to direct the material into the chopper. Figure 19 shows the location of the corn stover mass flow sensor and flat slide between the discharge beater and the chopper. The corn stover material flow is also shown in red.
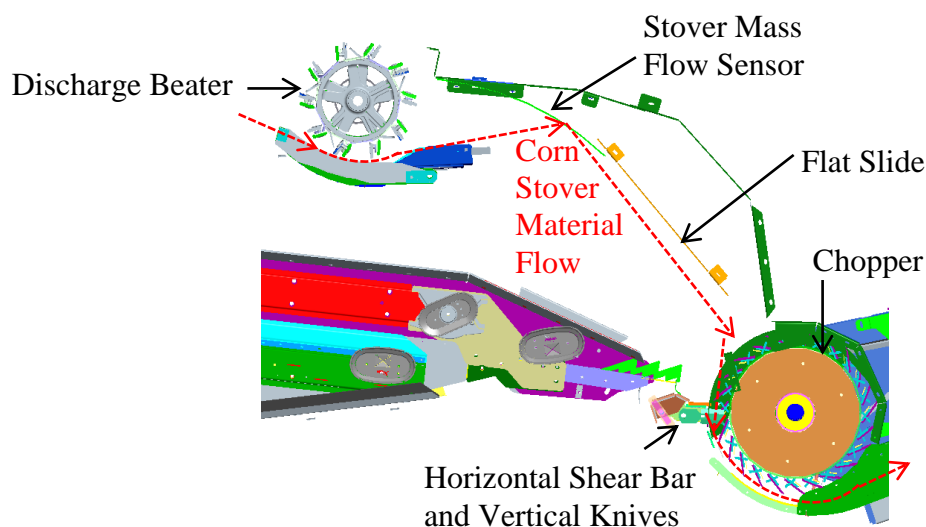
Figure 19: Stover mass flow sensor and flat slide between discharge beater and chopper.

Another modification from a production John Deere 9860 STS combine was the chopper. The chopper installed on this combine is a dual axis chopper. This chopper cuts material in two different orientations in order to reduce particle size. A horizontal shear bar cuts material as the chopper spins. Below the horizontal shear bar are vertical knives that cut material in the opposite direction. The location of both the horizontal shear bar and vertical knives are shown in Figure 19.

After the dual axis chopper, the corn stover enters a transition area. In this area, vanes were installed to divert material to the ground or to be collected. The MOG split vanes divided material flow by volume. A linear actuator with a linear potentiometer was installed on the top side of the transition (Figure 20). The potentiometer voltage output was between 0 and 5 volts which could be calibrated to a 0% position (0% collection) and a 100% position (100% collection of corn stover in machine). Figure 20 also shows the location of the transition between the chopper and the blower. The MOG split vanes are shown in Figure 21. Material that hits the outside of these vanes is diverted to the ground while material that hits the inside of the vanes enters into the blower and is collected.
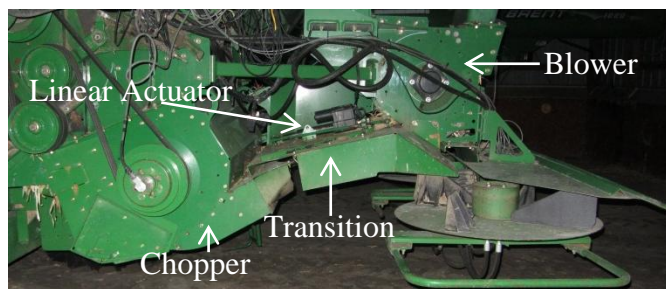
Figure 20: Transition between chopper and blower.
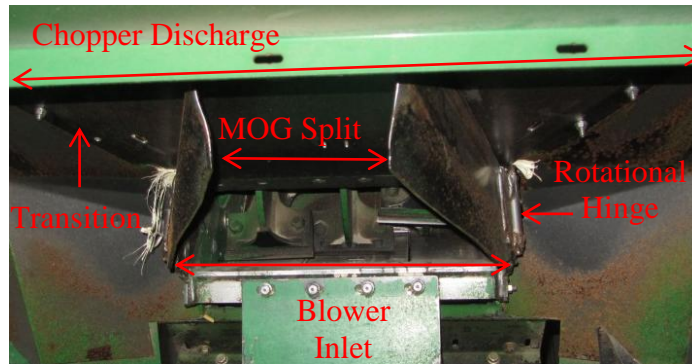
Figure 21: MOG split vanes on single pass dual stream harvester.

Material that traveled between the MOG split vanes then enters into a forage blower in order to accelerate the material to be collected. The blower was connected to a forage spout which conveyed the material to a forage wagon or truck to be collected as shown in Figure 22.

Figure 22: Modified 9860 STS combine for grain and corn stover collection.

3.2 Biomass Collection Corn Head

A modified John Deere 612C corn head was used to gather ears and corn stover above the ear shank. Instead of collecting only ears, husks, and a few leaves like a conventional corn head, the biomass collection corn head cut the plant, and then pulled the cut portion of the plant into the head where the cross auger conveyed material so that it could enter into the combine. The corn head was set up for 12 rows of biomass collection.

Cut height is a desirable characteristic in which to measure how much corn stover is entering the combine, or how much corn stover remains on the ground. A potentiometer was attached to the feeder house in order to estimate the header height. Before harvest began, the distance from the ground to the cut height of the corn head was measured at various heights, and the voltage at each height was recorded. A linear equation between potentiometer voltage and cut height was developed to estimate cut height during harvest operations. Cut height equations for determining the amount of corn stover remaining on the ground operate as a percentage of total stover based on cut height.

3.3 Field Location and Crop for Cut Height Testing and MOG Split Testing

The fields used for cut height testing and MOG split testing were located north and west of the Iowa State University BioCentury Research Farm (BCRF) located west of Ames, Iowa, as shown in Figure 23. Three different moisture levels were tested at this location with each moisture level having three replications. The corn variety planted in both fields was Pioneer PO528 XR and was planted in a north and south direction in both fields. Field A was divided into two segments by cutting perpendicular through the corn about halfway across the field. This reduced the length of each pass while doubling the number of available

tests. Areas 1, 2, and 3 represent replications 1 and 2 of the high moisture, medium moisture, and low moisture levels, respectively. Areas 4, 5, and 6 represent the 3rd replication of the high moisture, medium moisture, and low moisture levels, respectively. Field A had an average dry grain yield of 9.54 Mg*ha^{-1} and an average pass length of 216.6 m. Field B had an average dry grain yield of 10.73 Mg*ha^{-1} and an average pass length of 249.1 m. All plots had a width of 9.144 m (12 row corn head).
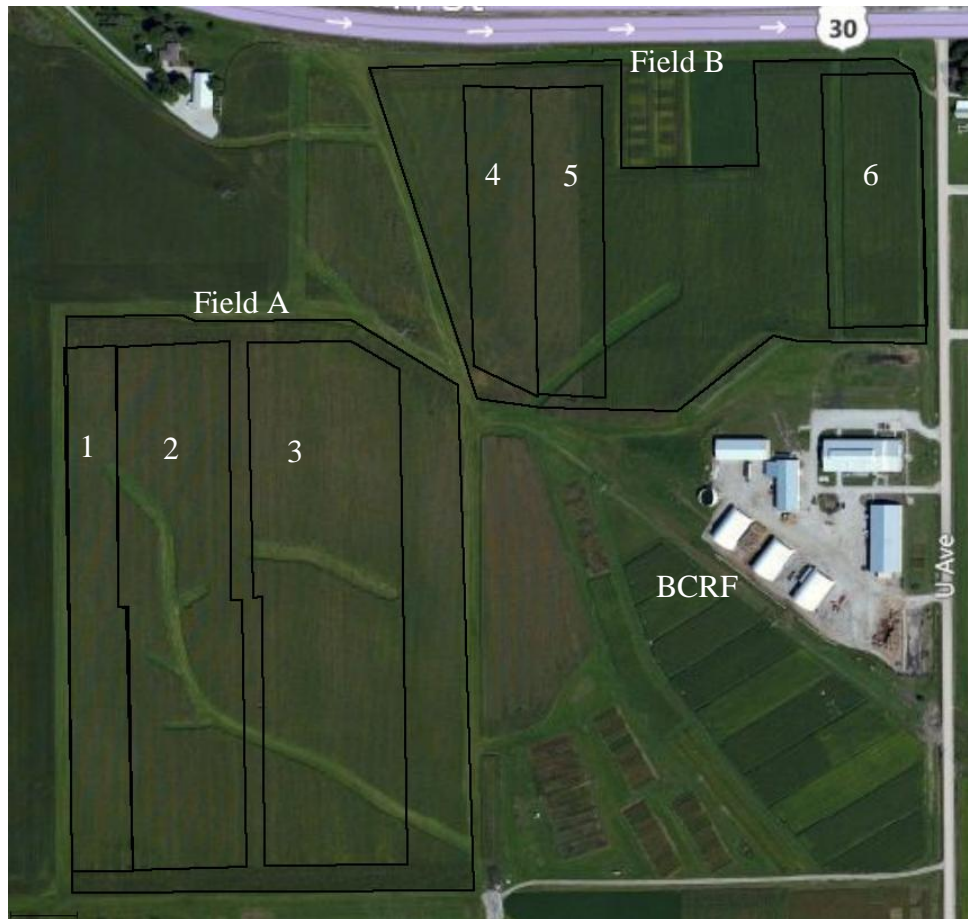
Figure 23: Field location and plot layout for cut height testing and MOG split testing.

