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# Design and Evaluation of Variable Rate Stover Collection Control System For a Single Pass Dual Stream Biomass Harvester System

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**Design and evaluation of variable rate stover collection control system  
for a single pass dual stream biomass harvester system**

by

**Robert Paul McNaull**

A thesis submitted to the graduate faculty  
in partial fulfillment of the requirements for the degree of  
MASTER OF SCIENCE

Major: Agricultural Engineering

Program of Study Committee

Stuart J. Birrell, Major Professor

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Iowa State University

Ames, Iowa

2010

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## 1.0 INTRODUCTION

With the continual growth of the world population, there is a need for a consistent food supply along with the energy needed to support the homes and needs of the world population. The combustion of fossil fuels to provide the needed energy releases excess carbon into the atmosphere and excessively consumes limited resources. This requires that alternative and renewable energy resources be developed to meet these needs. Due to the increase in demand for renewable and sustainable fuels sources, corn stover is considered as a valuable feedstock to help meet these demands with estimated an 35.2 million hectares of corn (NASS, 2009) planted in the United States. Corn stover is the single largest available biomass feedstock in the U.S. with an estimated available 68 million dry Mg per year (Oak Ridge National Laboratory, 2005) without any current increases in corn yield. The use of corn stover as a renewable energy feedstock over the use of corn grain has the benefit of utilizing a currently unused resource as well as allowing corn grain to continue to be used for food.

As the subject of harvesting corn stover is approached several questions must be answered as to the best methods to harvest corn stover, do it sustainably, and efficiently store and transport the material. Previous research has focused on cost analysis of stover harvesting, logistics, energy conversion, and estimations of total harvestable stover with some sustainability studies on a macro scale. Sustainability of harvesting corn stover is determined by carbon removal, nutrient removal, increased field traffic, and soil erosion by wind and water. The initial research focuses on the development of a system for sustainable

corn stover harvesting to limit soil erosion to a tolerable level. However, the system is capable of expansion to include other critical environmental factors.

Soil erosion is a spatially variable problem as multiple factors affect the rate of erosion including; soil type, slope, climate, upslope area, tillage, and residue levels. The implementation of real time sensing and control must be applied to account for the spatial variability that is present in any crop environment. This requires the development and application of a variable rate technology system to control stover removal, focusing specifically on utilizing this system with a single pass dual stream harvester.

### **1.1 Objectives**

The purpose of this research was to apply variable rate technology to the stover collection rate of a single pass dual stream combine harvester. The goal was to create a platform to remove stover at any specified target removal rate on a site specific basis. The method for determining a stover removal rate in this research was soil erosion, but is not the sole means for determining a sustainable stover removal rate. The direct objectives specified are as listed:

1. Develop control logic to determine stover material flow into the combine based on real time grain yield sensing, cut height, and grain to stover correlations.
2. Develop control algorithm to vary the rate of stover collection and return based on a determined stover harvest or return rate.
3. Develop process for determining optimal removal rates based on yield, topography, soil type and texture

4. Evaluate the performance of the variable rate collection system during field operations.

The research focused on development of a robust variable rate stover removal control system. Input variables were identified and data acquisition implemented to collect information in real time as the system operated in a spatially variable environment. Stover yields were estimated using real time grain yields and a mass flow balance applied to determine stover removal rates and control decision making. The mass flow balance relied on several inputs such as stover yield, cut height, and MOG split position of the stover flow control mechanism on the harvester and correlations were developed for all areas to successfully create a mass flow balance.

Validation testing of the system occurred in actual harvest operations to fully evaluate the system in true operating conditions. Test passes were long enough to develop a steady state flow of stover and grain in the harvester so that the system could be evaluated in real time.

Development of a process for determining optimal removal rates to limit soil erosion is key, but implementation of this process into the rest of the control system is not an objective of this research. Completion of these objectives will create an operable variable rate collection system that is capable of collecting a range of stover removal rates within a range of  $\pm 1.12 \text{ Mg-ha}^{-1}$  that can be utilized with any optimal removal rate decision making tools.

## 1.2 Literature Review

The amount of stover that can be harvested is affected by several factors such as erosion by wind and water, carbon removal, and nutrient removal (Hoskinson, 2007). As the need for corn stover increases for energy feedstock, there must be care taken to limit the amount of stover harvested to meet sustainable constraints. Current practices of harvesting corn stover such as multi-pass baling result in a constant removal rate, or simply what is available, is harvested. However, spatial variability within a field requires different removal rates to meet the site specific needs for controlling erosion and minimizing nutrient and carbon removal. Multiple removal rates are achieved through the implementation of variable rate technology (VRT). Previous studies have been conducted for VRT application of fertilizer and herbicides which is built on the structure of what Plant (2001), calls site-specific management (SSM). Plant (2001) defines three areas of SSM: measuring field spatial variability, analysis of site-specific data, and managing spatial variability. Fertilizer application uses pre-processed fertilizer maps with multiple management zones that are determined on several factors such as yield, soil type, and soil sampling results. VRT is used in these applications to maintain or improve production while reducing input costs and improving profitability while similar tactics were implemented to harvest corn stover for the purpose of this research to meet target stover return rates.

The first step of implementing VRT to stover collection was to determine a target stover return or removal rate. Several studies have been conducted to estimate the total amount of corn stover that could be harvested sustainably across the U.S. for different conservation and rotational practices. Nelson and associates used the Revised Universal Soil Loss Equation (RUSLE) and the Wind Erosion Equations (WEQ) to estimate the available

stover residue that can be removed while maintaining the tolerable soil loss limits established by the Natural Resource Conservation Service (NRCS) (Nelson 2002, Nelson et al. 2004). The estimated removal rates were calculated by aggregating land use on a county basis for determining the required parameters for the RUSLE and WEQ soil loss by averaging parameters such as soil erodibility, tillage practices, and terrain. Three different tillage types were applied by reducing the usable practices to; conventional tillage consisting of moldboard plowing and heavy disking, mulch tillage using light disking and chisel plowing, and no-till consisting of low soil disturbance operations. Nelson's aggregation to a county basis resulted in an average estimation when considering the spatial variability that can be present across a county with the purpose to estimate the available harvestable biomass as shown in Figure 1. Wilhelm et al. (2004) reported the effects of stover removal on overall soil impacts for compaction, soil organic matter content, and erosion. Wilhelm suggested that estimating sustainable removal rates be based on grain yields, climatic conditions, and cultural practices. Stover removal has a large impact on soil erosion and fertility requiring that soil impacts always be considered when determining an acceptable stover removal rate. Sustainable practices should always be applied when harvesting corn stover due to the erodibility of a large percentage of U.S. corn production land shown in Figure 2.

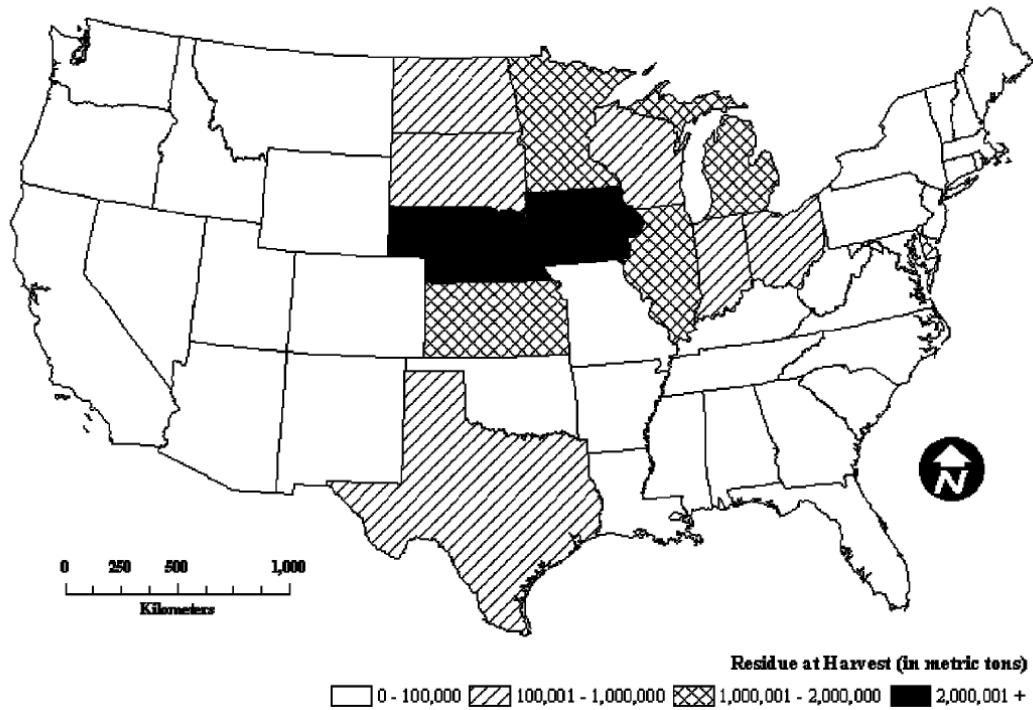


Figure 1: Removable residue quantities of corn stover subject to mulch till estimated by RUSLE and WEQ using NRCS tolerable soil loss limits (Nelson, 2002)

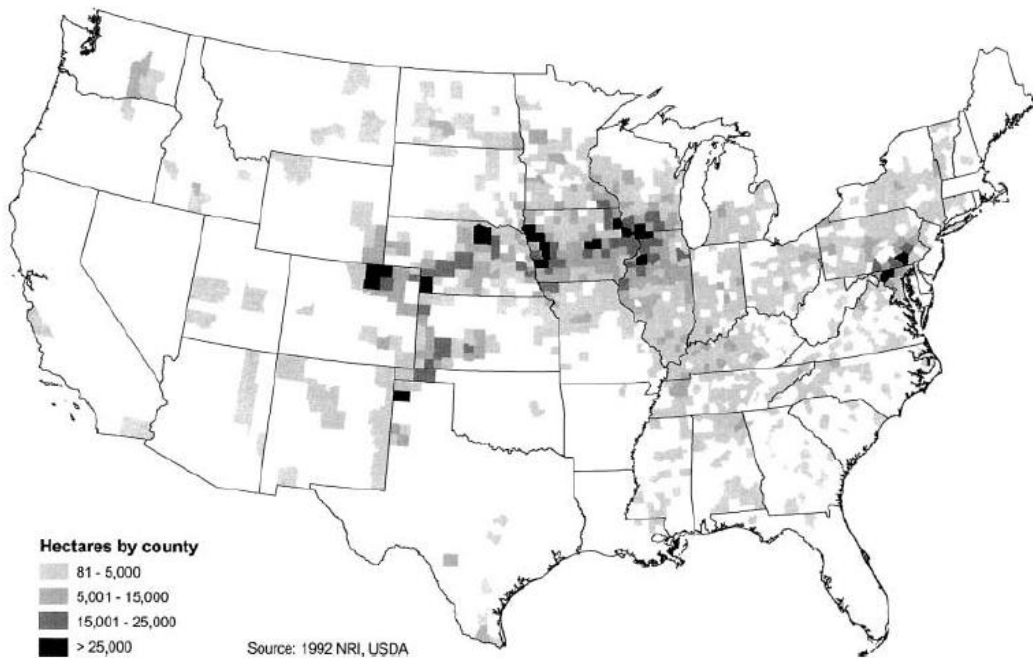


Figure 2: Corn production on land classified as *highly erodible land* by NRCS (Wilhelm et al. 2004)



Stover removal rates also affect crop yields. Linden et al. (2000) reported 22% higher grain yields for zero stover removal plots during dry years in a 10 year study with different tillage and stover harvesting treatments. The increased biomass on zero removal plots reduced moisture loss by evaporation through increased ground cover and increased moisture retention in the soil due to higher organic matter content.

Nutrient removal is a concern in corn stover harvesting as the nutrients must be replaced by fertilizers and the net cost to benefit ratio of stover removal and stover income must be taken into account. Harvesting using a single pass dual stream harvesting system results in residue being left on the ground below the cut height of the plant as it is harvested. Johnson et al. (2010) reported the nutrient removal from harvesting corn stover based on cut height with a resulting higher nutrient content in the plant portions below the ear at grain harvest as shown in Figure 3. Therefore, collection of the upper most portions of the corn plant may help reduce nutrient removal minimizing nutrient replacement costs, and increasing the sustainability of corn stover harvesting.

Knowing the amount of stover left by the cut height during single pass stover harvesting is essential in controlling the rate of stover return and has been addressed in several studies. D'Amours et al. (2008) vertically partitioned the plant by upper and lower fractions reporting 54% of the plant dry matter (DM) residing in the grain, 14% in the bottom stalk (below the ear), 6% in the top stalk, 5% bottom leaves, 7% top leaves, 5% husk, and 9% cob. Wilhelm et al. (2010) more recently reported approximately 50% of the total dry biomass resides above the ear including cobs. Wilhelm and colleagues also reported a linear relationship for the percentage of total stover remaining in the field based on the percentage of total cut height at physiological maturity (cut height/plant height) shown in Equation 1.

By using percentage of cut height of the total height and the result as a percentage of the total biomass remaining in the field, the equation can be applied to all yields and growth qualities of corn.

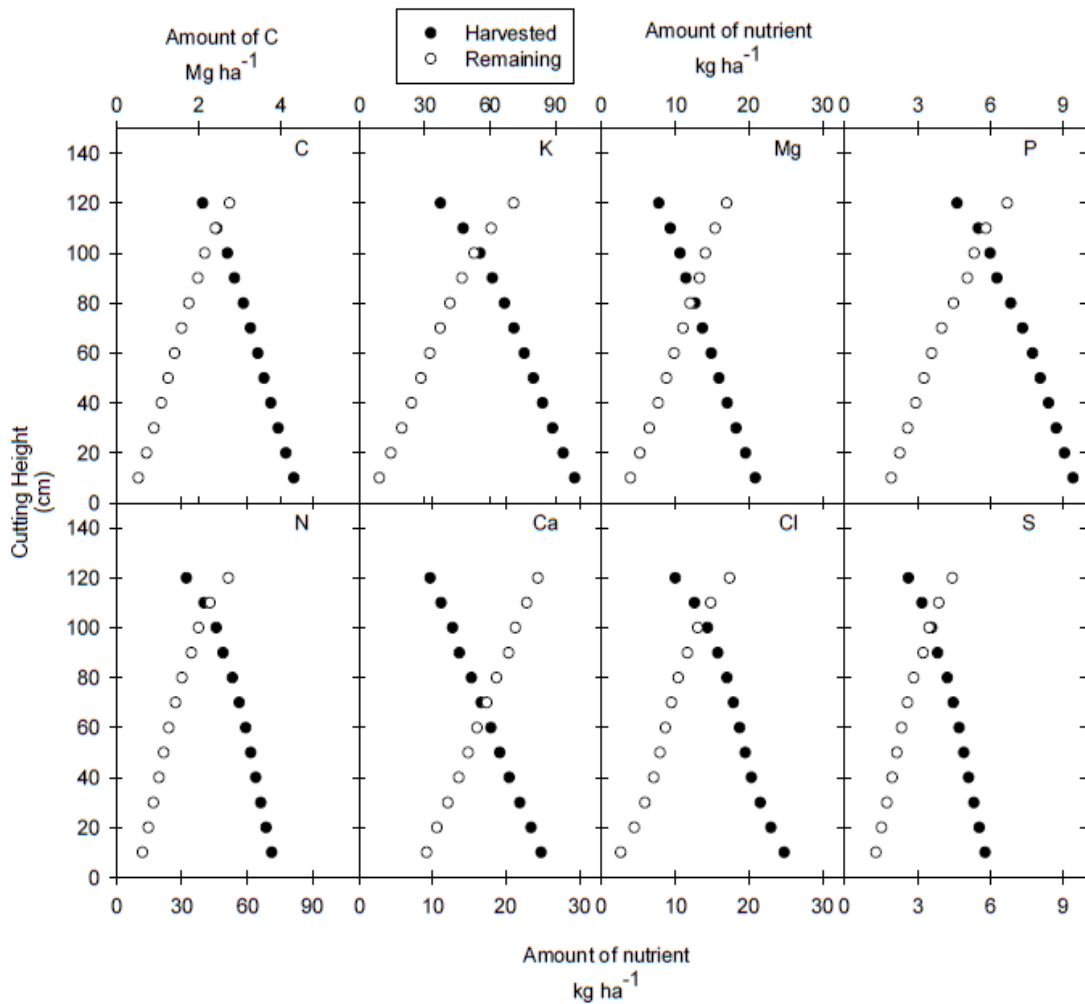
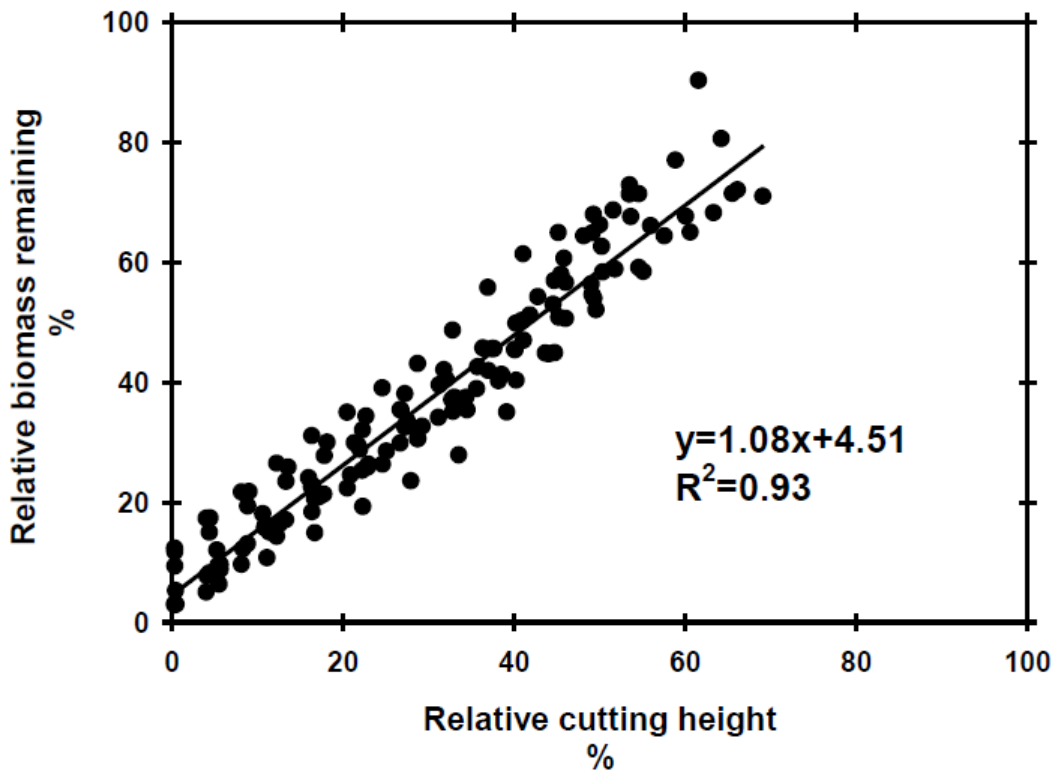


