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Modeling and Economic Analysis of a Crop-Livestock Production System Incorporating Cereal Rye as a Forage

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MODELING AND ECONOMIC ANALYSIS OF A CROP-LIVESTOCK PRODUCTION SYSTEM INCORPORATING CEREAL RYE AS A FORAGE

by

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This thesis consists of two chapters using agent-based modeling for a crop-livestock production system incorporating human labor. The first chapter examines the principles used to develop a fundamental simulation pertaining to grazing cereal rye (Secale cereal L.) with calves. Within the software guidelines, the base model has the ability to capture diverse system interactions between livestock/plants and land management with human labor efficiency. AnyLogic incorporates agent-based modeling while combining with discrete event modeling and system dynamics. The purpose of the model was to find the economic returns of grazing cover crops relative to the area of Mead, Nebraska. In our simulation model, we used data from the University of Nebraska-Lincoln Climate Center. The model was developed to create more in depth case studies to help further the understanding of crop and livestock interactions through simulation. AnyLogic is a complex tool that has the capabilities of discovering the interactions between crops, livestock, land, and humans.

In the second chapter, we examined the economic returns of grazing cereal rye with calves versus mechanically removing the cover crop. This analysis evaluated production risks due to weather variability and cattle market risk to determine the theoretical best outcome using existing weather and market data. Working with the University of Nebraska-Lincoln's agronomy and animal science departments, we

modified a cereal rye growth production model first proposed by Feyereisen et al. (2006) to match recent on-farm production trial experience in Mead, Nebraska. Based on simulation results over multiple years, it was determined that mechanically harvesting cereal rye is a better option as a long term fixed strategy than grazing cereal rye. This is largely due to cattle market risk during the spring grazing period. The costs associated with mechanically removing the crop depend on farm size and equipment used.

Both chapters utilize a model simulating the grazing of cover crops developed using the AnyLogic software while the analysis on mechanically removing the forage was completed with the use of a University of Nebraska-Lincoln cover crop budget. Through bridging the gap between production and economic information, this study sought to develop a financial comparison between the two cover crop strategies for eastern Nebraska farmers.

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Chapter 1: Modeling Crop-Livestock Production Systems Using Agent Based Principles/Techniques

I. Introduction and Review of Literature:

Agricultural systems research has been at the forefront of numerous studies aimed at evolving toward better management practices for farmers and ranchers (Jaleta et al., 2015; Jones, 2016). Interest in farming systems research began in the 1970's to help spread extension methods that provided sustainability while discovering the complexities of farm productivity (Dobbs, 1987). These systems are commonly studied using simulation tools. To date, there are three general methods used as simulation modeling frameworks: (1) discrete event modeling; (2) system dynamics; and, (3) agent-based modeling (Borshchev, 2013).

Discrete event modeling is a simulation method dating back to the early 1960's. Discrete event modeling uses events at specific instances to coordinate system components as a function of time. It is the most common form for simulation modeling of agricultural production systems and is done using multiple software platforms including many models built in Excel spreadsheets or workbooks.

System dynamics modeling began in the 1950's with the work of MIT professor Jay Forrester. It creates more of a big picture approach by simulating agricultural production systems as a series of interrelated stocks and flows.

Recently, this has been accomplished using systems modeling software packages such as STELLA (Richmond, 2004) or Vensim (Ventana Systems, 2018).

The complexities of integrated farming systems involve analyzing the crop and animal production while managing and/or tracking environmental variables, in addition to human factors. Due to this complexity, modeling integrated farming systems can be a challenge for many researchers to simulate. Agent-based modeling was developed in the early 2000's with the ability to capture an environmental network of a group of systems while including detailed orientated agents. Agents (objects) have a common structure and behavior with the ability to attach state information used in defining behaviors (Borschchev, 2013). With this capability, agent-based modeling can optimize complex systems and processes. The agent-based approach is further advanced to handle multiple system interactions than system dynamics and discrete event modeling. AnyLogic displays agent-based modeling in the Harvest Simulator (AnyLogic, 2018). The Harvest Simulator presentation depicts the logistical dynamics of a combine, grain cart, and truck during harvest. Within AnyLogic libraries, however, no one has applied integrated farming systems to this complex modeling tool. Therefore, the work presented here represents one of the first simulations of an integrated crop-livestock production system using agent-based modeling.