3.4 Field Location and Crop for Variable Corn Stover Return Rate Testing

Testing was also conducted for the variable corn stover return rate system. This testing was completed on two fields at the Uthe Farm located southwest of Ames, Iowa. The Uthe Farm is a part of the Iowa State University Committee for Agricultural Development (CAD). Corn was planted throughout both of these fields. Figure 24 shows the location of the two fields and the plots where variable corn stover return rates were used. The field in the upper right corner was called the Northeast Field while the field in the lower left corner was called the Southwest Field. These two fields were a part of a larger study that included conventional corn harvest and removal of the top 50% of the corn plant (all plant material above the ear shank including the cob and husks). The corn variety planted in the Southwest Field was Pioneer 0463XR and was planted in an east/west direction. In the Northeast Field, the corn varieties were Channel 209-77BT3, AgriGold 6395RR, and AgriGold 6458RR. Corn was planted in a north/south direction in the Northeast Field. In the Northeast Field, the plot layout was perpendicular to the rows due to the field topography. By laying out the plots in an east/west direction, each plot was able to capture the only slope that was in this field, a downward slope on the eastern edge (shown previously in Figure 8). As a plot boundary was encountered in the Northeast Field, the MOG split position would adjust to return the proper amount of corn stover depending on the plot.
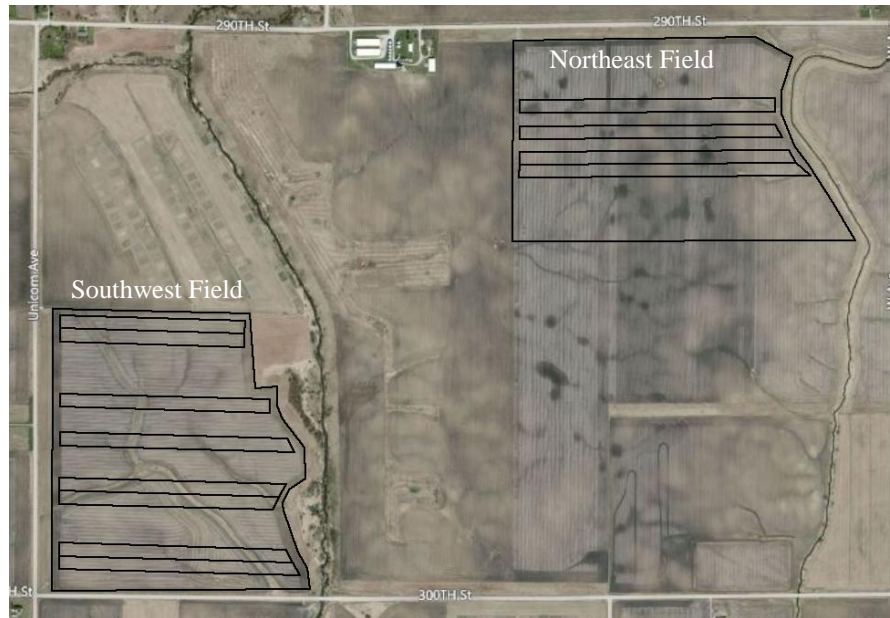
Figure 24: Field locations for variable corn stover return rate testing.

3.5 Data Acquisition System

An Athena II single board computer/data acquisition system was used as the primary data acquisition system. Analog signals were converted to digital signals using the board's 16 bit analog to digital (A/D) conversion system. The vehicle CAN bus was accessed using a CANUSB. The primary CAN message needed in this system was estimated grain yield from the grain mass flow sensor. A USB-4300 Measurement and Computing counter module was utilized for counting operations. A relay board with 20 single pole single throw relays was used for controls. Figure 25 shows the user interface of the data acquisition system.

Figure 25: User interface of data acquisition system.

The USB-4300 counter module read speed information from Hall Effect sensors on the rotor and discharge beater. Chopper speed and blower speed were sent to the USB-4300 counter module from quad encoders. These four speeds were displayed in the "Counters" section on the user interface. The quad encoders also sensed torque on the chopper and blower and were read by the SmartBoard. The SmartBoard also recorded voltage signals from six force sensors on the corn stover mass flow sensor. Grain yield was read over the combine's CAN bus. The header height and MOG split position were read by the Athena A/D and converted to inches and a percentage, respectively. The Athena A/D also interpreted information from a pressure transducer on the rotor and a DICKEY-john moisture and temperature sensor in the spout. The MOG mass flow sensors in the blower and spout

and a second MOG moisture sensor were not connected. GPS information from a Starfire 3000 receiver was sent serially from the receiver to a serial port on the computer and was displayed in the GPS information section. The RUSLE2 prescribed return rate from the Variable Corn Stover Return Rate Program was processed on a separate computer. The RUSLE2 prescribed return rate was then sent serially to the Athena computer and was displayed in the "Rusle Ret Rate" box. All of this information was recorded in a csv file at about 5 Hz. The "Stover Harvest Selection" section looks similar to the same section in the Variable Corn Stover Return Rate Program. The two programs communicated the stover harvest selection and any values associated with that harvest method over serial communication so that the two programs were configured in the same manner. The data collection section for this program and the Variable Corn Stover Return Rate Program communicated over serial so that both programs had the same name and started recording at the same time.

3.6 RUSLE2 Variable Corn Stover Return Rate

The Variable Corn Stover Return Rate Program using RUSLE2 was previously discussed in the Control Development chapter. The user interface of this program is shown again in Figure 26. GPS location, time, speed, slope steepness, slope length, soil type, grain yield, estimated biomass yield from the RUSLE2 program, and both prescribed return rates and associated SCI values and subfactor values were recorded in a csv file each time that an iteration was processed. An iteration was completed about once every second.
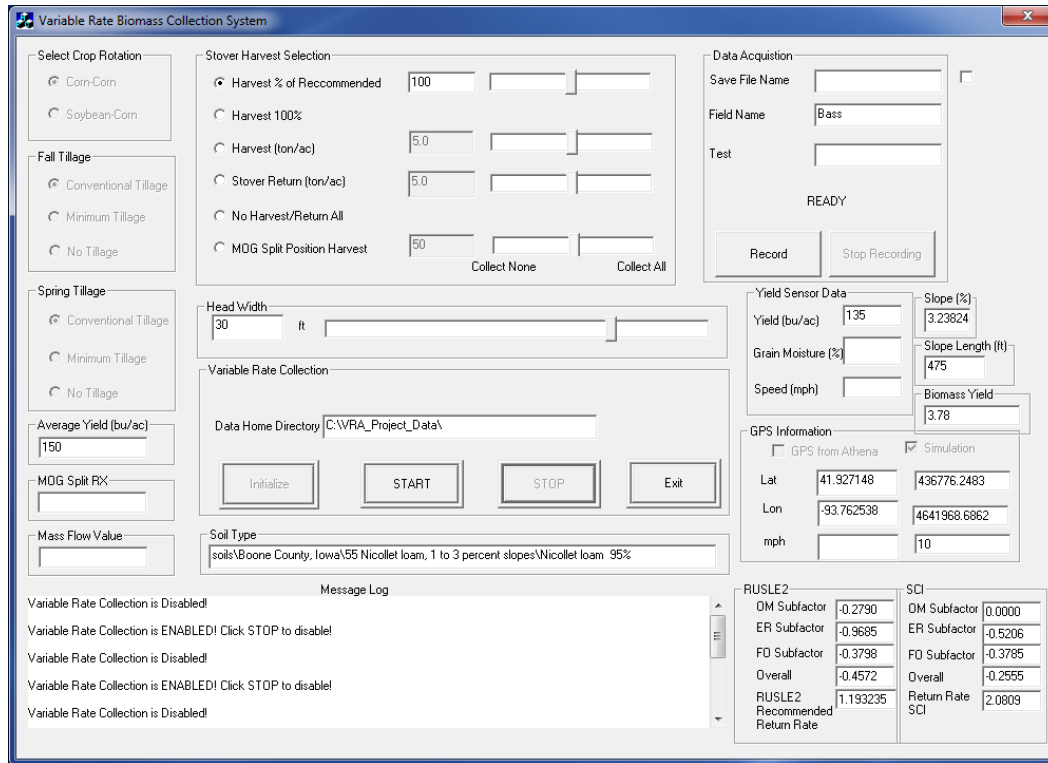
Figure 26: Variable Rate Corn Stover Return Rate Program user interface.

CHAPTER 4 METHODS PROCEDURES AND EXPERIMENTAL DESIGN

Tests were conducted at three different times throughout the harvest season at the BCRF location. These tests were conducted at three different corn stover moisture levels to determine if moisture was a key factor in cut height and MOG split position relationships. Corn stover moisture ranged between 9% and 52% while grain moisture ranged between 14.3% and 18.3%. Variable rate corn stover return rate testing was conducted at the Uthe Farm between the second and third moisture level tests at the BCRF location. Data was recorded using the data acquisition system described earlier. Data was processed using Microsoft Excel© and JMP© statistical software.

4.1 Field Testing Procedures

All machine tests were conducted using the John Deere 9860 STS single pass dual stream grain and biomass harvester with the John Deere 612C biomass collection corn head with 12 row collection as previously described. Data for determining grain yield, corn stover collection, and residue measurement followed similar data collection procedures for all tests.

4.1.1 Grain Yield

Grain yield was determined by using a CANUSB to extract the grain mass flow data from the CAN bus in $kg*s^{-1}$. Grain mass flow was then converted to a yield value of $Mg*ha^{-1}$. After each test pass was completed, the accumulated grain in the combine grain tank was weighed in a Brent 1080 grain cart equipped with a Digi-Star Model 410 scale indicator (Unverferth Manufacturing, Shell Rock, Iowa) with a resolution of 2.27 kg. This allowed for the grain yield sensor data to be corrected after harvest. The grain yield sensor

was calibrated prior to the first moisture level testing at the BCRF location. This calibration was used throughout the harvest season. Corrections due to moisture were made after harvest to account for the three different grain moisture levels tested. The grain yield sensor outputs the grain yield on a wet basis on the combine CAN bus. This yield was then converted to a dry grain yield by using the average grain moisture for that particular moisture level in order to determine the total amount of corn stover available by using the Harvest Index. For a high moisture level, the grain moisture was 18.3%, 15% for a medium moisture level, and 14.3% for a low moisture level. At the Uthe Farm, the combine grain tank was unloaded each time that the forage wagon was unloaded. The average grain moisture for the Uthe Farm was 15%.

4.1.2 Stover Collection Procedures

All collected corn stover was blown into a Meyer forage wagon equipped with a Digi-Star Model EZ 2400 scale indicator and four Digi-Star Model CT30KTC load cells (Digi-Star, Fort Atkinson, Wisconsin) with a resolution of 4.54 kg. After each test pass, the accumulated corn stover mass in the Meyer forage wagon was recorded. The forage wagon weight was also recorded on a CyCAN logger every two seconds to determine location and stover removal rate. At the BCRF location, the forage wagon was unloaded after each test pass. A sample was collected from the corn stover in the Meyer wagon to determine moisture content. Each sample was weighed, dried at 60° C for a minimum of three days, and reweighed.

At the Uthe Farm, the forage wagon was unloaded when it was full. Stover was unloaded in a central location to be baled with a Kuhn 3 foot by 3 foot by 7 foot large square baler at a later time.