Figure 3: Nutrient removal rates by cut height (Johnson et al. 2010)

$$\% \text{ mass remaining} = 1.08 \cdot \frac{\text{cut height}}{\text{plant height}} + 4.51 \quad (1)$$



v

Figure 4: Percentage of total biomass returned based on relative cut height as a percentage of the total plant height (Wilhelm et al. 2010)

Controlling the stover return rate requires that the stover yield be determined. The yield of corn stover has typically been estimated using the Harvest Index (HI) which is defined in Equation 2, based on the grain mass and the above ground plant mass on a dry matter basis. The HI is a more commonly used value for evaluating the grain against the entire plant growth at physiological maturity and is used in many cases for evaluating corn silage yield. Previous studies have determined the HI to be in the range of 0.4 to 0.6 with an average of 0.56 shortly after physiological maturity by Linden et al. (2000). A ten year study by Sokhansanj et al. (2002) resulted with an HI ranging from 0.35 to 0.75 with the ratio increasing with increasing grain yields and concludes that using a 1:1 ratio for estimating

stover yield from grain yield is a reasonable assumption, but requires caution. Sokhansanj also observed variability within the HI was affected by the time of harvest as lower HI were predominant in early harvest and progressively increased into the late harvest season as dry matter losses increased. Pordesimo et al. (2004) reported an HI of 0.459 at grain maturity at 108 days, but increased over time during the harvest season resulting in a final HI of 0.568 at 213 days. The HI increased as dry matter loss occurred as leaves, husk and stalk fractions experienced dry matter loss of 74%, 54%, and 38% respectively from the maximum recorded dry matter values for each fraction. The dry matter loss causes variability in the HI for each crop and location and is an estimation of the relationship of grain mass to stover mass and many factors can vary the HI such as time, weather, grain yield, and hybrid type.

$$HI = \frac{Grain\ Mass}{Grain\ Mass + Stover\ Mass} \quad (2)$$

In more recent studies Wilhelm et al. (2010) developed Equation 3 to estimate the total stover yield based on the grain yield by dry mass (units are Mg-ha<sup>-1</sup>). The equation had a resulting R<sup>2</sup> of 0.73 providing sufficient results that the HI has variance with grain yield. Wilhelm and colleagues concluded that the HI can be used to estimate stover yield at physiological maturity, but also reported increases in HI during dry down until grain harvest.

$$Stover\ Yield\ (Mg \cdot ha^{-1}) = 0.85 \cdot Dry\ Grain\ (Mg \cdot ha^{-1}) - 0.56 \quad (3)$$

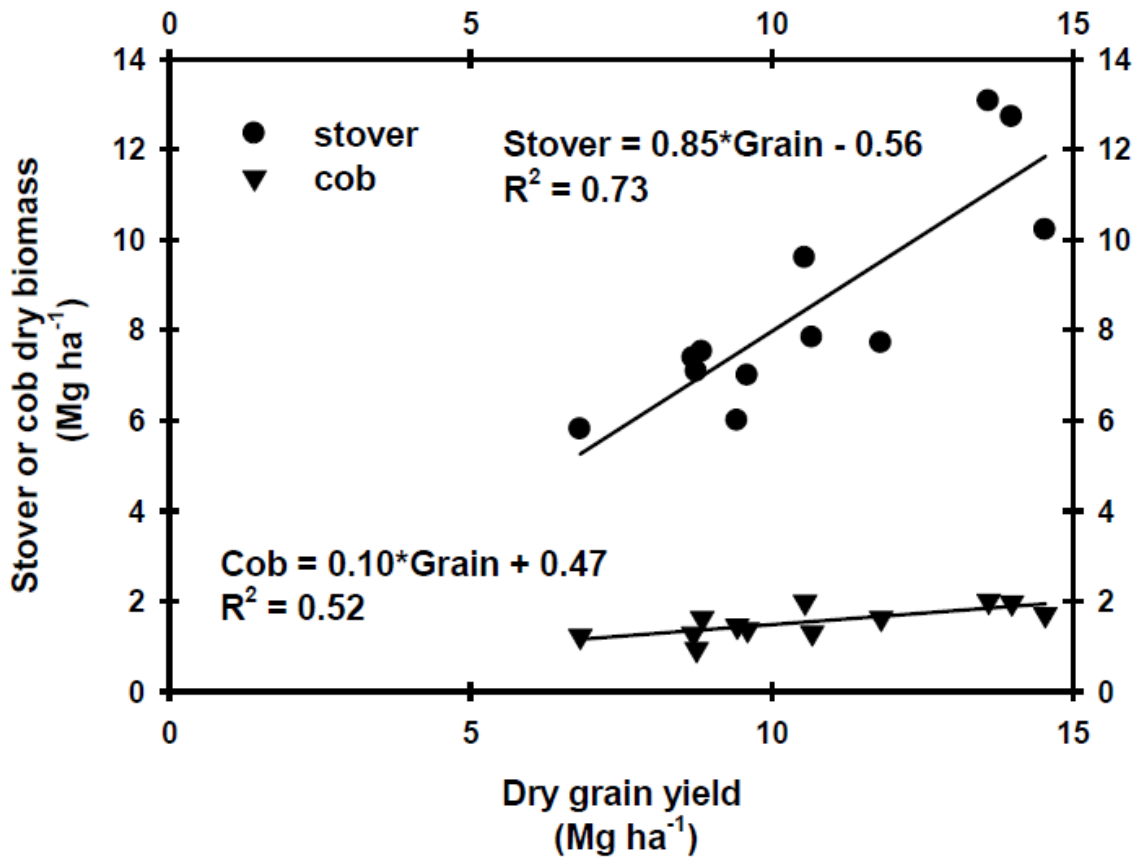


Figure 5: Estimation of stover yield using dry grain yield at physiological maturity (Wilhelm et al. 2010)

The HI provides a baseline for estimating stover yield but varies by site as many factors affect dry matter loss that occurs during dry down periods until the corn and stover is harvested. By applying the current knowledge of the HI, cut height, and machine configurations of the single pass dual stream harvester, a basic control strategy for variable rate stover collection can be developed and applied on a site specific basis.

## **2.0 CONTROLLER DEVELOPMENT**

In the ideal situation a controller processes real time data such as grain and stover yields, nutrient contents of stover fractions, soil type, slope and slope length. This coupled with current cropping and tillage practices are applied to minimize soil erosion, soil carbon removal, and nutrient removal while maximizing harvestable stover by varying cut height and returning required stover target return rate. This would essentially meet all current sustainability concerns while maximizing producer profits in an ideal control scenario. This research focused on utilizing the RUSLE to determine a required corn stover application rate to control soil erosion to a specified tolerable soil loss in real time and apply VRT to control the stover removal rate to within a tolerable range of the target removal rate.

### **2.1 Stover Prescription Return Rate Utilizing the RUSLE**

The RUSLE is widely used for estimating soil loss and providing a guidance tool for producers to make decisions regarding crop rotations, tillage practices, and crop residue removal. Previous studies (Nelson, 2002, Nelson et al. 2004) have used the RUSLE to estimate allowable removal rates of corn stover for estimating possible harvestable biomass crop totals across the U.S. that would be available for energy feed stocks. Further investigation into the use of the RUSLE for providing a stover prescription return rate in real time is essential to variable rate stover application as many of the parameters required for the RUSLE calculation have high spatial variability and require SSM.

The RUSLE model developed by Renard et al. (1997) uses the factors listed below to calculate the estimated soil loss of a point of interest in Equation 4. The focus of this research is the ability to apply the RUSLE in a manner for SSM of corn stover removal.

$$A = R \cdot K \cdot L \cdot S \cdot C \cdot P \quad (4)$$

- A* -Estimated average soil loss (Mg-ha<sup>-1</sup>)
- R* -Rainfall runoff erosivity factor
- K* -Soil erodibility factor
- L* -Slope length factor
- S* -Slope steepness factor
- C* -Cover management factor
- P* -Support practice factor

The cover management factor is determined by crop rotation, soil cover, soil biomass, and tillage practices. Returned biomass is a vital component of the soil cover management factor. Crop rotation and tillage practices are inputs on a field basis, while the soil cover and slope would be site specific and spatially variable across a field. The tillage practice selections are reduced to a generic type tillage selection, no-till, minimum tillage, conventional tillage, and split into a spring and fall category to reduce the time required for a producer to set up the harvesting system. The crop rotation is selectable as a corn-corn or a corn-soybean rotation which is the most common rotation in the Midwest and could be expanded for other crop rotations.

The rainfall erosivity factor and soil erodibility factor are available via data bases and are spatially variable, and values can be extracted based on the current GPS location of the

machine. The soil data is available by county database while the rainfall is a national map and is uploadable as a database.

Slope and slope length are spatially variable for estimating the annual average soil loss. National Digital Elevation Models (DEM) are available through USGS on 1 and 1/3 arc second resolutions and can be processed to determine slope and slope length values. The mobility of a combine harvester requires that databases with the information required be compiled and provided in a package that is easy to operate and requires as little input from the operator as possible.

RUSLE2 dynamic libraries are available for implementing the RUSLE as a stover prescription rate source along with the associated required database files. Solving for a stover return rate is done by holding a particular set of input variables constant for a specific location and solving for the optimal removal rate. This method requires no modification to the RUSLE calculations and allows for utilization of the operable open source program that is widely used.

### **2.1.1 Digital Elevation Model Processing**

The United States DEM data set was provided from USGS on 1/3 (approximately 10m) arc second resolution. The data sets are file structured by 1 degree latitude and 1 degree longitude. This allows the data set to be easily indexed by GPS location to open the data file that the machine is operating in. On entering a field the producer will initialize the system that begins the DEM data extraction and processing. A square area around the starting point is extracted, the size of the area is adjustable with a default size of 256 ha and the elevation data is extracted and compiled together from multiple files if required.



Slope length and slope functions from GRASS GIS open source software were implemented to determine the slope and slope length of each grid cell area of the DEM. The basic function of the algorithm first inverts a digital elevation model making uphill downhill as shown in Figure 6. The downhill run length is then calculated using the inverted DEM which is actually the upslope run length which is the needed parameter. This is a simple but effective method of determining the uphill run length from any point.

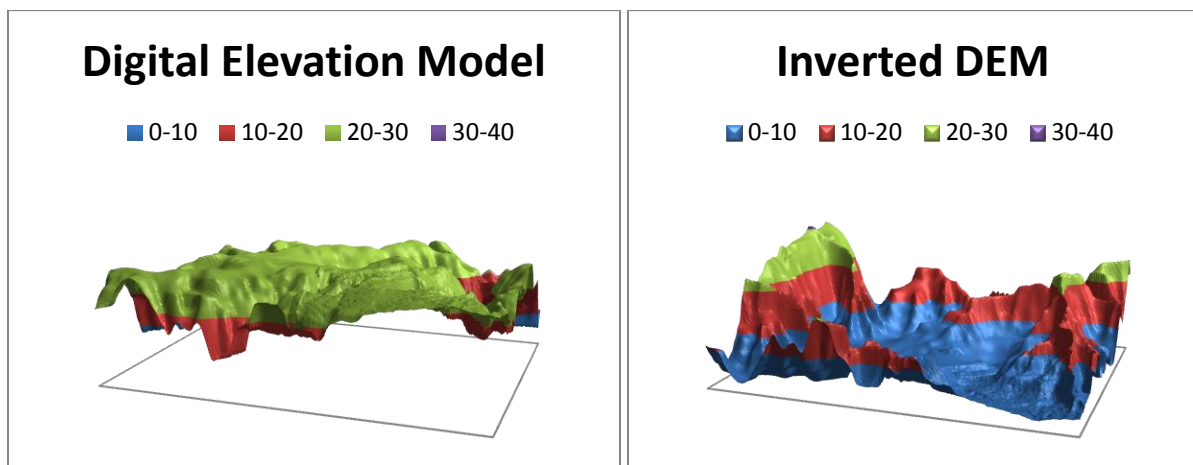


Figure 6: DEM and inverted DEM for processing slope and slope length

The resulting slope and slope length maps are stored for use during harvest in that particular location. These maps are used in real time in conjunction with the soil data, real time yield, weather data, management practices, and crop rotations to estimate a minimum stover return rate to meet soil erosion sustainability requirements using the RUSLE.

## **2.2 Determination of the Material Flow Split Control Algorithm**

Several parameters are needed for developing the control for variable rate stover application. Since the product that is being applied is a biological system with spatial variability due to many factors, SSM must be applied to reach the target return or harvest rate of the stover. To determine the stover mass flow balance the following inputs are required: stover yield, stover left by cut height, and prescribed stover rate, and must be processed in real time. Other data is needed to complete this mass flow balance but are easily attainable through sensors and instrumentation already in place on the standard combine harvester.

### **2.2.1 Determining Stover Yield**

The stover mass can be estimated from the instant grain yield determined by the yield monitoring system, utilizing the HI. Typical yield data recording systems in use today use an impact based sensor at the top of the clean grain elevator as the grain is expelled from the elevator and falls into the grain tank auger. The impact plate is mounted directly to a load cell that determines the force delivered by the grain and a  $\text{kg}\cdot\text{sec}^{-1}$  flow rate value is calculated from the force.

There is a delay associated with the impact based grain mass flow sensor located at the top of the clean grain elevator versus the time at which the grain and crop material enter the head of the combine. The delay is due to the grain having to travel from the head to the mass flow sensor after being threshed. A default yield value was used to avoid errors from the delay as the control system would revert to the default yield input specified by the user after the grain mass flow rate was recorded as zero for a certain time length. This facilitated the control system to set the position of the MOG split during validation testing relatively

close to the correct position for when harvesting would resume. The default value was approximately the field average for grain yield.

Stover flow through the machine sees no potential delay as it exits the machine at or before the rear of the machine reaches the point at which it was harvested. This has not been measured but is necessary for the function of the combine. For example, if the stover flow were to have any significant lag it would accumulate in the combine and cause plugging in the machine.

The moisture content of the MOG and grain can significantly affect the calculation required to determine the actual dry matter yield of the stover. By design however, the MOG splitter does not split flow by mass but rather by volume, but these affects are limited as the mass flow balance equations were developed based on dry matter. Stover moisture varies by the fraction of stover, upper and lower leaves, upper and lower stalk, grain, cob, and husk, with the moisture content varying over time and conditions, but the lower to the ground the fraction the higher the moisture content as reported by D'Amours (2008).

### **2.2.2 Stover Fractions by Height**

Creating a mass balance for determining the amount of stover left on the ground requires knowing how much stover mass is left on the field by the cut height of the crop and how much of the mass is brought into the machine. Stover at the ear height and above will always enter the machine based on the configuration of the corn head as the cut must be below the ear to ensure harvesting the grain. Cut height calibrations were developed in this study, but the cut height correlation developed by Wilhelm et al. (2010) shown in Equation 5 will be used in the future due to the length and depth of the study into this relationship. The

additional requirement when using this equation is the addition of the relative total plant height. There is no current sensors for measuring this in real time and will require an average height input by the operator.

$$\%Returned\ After\ Cut = \frac{Cut\ Height}{Total\ Plant\ Height} \cdot 1.08 + 0.045 \cdot \quad (5)$$

### 2.3 Stover Mass Flow Balance

Development of a stover flow mass balance as the combine harvests creates a set of equations that can be utilized to return the desired rate of stover to the ground. Figure 7, illustrates the stover flow process as the harvester moves through the field. As seen in the illustration the process is relatively straight forward as the plant material above the cut height enters the machine which is the first control point for variable rate control. The second control point is the MOG splitter as it splits the flow of stover in the combine to return it to the ground or allow it to be transferred to the blower for harvesting.