An agricultural system is a whole collection of individual components that produce livestock and crops for food, fiber, and energy (Jones, 2016). With the variability of theoretical outputs for producers, a solid foundation to build and implement new techniques in farming must be solidified through a sound economic framework with little risk and some profitability (Arriaza and Gómez-Limón, 2003). An improved understanding of crop-livestock systems must target the trade-offs and outcomes of realistic economic returns, labor demands, and land resource conservation factors in a single model (Komarek, 2015). Interactions among certain components within a system must be examined versus isolating single components to help draw conclusions (Hieronymi, 2013). Each individual component of a system interacts with one another to define its behavior.

The integration of livestock and cropping systems into a farming system provides the opportunity to explore the interaction of the socioeconomic and physical landscape of specific farms (Walters, 2016; Hendrickson et al., 2008). The next generation of models must include the various outputs of comprehensive systems that analyze climate changes, new policies, and alternative technologies. Many problems stem from research that aims to improve a situation rather than solving fundamental problems within agricultural systems (Bawden et al., 1984). For animal and crop interactions, quantifying specific indicators has become a problem within measuring many outcomes. Agricultural systems modeling needs a process based outcome with defining characteristics for every interaction on the farm level. For strategic planning, farmers have multiple responses or tradeoffs to certain situations, which in time should be modeled to help understand the external driving forces. Agent-based modeling will provide the necessary framework to model these uncertain situations within a system while maintaining the integrity of each individual component.

Discrete event based modeling research has resulted in the development of specific Excel models depicting the synergy of integrated crop and livestock systems. Cover crop grazing is a common recent example where integrated crop livestock systems have been depicted. Higgins (2017) concluded that additional research must be done on the economic returns of cover crop grazing by determining efficient stocking rates and days of grazing while developing a plan to evaluate average daily gains. Through various studies, the USDA has developed tools to help manage and evaluate potential benefits of system diversification. For example, Rotz (2018) modeled the management of feed use, crop production, and manure nutrients for integrated crop and dairy production to help display greenhouse gas emissions.

Several studies continue to try to understand the implication of inserting cover crops into a cropping enterprise. Soil amendments in a mixed crop livestock system have been shown to be beneficial in regards to better soil nutrients from cattle manure (Bonifacio et al., 2017), improving biodiversity within the landscape (Lemaire et al., 2014), and building soil organic matter (Sulc and Tracy, 2007). In a case study done by the USDA (Mine et al., 2017), Datu Research analyzed the soil health benefits in a partial budget analysis of cover crops in Illinois. The five-year analysis showed negative returns for the first three years followed by positive returns for the final two years. However, over the past decade, discrete event modeling has shown limited capabilities in capturing the complex interaction between plants, livestock, soil, climate, and people.

System dynamics has changed the scope of decision-making through the use of modern technology such as the modeling software STELLA (Richmond, 2004). The implementation of integrated animal crop systems could represent the future of agricultural resiliency in changing climatic and economic conditions (Ghimire et al., 2012). Having a diverse portfolio in agriculture can reduce risk in an unpredictable climate, while maintaining soil quality and productivity (Ghimire et al., 2012). Walters (2016) concluded the most favorable and desirable economic sustainability action was through crop and animal diversification. Walters (2016) used system dynamics to study the sustainability in three different production systems. He concluded that integrated production systems have the highest likelihood of greater economic returns, but have a lower social quality index due to high time-intensive activities from having two distinct production enterprises. Social quality examines both the internal and external aspects of farming. For example, increasing labor requirements affects a farmer's flexibility from an internal perspective of social quality. From an external perspective, elevated manure levels impact the odor contributing to non-market externalities. Animals and crops have the greatest chance of environmental sustainability, but may decrease overall social quality. Walters (2016) noted that future simulation modeling efforts analyzing production systems by comparing economic, environmental, and social impacts of decisions will enable creation of more suitable management practices. Future analysis of modeling could be a frontrunner towards new practices for farmers.