4.1.3 Manual Residue Sample Collection

At the BCRF location, manual residue samples were collected from three random locations within each test pass where the MOG split position was set to 25% or 50%. At the Uthe Farm, a manual residue sample was randomly collected from each plot. To collect a manual residue sample, a 0.9 m by 9.1 m area was marked off for each sample. This measured the width of the test pass. Then, the remaining corn stalks were cut at the top root braces and collected in a yard waste bag. The remaining corn stover was then carefully raked, collected, and placed in the yard waste bag for that plot. Each sample was marked with the plot number and sample number to later identify each bag. Then, each sample was weighed and placed in a 60° C dryer for a minimum of three days. After drying, each sample was again weighed in order to determine moisture content.

4.2 Harvest Index Determination

Harvest Index is an important characteristic that needed to be determined in order to estimate the total stover available in a particular location based on grain yield. At the BCRF location, six manual plant samples were randomly collected throughout each moisture level. Each manual plant sample was collected by marking off a 0.9 m by 9.1 m section measuring the width of the test pass. At the Uthe Farm, a 1.8 m by 9.1 m section measuring the width of the corn head was randomly selected in each plot.

To collect a manual plant sample, first, the ears were collected to be shelled later. Then, the corn plant was cut at a location just below the ear shank and collected. This portion plus the cob and husks accounted for the top 50% of the corn plant, or the fraction of the plant that would enter the machine for a high cut (just below the ear shank). Then, the plant was cut at ground level and collected. Finally, the corn residue on the ground was collected. These last two segments of the plant account for the bottom 50% of the plant and would be the fraction remaining in the field for a high cut test plot (just below the ear shank). Each of these samples was weighed, dried, and reweighed to calculate sample moisture.

4.3 Developing Cut Height Calibration Curves

One of the inputs for determining a corn stover return rate is cut height. A correlation between the cut height of the corn head and the percentage of stover that is left in the field needs to be determined. The fraction of corn stover that is left in the field was determined by estimating the total corn stover amount from the Harvest Index and dry grain yield (0% moisture), subtracting the amount of dry corn stover collected in the Meyer forage wagon, and dividing by total stover (Equation 12). For a MOG split position of 100%, this value is approximately equal to the amount of dry corn stover entering the combine.

$$X_{Cut\ Height} = \frac{M_{stover} - M_{wagon}}{M_{stover}} \tag{12}$$

M_{wagon} = Weight of collected corn stover in Meyer forage wagon

(approximately equal to $M_{machine}$ for a MOG split position of 100%)

The John Deere 9860 STS single pass dual stream harvester and John Deere 612C biomass collection corn head were used throughout cut height testing. At the BCRF location, two different cut heights were conducted at two different speeds at each moisture level. Two

different speeds were used to determine if speed had an effect on how the corn plant was cut. One possibility could be that at a higher speed, the plant would bend slightly forward before being cut resulting in a plant cut height that is higher than the plant cut height for the same corn head height at a slower speed. Each moisture level had three replications. For all cut height tests, 100% corn stover collection was used in order to determine material flow through the combine. Cut heights were a high cut (just below the ear shank) and a low cut (as low as the corn head could be without digging into the ground). Speeds used were about 3.4 km/h and 4.8 km/h. Table 1 shows the different tests used for cut height testing. At the high moisture level, the high speed tests at both cut heights could not be completed because the combine could not handle that material flow.

Table 1: Experimental design for cut height calibration tests.

Cut Height	Speed (km/hr)
High	3.4, 4.8
Low	3.4, 4.8

4.4 Developing MOG Split Calibration Curves

The final control point for a variable corn stover return rate is at the MOG split vanes located between the chopper and the blower. The MOG split vanes divert material to the blower to be collected or to the spreaders to be returned to the ground. Tests were conducted to develop a correlation between MOG split position and the percentage of corn stover in the machine being returned to the ground at the BCRF location. At each of the three moisture levels, three different MOG split positions were tested at two different speeds. Each moisture level had three replications. The three MOG split positions tested were 25%, 50%, and 100%. A MOG split position of 100% indicates 100% collection of corn stover in the

combine while a MOG split position of 0% indicates 0% collection and all corn stover in the combine is being returned to the ground. Speeds used were about 3.4 km/h and 4.8 km/h. Table 2 shows the set of tests used for MOG split position testing. At a high moisture level, all high speed tests could not be completed because the combine could not handle the material flow. A high cut height (just below the ear shank) was used for all MOG split position tests. This was done because this was the cut height used for the variable corn stover return rate testing.

Table 2: Experimental design for MOG split position calibration tests.

MOG Split Position	Speed (km/hr)	Cut Height
25%	3.4, 4.8	High
50%	3.4, 4.8	High
100%	3.4, 4.8	High

In order to normalize results across various total stover amounts, a fraction of the material in the machine returned to the ground was developed. This was determined by subtracting the mass of dry corn stover in the Meyer forage wagon from the estimated mass of dry corn stover in the machine. This value was then divided by the estimated mass of dry corn stover in the machine as shown in Equation 13. The estimated mass of dry corn stover in the machine was determined from Equation 7.

$$X_{MOG\ split} = \frac{M_{machine} - M_{wagon}}{M_{machine}} \tag{13}$$

4.5 Variable Corn Stover Return Rate Testing

Variable corn stover return rate testing was conducted at the Uthe Farm between October 31, 2011, and November 15, 2011. A high cut height was used throughout this testing (just below the ear shank). A constant speed of about 3.2 km/h was used throughout

this testing. Based on GPS position, the Variable Corn Stover Return Rate Program determined a sustainable corn stover return rate based on erosion control and organic matter control as previously described. Then, the higher return rate was sent to the Athena computer by serial communication. The Athena computer would then control the MOG split position to attempt to meet the recommended corn stover return rate.

Data from the Athena control program and the Variable Corn Stover Return Rate Program were recorded to analyze later. Based on grain yield, header height, and MOG split position as recorded by the Athena control program as well as an average Harvest Index, an instantaneous corn stover return rate could be estimated. This was compared to the RUSLE2 prescribed corn stover return rate using Ag Leader Technology SMS (Spatial Management System) Advanced software.

CHAPTER 5 RESULTS AND DISCUSSION

5.1 Harvest Index Determination

The data results from the plant samples at the BCRF location are shown in Table 3. The first six plots are from a high moisture level, the next six plots are from a medium moisture level, and the final six plots are from a dry moisture level. The top 50% stover yield, bottom 50% stover yield, and grain yield are all presented on a dry basis (0% moisture). As the corn plant material dried throughout the harvest season, the amount of material in the top 50% of the plant decreased. This was due to leaves on the upper part of the plant drying and falling to the ground. The leaves would then be reclassified as being in the bottom 50% of the plant because they would not be collected by the corn head. This relationship can also be seen in the increase in the amount of material in the bottom 50% of the plant throughout the harvest season.

An overall average Harvest Index of 0.51 was observed at the BCRF location. An overall average dry grain yield of 10.77 Mg*ha^{-1} was observed throughout the harvest season for the manual plant samples. The bottom 50% of the plant started at about 55% moisture and dried down to about 22% moisture after about six weeks. The top 50% of the plant was always drier than the top 50%, making it a more desirable biomass feedstock.

Within each moisture repetition, the Harvest Index varies. At a low moisture level, the Harvest Index varied the most, between 0.44 and 0.54. For a variable corn stover return rate system, this variability will cause errors in the actual return rate.

Table 3: Harvest Index results for BCRF field location. Plots 1-13 were high moisture tests, plots 16-41 were medium moisture tests, and plots 46-70 were low moisture tests. Stover yield and grain yield reported on a dry basis (0% moisture).

Plot	Top 50% Stover Yield (Mg*ha^{-1})	Bottom 50% Stover Yield (Mg*ha^{-1})	Top 50% Moisture	Bottom 50% Moisture	Grain Yield (Mg*ha^{-1})	Harvest Index
1	4.74	5.72	26.39%	55.58%	10.63	0.50
4	3.95	4.76	20.67%	53.40%	10.36	0.54
8	4.88	5.45	17.74%	55.47%	12.26	0.54
9	5.57	4.57	19.93%	57.56%	11.57	0.53
11	4.59	7.68	37.25%	56.06%	13.06	0.52
13	4.88	6.10	26.62%	51.72%	11.72	0.52
Averages	4.77	5.71	24.77%	54.97%	11.60	0.53
19	4.28	5.60	9.60%	34.27%	10.33	0.51
21	4.57	6.53	9.05%	35.92%	10.90	0.50
32	4.14	5.12	8.47%	28.67%	9.29	0.50
33	3.95	5.29	8.33%	24.83%	9.74	0.51
34	4.86	6.67	9.38%	34.81%	11.25	0.49
37	4.40	5.53	6.60%	19.51%	10.98	0.53
Averages	4.37	5.79	8.57%	29.67%	10.41	0.51
51	4.02	5.21	10.16%	21.30%	9.63	0.51
54	4.21	5.62	9.28%	12.96%	8.28	0.46
57	3.68	5.79	9.94%	19.60%	10.03	0.51
61	3.90	6.29	12.37%	23.99%	8.07	0.44
66	4.50	6.58	11.74%	35.75%	13.16	0.54
68	4.38	6.36	11.59%	19.64%	12.69	0.54
Averages	4.12	5.98	10.85%	22.21%	10.31	0.50

Similarly, a plant sample was collected from 30 different plots at the Uthe Farm. Results are shown in Table 4 and appear very similar to the results from the last two moisture repetitions at the BCRF location. The Uthe Farm was harvested between the last two moisture repetitions at the BCRF location.

Table 4: Manual plant samples collected at the Uthe Farm to determine Harvest Index. Stover yield and grain yield reported on a dry basis (0% moisture).