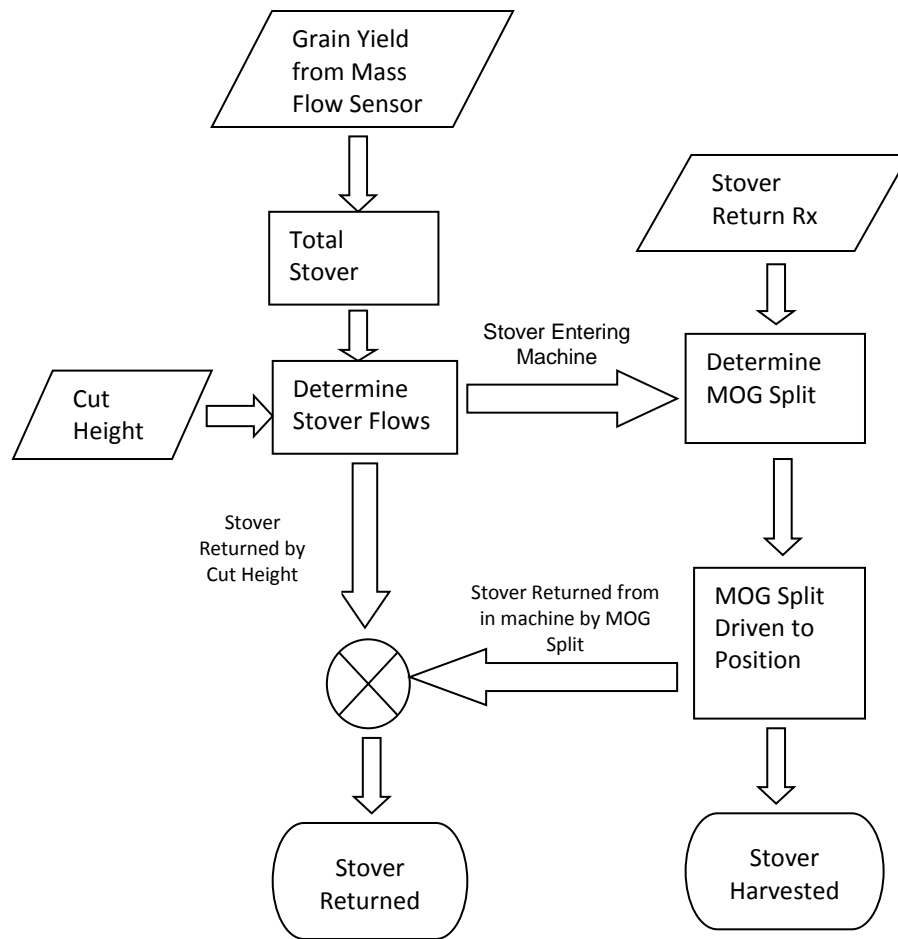


Figure 7: Flowchart illustrating stover flow and decision making process

Equations were developed to create a mass balance of stover for the system so that control of the stover flow could be implemented. The control point for the stover harvesting rate is the MOG split position at the rear of the machine between the chopper and blower. The MOG splitter is a mechanism that is used to divide the stover flow to harvest part of it and return the other portion to the ground. The MOG split is further described in the materials and methods.

The grain mass flow value is first converted to grain yield on Mg-ha<sup>-1</sup> basis as the prescription return rates for the stover are all handled in the same units, Equation 6

$$M_{grain} = m_{grain} \cdot \frac{10,000 \cdot m^2 \cdot ha^{-1}}{Sp \cdot W \cdot 1,000 \cdot kg \cdot Mg^{-1}} \quad (6)$$

$m_{grain}$	-Grain mass flow (kg-sec <sup>-1</sup> )
$M_{grain}$	-Grain yield DM (Mg-ha <sup>-1</sup> )
$W$	-Width of corn head (m)
$Sp$	-Combine ground speed (m-sec <sup>-1</sup> )

. The stover yield is then calculated from the grain yield by applying the HI in Equation 7, however considering new results from Wilhelm et al. (2010), the HI could become a dynamic variable as it would change with yield.

$$M_{stover} = M_{grain} \cdot \frac{1}{HI} - 1 \quad (7)$$

$M_{stover}$	-Stover yield (Mg-ha <sup>-1</sup> )
--------------	--------------------------------------

The stover mass entering the machine is determined by taking the difference of the total stover and the stover left on the ground by the cut height. The fraction value used to

determine the amount of stover left on the ground by the cut height is calculated using correlation equations developed in testing similar to what Wilhelm et al. (2010) had previously developed.

$$M_{in} = M_{stover} (1 - Tx_{Cut\ Ht}) \quad (8)$$

$Tx_{Cut\ Ht}$  -Stover fraction returned by cut height

$M_{in}$  -Stover entering combine ( $Mg\cdot ha^{-1}$ )

The mass flow of stover entering the combine is described by Equation 8 and is a function of the cut height and total available stover. This is the basic mass balance that is used to determine the final position of the MOG splitter to reach the desired Target stover return rate.

$$Rx_{MOG} = Rx_{stover} - M_{stover} \cdot Tx_{Cut\ Ht} \quad (9)$$

$Rx_{MOG}$  -Prescribed stover return rate for stover in the machine ( $Mg\cdot ha^{-1}$ )

$Rx_{stover}$  -Target stover return rate ( $Mg\cdot ha^{-1}$ )

$$Tx_{MOG\ split} = \frac{Rx_{MOG}}{M_{in}} \quad (10)$$

$Tx_{MOG\ split}$  -Stover fraction in combine returned by MOG split

Applying the MOG split fraction determined in Equation 10 to a functional relationship between position and mass flow provides the MOG split position (Equation 11). The resulting desired MOG split position is applied to achieve the target stover return rate.

$$Split\ Position = fn\ Tx_{MOG\ split} \quad (11)$$

A new stover yield value is generated every time a new grain mass flow value is received via the CAN Bus on a 1 Hz basis. Due to the continuously changing inputs of cut height and yield as the inputs are spatially variable throughout a field, the system operates on a site specific management basis, continuously adjusting the machine control parameters to return the targeted stover rate.

## 2.4 Operator Interface

Determining the amount of stover to be harvested or returned to the field must be done in a manner that is sustainable and provides positive economic rewards for the producer. Several scenarios were considered when deciding the options to which a producer has to choose from in harvesting stover.



1. Constant harvest rate: This would be a producer set harvest rate ( $\text{Mg}\cdot\text{ha}^{-1}$ ) of stover. This provides the producer the ability to select a constant removal rate to suit different management and economic strategies.
2. Constant stover return rate: The producer sets the return rate of stover ( $\text{Mg}\cdot\text{ha}^{-1}$ ) to meet a desired minimum return rate while harvesting the rest of the available stover.
3. Soil loss based return rate: This is a stover return rate that is set by site-specific calculations of soil loss based on the RUSLE 2 soil loss equation. Utilizing real time yield data, digital elevation models (DEM), and soil maps, a required return rate of stover would be generated to maintain a set soil loss requirement.
4. All or none harvest rate: The producer has the ability to harvest all of the stover brought into the machine as well as select to not harvest any stover by returning all stover to the ground.
5. Variable rate removal map: A pre-processed variable rate stover application or removal map could be generated using geographical information systems (GIS) software using whatever attributes the producer chooses to develop management zones and their corresponding stover rates.

Any application that uses a varying stover return rate requires the ability for SSM..

The control for the variable rate stover collection was developed as a return rate based

control system. A user interface was developed with basic inputs to simplify the menus and reduce set up time for the operator in the field.

Figure 8: Developed user interface for variable rate stover collection

The interface was designed to provide the operator the choice of all of the previously listed stover harvest selections for control. The recommended harvest selection is the stover removal rate determined by the RUSLE 2 soil loss equation. The ability to adjust the prescribed rate from the RUSLE 2 was added to allow the operator to apply or remove stover more or less aggressively than recommended by the RUSLE 2. This was provided so a producer can effectively raise and lower acceptable soil losses to meet more specific needs of the producer while still providing a real time variable rate removal of corn stover.

### 3.0 EQUIPMENT AND MATERIALS

#### 3.1 Single Pass Dual Stream Combine Harvester

The single pass dual stream biomass harvester previously co-developed by Iowa State University in conjunction with Deere & Company of Moline, IL, allows for the corn harvesting operation to not only collect grain, but simultaneously collect corn stover as well. The machine used for testing was a John Deere 9860 STS combine. The crop portion of the machine, feeder house, rotor, concaves, and sieves were not modified. The machine was fitted with a custom chopper to provide a smaller particle size more suitable for later energy conversions when the stover would be processed. The machine had also been fitted with a forage harvester blower and forage harvester spout to convey the harvested material into a truck or wagon.

The modified chopper has two main adjustments that affect the chop quality of the stover. The first is a shear bar that the chopper blades pass by that creates a close clearance against the tangential motion of the chopper. The second adjustment is vertical knives that can be installed or uninstalled. The vertical knives protrude into gaps built into the chopper blades to create a shear point perpendicular to that of the shear bar and blades. The chop quality can also affect the conveyance and flow properties of the stover as it exits the chopper and enters the blower.

The transition between the chopper discharge and the blower intake had been designed with the implementation of adjustable vanes to split the flow of material of mass other than grain (MOG). The transition and the direction of material flow is shown in Figure 9. The MOG split vanes pivot at the corner of the blower intake to open and close allowing

them to divide the flow of the MOG. The material that passes between the vanes enters the blower and is harvested while the material outside the vanes is deflected back to the ground. This allows for variable rate collection of the material passing through the machine by adjusting the position of the vanes. The vanes are controlled by a linear actuator and connected by linkages. The linear actuator has a built in linear potentiometer that outputs a position signal of 0 to 5 VDC for which a calibration curve was developed for relationship to the open and closed position of the vanes for 0 to 100%, with 0 being the vanes fully closed (return all), and 100% full open (collect all).



Figure 9: Transition from chopper to blower with MOG split vanes

### 3.2 Corn Head

A modified John Deere 612C chopping corn head was used to harvest the corn. The head had been modified to cut the corn plant off at the entry point to the head and pull the remaining portion of the plant above that cut point into the combine. The configuration used for corn stover harvesting also created a desirable point from which to measure cut height using the feeder house position sensor. A calibration curve for the feeder house position sensor output and the height of the cutting point was developed in the Ag Engineering shop on a level surface. The height of the head was measured for multiple heights and the voltage output of the feeder house position sensor recorded to develop a calibration curve relating the output voltage to a cut height. This cut height coupled with calibration curves developed later provide the ability to determine the amount of stover that is entering the combine based on the cut height.

Current equations for determining remaining stover based on cut height operate by the input of the cut height as a percentage of the total height. This may be modified and automated by converting this to a percentage of the cut height under the ear. At the beginning of harvesting in each new field, the operator would raise the head cut position to the ear height and trigger the control system, informing it that this is the average ear height for the field. An average height would need to be selected for this operation as there is spatial variability throughout a field for plant height, and a new calibration for each field would be a minimal input requirement from the operator.

### **3.3 Location, Field, and Crop**

The harvest tests were conducted south of Ames, IA, on the Iowa State University Dairy Facility grounds. The corn variety was Agrigold 6395 Clearfield and was planted in the north south direction. The overall average of the testing area was  $10.33 \text{ Mg}\cdot\text{ha}^{-1}$  dry grain. The field was divided in to two by cutting perpendicular, east to west, across the field to divide it into to equal halves, shortening the length of a test pass while doubling the number of available test passes. The field was measured length wise using an Ag Leader SMS Mobile PDA equipped with a WAAS GPS receiver and the central split line of the field was determined using this device. Each pass length was approximately  $149 \text{ m} \pm 2 \text{ m}$  with a width of  $9.144 \text{ m}$  (12 row corn head). The corn head was fitted for full 12 row collection for all sets of tests.

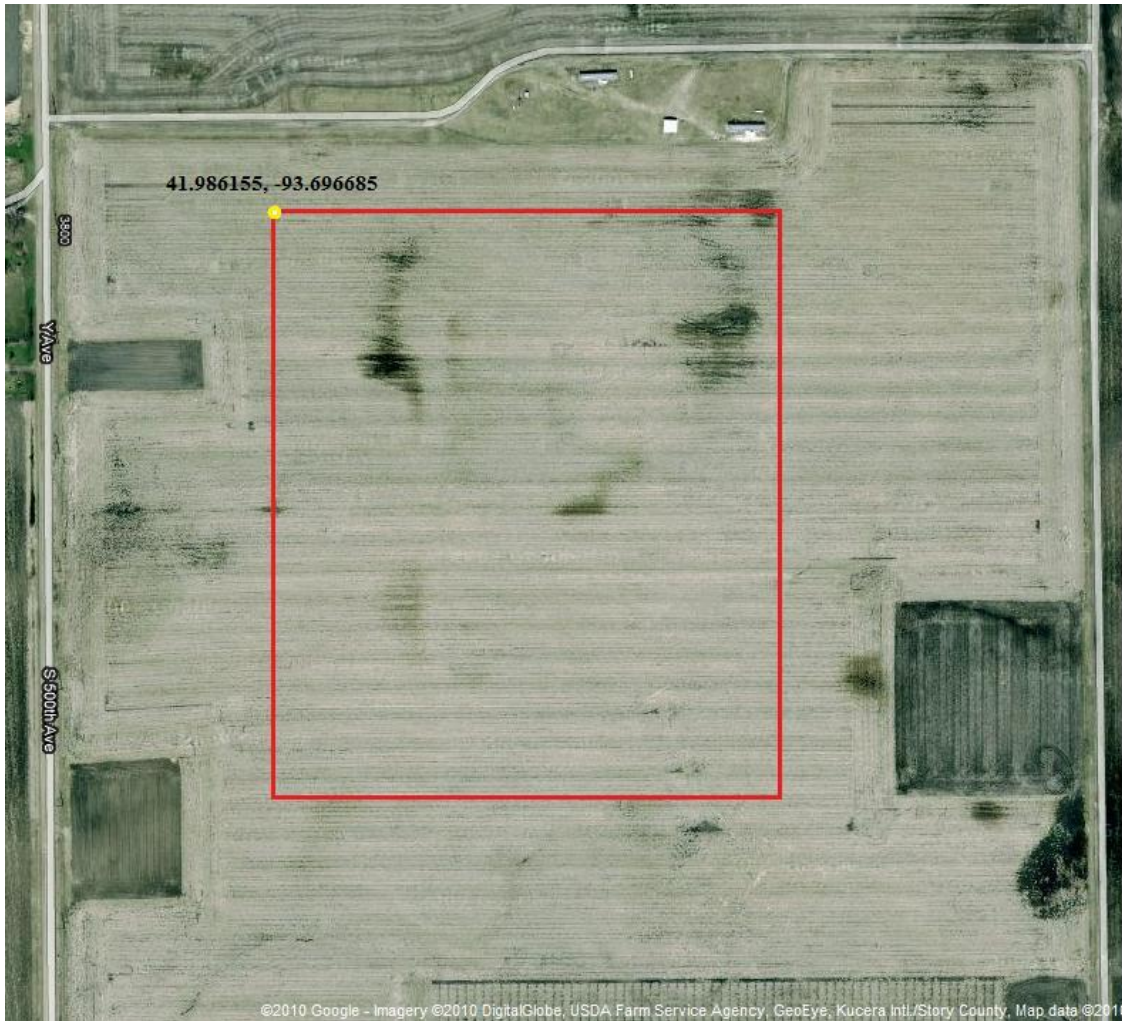


Figure 10: Testing field and location South of Ames, IA

### 3.4 Data Acquisition System

A data acquisition system was assembled using an Athena II single board computer/data acquisition system. The board contained a 16 bit analog to digital conversion system for analog signals. CAN USB was used for accessing the vehicle CAN Bus. A USB-4300 Measurement and Computing counter module was used for all needed counting

operations. An internal relay board with 20 single pole single throw relays was available for controls.

The screenshot displays a software interface titled "Form1" with several functional panels:

- Select Crop Rotation:** Radio buttons for "Com-Corn" (selected) and "Com-Soybean".
- Fall Tillage:** Radio buttons for "Conventional Tillage", "Minimum Tillage", and "No Tillage".
- Spring Tillage:** Radio buttons for "Conventional Tillage", "Minimum Tillage", and "No Tillage".
- Stover Harvest Selections:** Radio buttons for "Harvest % of Recommended", "Harvest 100%", "Harvest (ton/ac)", "Stover Return (ton/ac)" (selected), "No Harvest/Return All", and "MOG Split position harvest %". Below are "Collect None" and "Collect All" options.
- Head Width:** A text box containing "Text4" followed by "ft" and a slider.
- Load DEM:** A "Select Data Drive" dropdown set to "c:", a "load DEM" button, and a file list showing "Head\_Ht\_cal.xlsx", "MSD1033.acl", and "Test\_Location.jpg".
- Initialize DAQ:** Buttons for "Set Up DAQ", "DAQ Set", "Cal Strain Gauge", "Tare Strain Gauge" (with input "0"), "Start DAQ", "Stop DAQ", and "Exit".
- Data Collection:** "Save file name" (Cut\_hrs), "Field Name" (North Woodruff), "Test" (100% cut yield calcs), and "Record" / "Stop Record" buttons.
- Counters:** A vertical column of six empty input fields.
- SmartBoard Values:** A vertical column of six empty input fields.
- Athena A/D:** A vertical column of six empty input fields.
- GPS Information:** Input fields for "Lat", "Lon", and "mi/hr".
- Yield and Mass Flow:** "Yield bu/ac" (130), "Mass Flow Value" (Text4), and "MOG Split Fix" (Text4).
- CAN Data:** Input fields for "Byte 0", "Byte 1", and "MSG cnt".
- Other:** "Save Load" and "Load Number" fields.