With the development of new technologies, a new approach to modeling could be the optimal strategy. Systems modeling can be accomplished using agent-based modeling tools capable of incorporating both the discrete event modeling details and the abstract system dynamic approach in one package that is better equipped to handle the relationships between a field, animals, and people. Agent-based modeling offers an integrated approach that involves social and ecological systems (Leahy, 2013). Agent-based modeling allows you to see a human agent react to a production environment through a decision making process. Due to the complex behavior of crops and livestock, agent-based modeling can be an excellent source to capture a farmer's decision-making process in a simulated environment that includes labor efficiency. The user must be aware of the limitations and assumptions present within this resource. Agent-based modeling can present the social, ecological, and economical results of an integrated crop-livestock approach. However, through integration, a farm works as a single complex system that has multiple objectives of being profitable while maintaining or improving sustainability. As with all simulation, the level of detail included limits the effectiveness of agent-based modeling to simulate reality.

Analysis of agricultural cropping systems in the production sciences has typically been done using univariate evaluation models based on trial data in controlled experiments (Ghimire et al., 2012). Ghimire et al. states that these evaluation systems may be insufficient at modeling the complexities and problems of a farming system. They express the need to diversify away from decision support tools that are important to management activities on a farm level basis, but fail to serve as a way to evaluate a system performance through interactions among many different variables. Multivariate approaches could better define the dynamic integrated crop-livestock production sector by diagnosing labor efficiency, logistical development, and environmental impacts. Multivariate evaluation models would link livestock and crop production through economic and environmental variables creating a dynamically integrated production approach (Ghimire et al., 2012).

II. Objectives:

The current paper presents a multivariate approach using an agent-based model to measure the efficiency and profitability of grazing a cereal rye cover crop. Enterprises with both crops and livestock are becoming less common as farmers have chosen to become specialized in either livestock or crop production. A traditional system in eastern Nebraska is corn and soybeans in a two or three-year crop rotation. Cover crops, such as cereal rye, are becoming a more common production practice to help retain moisture, recycle soil nutrients, and reduce soil erosion (Clark, 2010). The synergy of integrating livestock grazing into a crop production system comes from producing manure deposits that promote soil fertility while maintaining ecosystem services. This study examined the net returns of grazing cereal rye in an integrated crop and livestock production system in eastern Nebraska compared to mechanically harvesting cereal rye.

The Eastern Nebraska Research and Extension Center has several studies analyzing cereal rye production near Mead, Nebraska. The first of these studies began two years ago under the Beef Systems Initiative funded by the University of Nebraska - Lincoln. This collaborative effort uses a team-based extension program approach to develop the integration of multiple enterprise production systems while maintaining positive economic and environmental conditions. The goal of the Beef Systems Initiative is to support producer production systems through improved management of land resources and cattle production. Working with a local producer, the aforementioned study examined the incorporation of a cereal rye with spring grazing into a traditional eastern Nebraska crop rotation. The average daily gain of cattle was tracked while grazing the rye crop. The cattle weighed between 600 and 650 pounds before grazing commenced on or about April 4th.

Input costs must be examined to help provide an understanding of both the crop and livestock enterprises for a farm. Reviewing common grazing requirements, we can analyze the necessary components for watering livestock and placing fence, which are two issues in grazing cropland. The relatively inexpensive and rapid growth provided by cereal rye may help sustain system diversification and recycle soil nutrients (Clark, 2010). This option could help facilitate the integration of crops and livestock by capitalizing on the importance of recycling nutrients between systems. Although nutrient cycling may be beneficial, the costs associated with grazing a cover crop can impact a farmer's profitability.

In recent years, cattle feeders have been looking for alternative ways to feed their animals. Meanwhile, many farmers are beginning to incorporate a cereal rye cover crop into their crop rotation as a way to provide ecosystem service benefits to the operation. Some farmers report yield benefits from incorporating cereal rye (Mine et al., 2017; CTIC, 2017). Several other farmers are trying to build additional profitability from an alternative crop on a fixed amount of land by adding a cereal rye cover crop. Today, farmers are finding ways to incorporate beef cattle into their operations as a way to graze the cover crop and capture additional value. However, there has been little research to date determining the returns of cover crops, such as cereal rye, as a grazing resource. If found to be profitable, cereal rye may play a big role in diversifying operations across the state of Nebraska. Integrated systems of crop production, animal production, and labor are connected through complex activities (Figure 1.1).