Plot	Top 50% Stover Yield (Mg*ha⁻¹)	Bottom 50% Stover Yield (Mg*ha⁻¹)	Top 50% Moisture	Bottom 50% Moisture	Grain Yield (Mg*ha⁻¹)	Harvest Index
1.1	5.17	5.36	13.40%	25.54%	12.08	0.53
1.2	4.22	4.26	8.53%	14.80%	9.07	0.52
1.3	4.12	4.52	8.73%	20.38%	9.98	0.54
1.4	5.30	5.13	10.30%	36.20%	12.80	0.55
1.5	4.45	4.83	9.25%	31.36%	9.98	0.52
1.6	4.27	4.28	8.91%	29.47%	9.92	0.54
1.7	4.15	4.52	13.65%	26.97%	9.64	0.53
1.8	4.89	4.50	9.29%	23.99%	10.27	0.52
1.9	4.62	4.62	12.64%	31.26%	10.47	0.53
1.10	4.75	4.87	13.85%	33.33%	11.38	0.54
2.1	4.06	4.30	11.46%	37.82%	10.08	0.55
2.2	4.09	8.93	8.53%	17.80%	9.08	0.41
2.3	4.46	6.55	12.62%	39.93%	10.43	0.49
2.4	4.49	6.03	13.56%	44.93%	10.90	0.51
2.5	3.96	5.78	12.40%	47.39%	9.67	0.50
2.6	4.52	7.35	10.19%	28.37%	11.30	0.49
2.7	4.55	5.54	13.80%	49.18%	10.94	0.52
2.8	4.87	4.95	23.88%	26.94%	10.42	0.51
2.9	4.40	6.39	13.79%	41.34%	11.14	0.51
2.10	4.77	8.33	9.09%	29.28%	10.42	0.44
3.1	4.32	7.07	12.14%	28.07%	12.50	0.52
3.2	4.36	4.73	10.10%	16.28%	10.93	0.55
3.3	4.26	5.32	12.29%	26.16%	11.42	0.54
3.4	3.84	4.21	10.31%	15.95%	9.87	0.55
3.5	4.31	5.43	11.52%	36.81%	10.53	0.52
3.6	4.42	5.14	10.19%	20.92%	11.21	0.54
3.7	4.15	5.07	11.68%	21.00%	10.70	0.54
3.8	4.06	6.16	10.29%	26.91%	10.96	0.52
3.9	3.39	4.31	10.97%	22.70%	9.43	0.55
3.10	3.47	6.90	12.35%	26.93%	12.05	0.54
Averages	4.36	5.51	11.66%	29.27%	10.65	0.52

An estimate of the total corn stover available needed to be made in all plots. To determine total corn stover, the Harvest Index equation was used (Equation 5). The average Harvest Index for that moisture level was used to determine the total amount of corn stover. The Harvest Index was 0.53 for the high moisture level, 0.51 for a medium moisture level, and 0.50 for a low moisture level. For the Uthe Farm, a Harvest Index of 0.52 was used.

5.2 Cut Height Test Results

At each moisture level, cut heights and speed variations were plotted to evaluate the effects of speed and material flow on the fraction of corn stover left in the field by different cut heights. At a high moisture level, high speed tests were not attainable due to the combine not being able to process material fast enough, and the combine would plug. An average speed of 3.4 $km*h^{-1}$ was used throughout the high moisture plots. Figure 27 shows the relationship between the fraction of corn stover left on the ground by the cut height and the cut height. Generally, as the cut height increases, the fraction of corn stover remaining on the ground also increases. A linear regression of all points at a high moisture level showed a corresponding R^2 value of 0.4687 indicating that other factors may be affecting the fraction of corn stover remaining on the ground due to cut height.

Cut Height Fraction (High Moisture)

$X_{Cut\ Height} = 0.0047(Header\_height) + 0.1768$

$R^2 = 0.4687$

Y-axis: Cut Height Fraction (fraction left on ground)

X-axis: Cut Height (cm)
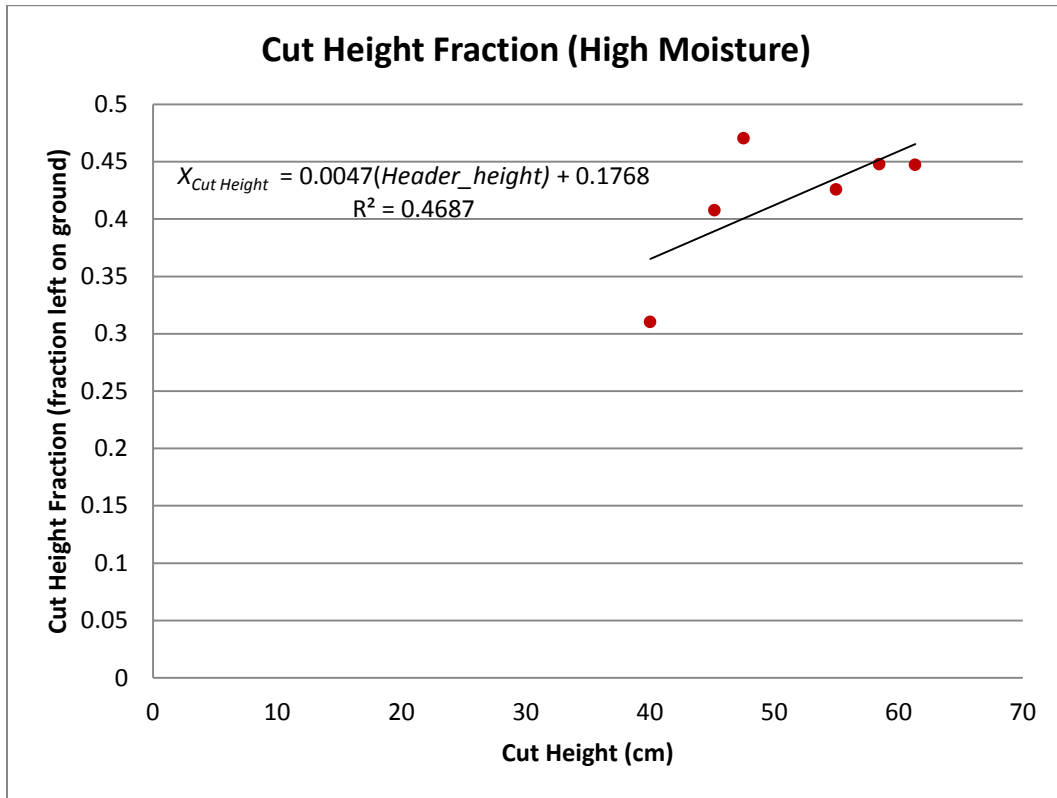
Figure 27: Cut height fraction at a high moisture level.

Figure 28 shows the relationship between cut height and the fraction of material remaining on the ground for a low moisture level at two different speeds. A linear regression for all data points shows an R^2 value of 0.5713. This is the highest correlation of the three moisture levels. One reason for this could be that by the time a low moisture level was achieved, the variability of moisture was low.
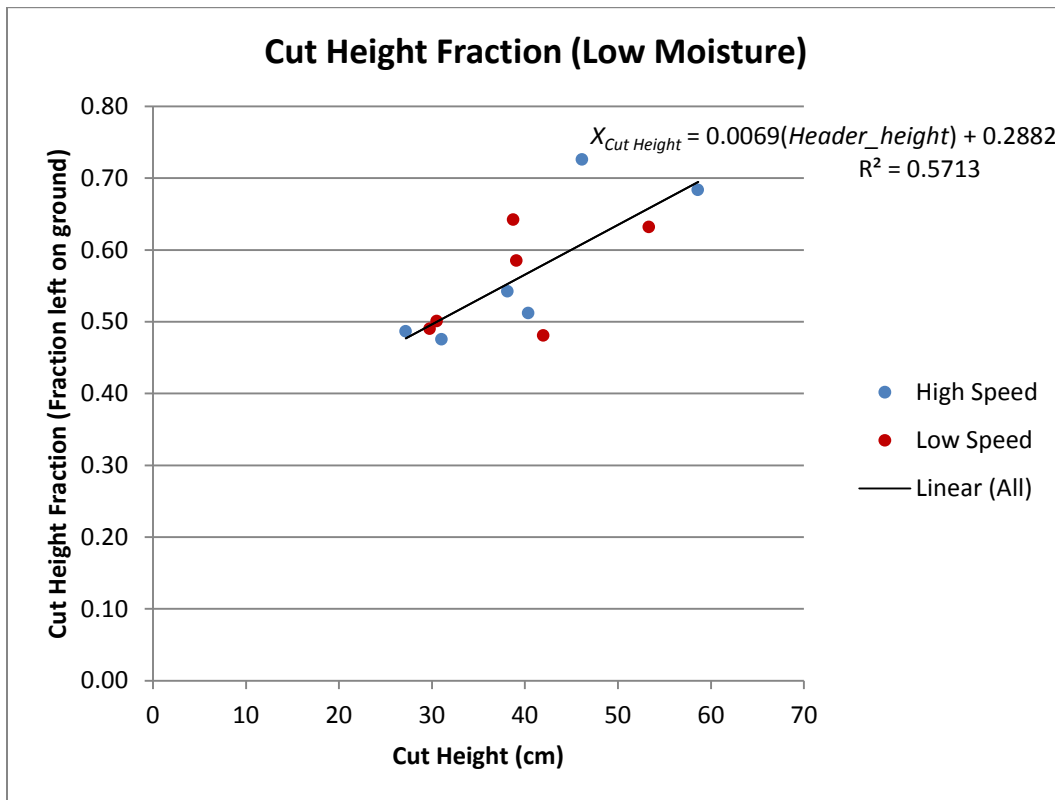
Figure 28: Cut height fraction for a low moisture level.

At a medium moisture level, the variability in corn stover moisture was so great that a relationship between cut height and a fraction remaining on the ground could not be determined accurately. The moisture level of the corn stover was determined from a grab sample of the corn stover collected in the Meyer forage wagon. If this small sample did not accurately represent all of the corn stover in the Meyer forage wagon, an inaccurate corn stover moisture level would result.

A statistical analysis was completed using JMP© software. Table 5 shows the Analysis of Variance (ANOVA) table for a model of cut height fraction remaining on the ground with cut height and stover moisture as factors. The probability that the means of the cut height fraction are the same is 0.0099, which indicates that the means are significantly

different. Table 6 shows the parameter estimates for a model of cut height fractions with cut height and stover moisture as factors. The estimate for stover moisture is -0.5867 which indicates that as stover moisture decreases while at the same cut height, the fraction of stover remaining on the ground increases. This reflects the results observed between high moisture tests and low moisture tests. The estimate for cut height is 0.0048 which indicates that as the cut height increases at a constant stover moisture level, the fraction of stover remaining on the ground due to cut height increases. Both stover moisture and cut height are significant factors as indicated by the probability that each factor explains the difference in means being less than 0.05. When stover moisture and cut height are crossed, the factor is not significant as indicated by a small t ratio and a probability of the t ratio being greater than t equal to 0.3602.

Table 5: Analysis of Variance for cut height fraction with cut height and stover moisture as factors.

Source	Degrees of Freedom	Sum of Squares	Mean Square	F Ratio	Prob > F
Model	3	0.1008	0.0336	5.5767	0.0099*
Error	14	0.0844	0.0060		
Total	17	0.1852			

Table 6: Parameter estimates for a model of cut height fractions with cut height and stover moisture as factors.