Figure 11: Image of Data Acquisition GUI

A Visual Basic interface was developed for operating the data acquisition system as well as controlling the MOG split position. Data was collected using the system and stored in binary and value formats in csv files and was collected at a rate of 200 Hz. Data collected for each test pass and its source was:



1. Grain mass flow, grain moisture (vehicle CAN)
2. Rotor Speed (hall effect sensor)
3. Cut Height (feeder house position sensor, rotary POT)
4. MOG split position (linear POT)
5. Discharge beater speed (hall effect sensor)
6. GPS coordinates, speed, time (Starfire I)
7. Rotor pressure (pressure transducer)
8. Chopper Speed (quad encoder)

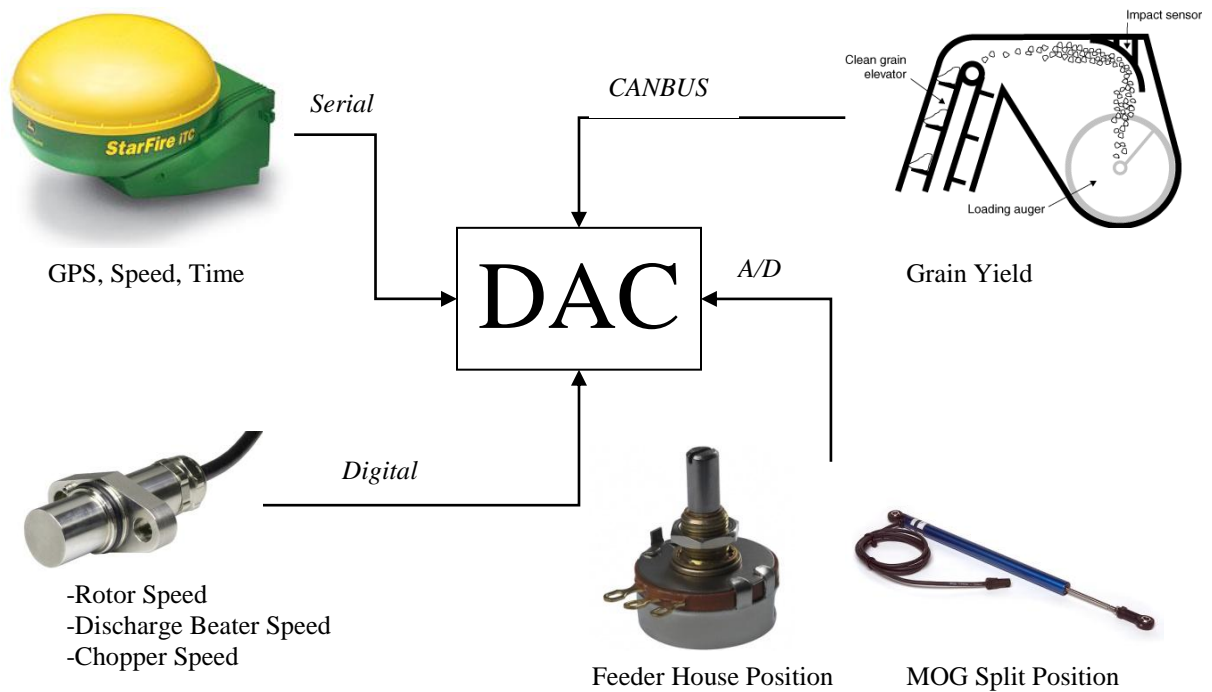


Figure 12: Data acquisition system diagram

## **4.0 METHODS PROCEDURES AND EXPERIMENTAL DESIGN**

A first set of tests were conducted in early November to develop calibration equations for determining stover returned based on cut height and to develop a relationship of the position of the MOG splitter to the mass of stover passing through the machine returned to the ground. The second set of tests, the validation testing, applied the calibration equations developed from the first set of tests to control the stover return rate on an  $\text{Mg}\cdot\text{ha}^{-1}$  basis. Data was recorded via the data acquisition system previously described and stover masses were manually collected and recorded. Data was processed using Microsoft Excel© and JMP© statistical software.

### **4.1 Field Testing Procedures**

All machine tests followed similar data collection procedures for determining grain yield, stover collection, and residue measurement. The methods were standardized across all tests utilizing the combine for harvesting.

#### **4.1.1 Grain Yield**

The average corn yield was determined by using a CANUSB to extract the grain mass flow data from the CANBUS. The grain mass flow was then converted to a yield value of  $\text{Mg}\cdot\text{ha}^{-1}$  as previously shown in Equation 7 and converted to a stover yield by applying the HI as shown in Equation 8 and was used for live data collection and control purposes.

The data for each test pass was processed to calculate the accumulated grain mass of each pass using the grain mass flow data collected from the CANBUS and impact based yield sensor given by:

$$M_{pass} = m \cdot \Delta t \quad (12)$$

$m$             -Grain mass flow ( $\text{kg}\cdot\text{s}^{-1}$ )

$\Delta t$            -Time step for data point

where the mass is summed over the time of the entire test pass. The grain yield sensor had been calibrated at the beginning of the harvest season and was periodically checked for accuracy and can show a maximum error of 6% following calibration. The accumulated mass using the grain mass flow sensor provided an average grain yield for each test pass from which an average stover yield was determined using the HI. The results were compared to the measured stover yield from the collected stover.

#### **4.1.2 Stover Collection Procedures**

All stover that was collected was blown into Oxbo cob carts, which were then transported to the Iowa State University Compost Facility and weighed on the calibrated truck scales with a resolution of  $\pm 9$  kg, unloaded at the compost facility, and weighed again to determine a tare weight. The grain was unloaded onto a calibrated grain weigh wagon and weighed after each test pass.

#### **4.1.3 Manual Residue Sample Collection**

Manual stover samples were collected in three random locations of each test pass. The samples were picked up from a 0.9 m by 9.1 m area to cover the full width of the test pass. In these sample areas, remaining stalks were cut off at the top root braces and collected, while the remaining stover was carefully raked and also collected. The manual

samples were collected and placed in yard waste bags and dried at 60° C until there was no change in mass. The samples were weighed before and after drying to determine moisture content.



Figure 13: Hand mass fractioning and hand collected ground samples

## 4.2 Developing Cut Height Calibration Curves

Before variable rate stover removal can be achieved, the inputs must be defined. The first input that must be solved is the correlation for the percentage of stover that is left on the field due to the height of the cut by the corn head. Two approaches were taken to developing the correlations for cut height. The first was a set of manual samples, fractionating the corn

plants into sections, and the second was the utilization of the combine and performing test passes at varying cut heights to evaluate the effects of different operating conditions.

#### **4.2.1 Hand Mass Fractions**

The hand mass fractions were to provide an ideal baseline of a correlation curve of cut height of the plant to the percentage of stover left on the ground below the cut height. The sample collections were conducted out in the field to provide a consistent environment to which most of the field would experience at several locations to provide a more representative sample of the field.

#### ***Experimental Design***

An initial harvesting of three locations within the test field was conducted on November 11, 2009, harvesting by hand fractioning the entire corn plant for 8.23 meters of a row. The locations were randomly selected and the material on the ground on the east side of the row was collected as ground material (leaves that have fallen off). The ears with cob and husk were then collected followed by the top portion of the plant cutting it off just below the ear or approximately 76.2 cm. The remaining stalk and leaves was fractioned at 15.2, 30.5, 45.7, and 61 cm. The stover fractions were weighed, dried at 60° C until there was no change in mass, and weighed again. The corn was shelled from the cob, the cob and husk were separated and all three fractions were weighed.

#### ***Data Analysis***

The accumulated mass of the stover starting at the ground and moving up was calculated and plotted as a percentage of the total mass of stover material. A linear

regression was fit to this plot developing a correlation curve to determine the percentage of return of the total stover based on the cut height of the plant.

#### **4.2.2 Field Tests Utilizing Combine**

Field tests were conducted to evaluate the effects of varying operating parameters. Independent variables used in the field tests were incrementing cut heights and two harvesting speeds were used in multiple test treatments. By operating at two different speeds, a high and low material flow rate could be introduced into the machine. However the cut height also effects the flow rate of material into the machine, as the cut height is raised the entering flow rate decreases, but provides a basis by which to compare different flow rate effects for each cut height scenario.

#### ***Experimental Design***

Cut height tests were conducted using the biomass combine with the modified corn head on November 11<sup>th</sup> and 12<sup>th</sup>, 2009. As previously described the cut height field tests were designed to provide two different material flow rates for each cut height tested. The two speeds used were 2.4 and 4 km/h for all tested cut heights. A full test plan is shown in Table 1.

Table 1: Experimental design for cut height calibration tests

Speed (kph)	Cut Increments (cm)
2.4	15.2, 30.5, 45.7, 61, 76
4	15.2, 30.5, 45.7, 61, 76

### ***Data Analysis***

The resulting data of the cut height tests conducted using the combine was plotted as percentage return rate versus cut height. A linear regression was fit to the data for the single independent variable cut height. Further analysis revealed that the data was divided by speed and cut height and an ANOVA model was fit to the data using JMP® statistical software. The effects of stover flow rate entering the machine was also assessed to determine if it added statistical significance to model. The data results of the field tests were compared to that of the hand mass fractions and the resulting comparison was used to decide which correlation equations to use in control operations of the variable rate collection (VRC) system.

### **4.3 Developing MOG Split Calibration Curves**

The MOG split is the final control point for variable rate stover collection at the transition between the chopper and the blower. A set of tests were conducted to develop calibration equations of the MOG splitter to create a correlation between the percentage of stover collected based on the amount of stover passing through the machine versus the position of the MOG splitter.

### ***Experimental Design***

The design of the MOG split test was to develop a calibration curve for the percentage return of stover as well as determine the effects of material flow rate on the return rate of stover passing through the MOG split transition as well as the effects of different plant fractions. Different material flow rates were attained by two different strategies.

1. High and low harvesting speed
2. High and low cut height

By using two different cut heights, the amount of material being pushed through the machine changes as well the moisture content of the material. The lower cut includes the lower stalk portion that has a much higher moisture content essentially testing the effects of different stover moistures on MOG splitting performance. The two different speeds change the rate at which stover is brought into the combine as was done in the cut height calibration tests. The test plan is shown in Table 2.

Table 2: Experimental design for MOG split tests

Speed (kph)	MOG Split Position (%)	Cut Height (in)
2.4	15, 30, 50, 70, 85	12
4	15, 30, 50, 70, 85	12
2.4	15, 30, 50, 70, 85	28
4	15, 30, 50, 70, 85	28

### ***Data Analysis***

The grain mass for the MOG split tests were calculated as previously described by summing the grain mass from each test pass from the grain mass flow data. Calculating the actual stover flow split required the estimated calculation of the stover flow entering the combine by applying the equation developed from the stover hand mass fractions. After determining the stover flow rate into the combine and a stover mass already placed on the ground, the excess amount of stover returned to the ground by the MOG split could be determined. The stover return rate of the machine stover flow was plotted against the MOG



split position with the data separated by treatment to evaluate the possible effects of each treatment type.

The data was then plotted as the MOG split position versus the stover return rate and a linear regression was fit to the data. Later an exponential regression was fit to the data. This regression equation allowed for the input of a desired stover return rate of the stover in the combine and the resulting value was the needed MOG split position to attain the desired return rate.

#### **4.4 Validation Testing**

The validation testing was designed to apply the cut height and MOG split calibration curves to the mass flow balance equations previously developed. By implementing the mass flow balance equations into the controller on the combine harvester a variable rate stover removal control system was created. Utilization of these equations ultimately provides a desired position for the MOG split to meet the target stover return rate.

##### ***Experimental Design***

Each test pass for the validation testing used a specified target return rate as  $\text{Mg}\cdot\text{ha}^{-1}$  value. This was done rather than a collection target rate because most likely the stover collection rate will be determined by the remaining stover mass required to meet sustainable practices on an  $\text{Mg}\cdot\text{ha}^{-1}$  basis. Three stover target return rates were used, 2.24, 4.48, and 6.72  $\text{Mg}\cdot\text{ha}^{-1}$  in conjunction with three different cut heights of 30.5, 46, and 70 cm. These tests were also conducted using two different speeds of 2.4 and 4 km/h. The variations were to create several stover flow rates and moisture contents to fully evaluate the effectiveness of the control algorithm and the MOG splitting capability.

### ***Data Analysis***

The average and standard deviation of the resulting measured stover return rates were calculated, plotted, and a linear regression equation applied. An ANOVA model was fit to the resulting data with the treatment variations as inputs and stover yield to determine the statistical significance of each variable on the model.

The instantaneous stover flow rate was calculated using the HI and the grain mass flow ( $\text{kg}\cdot\text{sec}^{-1}$ ) while applying the stover cut height calibration equation to determine the flow rate of stover into the combine. The stover flow rate was converted to an instantaneous yield  $\text{Mg}\cdot\text{ha}^{-1}$ . The MOG split position was then used to determine the final division of the stover flow and an overall stover return rate estimated by the control program was calculated. The results were plotted to evaluate the performance of the control system based on the perceived real time stover return rate of the controller. The resulting plots were also used to identify errors in the system that prevented proper operation during some test passes.

Estimated return rates were calculated for middle sections of each test pass starting at 20m into the test pass and stopping at 120m of the test pass to get an estimated return rate for a steady state flow portion of the test pass. The estimated return rate was also calculated utilizing cut height equations and HI equations by Wilhelm et al. (2010) and implementing them in place of the previously used cut height calibration equation and of the estimated constant HI. The new estimated resulting stover return rates were compared against the measured results and the average and standard deviation of the difference of the measured and estimated stover return rates were analyzed.

## 5.0 RESULTS AND DISCUSSION

### 5.1 Cut Height Calibration

The two different forms of cut height tests were conducted to evaluate certain parameters. The hand mass fractions provided a baseline for plant material distribution along its height and to provide samples from undisturbed areas of the testing area. The machine tests were to evaluate the effects of varying machine parameters and to develop correlations for actual operating conditions. The processed data provided largely differing results in comparison of the hand mass fractions to the machine tests along with high variability within the machine field tests.

#### 5.1.1 Hand Mass Fractions

The data results of the hand mass fractions are displayed in Table 3 by fractionated section. As seen the average mass of the fractions below the ear are similar and carry an overall average for the five fractions from 0 cm to 76 cm of  $0.47 \text{ Mg-ha}^{-1}$  with a standard deviation of  $0.07 \text{ Mg-ha}^{-1}$ .

Table 3: Distribution of stover mass by cut height based on manual hand mass fraction tests

	Grain	Cob & Husk	Top	76-60 (cm)	61-45.7 (cm)	45.7-30.5 (cm)	30.5-15.2 (cm)	15.2-0 (cm)	Ground Cover
Average ( $\text{Mg-ha}^{-1}$ )	8.98	2.02	2.03	0.47	0.49	0.54	0.47	0.41	0.88
Std. Dev. ( $\text{Mg-ha}^{-1}$ )	1.19	0.26	0.45	0.06	0.03	0.09	0.06	0.09	0.16
Percentage of stover Mass		27.62%	27.88%	6.39%	6.65%	7.42%	6.39%	5.63%	12.02%

The hand mass fractionated stover provided a clear linear relationship between the cut height and the percentage of stover mass remaining in the field. A linear fit trend line returned an  $R^2$  value of 0.9294 for the percentage of dry mass returned by the cut height. The resulting trend line and correlation equation are in Figure 14.

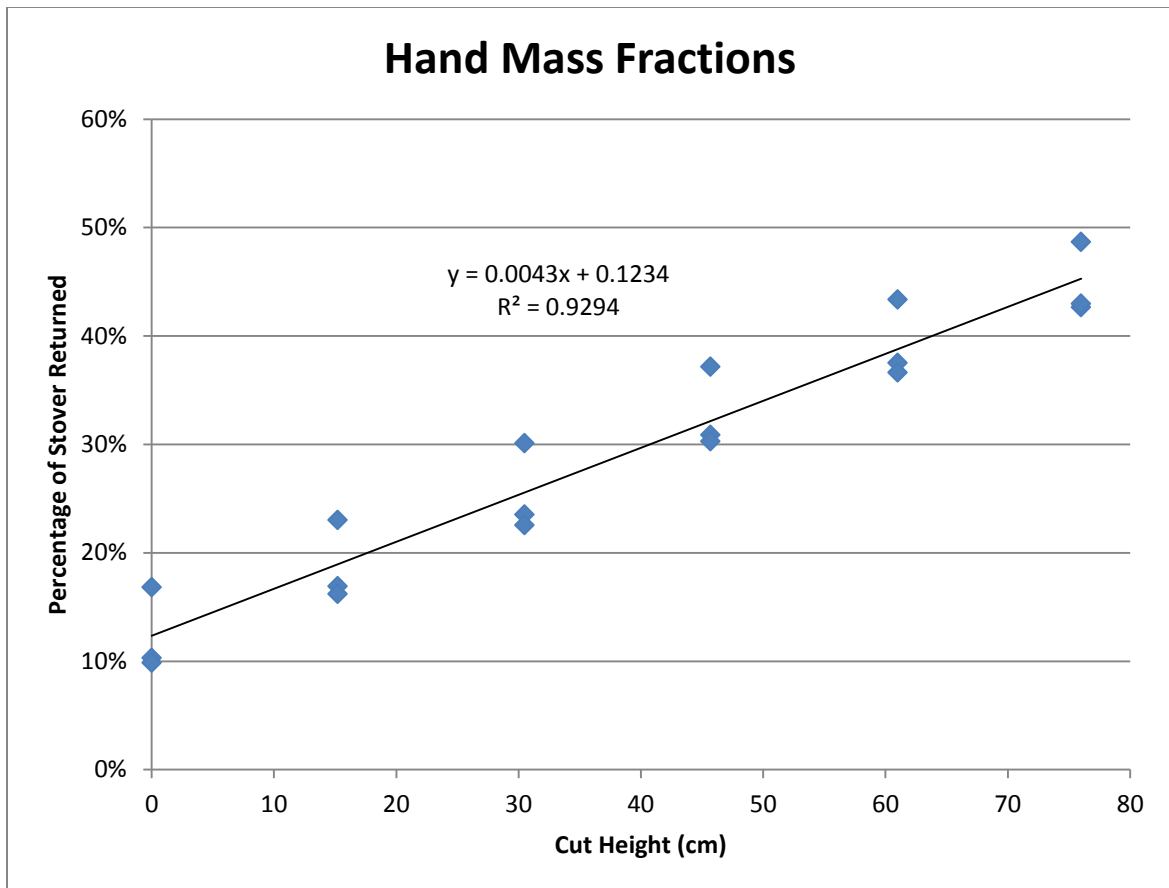


Figure 14: Plot of percentage of stover mass returned by cut height based on hand mass fractionated samples

The y-intercept value is the percentage of stover that was picked up off of the ground from the east side of the row. Basing this equation on the total amount of stover versus cut height allows for the amount of stover left on the ground by cut height to be estimated

despite changes in yield. This however does not take into account changes in plant height and ear height as this is a biological variable that relies on plant genetics and growing conditions.