For the western Corn Belt, we modeled a simple corn-cover crop-soybean-cover crop system. The most popular choice for a cover crop species in Eastern Nebraska is cereal rye drilled directly into the primary crop stubble after harvest. This situation requires that the soil still be above freezing in order for germination to occur. Cereal rye is a winter annual with enough hardiness to withstand cold temperatures during most winters. This specific cover crop will reduce soil erosion while outcompeting weeds. One benefit of cover crops (Secale cereale) is high-quality forage for animals that does not severely compact soils (Franzluebbers et al., 2008). Farmers in the U.S. Corn Belt have the potential to be profitable, enhance production efficiency, and environmental quality through integrated crop-livestock systems (Sulc and Tracy, 2007).

Cover crops have the ability to manage wind or water erosion, provide soil fertility and productivity, manage soil compaction, and produce forage for grazing or haying (Blanco et al., 2015). Cereal rye has the ability to produce a large quantity of forage while suppressing weeds (Ryan et al., 2011). In an integrated system of livestock and crops, cereal rye can help retain soil moisture by trapping snow in the winter (Clark, 2010). Together with the long-term utilization of no till production practices, this helps build soil residue and soil organic matter.

With livestock, grazing to less than a 4-inch residue height could be detrimental to the accumulated cover crop benefits associated with production (Fisher et al., 2014). After the grazing period, farmers can use a chemical to help terminate the cover crop that is present. Additional benefits provided from cattle grazing include manure deposits on the land that influence the growth of soil microbial populations and the biological fertility of soils (Diacono and Montermurro, 2010). One major restriction to grazing cover crops is the ability to graze during the wet season. The cover crop must have greater than two tons of vegetation biomass per acre in order to graze during wet conditions (Fisher et al., 2014).

The higher labor costs associated with animal production relative to crop production is one of the main reasons why the animal industry struggles to keep pace with cropping systems (Peyraud et al. 2014). When larger operations are present within an area, specialization into crop production is increasing due to labor costs. Peyraud (2014) states with the drastic changes in technology, the improvements in costs of energy continue to grow in crop production and make cropping systems less labor intensive than animal production. The identification of issues surrounding the crop-livestock integration at the farm level is becoming scarce due to the specialization into crops or livestock systems (Peyraud et al. 2014).

Animal production needs alternative technology to help improve the profitability in livestock enterprises to further the integration of crops and livestock. If livestock enterprises are struggling to keep pace with crop production, implementing a cereal rye cover crop as a grazing scenario could be an option for an alternative technology. Animal production combined with the efficient costs of energy in crop production could be the alternative scenario needed to help improve profitability among livestock enterprises. A grazing scenario with cereal rye has the opportunity to enhance the integration of crops and livestock while improving biodiversity.

III. Methods/Data

For our simulation, we combined system dynamics, discrete event modeling, and agent-based modeling to develop a realistic multi-method model. Agent-based modeling will give a deeper insight into modeling technologies by allowing for the combination of graphical editors and scripts (Borschchev, 2013). Agents can represent many diverse things that do not necessarily need to be an object. Each agent has a state in which actions and reactions coordinate its movements depending upon the individual agent state. With this type of modeling, the agent can interact with other agents within a single environment while manipulating their behaviors through specific events. Statecharts are used to transition agents through their behaviors. A statechart consists of states and transitions used to define events that are time-driven based on the behavior of various objects (Borschchev, 2013).

In our model, agents include machinery, a field, a human in the form of a farm operator, and cattle. Statecharts are used to transition agents through their respective behaviors to simulate a crop-livestock interaction incorporating a cereal rye cover crop. The development of agents with parameters enables the ability to attach costs to each agent and subagent within the model. The farm is considered the main agent of this agent-based model. Within the farm agent, an environment is set up to hold the required human, machinery, field, and cattle agents. Using appropriate coding sequences, the movement of machinery, cattle, and the human agents across a field agent provides a graphical representation of farming the land.