Term	Estimate	Standard Error	t Ratio	Prob > |t|
Intercept	0.4537	0.0847	5.36	0.0001*
Stover Moisture	-0.5867	0.1819	3.23	0.0061*
Cut Height	0.0048	0.0022	2.15	0.0494*
(Cut Height-43.48)*(Stover Moisture-0.23)	-0.0182	0.0193	-0.95	0.3602

At both ends of the moisture spectrum, a moderate linear relationship exists between cut height and a fraction of corn stover remaining on the ground. However, when these two moisture levels are combined, a linear relationship is inadequate. As stover moisture content decreases throughout the harvest season, the slope in the two cut height fraction equations increases meaning that more stover is left in the field at the same cut height as moisture content decreases. Also, the y-intercept of the two cut height fraction equations increases as stover moisture content decreases meaning that more stover is on the ground as stover moisture decreases. Both of these scenarios are true throughout the harvest season. As the plant material dries, the top leaves of the plant dry and fall to the ground where they cannot be collected with the present biomass collection corn head. Therefore, stover moisture content was added to the analysis to develop a scaled equation. At low moisture content, the average corn stover moisture was 14.2% while the average corn stover moisture was 38.7% at a high moisture content. Equation 14 shows the scaled equation used to determine the cut height fraction.

$$X_{Cut\ Height} = \left[\left(\frac{MC_{stover} - 14.2}{38.7 - 14.2}\right)(0.0047 - 0.0069) + 0.0069\right](Header\_height) +$$

$$\left[\left(\frac{MC_{stover} - 14.2}{38.7 - 14.2}\right)(0.1768 - 0.2882) + 0.2882\right] \tag{14}$$

MC_{stover} $\qquad$ = Average collected corn stover moisture (%)

5.3 MOG Split Position Testing Results

Figure 29 shows the results from the MOG split position testing across all moisture levels. A linear regression line was fit to all data points with an R^2 value of 0.9125. At a MOG split position of 100%, less than 0% of the fraction in the machine could not be physically returned to the ground. This error resulted from a poor estimation of the amount

of material in the combine due to the estimated Harvest Index and the cut height equation. The total stover available was calculated by using the grain mass flow from the grain yield sensor, correcting for moisture, with the Harvest Index (Equation 5). From this, the amount of stover in the combine was determined by the cut height calibration curve (Equation 14).

The different moisture levels were separated in order to see if moisture had an effect on the MOG split position equation. This equation shows that as MOG split position decreases, the fraction of material in the combine returned to the field increases.
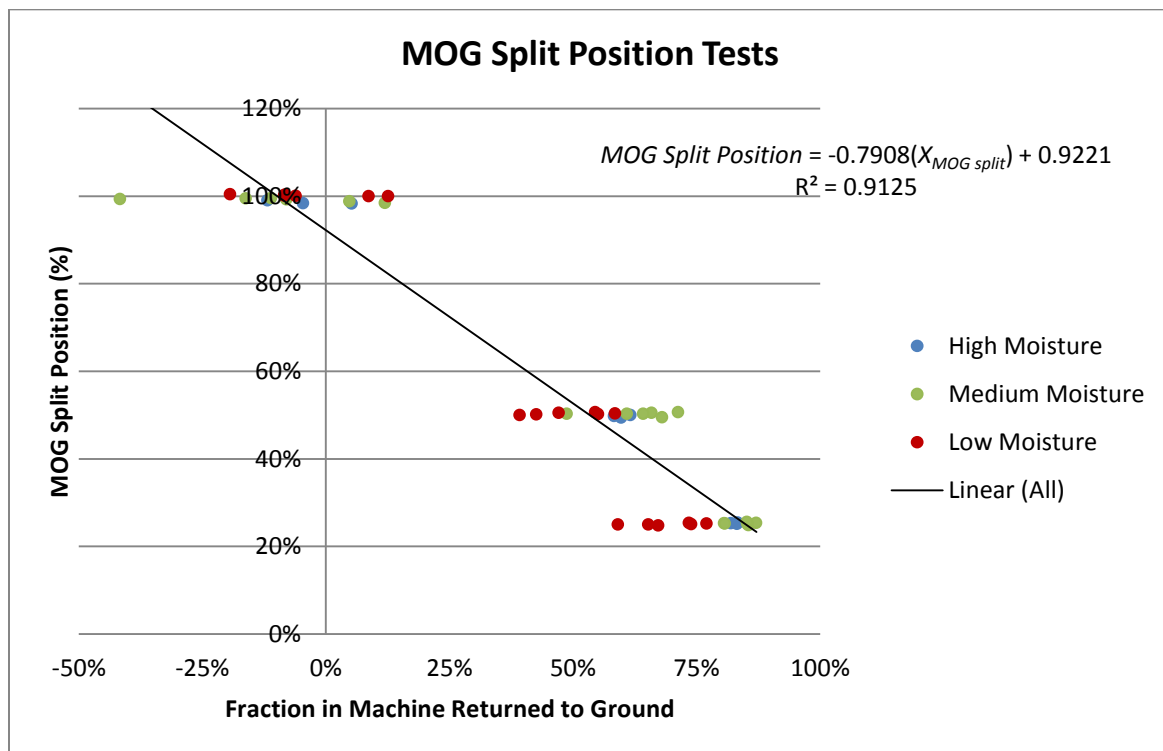
Figure 29: MOG split position results for all moisture levels.

Table 7 shows the average fraction of corn stover in the combine returned to the ground for each of the three MOG split positions along with the standard deviation for each MOG split position. Also, a 95% confidence interval and 95% prediction interval for each

MOG split position across all moisture levels were calculated. For a MOG split position of 100%, a negative fraction of corn stover in the machine could not realistically be returned to the ground. This would imply that more corn stover is returning to the ground than was collected by the corn head. Negative values for a 100% MOG split position are due to inaccuracies in the estimation of material entering the machine. The material collected was directly measured and therefore fairly accurate. However the material entering the machine was not directly measured, and was calculated from the total corn stover mass, determined using the Harvest Index. The material entering the machine was then determined based on the cut height calibrations. Therefore, any errors in Harvest Index or cut height calibration would cause corresponding errors in the estimation of the mass of material entering the machine, and subsequent determination of the mass returned to the ground.

Table 7: MOG split averages, 95% confidence intervals, and 95% prediction intervals.

MOG Split Position	Average Percent in Machine Returned to Ground	Standard Deviation	95% PI	95% CI
25%	77.97%	8.47%	84.99% ± 24.42%	84.99% ± 5.23%
50%	57.09%	9.27%	53.38% ± 24.14%	53.38% ± 3.68%
100%	-6.13%	14.04%	-9.85% ± 24.60%	-9.85% ± 5.99%

In Table 7, the 95% prediction intervals have a wide band of about 25%, which may seem to be too large for a controls application. However, this band is for the fraction of corn stover in the machine that is returned to the ground. For a corn grain yield of about 11.3 Mg*ha^{-1} at 15% moisture, the dry corn grain yield is about 9.6 Mg*ha^{-1}. Using a Harvest Index value of 0.52, the total amount of corn stover available is about 8.9 Mg*ha^{-1}. By looking at Figure 27 and Figure 28, roughly about 50% of the total corn stover available is

brought into the machine. This corresponds to about 4.5 Mg*ha^{-1} actually entering into the machine. Of the corn stover in the machine, there is a band of about 25% for the 95% prediction interval. This corresponds to about 1.1 Mg*ha^{-1}.

A visual difference can be seen between a 100% MOG split position harvest plot and a 50% MOG split position harvest plot as seen in Figure 30. A red arrow separates the 100% MOG split position plot from the 50% MOG split position plot. The plot in the foreground is a 50% MOG split position, which resulted in some corn stover in the combine being returned to the ground. In contrast, the plot farther back is a 100% MOG split position plot, which resulted in almost no corn stover from the combine being returned to the ground. All corn stover that entered the combine was collected in this plot.

Figure 30: Visual difference between a 100% MOG split position plot and a 50% MOG split position plot.

5.4 Variable Corn Stover Return Rate Testing Results

Results for the variable corn stover return rate tests for the Southwest Field at the Uthe Farm are shown in Figure 31. The top left map shows the grain yield (15% moisture level) for the variable corn stover return rate plots based on the grain mass flow sensor in the combine. The map in the top right corner shows the actual MOG split position on the combine. A MOG split position of 0% means that all corn stover in the combine is being returned to the ground, or 0% collection. A MOG split position of 100% means that all corn stover in the combine is being collected and little material is being returned to the ground. The map in the bottom left corner shows the prescribed dry return rate based on the Variable Corn Stover Return Rate Program using the RUSLE2. The bottom right map shows the estimated dry return rate based on a constant Harvest Index of 0.52, grain yield (0% moisture level), the cut height equation for low moisture (Figure 28), and the MOG split position equation for low moisture (Equation 15). These two equations were used because the corn stover moisture at the Uthe Farm was closest to this moisture level.

$$X_{MOG\ split} = \frac{\frac{MOG\ Split\ Position}{100} - 0.9729}{-0.9654} \qquad (15)$$

For most of the plots, the estimated return rate is greater than the prescribed return rate. This is mainly due to a low return rate being prescribed by the Variable Corn Stover Return Rate Program. With a header height just below the ear shank, the amount of corn stover remaining on the ground is greater than the prescribed return rate. If the estimated return rate is less than the prescribed return rate, such as in the northeast corner (Location 1) of this field, the amount of corn stover available was less than the prescribed return rate. At this location, the combine has a MOG split position of 0%, or returning all corn stover to the

ground. However, due to a low grain yield, there is not enough corn stover available to meet the prescribed return rate in this area.

Figure 31: Variable corn stover return rate plots for the Uthe Southwest Field. Maps shown are grain yield (15% moisture) from the grain mass flow sensor (top left), actual MOG split position (top right), prescribed dry corn stover return rate (bottom left), and estimated dry corn stover return rate (bottom right).

In the first two plots on the northern edge, the prescribed return rate increases from 3.25 – 4.50 Mg*ha^{-1} to 4.50 – 5.75 Mg*ha^{-1} at Location 2 in Figure 31. In this location, a gradual incline begins causing a higher prescribed return rate. The machine responds to this increased prescribed return rate by changing the MOG split position from about 100% (100% collection) to about 50%. With a lower MOG split position, the biomass stream is split into two fractions. One fraction is returned to the ground and the other is being collected.

The next two variable corn stover return rate plots (Locations 3 and 4 in Figure 31), have a prescribed return rate that remains below 5.75 Mg*ha^{-1}. With a higher grain yield in these two plots compared to the northern two plots, a return rate of 5.75 Mg*ha^{-1} can almost be achieved by the corn stover that is left by the cut height. As shown in the MOG split position map, these two plots have a MOG split position close to 100% (100% collection) most of the time.