It can be seen by Figure 15 that mass fractions produced similar results to Wilhelm et al. (2010) results when plotted as percent of biomass returned versus the percentage of cut height relative to the entire plant. The mass fractions returned a lower slope value as well as a larger intercept value than that of Wilhelm. The larger intercept can be attributed to the large loss of leaf material onto the ground due to harsh fall weather conditions.

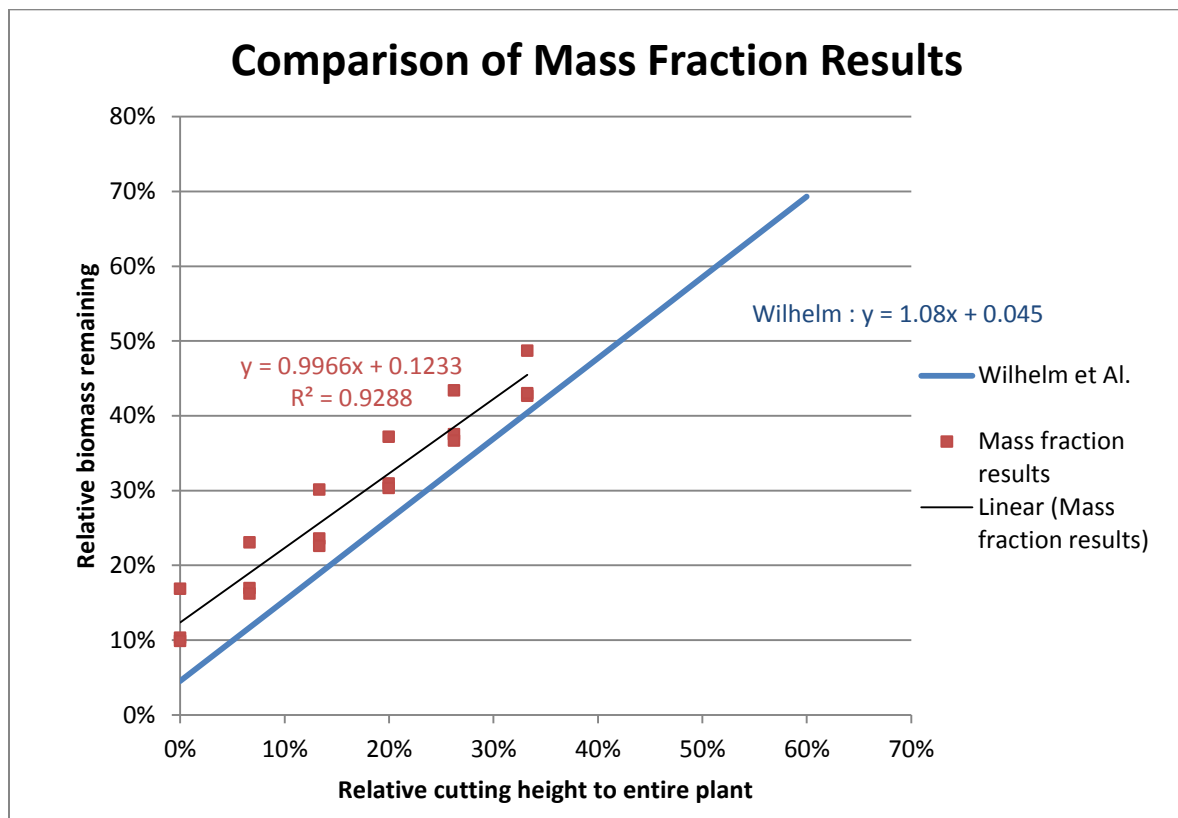


Figure 15: Percentage of biomass remaining by relative cutting height to plant height compared to results of Wilhelm et al. 2010

The y-intercept value could also vary from field to field depending on the amount of plant material that has fallen to the ground. The corn in the test field was relatively dry resulting in the loss of many of the lower leaves from the plant. Even though the leaves account for a low percentage of the total plant mass, this adds error to the estimation of the stover on the ground. Figure 16, the crop material already on the ground is on the left half of the figure while the side where the material had already been picked up is on the right during the hand mass fraction tests.



Figure 16: Crop material on ground providing resulting Y-intercept value for calibration equations

The moisture content of the stover decreased with increasing height of the plant with the lowest stalk portion of the plant having approximately 50% moisture content. Above 30.5 cm, the moisture content dropped to a stabilized level under 20% making the material

above this point more desirable for storage. This supports the premise of raising the cut height when a higher stover return rate is required as it lowers the collected stover moisture content and reduces the amount of material that must pass through the combine.

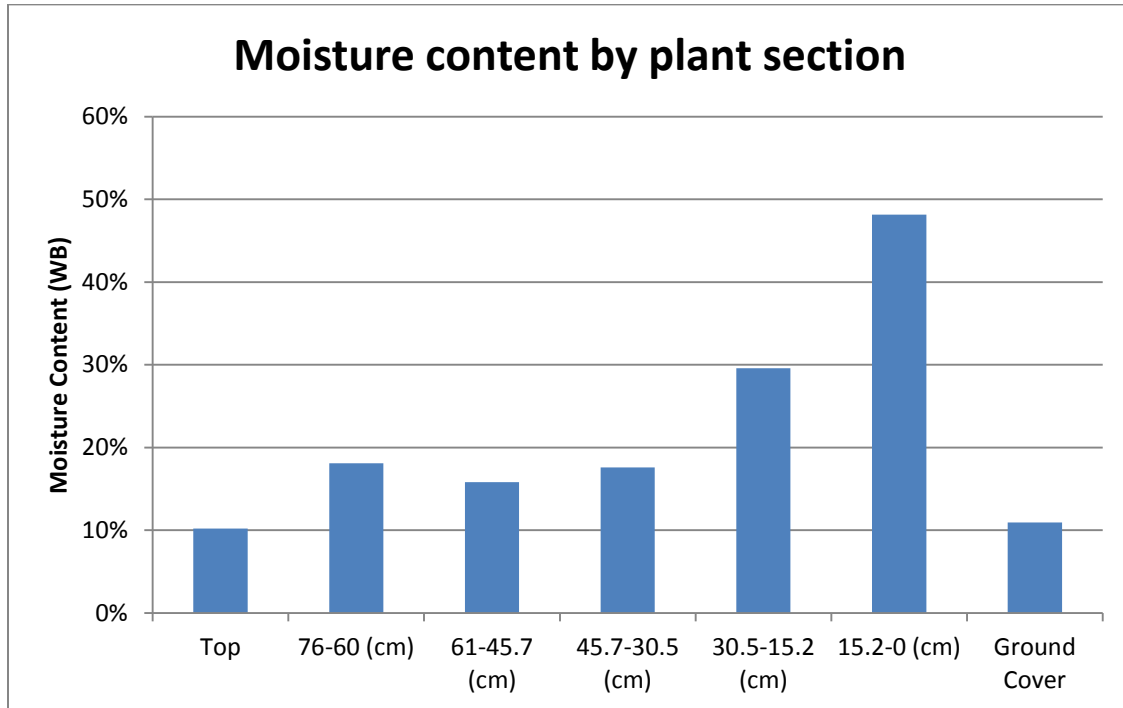


Figure 17: Stover moisture content by section for hand mass fractionated samples

### 5.1.2 Combine Cut Height Tests

The field tests of the cut heights and speed variations were plotted to evaluate the effects of speed and material flow rate on the stover return rate and to observe any trends in the results. Figure 18, shows the linear regression of all data collected split into high speed and low speed which refers to the two different ground speeds of 2.4 and 4 km/h for which the tests were conducted. A linear regression of all points regardless of speed resulted with a

corresponding  $R^2$  of 0.3155. This low  $R^2$  indicates that more factors are affecting the return rate than just the cut height.

The linear regression of the two speeds provided similar slopes but largely different y-intercepts. The similar slopes show that there is essentially an offset between the two data sets of approximately 15%.

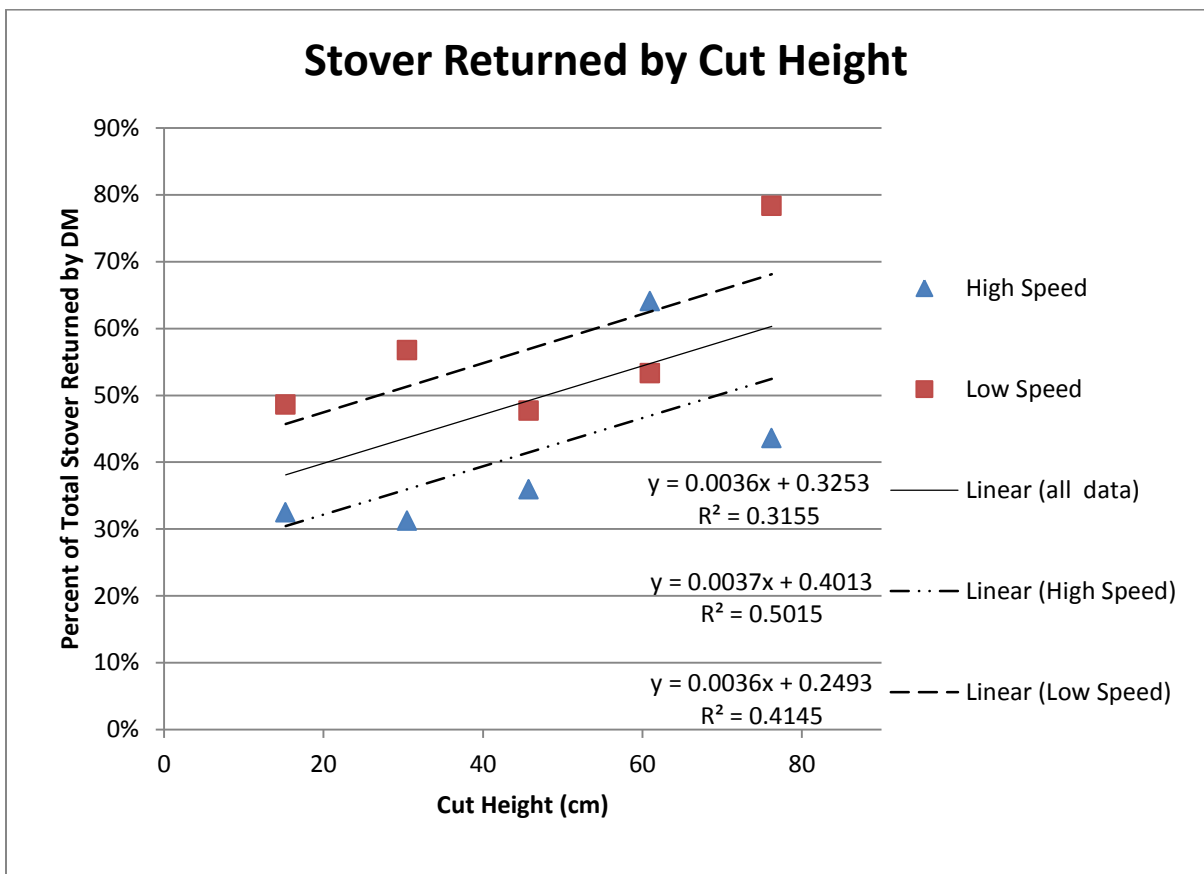


Figure 18: Percentage of stover returned by cut height for field machine tests separated by speed (2.4, 4.8 km/h)



The large offset of the two speeds also provided very low  $R^2$  values of 0.5015 and 0.4145 for the low speed and high speed tests respectively. Compared to the hand mass fractions these results are unacceptable to be used for control applications.

An ANOVA model produced in Jmp© resulted in Equation 12 using speed and cut height as inputs. The results of the model utilizing the inputs speed and cut height resulted in an adjusted  $R^2$  of 0.513 and both speed and cut height being statistically significant with resulting P-values of 0.0464 and 0.0494 respectively.

$$\% \text{ Returned} = (-0.09176 \cdot \text{Speed} + 0.0036467 \cdot \text{Cut Height} + 0.634825) \times 100 \quad (12)$$

The scattered results of the cut height data caused concern in the effectiveness of estimating the stover returned based on cut height. The low  $R^2$  values of the linear fit of the separated speeds and the ANOVA model indicates other factors could be causing the variability in the system. The issue also arises that the crop is a biological system in which spatial variability inherently exists that will cause variation in results. Evaluation of the harvesting the system has identified two key areas that attribute to the scattered data as well as the difference in the results based on speed.

1. Air exhaust points at the rear of the combine forward of the chopper.
2. Material loss in transition between chopper discharge and blower intake.

The main cause of error of the harvesting system in controlling the return rate based on the cut height of the machine is the air exhaust points located at the rear of the machine

and forward of the chopper. The holes are approximately  $0.21 \text{ m}^2$  on the left and right side of the combine. These holes help facilitate material flow by allowing air flow generated by the fan to be exhausted. During preliminary functional testing of the combine the holes were covered and caused extreme material conveyance problems as the restricted air flow facilitated the buildup of stover material on the tail board at the transition point between the upper sieve and chopper. The side shields had to remain off of the combine for testing to generate enough air flow to effectively convey the material.

The exhaust holes then allowed material to exit the machine due to the high air flow being exhausted through them without the possibility of being collected. The shift in the cut height data by speed is different than first expected, since the higher return rate occurred during the slower speed tests, which have lower internal stover flow rates, when compared to higher speeds. The original perception was that the higher material flow rates would result in higher material loss through the exhaust holes, but the lower flow rates actually resulted in higher material loss. After extensive evaluation, it was determined that the cause of the lower return rate is due to the higher internal stover flow rates actually caused partial plugging of the exhaust holes, thus restricting the material flow at the exit points. The lower flow rates created lower more consistent material flow that allowed the exhaust holes to stay cleaner and a greater proportion of the material could freely exit resulting in the low speed having a higher return rate.

The material that had exited from the exhaust holes was partially identifiable due to its larger particle size. As seen in Figure 19, the whole cobs and intact husks are material that exited the machine before passing through the chopper. The cobs were the most identifiable material because of the easy comparison to a cob that had passed through the

chopper. It was never attempted to measure the amount of material exiting through the air exhaust points as most of the material was not discernable from other stover returned to the ground.



Figure 19: Image showing material that was lost through air exhaust points forward of the chopper

By fitting a model utilizing speed and cut height to calculate the percentage of stover returned, some of these errors were more definable. The use of speed in applying a regression takes into account the corresponding increased flow rate of material. However the material flow rate effects of grain or the corresponding stover yield were not statistically significant to include in the model of predicting the stover return rate by cut height.

Despite the cut height model including the speed parameter not being used for the validation testing, it is useful for analyzing the data from the validation tests to determine areas that caused errors in the results. The second cause of error was the loss of material at the transition between the chopper discharge and the blower intake. High material flow rates were the main cause of this “poor handoff” problem as large chunks of material would occasionally exit the chopper and partially plug the blower intake. This would in turn cause a material buildup across the entire blower opening and stover would then be deflected to the ground due to the inability to enter the blower for collection. Lower cut test passes also caused this as the low cut increased material flow and the increased moisture content of the lower material was tougher to chop and resulted in larger material particles such as partial to full stalk lengths.

The addition of the vertical knives to the chopper might have reduced this problem by reduction of the particle size of stover and may have produced a more uniform flow of stover across the chopper discharge. Part of the issue was that the buildup of material on the tailboard forward of the chopper would cause large quantities of material to enter the chopper as it would build up, be moved back by the motion of the sieves and would be drawn into the chopper as a large chunk. This large chunk would then be discharged to the blower opening

causing the previously described problem of a poor handoff with the results shown in Figure 21.

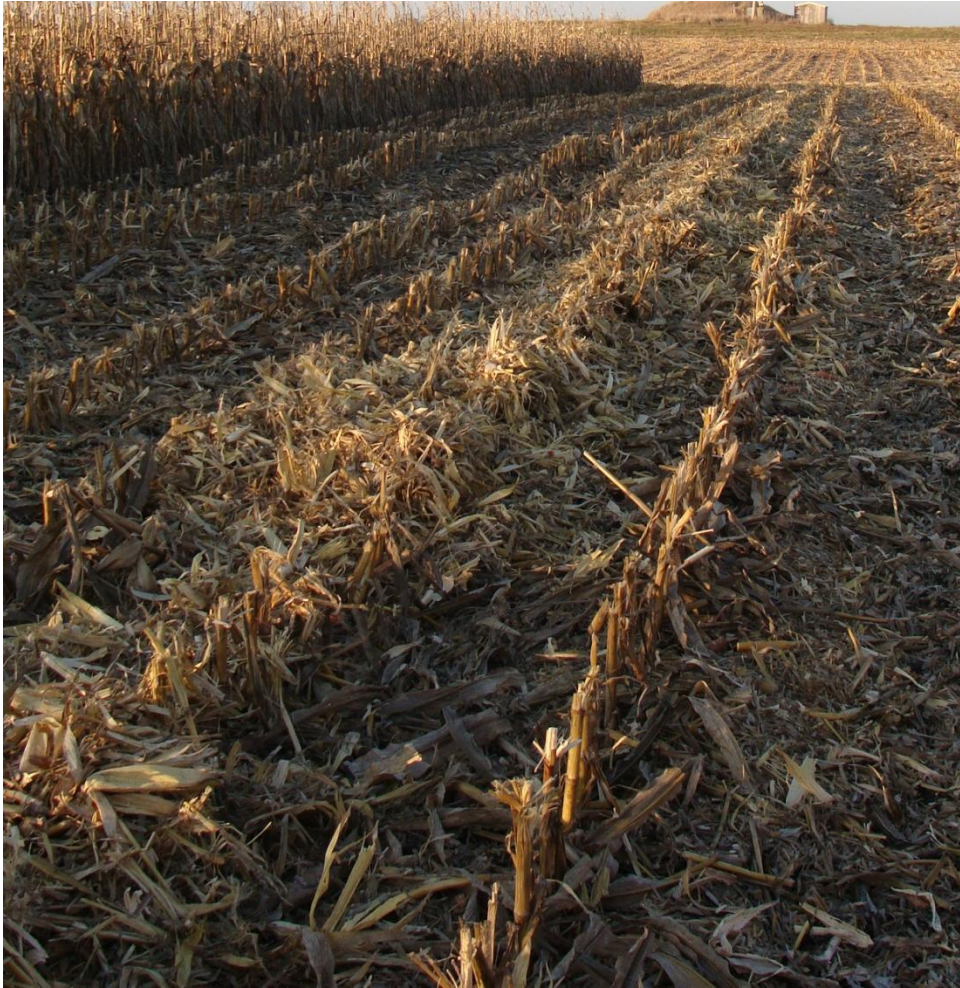


Figure 20: Example of dropped material at chopper to blower transition

Table 4, compares the results of estimating the stover return rate for the cut height tests using the hand mass fractions calibration equation versus the machine test results. The table was sorted by speed to help show the effects of speed on the results as well as the reduction in errors to the estimated return rate as the cut height was increased. The high

speed does have an erratic point at 61 cm cut height with a difference of 1 Mg-ha<sup>-1</sup>, which is inconsistent with the trend of the rest of the values. The higher speed does produce a much lower average error of 0.47 Mg-ha<sup>-1</sup> versus 1.54 Mg-ha<sup>-1</sup> of the low speed. This strongly supports the previous conclusion that the higher flow rate of material helps reduce error losses through the exhaust ports except in select cases of the poor handoff.