AnyLogic provides a system layout for agent-based modeling in which time and space can be distinguished (Borschchev, 2013). Time in agent-based models has the ability to be asynchronous meaning that events occur at arbitrary moments. This is practical since farmers can make individual decisions that affect their operation without having to wait for a synchronous time step. Our model runs on an hourly basis, but can be manipulated to perform behaviors or actions on a minute basis. A scheduled event can be made to portray actions by an agent on any calendar date. For example, the combine machinery agent can be given a command by the human agent to "Harvest" on October 20 at 1:15 p.m. if that is the desired request.

Model run time happens within space that is characterized as discrete or continuous. Within continuous space, an agent can be placed in Geographic Information System (GIS), 2D, and 3D graphical mode. For our model, continuous 3D is used to show a graphical representation of cover crop grazing. In the future, GIS space may have the ability to access specific field level data, such as acres and elevation of the field. The model is characterized on a continuous space concept for the farm level agent while holding the field agent at a discrete level. The field agent contains within it the fence, tank, and workspace agents. This was necessary to simulate the discrete actions taken by the human agent to complete specific tasks within specified cells in the field agent such as building fence. Therefore, the field agent is a discrete type that contains a subagent called workspace, which is a continuous agent type that enables the human agent to operate on both the farm and field agent at the same time.

Within time and space, our model is placed in the eastern part of Nebraska in a time period from October 20, 2006 to October 20, 2017. Uncertainty in weather patterns has made it difficult to forecast cover crop performance in this region due to inconsistent growing conditions. Our model incorporates stochastic programming concepts by making a random draw of annual growing conditions presented as precipitation and heat units. Similar to calculating a growing degree-day, a daily heat unit is a measurement of the maximum and minimum air temperatures using a base temperature for cereal rye (Feyereisen et al., 2006). The random distribution was formed from a weather dataset provided by the Climate Center at the University of Nebraska-Lincoln (High Plains Regional Climate Center, 2018). The data is specific to the Mead, Nebraska area to coincide with our case study location.

Crop production functions were built using daily data for precipitation, temperature, and heat units as inputs. All temperature data was converted to degrees Celsius for the production function of rye. If any days were missing records, the average of the previous and following day were used to fill in missing data. After transforming the temperature records, a heat unit function was constructed using Equation 1.1:

$$1.1)\quad \textbf{Heat Units} = \left(\frac{(\text{High Temperature}+\text{Low Temperature})}{2}\right) - \text{Plant base temperature}$$

This formula was developed for general use with a specific base temperature used for each specific species of plant.

A random draw was used to specify the year for our simulation. The simulation began on October 20 with the assumption that the planting of the cereal rye cover crop on November 1st follows harvest of the primary crop. These dates were chosen to allow flexibility in the plant date. Cereal rye continues to grow from November 1st until entering winter dormancy based on daily heat units. It emerges from dormancy in the spring as daily heat units rise above zero and continues to grow through the month of April. In the grazing scenario, grazing begins on April 4th and ends on April 30th. In the mechanically harvested scenario, the rye is harvested as ryelage on April 30th. The simulation runs through October 19 of the following calendar year. This allows our simulation to predict a full year with real life data pertaining to the markets and weather. The 11-year dataset allows the model to run multiple times enabling alternative results. With this capability, the simulation provides the ability to run risk scenarios with real weather and pricing data. This is a solid foundation as we continue to gather weather and pricing data to simulate an efficient outcome for previous grazing years.

Cost parameters for machinery and materials were uploaded into the model on a per acre basis using the University of Nebraska – Lincoln cover crop budgets (Klein et al., 2018). The operating expenses for machinery included wages, diesel, and lubrication expenses. The fuel price was calculated at $3.25 per gallon for diesel. Appropriate depreciation, interest, taxes, housing, and insurance costs were accounted for as ownership costs on a tractor, combine, truck, grain cart, sprayer and tanker (water truck). The crop budgets were static in regards to the previously mentioned operating and ownership costs. The crop budgets had initial annual hours allocated to all power units existing on the farm. When adding a cereal rye crop, the additional equipment operating hours needed to complete this task increased the annual operating hours on equipment. Ownership costs allocated across more annual hours of operation reduced ownership costs on a per acre basis for any additional acres covered.