Going south to the next two variable corn stover return rate plots, a terrace running north and south splits the plots in the middle. To the west of this terrace, the terrain is fairly flat while on the east side of this terrace, the terrain is hilly. In the center of these plots, an area is highlighted by Location 5 in Figure 31. This is the area immediately east of the terrace. A high prescribed return rate of 7.00 – 8.25 Mg*ha^{-1} was calculated by the Variable Corn Stover Return Rate Program. The MOG split position on the combine responded by setting itself to a value of almost 0% which returned all of the corn stover to the ground. The estimated return rate shows a high return rate in this area of over 8.25 Mg*ha^{-1}. One note that should be made on these two plots is the missing data. This occurred because the computer was not properly recording in these locations.

The final two variable corn stover return rate plots in this field are located on the southern edge. These two plots were similar in terrain to the previous two plots discussed. They were divided by a terrace about midway through the plots. On the west side of the terrace and the east side of the plots, the terrain was fairly level. This corresponds with a low prescribed return rate as shown in Figure 31. Immediately east of the terrace, hilly terrain exists. Here the Variable Corn Stover Return Rate Program using RUSLE2 prescribed a higher return rate to prevent erosion. This area is outlined at Location 6 in Figure 31. The MOG split position is less than 30% in this location, so most of the corn stover is being returned to the ground which corresponds with a higher estimated return rate.

Figure 32 highlights the grain yield (15% moisture level), MOG split position, prescribed dry corn stover return rate from the Variable Corn Stover Return Rate Program using the RUSLE2, and estimated dry corn stover return rate for the variable corn stover return rate plots in the Uthe Northeast Field. In this field, the rows ran north and south while the plot layout was designed in an east and west direction so that all the plots captured the only terrain that existed in this field, a downward sloping hill on the eastern edge. The combine traveled north and south along the corn rows, and then adjusted the MOG split position for the different plots in this study when a plot boundary was crossed.

In this field, there were several locations that had very little or no corn grain yield due to poor drainage causing these areas to have little or no corn stover available. These areas are highlighted by Locations 1, 2, and 3 in Figure 32. The prescribed return rate was not affected by the low corn grain yield, which is why these locations are not marked on the prescribed return rate map.
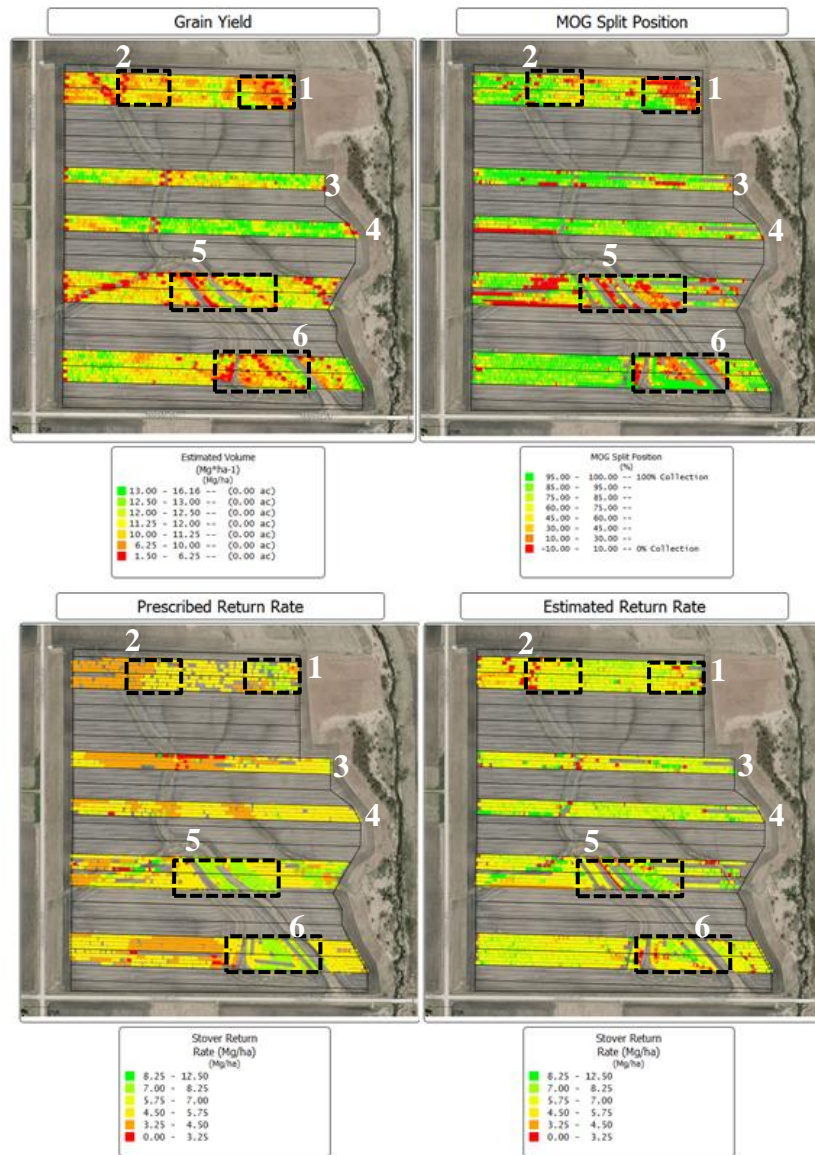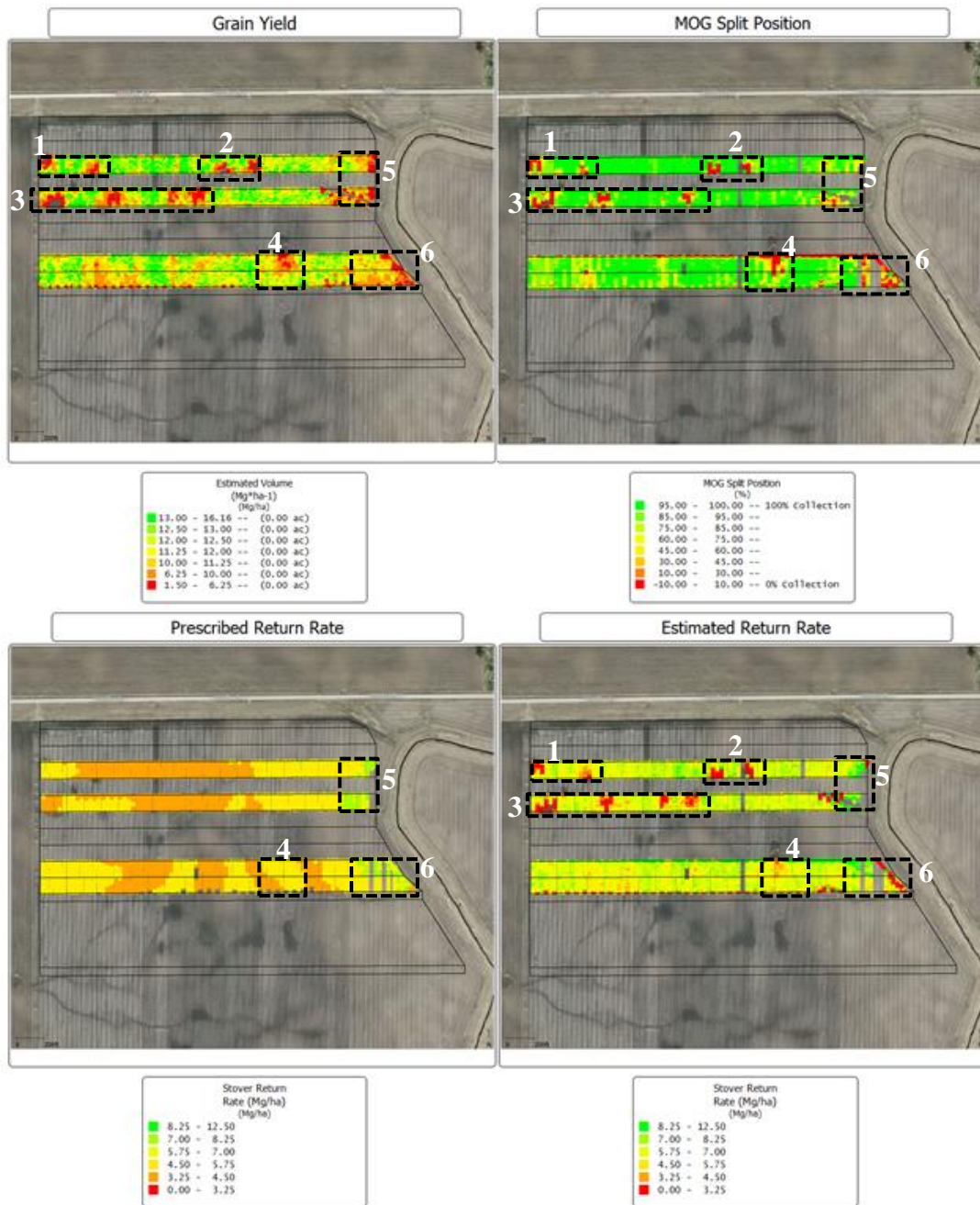
Figure 32: Variable corn stover return rate plots for the Uthe Northeast Field. Maps shown are grain yield (15% moisture) from the grain mass flow sensor (top left), actual MOG split position (top right), prescribed dry corn stover return rate (bottom left), and estimated dry corn stover return rate (bottom right).

Location 4 in Figure 32 is an interesting location. In this area, the corn grain yield was lower than the surrounding areas causing the total stover available to be lower than the surrounding areas. However, there was enough corn stover available to meet the prescribed return rate. In the MOG split position map, the MOG split position changes to about 0%, or returning all corn stover to the ground, but there is little difference in the estimated return rate map.

Locations 5 and 6 in Figure 32 are located along the eastern edge where the downward slope is located. In these locations, the erosion control return rate is higher than the organic matter control return rate. A prescribed return rate of 7.00 − 8.25 Mg*ha^{-1} is higher than the surrounding locations. The MOG split position is between 0% and 50%, which causes the estimated return rate to be higher than the surrounding locations.