Table 4: Comparison of estimated return rate by hand mass fraction calibration curve to machine cut height test manual samples

Speed (km/h)	Cut ht (cm)	Estimated Return Rate (Mg-ha <sup>-1</sup> )	Actual Return Rate (Mg-ha <sup>-1</sup> )	Difference (Mg-ha <sup>-1</sup> )
2.41	15.2	1.17	3.05	1.88
2.41	30.5	1.61	3.63	2.02
2.41	45.7	2.13	3.20	1.07
2.41	61.0	2.61	3.63	1.03
2.41	76.2	2.26	3.95	1.69
4.02	15.2	1.12	1.96	0.84
4.02	30.5	1.39	1.73	0.34
4.02	45.7	1.79	2.03	0.24
4.02	61.0	1.47	2.47	1.00
4.02	76.2	1.95	1.90	-0.05

A visual increase in stover material on the ground could be seen with increasing height during the tests as shown in Figure 21. Height measurements were randomly taken on each test pass to verify the approximate cut height of the corn plants. The cut height for each pass did fluctuate across the field as variability in terrain caused the cutting point of the head to fluctuate during the test pass.



Figure 21: Photo showing two different cut heights (15.2 cm, 30.5 cm)

## 5.2 MOG Split Testing Results

The MOG split tests resulted in data that had a visual trend with scatter along the trend. Similar to the cut height tests the data was split into groups by test settings to assess the factors causing variation in the results. A treatment breakdown of the test results is shown in Figure 22. The resulting trend was linear until it reached approximately the 70% position of the MOG splitter at which point the response flattened out. The return rate levels off at the more open positions of the MOG split due to the geometry and flow pattern of stover at the edges of the MOG split transition between the chopper and blower. The

second cause of the trend leveling off is due to the loss of stover from the fan exhaust points ahead of the chopper that returns material back to the ground before it can be processed through the MOG split. This also accounts for the trend not approaching zero with the MOG split at 85% open as the material never reaches the point at which it can be conveyed into the blower and harvested.

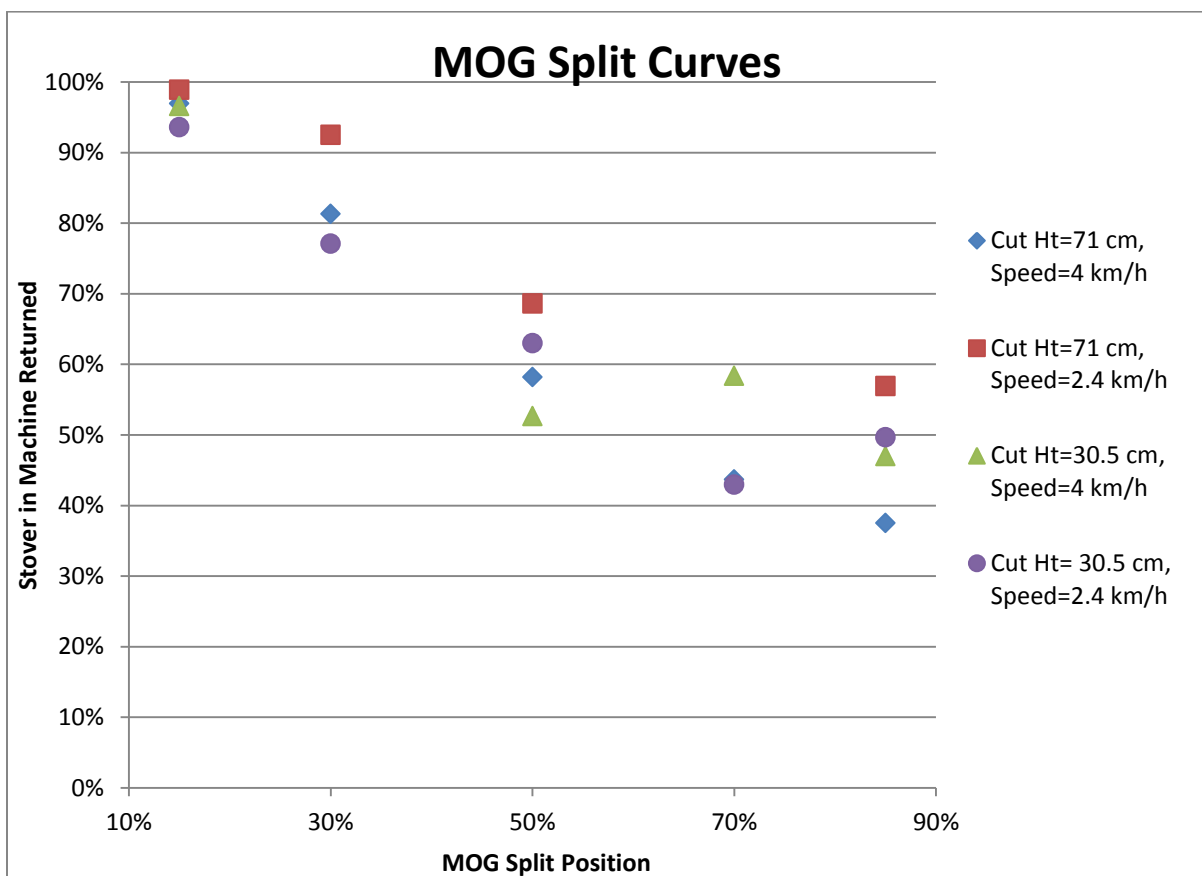


Figure 22: Percent of stover in machine returned to the ground based on MOG split position for varying cut height and speed treatments

The calculation of the stover entering the combine is derived by using the cut height calibration curve and the estimated stover yield from the grain mass from the yield sensor in



conjunction with the HI. The MOG split tests were also subject to the same issues as seen in the cut height calibration tests with the loss of stover from in the machine at the air exhaust points and at the transition area between the chopper and blower. The consistent linear trend from Figure 22 in conjunction with four test configurations for each MOG split position supports the hypothesis that the material flow split can be calculated using the MOG split position.

Table 5: MOG split test results aggregated for all speeds (2.4, 4 km/h) and cut heights (15.2 cm, 71 cm)

MOG Split Position	Average Return	Standard Deviation	95% CI
15%	96.2%	2.13%	96.2% ± 2.09%
30%	80.8%	9.65%	80.8% ± 10.92%
50%	56.9%	7.67%	56.9% ± 7.52%
70%	41.9%	4.56%	41.9% ± 5.16%
85%	45.9%	4.49%	45.9% ± 4.40%

The calibration equation originally developed for the MOG split was a linear fit resulting in an  $R^2$  of 0.86 was used for the validation testing. After reprocessing the calibration equation data, it was found that an exponential provided a better fit for the data with a corresponding  $R^2$  of 0.89 as it is capable of accounting for the trend leveling off to a constant value. Equations 13, and 14, are the developed linear fit and exponential fit calibration curves respectively and are shown in Figure 23.

$$Y = -1.1734 \cdot x + 1.2923 \quad (13)$$

$$Y = 3.0864 \cdot e^{-2.96 \cdot x} \quad (14)$$

The MOG split position is driven by the amount of stover that needs to be returned in addition to the amount of material which has already been returned based on the cut height. The excess return rate required by the MOG split is calculated as a percent of the stover mass passing through the machine so that the equation is universal for any stover flow rate entering the combine. The use of percentages also coincides with the form in which the cut height determines the entering stover flow rate to the combine as it is also calculated by a percentage.

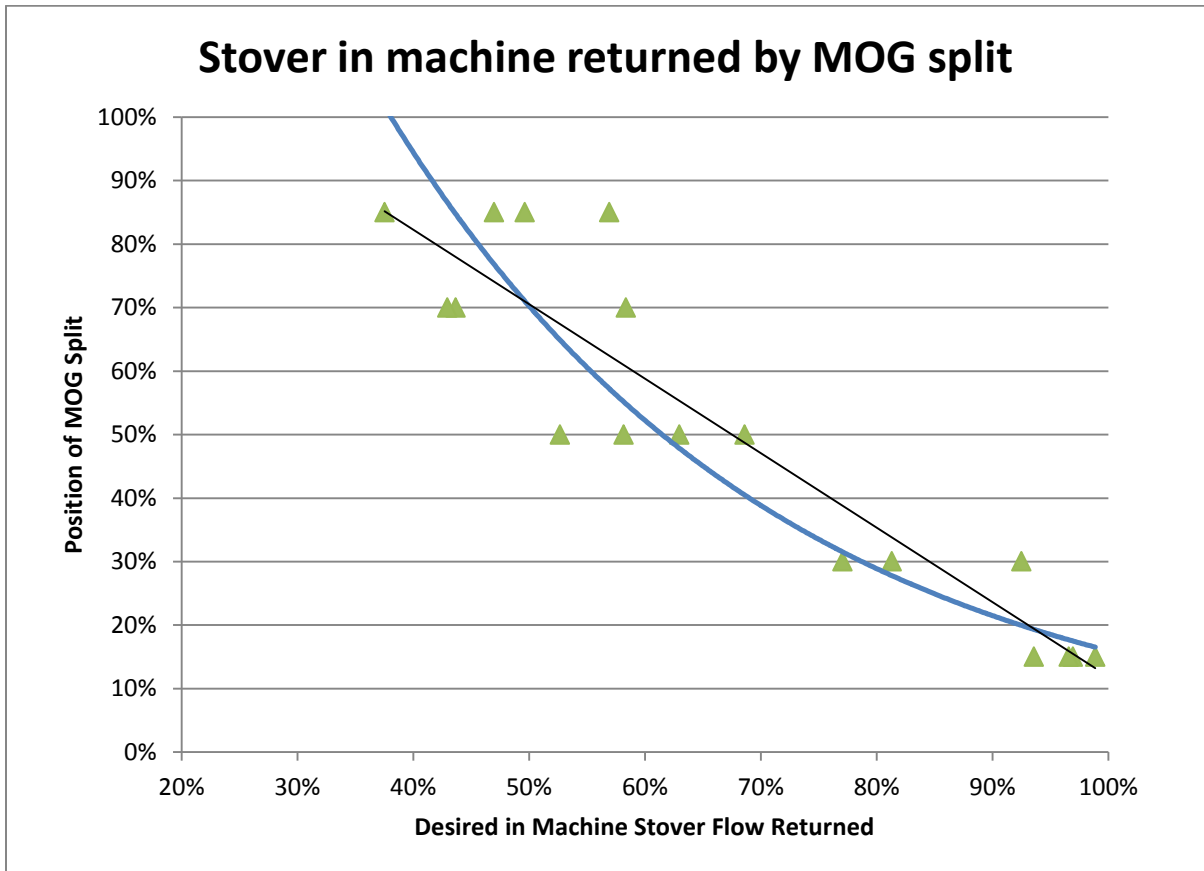


Figure 23: Calibration equation for determining MOG split position based on the amount of material in the machine that is desired to be returned

At the desired stover return flow rate of stover in the machine of 40% or less, it should be noted that the MOG split position is maxed out at 100%. This is most likely due to the air exhaust points creating almost a 40% loss of the stover flow rate in the combine. These results also suggest a possible offset carried through by the cut height calibration curve.

### 5.3 Validation Tests

The overall results of the validation tests are shown in Table 6. The average measured return rates varied and some tests met the overall desired variance from the target rate of  $\pm 1.12 \text{ Mg}\cdot\text{ha}^{-1}$  of returned stover.

Table 6: Validation test results for target return rates aggregated by cut height and target rate for two different speeds (2.4 and 4 km/h)

Target Rate (Mg/ha)	Cut Height (cm)	Test Average (Mg/ha)	Error (Mg/ha)	Std. Dev (Mg/ha)	95% CI
2.24	30.5	3.85	1.61	-	-
4.48		6.30	1.82	-	-
6.72		6.68	-0.04	-	-
2.24	61	5.09	2.85	1.729	5.09 $\pm$ 2.396
4.48		4.44	-0.04	0.923	4.44 $\pm$ 0.904
6.72		5.81	-0.91	0.291	5.81 $\pm$ 0.255
2.24	76	5.56	3.32	0.334	5.56 $\pm$ 0.463
4.48		5.69	1.21	1.215	5.69 $\pm$ 1.683
6.72		6.06	-0.66	0.950	6.06 $\pm$ 0.931

The previously specified calibration curves for the cut height and MOG split were implemented with the mass balance equations for the validation testing of the system. The

results for the test were scattered as seen in Figure 24. The positive slope of the line indicates that the actual return rate increased as the target rate was increased.

The cut heights used for the validation testing cause part of the error as the stover returned by the cut height is greater than the target rate. This is especially true for the low target rate of  $2.24 \text{ Mg-ha}^{-1}$  as the minimum return rate at 30.5 cm is approximately the same as the target rate, resulting in over application of stover at the low target rate for any cut height above 30.5 cm and is further explained in Table 7.

Table 7: Minimum estimated return rate by cut height

Cut Height (cm)	Cut Height Fraction	Min. Return Rate (Stover Yield $8.81 \text{ Mg-ha}^{-1}$ )
30.5	0.251	2.22
61	0.383	3.37
76	0.447	3.94

The validation test results were separated by configuration as also shown in Figure 24. The results for the cut height of 76 cm and test speed of 4 km/h had a negative trend based on the three collected data points. The low target rate,  $2.24 \text{ Mg-ha}^{-1}$ , had a high result due to poor handoff from the chopper to the blower for most of the pass, creating essentially a windrow of stover behind the combine from the excess loss of stover onto the ground.

The actual return rate for the  $2.24$  and  $4.48 \text{ Mg-ha}^{-1}$  target rates were higher than the target rates. This is due to the losses of material through the exhaust ports ahead of the chopper and losses between the chopper and blower transition. The results of the high target rate,  $6.72 \text{ Mg-ha}^{-1}$ , were lower than the target rate. This was caused by using a HI value that

caused an overestimation of the available stover, resulting in the system not having the ability to actually reach the target rate as the actual stover availability was less than the target.

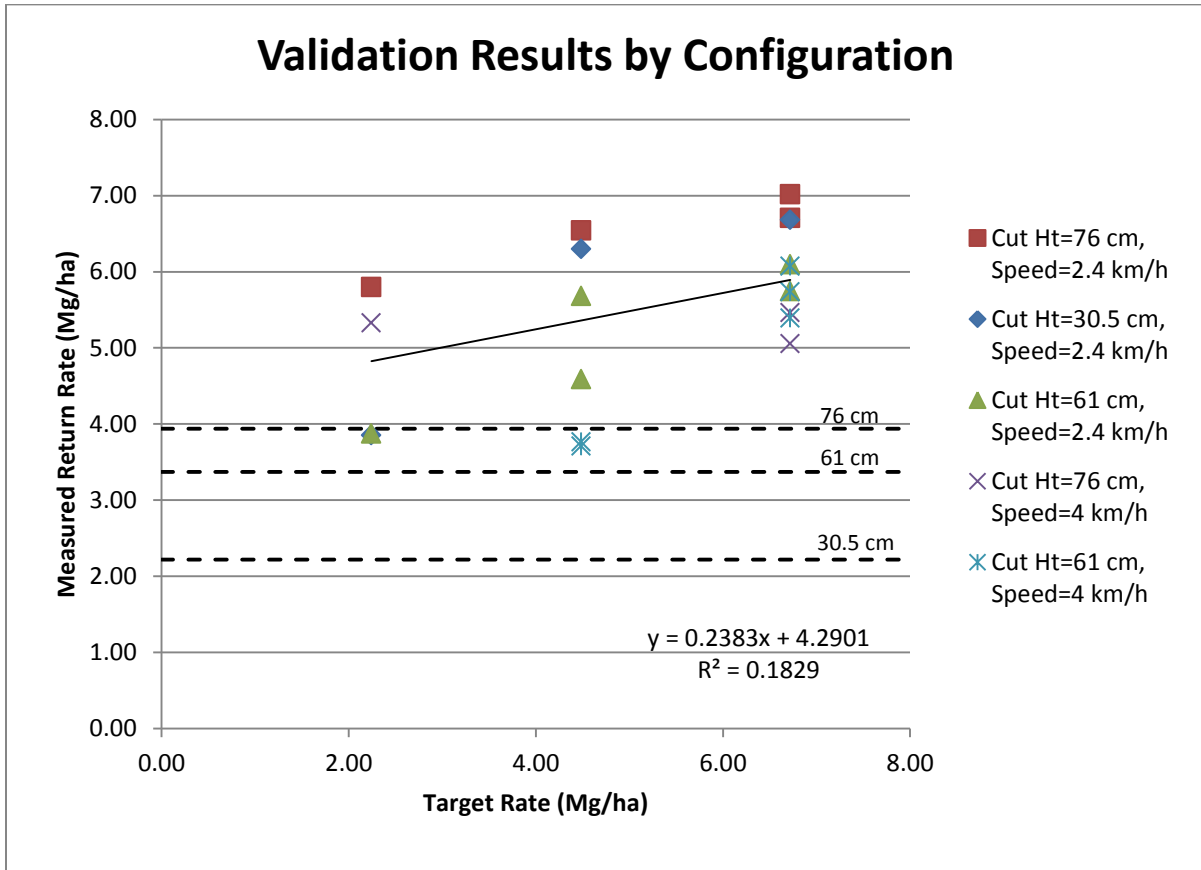


Figure 24: Validation results by test configuration of cut height and speed with indication of return rate just by cut height (dashed lines)

Some field conditions and system function problems caused excessive errors on certain test passes. Passes 39 to 41 had plugging problems at the discharge of the chopper as the MOG split vanes adjusted in and out to control the stover return rate, stover caught on the forward ends of the vanes and caused a blockage across the discharge of the chopper

stopping material flow and plugging the chopper twice per test pass. The plugging was due to the material getting slightly tougher as the temperature decreased later in the day resulting in the stover having a poor chop quality with large pieces of stover catching on the front of the MOG split vanes.