At this time, AnyLogic is not capable of performing area tasks on a per acre basis. Therefore, we must convert the task parameters with our field capacity formula given below to obtain acres per hour (Equation 1.2):

1.2) Speed = MPH; Width = feet; Field Efficiency = %

8.25 = 43,560 sq. ft. per acre / 5280 ft. per mile

Acres/Hour = (Speed * Width * Field Efficiency) / 8.25

The above formula is used to calculate labor for the machinery and implement used in a given operation (Hancock et al., 1991). For example, the width and speed may be different for a tractor and drill versus a combine. The tractor and drill in the model operate at a speed of 5 miles per hour with a width of 25 feet and a field efficiency of 79.2% which equates to 12 acres per hour (Hancock et al., 1991). For an 80-acre field, it would take 6.67 hours to complete the planting operations. With a labor multiplier of 1.1, a wage of $20 per hour would be equivalent to $22 per hour of operation. Then, $22 per hour times 6.67 hours divided over 80 acres results in a labor calculation per acre of $1.83. The machinery for cover crop grazing and mechanically harvesting cereal rye use similar calculations to arrive at a labor cost per acre for each respective agent (tractor, sprayer, etc.).

All agents that are machinery may only move at separate times to account for labor costs. Therefore, if the tractor agent is moving, the combine or any other type of machinery requiring an operator cannot be moving in a similar time period. The human agent in the model can only drive one piece of equipment during a given time period. For mechanically removing the cereal rye crop, outside sources are hired for hauling cereal rye at a custom rate of $5 per ton hauled (Klein et al., 2018). The chopper and the operator are also hired on a custom rate at $10 per acre (Klein et al., 2018).

Temporary fencing is used to allow grazing of the cereal rye cover crop in April after it emerges from dormancy. To accommodate this in the simulation, a fence agent is added to the perimeter of the field agent in early April using a statechart to transition the human agent through a series of tasks. The field agent is placed within a discrete environment allowing each fence agent (north and south, east and west) to be placed within a gridded system of rows and columns on the field. The human agent transitions include movement to the field, getting the fence agent, and placing the fence agent around the perimeter of the field agent to simulate construction of the temporary perimeter fence. It takes a similar amount of time to complete the transitions in reverse order at the end of April to simulate removal of the fence agent from the field.

The human agent transports the tank agent to the field to initiate the construction of the water system. Within the human statechart, it takes a similar path to get and place the tank. The tank is placed on the edge of the field to enable a quick unloading rate for the tanker agent. A tanker agent transports water to the tank on a daily schedule at eight in the morning. The tank has a stock agent that contains a water capacity for the cattle to drink. The cost associated with the tank includes an initial cost to purchase the tank of $500.

Within the field agent, charts display cattle weight and cereal rye biomass growth. The functions and parameters for cattle weight can be found under the cattle agent. Since the cattle agent is a subagent of the workspace and field agent, the cattle weight is calculated through a function called total weight and displayed on the upper level agents. The total weight is calculated as follows (Equation 1.3):

1.3) **Total Weight** = Initial Weight + (Days On Field x Average Daily Gain)

Calves have distinct parameters for grazing and drinking habits. They move randomly through the field grazing and return to the tank to drink when they become thirsty. This is controlled using a statechart. The cattle can only visit a tank that has an adequate water supply. The statechart used to simulate grazing has been formulated to a random grazing pattern within the field. In order to simulate total weight gain, the cattle are given an initial weight of 625 pounds for simplicity. The calves used for our case study weighed between 600 and 650 pounds. Farmers may purchase cattle at alternative periods and weights, but for this analysis calves were purchased at approximately 625 pounds on April 1^{st}. The growth function is linear for cattle while grazing on the field with an average gain of 3.2 pounds per day (Conway, 2018). While the cattle graze the cereal rye crop, the days on the field variable calculates the total number of days the cattle agent spends on the field.