5.5 Manual Ground Sample Comparison

In each plot at the Uthe Field, a residue ground sample was collected after harvest to measure how much residue remained on the ground. For the variable corn stover return rate plots, two residue ground samples were collected, one from a flat area and one from a hilly area. The amount of corn stover collected in a ground sample was then compared to the estimated corn stover return rate for that same area as shown in Figure 33. Generally, as the estimated corn stover return rate increases, so does the collected ground sample. The six points on the right that have a high estimated return rate are from plots that were harvested with a conventional combine and no corn stover was removed. Usually, the manual ground sample is about 2.5 Mg*ha^{-1} lower than the estimated stover return rate due to a small area being sampled in the manual ground sample and then being extrapolated to a much larger

area. If 0.50 kg of corn stover were not collected in a ground sample and should have been,

the ground sample would be about 0.6 Mg*ha^{-1} less than what it should be.
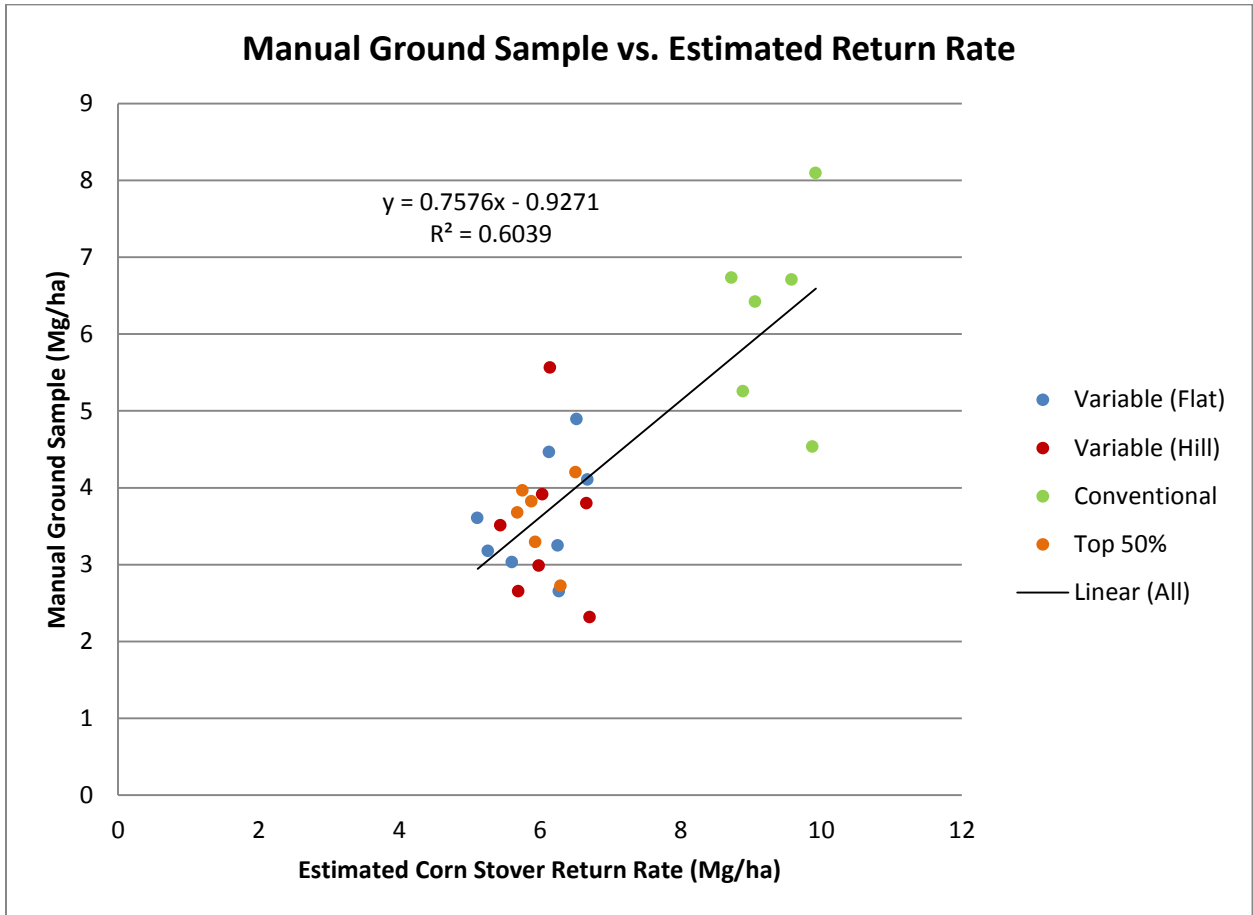
Figure 33: Comparison of ground sample and estimated stover return rate for the same area

in the Uthe Southwest Field.

CHAPTER 6 CONCLUSIONS

The Harvest Index provided sufficient results in order to predict a total corn stover amount. Harvest Index values varied from 0.41 to 0.55 showing that Harvest Index varies spatially throughout a field and different conditions. The manual plant samples also showed that the plant material dried down throughout the harvest season with the plant material above the ear being drier than the plant material below the ear.

The cut height tests resulted in two different equations, one for a high stover moisture level, and the other for a low stover moisture level. From a high moisture level to a low moisture level, the slope of the fraction of material remaining in the field due to cut height line increased, which corresponds to plant material drying and falling to the ground. At a medium stover moisture level, the variability between test samples was too great to accurately predict a cut height fraction.

The MOG split position tests provided good results for being able to accurately split a desired fraction of stover in the machine. Also, the MOG split vanes have a fairly quick response. Six seconds are required for the vanes to adjust from a fully open position to a fully closed position, which is an adequate response.

Integrating the Variable Corn Stover Return Rate Program using the RUSLE2 and the control system on the single pass dual stream biomass harvester was successful in the fall of 2011. The estimated return rate was usually greater than the prescribed return rate from the Variable Corn Stover Return Rate Program using the RUSLE2. If the estimated return rate was less than the prescribed return rate, the combine was returning as much corn stover as it could to the ground. Also, when a slope was encountered, the RUSLE2 program prescribed a

higher return rate in order to prevent erosion, and the MOG split position adjusted to try to meet this prescription return rate.

6.1 Recommendations

A stover mass flow sensor is currently in development in order to predict the amount of corn stover entering the combine. Further development of this sensor would improve control of the variable corn stover prescription return rate. This sensor would reduce errors from the Harvest Index and the cut height equations.

The DICKEY-john moisture sensor and temperature sensor was installed on the combine late in the 2011 harvest season and did not encounter a wide range of stover moistures or temperatures. Continued testing of this sensor would help to predict stover moisture so that a dry stover mass could accurately be determined in real time.

In the RUSLE2 database, a few states remain to be completed in order for the RUSLE2 program to be run in the entire United States. States completed cover the largest corn producing states and are located east of the Rocky Mountains.

WORKS CITED

Babcock, B.A., G.R. Pautsch. 1998. Moving from uniform to variable fertilizer rates on Iowa corn: effects on rates and returns. *Journal of Agriculture and Resource Economics,* 23, 385-400.

Bongiovanni, R., J. Lowenberg-DeBoer. 2004. Precision agriculture and sustainability. *Precision Agriculture,* 5, 359-387.

Bullock, D.S., J. Lowenberg-DeBoer, S.M. Swinton. 2002. Adding value to spatially managed inputs by understanding site-specific yield response. *Agricultural Economics*, 27, 233-245.

Graham, R.L., R. Nelson, J. Sheehan, R.D. Perlack, L.L. Wright. 2007. Current and potential U.S. corn stover supplies. *Agronomy Journal*, 99, 1-11.

Hatfield, J.L. 2000. Precision Agriculture and Environmental Quality: Challenges for Research and Education. National Soil Tilth Laboratory, Agricultural Research Service, USDA, Ames, Iowa. Document available at http://www.arborday.org.

Hoskinson, R.L., D.L. Karlen, S.J. Birrell, C.W. Radtke, W.W. Wilhelm. 2006. Engineering, nutrient removal, and feedstock conversion evaluations of four corn stover harvest scenarios. *Biomass and Bioenergy*, 31, 126-136.

Hubbs, M.D., M.L. Norfleet, D.T. Lightle. 2002. Interpreting the soil conditioning index, in E. van Santen (Editor) Proceedings of the 25th Annual Southern Conservation Tillage Conference for Sustainable Agriculture. Department of Agronomy and Soils, Alabama Agricultural Experiment Station, Auburn University, AL, 192-196. (2002).

Johnson, J.M.F., R.R. Allmaras, D.C. Reicosky. 2006. Estimating source carbon from crop residues, roots and rhizodeposits using the national grain-yield database. *Agronomy Journal*, 98, 622-636.

Johnson, J.M.F., W.W. Wilhelm, D.L. Karlen, D.W. Archer, B. Wienhold, D.T. Lightle, D. Laird, J. Baker, T.E. Ochsner, J.M. Novak, A.D. Halvorson, F. Arriaga, N. Barbour. 2010. Nutrient removal as a function of corn stover cutting height and cob harvest. *Bioenergy Resource*, 3, 342-352.

Karkee, M., R.P. McNaull, S.J. Birrell, B.L. Steward. 2011. Estimation for Optimizal Biomass Removal Rate Based on Tolerable Soil Erosion for Single Pass Crop Grain and Biomass Harvesting System. *Trans. ASABE. 55*, 1, 107-115.

Linden, D.R., C.E. Clapp, R.H. Dowdy. 2000. Long-term corn grain and stover yields as a function of tillage and residue in east central Minnesota. *Soil & Tillage Research*, 56, 167-174.

McNaull, R.P. 2010. Design and evaluation of variable rate stover collection control system for a single pass dual stream biomass harvester system. M.S. thesis. Ames, Iowa: Iowa State University, Department of Agricultural and Biosystems Engineering.

Renard, K.G., G.R. Foster, G.A. Weesies, D.K. McCool, D.C. Yoder. 1997. Predicting soil erosion by water: a guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE) in T.U. Agriculture, <u>Agriculture Handbook No. 703.</u> USDA, Washington, D.C., 1-367. (1997).

Wilhelm, W.W., J.M.F. Johnson, J.L. Hatfield, W.B. Voorhees, D.R. Linden. 2004. Crop and soil productivity response to corn residue removal: a literature review. *Agronomy Journal*, 96, 1-17.

Wilhelm, W.W., J.M.F. Johnson, D.T. Lightle, D.L. Karlen, J.M. Novak, N.W. Barbour, D.A. Laird, J. Baker, T.E. Ochsner, A.D. Halvorson, D.W. Archer, F. Arriaga. 2010. Vertical distribution of corn stover dry mass grown at several US locations. *Bioenergy Resource,* 4, 11-21.

APPENDIX: BCRF TEST RESULTS

Table A.1: High moisture test results from BCRF field location.