The plugging also caused the MOG split vanes to bend as the driving actuator would continue to drive the vanes to the desired position despite the blockage in their path of travel. This required the vanes to be straightened several times and re-centered which is the basic recalibration of the MOG split position. Plugging occurred the worst when the MOG split vanes were driven to the 75% to 90% position as it created an optimal pinching point for the stover between the vanes and the outer stops for the vanes and the shielding that funnels the stover from the outer edges of the chopper discharge into the MOG split area. As seen in Figure 25, the blockage started at the outer edges of the transition area and filled the discharge all the way to the center. Some plugging did occur when the MOG split vanes were operating in the center transition area in the MOG split positions of 0 to 15% when operating in tougher material that resulted in poor chop quality. The tougher material was typically the result of a lower cut height, producing a higher moisture stover sample.



Figure 25: Image illustrating plugging caused by the MOG split vanes at chopper discharge

Table 8 displays the average of the three ground samples collected from each pass along with average return estimated by the controller for the distance of 20m to 120m during the test pass. The ends of the test pass were excluded to analyze the steady state flow area of the test passes. As seen, test pass 40 has no estimated data as a result of the CANUSB software timing out and not recording data during that test pass. Test passes 43 and 44 resulted in erratic estimation values due to multiple starts and stops during the test pass due to chopper and blower plugging issues. The estimated return rate by the controller was in close range to the target values when the cut height did not return a higher stover rate than

the target rate. Test passes at the target rate of 2.24 Mg-ha<sup>-1</sup>, are examples of stover being over applied due to the cut height returning stover in excess of the target rate.

Table 8: Individual test results for 3 target rates (2.24, 4.48, 6.72 Mg/ha), three cut heights (30.5, 61, 76 cm), and two speeds (2.4, 4 km/h)

Test Pass	Target Rate (Mg-ha <sup>-1</sup> )	Cut Ht. (cm)	Speed (km/h)	Return Rates (Mg-ha <sup>-1</sup> )					
				Manual Samples			Estimated Return Rate		
				Average	Std. Dev	95% CI	Average	Std. Dev	95% CI
54	4.48	61	4.0	3.69	0.39	0.44	4.61	0.41	0.03
47	4.48	61	4.0	3.74	0.35	0.40	4.54	0.29	0.02
41	2.24	30.5	2.4	3.83	0.69	0.78	3.63	0.39	0.02
33	2.24	61	2.4	3.85	0.59	0.66	4.38	0.38	0.02
53	4.48	61	2.4	4.57	0.20	0.23	4.37	0.65	0.04
44	4.48	76	4.0	4.80	0.89	1.01	-	-	-
52	6.72	76	4.0	5.03	0.30	0.34	6.48	0.50	0.04
39	2.24	76	4.0	5.30	1.10	1.24	4.33	0.41	0.03
49	6.72	61	4.0	5.36	0.35	0.39	6.36	0.39	0.03
40	6.72	76	4.0	5.43	0.54	0.61	-	-	-
45	4.48	61	2.4	5.65	1.09	1.23	4.61	0.58	0.03
42	6.72	61	4.0	5.71	1.03	1.16	6.33	0.51	0.04
51	6.72	61	2.4	5.71	0.39	0.44	6.17	0.67	0.04
37	2.24	76	2.4	5.77	0.81	0.92	4.47	0.49	0.03
48	6.72	61	4.0	6.04	0.48	0.54	6.40	0.50	0.04
34	6.72	61	2.4	6.07	0.68	0.77	6.43	0.52	0.03
43	4.48	30.5	2.4	6.27	2.23	2.53	-	-	-
35	2.24	61	4.0	6.28	1.85	2.09	4.57	1.11	0.08
46	4.48	76	2.4	6.51	1.81	2.05	4.63	0.55	0.03
38	6.72	30.5	2.4	6.65	0.37	0.42	6.22	0.55	0.03
50	6.72	76	2.4	6.67	0.25	0.28	6.40	0.55	0.03
36	6.72	76	2.4	6.98	0.72	0.82	6.35	0.49	0.03



Figure 26, shows the results of the low return rate of  $2.24 \text{ Mg-ha}^{-1}$  in conjunction with the low cut height, 30.5 cm, resulting in the MOG split being driven to the 100% position for the entire pass. This supports the previous statements on the effects of the cut height on the minimum return rate that was displayed in Table 7. The figure also displays the estimated return rate, which shows that it is averaging around  $4 \text{ Mg-ha}^{-1}$ , almost double the target rate, but the estimated return rate is enveloped within the 95% confidence interval of measured return rate. Responses in Figure 27 and Figure 28 resulted in estimated averages at approximately the target rate with the MOG split operating in a reasonable range. The two higher return rate plots resulted in the estimated being greater than manual sample results due to the over estimation of the total available stover from using to low of an HI value. For all test passes that were conducted without plugging or CAN data errors, the resulting controller operation provided estimated stover return rates close to the target rates. Granted this is not the actual physical results of the validation test, but proves that the control system was operating at the desired level.

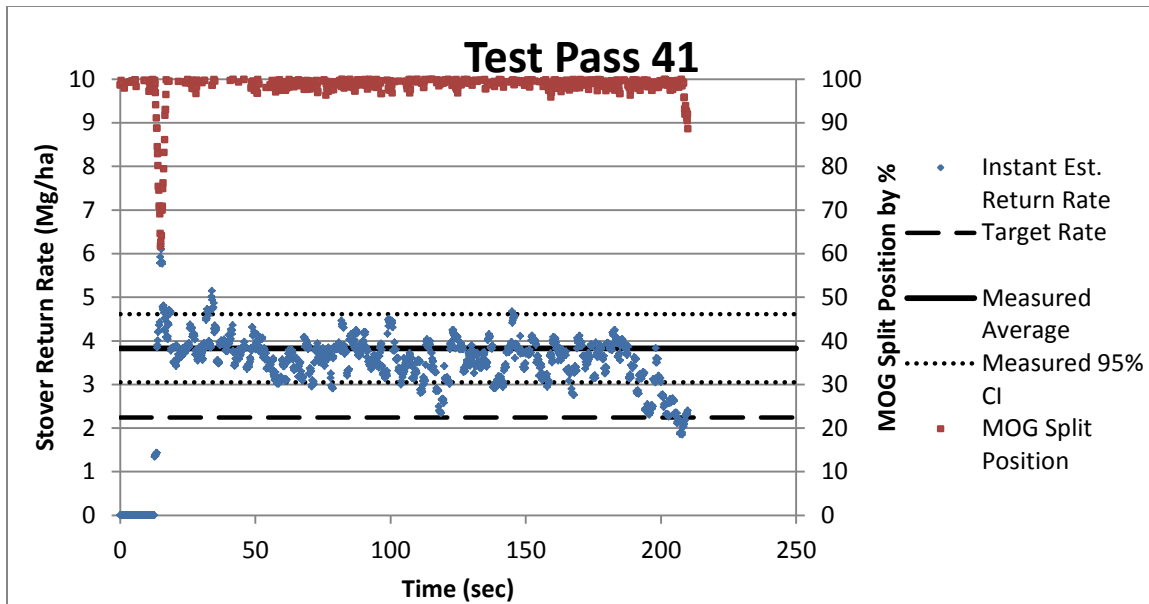


Figure 26: Estimated stover return rate and MOG split position for test configuration: target= $2.24 \text{ Mg}\cdot\text{ha}^{-1}$ , speed=4 km/h, cut height=30.5 cm

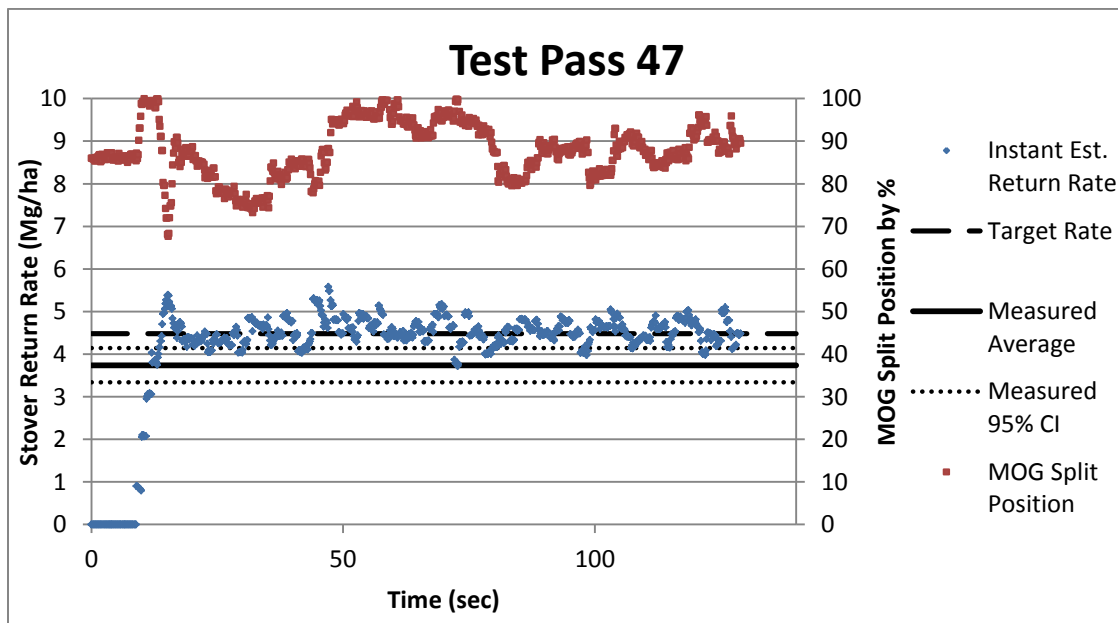


Figure 27: Estimated stover return rate and MOG split position for test configuration: target= $4.48 \text{ Mg}\cdot\text{ha}^{-1}$ , speed=4 km/h, cut height=61 cm

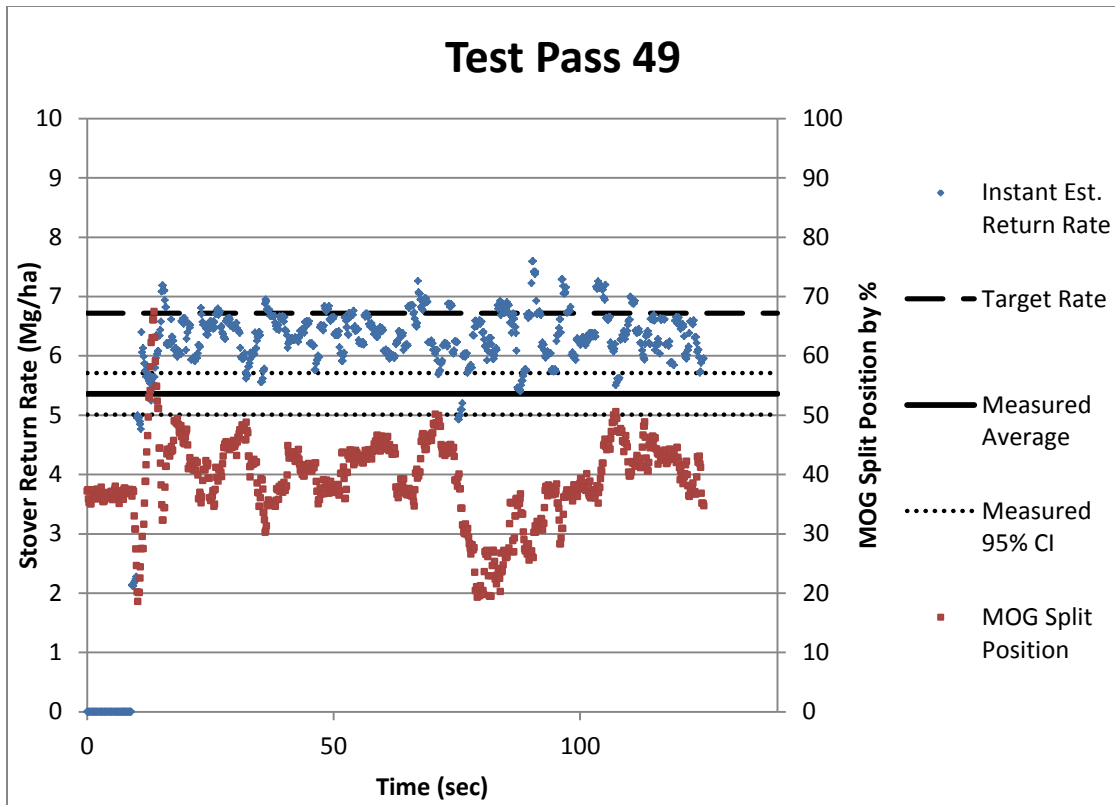


Figure 28: Estimated stover return rate and MOG split position for test configuration: target=6.72 Mg-ha<sup>-1</sup>, speed=4 km/h, cut height=61 cm

## 6.0 CONCLUSIONS

The cut height tests resulted in two different equations, one from the hand mass fractions, and the other from the machine tests. By comparing the results of the two tests, errors caused by material losses in the machine were identified and evaluated. The end decision resulted in the use of the hand mass fraction equations that provide a basic linear relationship between cut height and stover returned by the cut height. The hand mass fractions also produced results similar to that of Wilhelm et al. (2010) increasing the confidence in the accuracy of the measurement.

The MOG split calibration provided sufficient results for correlation of the desired split percentage and a corresponding MOG split position. The results of the test showed no significant variation in MOG splitting based on varying stover flow rates as cut height and speed was varied. Some of the scatter in the MOG split test results can be attributed to losses from the exhaust points and transition between the chopper and blower.

The results of the validation tests support the premise that a variable rate collection system can be implemented using a single pass dual stream harvester. The results, when taking into consideration the sources of error in the system provides a proof of concept that variable rate stover collection is possible despite validation testing returning a positive slope of 0.238, which is low, compared to the desired slope of 1.0 in Figure 24. The basic result of the research is that variable rate stover collection is a viable tool for sustainable corn stover harvesting.

## 6.1 Recommendations

With improvements in the mechanical system for harvesting corn stover and the development of new calibration equations with these changes would greatly increase the accuracy of the system. An increased number of repetitions in calibrations would provide better calibration equations that would facilitate a reduction in errors in meeting a target stover return rate. The application and testing of the cut height calibration and HI equations by Wilhelm et al. (2010) may also produce better results and should be investigated for variable rate collection.

The installation of the vertical knives into the chopper assembly would facilitate a finer chop quality and would reduce loss effects between the chopper and blower, helping the material to feed into the blower. The installation of a larger cleaning shoe would reduce the length of the tail board and enhance feeding to the chopper. Other improvements in conveyance would allow the exhaust points to be closed and the fan speed reduced to reduce stover losses and reduce power consumption.

Stover mass flow sensors are currently in development and the implementation of closed loop control would be an excellent step as it would reduce a large number of errors as the control system would bypass all of the errors caused by loss points. The implementation of the stover mass flow would be most beneficial at the blower as all collected stover could be measured allowing the calculation of the return rate using the estimated stover yield from the grain yield.