A graphical interface of functions and parameters associated with the cereal rye growth model can be found within the field (Figure 1.2). The parameters used in the cereal rye growth model are displayed in Table 1.1. All parameters except for plant optimum temperature and e (Radiation use efficiency) were selected based on Feyereisen et al. (2006). To better fit our model to actual production data from the case study, the plant optimum temperature and radiation use parameters were adjusted within the acceptable range presented by Feyereisen et al. (2006). Specific events trigger retrieval of data into datasets to incorporate soil moisture, precipitation, heat units, and average temperature. After the data is placed into their respective datasets, the cereal rye production model uses these numbers to calculate an accurate cereal rye growth biomass total. The production function for rye has the following parameters (Table 1.1) implemented into the model:

Table 1.1: The respective values for rye crop growth.

Rye Plant Parameter Values		
Parameter	Range of Values	Selected
Plant base temperature (ºC)	0[a] to 4[a]	1
Plant optimum temperature (ºC)	15[a] to 20[a]	17
Heat units to emergence (ºC)	100[a]	50
Heat units to maturity (ºC)	1700[a] to 2200[a]	2050
LAI_{max} ($m^2 m^{-2}$)	7[a]	7
e (Radiation use efficiency, kg DM ha^{-1} MJ^{-1} m^2)	2.8[a]	3.0
par (Fraction photosynthetically active radiation, MJ per time unit)	0.5[a]	0.5
Initial shoot BM (kg DM ha^{-1})	30[a]	30
Moisture Pressure	0.16[b] to 0.195[a]	0.18
Field Capacity	0.32[a] to 0.36[b]	0.35

[a] Feyereisen et al. (2006)
[b] Blanco-Canqui et al. (2017)

The field has a single growth function for the cereal rye crop. The production function in the model for the cereal rye crop uses weather data to simulate plant growth. The weather data consists of temperature, heat units, precipitation, and soil moisture. Although soil nutrients are not currently present in the model, future research can examine this topic within the model structure by easily adding this component. Temperature and soil moisture stress are calculated within the cereal rye production function model following Feyereisen et al. (2006). Figure 1.3 provides a graphical representation of the cereal rye growth model used in the simulation with a more detailed explanation provided below.

Starting on the top left of Figure 1.3, the initial aboveground cereal rye growth biomass total (Equation 1.5) is equal to the KGerm (Equation 1.4) equation times Initial Shoot Biomass (Feyereisen et al., 2006) calculated as:

1.4) **KGerm** = minimum value of 1.3 or 0.39 + 0.022 Precipitation (accumulative 14 days) + 0.075 Average Soil Moisture Content (accumulative 14-day average)

1.5) **Initial Aboveground Cereal Rye Growth Biomass Total** =KGerm x Initial Shoot Biomass (kg DM ha^{-1})

After calculating the initial aboveground cereal rye growth biomass total (Equation 1.5), the root to shoot ratio (Equation 1.6) is calculated based on daily heat units (HU_{index}).

1.6) **Root to Shoot Ratio** = 0.4 – 0.2 HU_{index}

(HU_{index} is the ratio of accumulated heat units during the period of growth and the heat units needed for maturity of the crop)

The root to shoot function times the initial aboveground cereal rye growth biomass total is then converted into Aboveground Biomass (An_{AG}) (Equation 1.7). Leaf area index (LAI) is determined as a function of assimilated aboveground biomass (Equation 1.8), according to the EPIC (Williams et al., 1984) and WEPP models (Arnold et al., 1995). Feyereisen et al. (2006) states that, "Solar radiation interception by the cereal rye canopy (fpar) (Equation 1.9) was represented as a function of the leaf area index (LAI), using Beer's Law extinction coefficient (Monsi and Saeki, 1953) of 0.65." This framework was derived from the Grosub model and displayed for biomass assimilation (Monteith, 1977). Feyereisen et al. (2006) used a basic equation from Monteith (1977) and reiterated by Campbell and Norman (1998) to display cereal rye growth (Equation 1.10) as a function of radiation use efficiency (e=2.8), the fraction of incident light intercepted by the cereal rye canopy (fpar), and par (50%), which is the photosynthetic active radiation portion of total solar radiation.