Plot	Date	Cut Height (cm)	Speed (kph)	MOG Split Position	Collected Stover DM (Mg/ha)	Collected Stover Moisture (%)	Grain Yield (Mg/ha) Wet	Grain Yield (Mg/ha) Dry	Total Stover Estimated by HI (Mg/ha)	Cut Height % of Total Stover Returned (100% MOG Split Position Only)	% of Total Stover Returned Using Cut Height Equation	Estimated Mass in Machine (Mg/ha)	% in Machine Returned
1	10/3/2011	61.34	#	98.97%	5.14	34.69%	12.62	10.31	9.30	44.72%	50.54%	4.60	-11.76%
2	10/3/2011	40.02	#	98.94%	6.63	36.79%	13.04	10.65	9.61	31.01%	38.04%	5.95	-11.36%
3	10/3/2011	58.87	#	49.38%	1.95	38.44%	12.10	9.89	8.92	-	45.61%	4.85	59.75%
4	10/3/2011	54.88	#	25.25%	0.89	37.50%	12.15	9.93	8.96	-	44.61%	4.96	82.01%
6	10/5/2011	56.44	3.50	49.76%	1.96	34.17%	12.45	10.17	9.17	-	48.57%	4.72	58.35%
7	10/5/2011	58.40	3.38	25.12%	0.82	37.75%	12.33	10.08	9.09	-	46.06%	4.90	83.22%
8	10/5/2011	45.20	3.41	98.24%	5.45	34.31%	12.49	10.20	9.20	40.74%	42.70%	5.27	-3.42%
9	10/5/2011	58.48	3.47	98.31%	4.84	36.61%	11.88	9.71	8.76	44.77%	47.21%	4.62	-4.61%
10	10/5/2011	55.00	3.40	98.27%	5.19	43.09%	12.26	10.01	9.03	42.56%	39.36%	5.48	5.27%
11	10/5/2011	62.16	3.45	49.94%	2.18	46.16%	12.71	10.39	9.37	-	39.34%	5.68	61.66%
12	10/5/2011	47.55	3.11	98.16%	5.17	51.92%	13.23	10.81	9.75	47.02%	28.37%	6.98	26.03%
13	10/5/2011	57.40	3.34	25.43%	0.92	43.58%	12.55	10.25	9.25	-	39.92%	5.56	83.36%

= GPS speed did not record. Low speed test with a speed of approximately 3.4 kph.

Table A.2: Medium moisture test results from BCRF field location.

Plot	Date	Cut Height (cm)	Speed (kph)	MOG Split Position	Collected Stover DM (Mg/ha)	Collected Stover Moisture (%)	Grain Yield (Mg/ha) Wet	Grain Yield (Mg/ha) Dry	Total Stover Estimated by HI (Mg/ha)	Cut Height % of Total Stover Returned (100% MOG Split Position Only)	% of Total Stover Returned Using Cut Height Equation	Estimated Mass in Machine (Mg/ha)	% in Machine Returned
16	10/20/2011	41.37	3.28	98.78%	3.95	13.55%	11.91	10.12	9.86	59.92%	57.90%	4.15	4.79%
17	10/20/2011	36.52	5.10	24.81%	0.62	21.18%	10.16	8.64	8.41	-	48.56%	4.33	85.57%
18	10/20/2011	41.40	5.45	50.44%	1.45	16.18%	11.63	9.89	9.63	-	55.74%	4.26	65.93%
19	10/20/2011	37.56	3.36	50.62%	1.31	22.05%	10.70	9.09	8.85	-	48.52%	4.56	71.32%
20	10/20/2011	37.35	4.01	98.61%	3.95	20.69%	11.91	10.12	9.86	59.90%	49.47%	4.98	20.64%
21	10/20/2011	41.36	5.17	98.39%	4.06	21.10%	11.53	9.80	9.54	57.46%	51.66%	4.61	12.00%
22	10/20/2011	44.18	3.33	25.34%	0.56	18.97%	11.72	9.96	9.70	-	55.24%	4.34	87.13%
23	10/20/2011	36.15	3.33	98.45%	3.86	19.66%	11.78	10.02	9.76	60.40%	49.51%	4.93	21.57%
25	10/21/2011	42.97	*	50.25%	1.51	17.71%	11.49	9.77	9.51	-	55.52%	4.23	64.25%
27	10/21/2011	41.82	*	25.05%	0.68	19.86%	11.94	10.15	9.88	-	52.97%	4.65	85.34%
28	10/21/2011	39.84	#	50.27%	1.65	13.70%	11.81	10.04	9.78	-	56.71%	4.23	60.97%
29	10/21/2011	42.92	4.89	99.47%	4.27	17.65%	10.44	8.87	8.64	50.62%	55.54%	3.84	-11.06%
30	10/21/2011	34.12	3.37	99.51%	3.86	26.40%	12.33	10.48	10.21	62.23%	43.08%	5.81	33.65%
31	10/21/2011	34.30	5.22	99.46%	4.98	17.20%	10.63	9.03	8.80	43.41%	50.20%	4.38	-13.64%
32	10/21/2011	39.21	3.33	99.42%	4.41	14.29%	10.37	8.82	8.59	48.65%	55.80%	3.79	-16.18%
33	10/21/2011	44.12	#	25.57%	0.57	13.91%	11.54	9.81	9.55	-	59.51%	3.87	85.22%
34	10/23/2011	51.15	3.16	25.22%	0.65	10.81%	12.30	10.46	10.18	-	67.21%	3.34	80.66%
35	10/23/2011	33.30	4.26	99.44%	4.87	22.16%	12.27	10.43	10.16	52.06%	45.80%	5.51	11.56%
36	10/23/2011	49.17	4.79	99.28%	4.83	13.25%	11.31	9.61	9.36	48.44%	63.60%	3.41	-41.63%
37	10/23/2011	47.83	4.66	25.19%	0.72	13.77%	11.94	10.15	9.89	-	62.21%	3.74	80.73%
38	10/23/2011	49.03	4.83	50.27%	1.89	15.19%	11.68	9.93	9.67	-	61.77%	3.70	48.78%
39	10/23/2011	49.41	3.46	99.18%	4.80	20.67%	12.52	10.64	10.36	53.70%	57.10%	4.45	-7.93%
40	10/23/2011	39.09	3.18	99.29%	6.19	34.44%	13.30	11.31	11.01	43.76%	39.49%	6.66	7.07%
41	10/23/2011	59.82	3.30	49.46%	2.39	38.67%	16.67	14.17	13.80	-	45.82%	7.48	68.05%

* = GPS speed did not record. High speed test with a speed of approximately 4.8 kph.

\# = GPS speed did not record. Low speed test with a speed of approximately 3.4 kph.

Table A.3: Low moisture test results from BCRF field location.

Plot	Date	Cut Height (cm)	Speed (kph)	MOG Split Position	Collected Stover DM (Mg/ha)	Collected Stover Moisture (%)	Grain Yield (Mg/ha) Wet	Grain Yield (Mg/ha) Dry	Total Stover Estimated by HI (Mg/ha)	Cut Height % of Total Stover Returned (100% MOG Split Position Only)	% of Total Stover Returned Using Cut Height Equation	Estimated Mass in Machine (Mg/ha)	% in Machine Returned
46	11/18/2011	39.98	3.43	25.21%	0.93	8.97%	12.11	10.38	10.32	-	60.66%	4.06	77.09%
47	11/18/2011	34.68	4.84	50.61%	2.09	10.23%	12.21	10.47	10.40	-	55.79%	4.60	54.51%
48	11/18/2011	38.75	3.36	99.96%	3.61	9.90%	11.83	10.14	10.08	64.19%	59.01%	4.13	12.64%
49	11/18/2011	31.05	4.60	100.70%	3.95	12.26%	8.84	7.57	7.53	47.53%	51.67%	3.64	-8.56%
50	11/18/2011	30.52	3.35	100.27%	4.21	12.77%	9.90	8.48	8.43	50.04%	50.93%	4.14	-1.80%
52	11/18/2011	37.53	3.37	50.17%	1.73	10.98%	10.58	9.07	9.02	-	57.27%	3.85	55.11%
53	11/18/2011	38.13	5.21	100.31%	3.86	11.00%	9.89	8.48	8.43	54.20%	57.68%	3.57	-8.24%
54	11/18/2011	39.62	5.07	25.34%	0.92	9.38%	10.19	8.74	8.68	-	60.07%	3.47	73.54%
55	11/18/2011	44.02	3.32	50.31%	1.43	11.24%	10.60	9.09	9.03	-	61.71%	3.46	58.58%
56	11/18/2011	27.20	4.77	100.36%	4.59	12.38%	10.49	8.99	8.94	48.64%	48.86%	4.57	-0.43%
57	11/18/2011	38.39	4.90	25.00%	1.05	11.11%	11.25	9.64	9.58	-	57.78%	4.05	73.96%
58	11/18/2011	40.37	5.81	100.40%	3.80	11.21%	9.14	7.83	7.79	51.19%	59.11%	3.18	-19.38%
59	11/18/2011	38.26	5.73	50.46%	1.96	10.38%	10.46	8.97	8.91	-	58.27%	3.72	47.18%
60	11/18/2011	29.78	3.52	100.41%	4.27	11.21%	9.82	8.42	8.37	49.00%	51.53%	4.06	-5.23%
61	11/19/2011	39.11	3.02	99.96%	3.79	15.73%	10.71	9.18	9.13	58.51%	54.57%	4.15	8.67%
62	11/19/2011	37.93	3.33	24.75%	1.32	15.79%	10.22	8.76	8.71	-	53.73%	4.03	67.28%
63	11/19/2011	46.18	2.92	99.29%	3.13	22.69%	13.39	11.48	11.41	72.58%	53.30%	5.33	41.28%
64	11/19/2011	58.61	4.56	24.93%	1.39	15.00%	12.69	10.88	10.81	-	68.47%	3.41	59.13%
65	11/19/2011	57.48	3.16	50.12%	2.10	16.30%	12.81	10.98	10.91	-	66.44%	3.66	42.62%
66	11/19/2011	52.54	3.11	24.95%	1.33	15.38%	12.46	10.68	10.62	-	63.97%	3.82	65.27%
67	11/19/2011	53.34	3.05	99.99%	3.93	14.58%	12.53	10.74	10.68	63.16%	65.27%	3.71	-6.05%
68	11/19/2011	55.22	4.31	49.94%	2.18	14.94%	12.46	10.68	10.62	-	66.21%	3.59	39.28%
69	11/19/2011	58.63	4.14	100.11%	3.46	12.66%	12.81	10.98	10.91	68.32%	70.79%	3.19	-8.44%
70	11/19/2011	42.02	2.87	100.10%	5.14	25.69%	11.63	9.96	9.91	48.07%	48.25%	5.13	-0.35%