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## APPENDIX APPENDIX A: CALIBRATION AND VALIDATION DATA

Table A.1: Hand mass fraction results for each sample collected

Mass Fraction #	Cob, Husk, Grain	Top	76-60 (cm)	Mass Fractions (Mg/ha)							Ground Cover	Cob	Husk	Grain
				61-45.7 (cm)	45.7-30.5 (cm)	30.5-15.2 (cm)	15.2-0 (cm)							
1	11.82	2.30	0.39	0.50	0.56	0.50	0.50	0.50	0.78	1.23	0.84	9.81		
2	9.42	1.51	0.34	0.39	0.45	0.45	0.39	0.39	1.06	1.06	0.67	7.62		
3	11.82	2.30	0.50	0.50	0.62	0.50	0.50	0.50	0.78	1.40	0.84	9.53		
% moisture	13%	10%	19%	17%	19%	32%	50%	11%						

Table A.2: Cut height test results by test pass and configuration parameters

Cut Height Test Data						
	Ground Cover	Collected	Grain (Mg/ha)		Stover	
	Avg DM	Stover DM	Wet	Dry	Estimated by	% of Total Stover
	(Mg/ha)	(Mg/ha)			HI (Mg/ha)	Returned
Pass 1	2.83	3.98	10.79	8.74	7.45	38.01%
Pass 2	3.05	3.01	9.09	7.36	6.27	48.60%
Pass 3	1.96	4.52	8.76	7.09	6.04	32.46%
Pass 4	3.63	2.73	9.26	7.50	6.39	56.75%
Pass 5	1.73	4.51	8.01	6.49	5.53	31.24%
Pass 6	3.20	3.33	9.73	7.88	6.71	47.69%
Pass 7	2.03	3.62	8.17	6.62	5.64	35.92%
Pass 8	3.63	2.74	9.88	8.00	6.82	53.31%
Pass 9	2.47	2.74	5.58	4.52	3.85	64.09%
Pass 10	3.95	2.35	7.31	5.92	5.04	78.34%
Pass 11	1.90	3.00	6.31	5.11	4.36	43.59%
Pass 12	2.03	3.61	9.15	7.41	6.32	32.21%

Table A.3: MOG split test results by test pass and configuration parameters

MOG Split Test Data													
Pass	Ground Cover		Collected		Grain (Mg/ha)		Stover		Machine (Mg/ha)	% of in machine returned	MOG Split Position	Speed (kph)	Cut Height (cm)
	Avg DM (Mg/ha)	Stover DM (Mg/ha)	Wet	Dry	HI (Mg/ha)	Estimated by HI (Mg/ha)	Returned	% of Total Stover Returned					
Pass 14	6.97	0.05	10.57	8.57	7.30	7.30	95.54%	2.16	97.66%	Split 15%,	2.41	61.0	
Pass 18	5.77	0.31	9.67	7.83	6.67	6.67	86.44%	1.98	84.36%	Split 30%	2.41	61.0	
Pass 22	5.84	1.49	11.09	8.98	7.65	7.65	76.33%	2.27	34.43%	Split 50%	2.41	61.0	
Pass 26	6.17	1.07	12.67	10.26	8.74	8.74	70.52%	2.59		Split 70%	2.41	61.0	
Pass 30	5.47	2.38	12.93	10.48	8.92	8.92	61.30%	2.64	10.08%	Split 85%	2.41	61.0	
Pass 16	5.84	0.14	11.02	8.92	7.60	7.60	76.84%	3.03	95.29%	Split 15%,	4.02	61.0	
Pass 20	6.07	1.01	12.67	10.26	8.74	8.74	69.39%	3.48	70.99%	Split 30%	4.02	61.0	
Pass 24	5.63	1.96	10.99	8.90	7.58	7.58	74.28%	3.02	35.07%	Split 50%	4.02	61.0	
Pass 28	4.68	2.73	11.38	9.21	7.85	7.85	59.67%	3.13	12.55%	Split 70%	4.02	61.0	
Pass 32	5.14	2.97	11.15	9.03	7.69	7.69	66.76%	3.06	3.01%	Split 85%	4.02	61.0	
Pass 13	4.69	0.24	7.07	5.72	4.88	4.88	96.24%	1.99	88.13%	Split 15%,	2.41	30.5	
Pass 17	5.09	1.25	10.49	8.50	7.24	7.24	70.30%	2.95	57.64%	Split 30%	2.41	30.5	
Pass 21	3.85	2.10	10.92	8.85	7.54	7.54	51.10%	3.07	31.57%	Split 50%	2.41	30.5	
Pass 25	3.91	3.35	11.31	9.16	7.80	7.80	50.06%	3.18	-5.42%	Split 70%	2.41	30.5	
Pass 29	4.44	2.84	10.86	8.79	7.49	7.49	59.26%	3.05	6.95%	Split 85%	2.41	30.5	
Pass 15	5.56	0.16	8.82	7.15	6.09	6.09	91.32%	3.10	94.97%	Split 15%,	4.02	30.5	
Pass 19	5.96	1.08								Split 30%	4.02	30.5	
Pass 23	4.40	2.67	10.86	8.79	7.49	7.49	58.78%	3.82	30.08%	Split 50%	4.02	30.5	
Pass 27	3.72	2.44	11.29	9.15	7.79	7.79	47.69%	3.97	38.50%	Split 70%	4.02	30.5	
Pass 31	3.70	2.67	9.69	7.85	6.69	6.69	55.28%	3.41	21.69%	Split 85%	4.02	30.5	

Table A.4: Validation test results by test pass and configuration parameters

Validation Test Results								
Pass #	Mg/ha	Speed	Cut Height	Grain (Mg/ha)	Stover Collected (Mg/ha)	Ground Stover (Mg/ha)	Available Stover by HI (Mg/ha)	Return rate error (Mg/ha)
33	2.24	2.4	61	10.58	2.24	3.87	9.01	-1.63
34	6.72	2.4	61	10.52	0.90	6.10	8.96	0.62
35	2.24	4.0	61	10.63	2.11	6.32	9.06	-4.08
36	6.72	2.4	76	10.58	0.65	7.02	9.01	-0.30
37	2.24	2.4	76	9.96	1.66	5.80	8.48	-3.56
38	6.72	2.4	30.5	10.30	0.44	6.68	8.77	0.04
39	2.24	4.0	76	9.73	1.41	5.33	8.29	-3.08
40	6.72	4.0	76	10.52	1.27	5.46	8.96	1.26
41	2.24	2.4	30.5	10.07	2.34	3.85	8.58	-1.61
42	6.72	4.0	61	10.63	0.93	5.74	9.06	0.98
43	4.48	2.4	30.5	10.13	1.76	6.30	8.63	-1.82
44	4.48	4.0	76	10.35	1.35	4.83	8.82	-0.34
45	4.48	2.4	61	10.30	1.10	5.68	8.77	-1.20
46	4.48	2.4	76	10.30	0.90	6.54	8.77	-2.06
47	4.48	4.0	61	10.24	2.70	3.76	8.72	0.72
48	6.72	4.0	61	10.52	0.81	6.07	8.96	0.65
49	6.72	4.0	61	10.35	0.67	5.39	8.82	1.33
50	6.72	2.4	76	10.80	0.35	6.71	9.20	0.01
51	6.72	2.4	61	9.79	0.34	5.74	8.34	0.98
52	6.72	4.0	76	11.26	1.19	5.05	9.59	1.67
53	4.48	2.4	61	9.22	1.80	4.59	7.85	-0.11
54	4.48	4.0	61	10.80	3.33	3.71	9.20	0.78

## APPENDIX B: CONTROL CODE

```

Private Sub Timer1_Timer()

    On Error Resume Next

'=====
'=====
'Get GPS Data from COM port 1

Select Case GPS_recieve.CommEvent
    Case comEvReceive
        buffer$ = buffer$ & GPS_recieve.Input

        start_pos = InStr(buffer$, "$GPVTG")
        end_pos = InStr(buffer$, "$GPRMC")

        If start_pos > end_pos And start_pos <> 0 Then
            str_len = Len(buffer$)
            buffer$ = Mid(buffer$, start_pos, str_len - start_pos + 1)
            end_pos = InStr(buffer$, "$GPRMC")
        End If

        If start_pos < end_pos And start_pos <> 0 Then
            str_len = Len(buffer$)
            str_pos(0) = InStr(buffer$, "$GPVTG")
            str_pos(1) = InStr(buffer$, "$GPGGA")
            buffer_gga$ = Mid(buffer$, str_pos(1), str_len - str_pos(1) +
1)

            buffer_vtg$ = Mid(buffer$, str_pos(0), str_pos(1))

            GPS_GGA = parseGGA(buffer_gga$)
            GPS_VTG = parseVTG(buffer_vtg$)
            GPS_lat = GPS_GGA(2)
            Lat_hem = GPS_GGA(3)
gps VTG                                     'latitude parsed from

            GPS_lon = GPS_GGA(4)
            Lon_hem = GPS_GGA(5)
gps VTG                                     'longitude parsed from

            GPS_Time = GPS_GGA(1)
synchronizing                               'GPS time for

            GPS_Alt = GPS_GGA(9)

            speed_knots = GPS_VTG(5)
knots                                       'parsed gps speed in

            speed_kph = GPS_VTG(7)
            speed_m = speed_kph / 3.6 'm/s
            Grnd_speed = speed_kph * 0.621371192 'mi/hr

```

```

speed_ft = Grnd_speed * 5280 / 3600      'ft/s

Mi_hr_text.Text = Grnd_speed            'display ground speed

'UTM_conv = convertgps(GPS_lat, Lat_hem, GPS_lon, Lon_hem, 15)
'Northing = UTM_conv(0)
'Easting = UTM_conv(2)

GPS_text.Text = buffer$
buffer = ""
Lat_text.Text = GPS_lat
Lon_text.Text = GPS_lon

End If
GPS_text.Text = buffer$
End Select

```

```

'=====
=====
CAN_retval = ERROR_CANUSB_OK

```

```
i = 0
```

```

While ((i < 1000) And (CAN_retval = ERROR_CANUSB_OK))
    'CAN_retval = canusb_Read(CAN_handle, CAN_msg)
    CAN_retval = canusb_ReadFirst(CAN_handle, CANUSB_MSG_ID_SA211,
128, CAN_msg)
    'CAN_retval = canusb_ReadFirst(CAN_handle, 128, CAN_msg)

```

```

If CAN_msg.data(0) = 79 And CAN_msg.data(1) = 9 Then
    MSG_CNT = MSG_CNT + 1
    CAN_CNT_text.Text = MSG_CNT
    For kk = 0 To 7
        CAN_bytes(kk) = CAN_msg.data(kk)
    Next kk
    CAN_ID = CAN_msg.id
    'byte 0 constant 0x4F
    'byte 1 constant 0x9
    'byte 2&3 mass per second units defined by byte 7 (LSB, MSB)
    'byte 4&5 moisture x 100 (LSB, MSB)
    'byte 6 status bits, don't use
    'byte 7 for scale factor for yield mass flow value
        '0 = kg
        '1 = kg x 10
        '2 = kg x 100
        '3 = kg x 1000

'set yield scale factor
Select Case CAN_bytes(7)

```

```

Case 0
    yield_gain = 1
Case 1
    yield_gain = 0.1
Case 2
    yield_gain = 0.01
Case 3
    yield_gain = 0.001
End Select
CAN_byte_text1.Text = CAN_bytes(0)
CAN_byte_text2.Text = CAN_bytes(1)

'grain mass flow calc in lbs/sec
grain_mass_flow = (CAN_bytes(2) + CAN_bytes(3) * 256) * yield_gain
* 2.20462262 'grain yield, kg/s * 2.20462262 to lbs/sec

'grain moisture in %
grain_moist = (CAN_bytes(4) + CAN_bytes(5) * 256) * 0.01 'grain
moisture in %, 0.01 scale value

moisture_text.Text = grain_moist

'%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
'%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
'Calculate an average grain mass flow value for stover Rx Control
If grain_mass_flow = 0 Then
    mass_flow_timeout = mass_flow_timeout + 1
Else
    mass_flow_timeout = 0
End If

If mass_flow_timeout < 10 Then
    'Get into a lbs/ac form and account for moisture to get dry
mass
    If mm < 4 Then
        mm = mm + 1
    Else
        mm = 0
    End If

    If speed_ft > 0.05 Then
        mass_flow_array(mm) = (grain_mass_flow - grain_mass_flow *
0.186) * 30 * speed_ft / (43560)

        accum_mass_flow = 0

        For n = 0 To 4
            accum_mass_flow = accum_mass_flow + mass_flow_array(n)
        Next n

        MA_mass_flow = accum_mass_flow / 5
    End If

```

```

        Else
            'if mass flow is zero long enough revert to average for
settings
            MA_mass_flow = Yield_average_txt.Text * 56
        End If

        If speed_ft < 0.05 Then
            grain_yield = 0

        Else
            grain_yield = grain_mass_flow * 43560 / (speed_ft * head_size
* 56)
            yield_average = (grain_yield + yield_average) / 2

        End If
        MA_mass_flow_text.Text = MA_mass_flow

        can_flag = 0

    End If

    CAN_msg.id = 0
    i = i + 1
Wend
    'Error fault fix
    If can_flag > 20 Then

        status = canusb_Flush(CAN_handle, FLUSH_WAIT)    'Stop and disable
CAN logger
        canusb_Close (CAN_handle)                        'Stop and disable
CAN Logger

        CAN_handle = canusb_Open(vbNullString, "250",
CANUSB_ACCEPTANCE_CODE_61394, CANUSB_ACCEPTANCE_MASK_61394,
CANUSB_FLAG_TIMESTAMP)
    Else
        can_flag = can_flag + 1
    End If

    yield_text.Text = grain_yield

'=====
'=====
'Get Analog Data

```



```
AD_Values(7) = ADVoltage(7) * MOG_split_gain + MOG_split_offset
MOG_split_pos = AD_Values(7)
```

```
AD_Values(1) = ADVoltage(1) * Rotor_press_conv
AD_Values(0) = ADVoltage(0) * Head_ht_gain + Head_ht_offset
```

```
cut_ht = AD_Values(0)
```

```
AD_Values(2) = ADVoltage(2) * MOG_moist_gain + MOG_moist_offset
```

```
For channelnum% = 3 To AD_ChancNT - 2
    AD_Values(channelnum%) = ADVoltage(channelnum%)
Next channelnum%
```

```
'Display values
```

```
kd% = 0
```

```
For channelnum% = 0 To AD_ChancNT - 1
    If AD_enabled_chan(kd%) = channelnum% Then
        Ath_text(kd%).Text = AD_Values(channelnum%)
        kd% = kd% + 1
    End If
Next channelnum%
```

```
'=====
=====
```

```
'Retrieve Smart Board data
```

```
SmartTemp = 0
```

```
SmartTemp = DRV_GetAmbientTemp(SMTB, 0)
```

```
SMTStat = DRV_GetFaultFlags(0)
```

```
If SMTStat <> 0 Then
```

```
Call FaultMessage(0)
```

```
End If
```

```
Call DRV_GetAllSensors(SMTB, SmartData(0))
```

```
kd = 0
```

```
For id = 0 To 5
```

```
    If Smart_chan_CNT(id) = 1 Then
```

```
        SmartValue(id) = SmartData(id)
```

```
        smarttext(id).Text = SmartValue(id)
```

```
    End If
```

```
Next id
```

```
'=====
=====
```

```

'Get USB Counter counts

''get time interval since last check
ULStat = cbCIn32(boardnum%, 5, CBCount)
If CBCount < UCBCountOld(4) Then
    UOverCount(4) = UOverCount(4) + 1
End If

UCounts(4) = CBCount + UOverCount(4) * 65535
Tint = (UCounts(4) - UCountsOld(4)) * 0.0002
UCountsOld(4) = UCounts(4)
UCBCountOld(4) = CBCount

''read all count channels
For z = 0 To 3
    k = z + 1
    ULStat = cbCIn32(boardnum%, k, CBCount)
    '''UCounts(z) = CBCount
    '''Check Counter Overflow
    If CBCount < UCBCountOld(z) Then
        UOverCount(z) = UOverCount(z) + 1 'Tally number of Timers
Counter(z) has overflowed
    End If
    UCounts(z) = CBCount + UOverCount(z) * 65535

    If z < 4 Then
        UFreq(z) = (UCounts(z) - UCountsOld(z)) / (Tint)
        URPM(z) = Format(UFreq(z) * 60 / CNT_scaler(z), "0000.")
        CNT_text(z).Text = URPM(z)
    End If

    UCountsOld(z) = UCounts(z)
    UCBCountOld(z) = CBCount

Next z

CNT_TMR(0) = UCounts(4) * 0.0002
CNT_text(4) = CNT_TMR(0)
'load_num = UCounts(4)

'=====
'Control Stover Collection

Select Case Rx_type

    Case 0      'RUSLE stover calculations
    'Rx=RUSLE results * harvest_nudge

    Case 1      'harvest all
    'Rx=0
    'bypass and set position of diverter to 0%

    Case 2      'Harvest specified tons/acre

```

```

'Rx=yield-MOG_harvest

Case 3      'Return specified tons/acre of stover
'Rx=MOG_ret_Rx

    Total_stover = MA_mass_flow * (1 / HI - 1) / 2000  'total stover
in tons from HI
    Cut_Tx = (cut_ht * 1.1188 + 11.314) / 100      'Stover left by
cut height by fraction
    Stover_split_Tx = (MOG_ret_Rx / Total_stover - Cut_Tx) / (1 -
Cut_Tx) 'fraction of stover in machine needed to return to ground
    MOG_Rx_pos = -117.34 * Stover_split_Tx + 129.23

    If MOG_Rx_pos > 100 Then
        MOG_Rx_pos = 100
    Else
        If MOG_Rx_pos < 0 Then
            MOG_Rx_pos = 0
        End If
    End If

    If MOG_split_pos > MOG_Rx_pos - 3 And MOG_split_pos < MOG_Rx_pos +
3 Then
        ULStat = dscSetRelayStdC(RSCB, 8, 0)

        ULStat = dscSetRelayStdC(RSCB, 9, 0)
    Else
        If MOG_split_pos > MOG_Rx_pos Then
            ULStat = dscSetRelayStdC(RSCB, 8, 0)
            ULStat = dscSetRelayStdC(RSCB, 9, 1)

        Else
            ULStat = dscSetRelayStdC(RSCB, 8, 1)
            ULStat = dscSetRelayStdC(RSCB, 9, 0)
        End If
    End If
Case 4      'Harvest no stover
'Rx=yield
'bypass and set position of diverter to 100%
Case 5
'Rx=?
'Directly specify position of MOG splitter

If MOG_split_pos > MOG_Rx_pos - 3 And MOG_split_pos < MOG_Rx_pos + 3
Then
    ULStat = dscSetRelayStdC(RSCB, 8, 0)

    ULStat = dscSetRelayStdC(RSCB, 9, 0)
Else
    If MOG_split_pos > MOG_Rx_pos Then
        ULStat = dscSetRelayStdC(RSCB, 8, 0)
        ULStat = dscSetRelayStdC(RSCB, 9, 1)

    Else
        ULStat = dscSetRelayStdC(RSCB, 8, 1)
    End If
End If

```

```
        ULStat = dscSetRelayStdC(RSCB, 9, 0)
    End If
End If

End Select

MOG_Rx_text.Text = MOG_Rx_pos

If Recordflag = 1 Then
    Write_ADDData ((TotalIndex& / AD_ChancNT) - 1)
End If

DoEvents

End Sub
```