1.7) $\boldsymbol{An_{AG}}$ = Initial Aboveground Cereal Rye Growth Biomass Total * Root to Shoot Ratio

1.8) $\boldsymbol{LAI} = LAI_{max}\{\frac{An_{AG}}{An_{AG}+5512\exp(-0.000608\, An_{AG})}\}$

1.9) **fpar** = 1−exp(− 0.65LAI)

1.10) **RyeGrowth =** e * fpar * par

The actual total assimilated biomass (A_{NACT}) (Equation 1.15) is calculated by taking the RyeGrowth function times the more limiting factor (K_P) of temperature

(K_t) or soil moisture (K_w). The following equations (Equation 1.11, 1.12, & 1.13) are used to calculate the limiting factor for soil moisture:

1.11) $\mathbf{K_w} = -0.15 + 1.53\left\{\frac{A_w}{100}\right\}$ for $9.8\% < A_w < 75\%$

1.12) $\mathbf{K_w} = 0.16 + 1.68\left\{\frac{A_w}{100}\right\}$ for $-9.5\% < A_w < 50\%$

1.13) $\mathbf{K_w} = 0.57 + 1.72\left\{\frac{A_w}{100}\right\}$ for $-33\% < A_w < 25\%$f

where soil water ($\boldsymbol{A_w}$) is defined as: $\boldsymbol{A_w} = 100(\theta - \theta_{wp})/(\theta_{fc} - \theta_{wp})$ (Larson, 1985). θ is the actual volumetric moisture content of the soil in the root zone, θ_{fc} is field capacity soil moisture content, and θ_{wp} is the soil moisture wilting point. Equation 1.14 is the daily temperature stress of cereal rye. The T_{avg} is the daily average air temperature while T_{opt} is the optimum temperature for the growth of cereal rye. Equation 1.15 displays the most limiting factor of soil moisture (K_w) or temperature (K_t) and becomes our K_p. RyeGrowth is the potential growth while actual total assimilated biomass (A_{NACT}) is the realistic growth after adjusting for temperature and soil moisture stress (Equation 1.16).

1.14) $\mathbf{K_t} = 0.9 - 0.0025(T_{avg} - T_{opt})^2$

1.15) $K_p = \min(K_w, K_t)$

1.16) $\mathbf{A_{NACT}} = \text{RyeGrowth} * K_p$

Growth begins after planting date and continues through until mechanically removing rye on April 30th. A continuous dataset displays the cereal rye growth based on daily biomass growth using the previous day's biomass total along with daily temperature and precipitation data.

To start the simulation, the run or play button found on the top or bottom left of the user interface will activate the model (Figure 1.4). After pressing play, the display has a toggle menu in the bottom right corner that will access zoom in and zoom out capabilities along with accessing any specific agent information. On the top of the simulation run interface, the three options of 2D, 3D, and charts give the user the opportunity to navigate the model. Within the 2D and 3D mode, the model is presented with a rectangular field, human, barn, house, and machinery agents (Figure 1.5). Under the charts tab, the display shows charts for total costs and bank balances of costs and revenues. The simulation for cover crop planting and grazing will start with the planting of cereal rye after harvest of the main crop. The tractor agent will drill every part of the field by accessing its location relative to the field agent. The next visible steps of cover crop grazing occur in the spring. The human agent visually places the fence and tank by accessing the location of the tank and each individual fence. The human agent interacting with the truck agent transports the cattle to the field for the grazing period. The human agent interacting with a tanker agent provides water for the cattle on a daily basis. The cattle graze randomly within the field while accessing the tank agent for their water needs. After grazing the cereal rye crop, the cattle, fence, and tank agents are all removed from the field agent by the human agent. The human agent interacting with a sprayer agent then terminates the cereal rye crop before the following main crop is planted.

After activating the model, the model randomly picks a year. For example, if the model chose the year 2016, it will progress from October 20, 2016 to October

19, 2017. The cattle begin grazing on April 4th, 2017 at 625 pounds and gain 3.2 pounds per day on the field agent for 27 days. After clicking on the 2D tab (Figure 1.5, top of picture), a chart displays the final weight of cattle as 711.4 pounds on April 30th, 2017 (Figure 1.6). A cereal rye biomass chart displays a dry weight of approximately 167.65 pounds on April 4th when the cattle arrive on the field (Figure 1.7). The cereal rye biomass continues to grow and acquire more biomass until April 30th. The simulation of grazing by cattle doesn't physically account for forage being consumed and removed from the field by the cattle at this time. Rather biomass growth by April 1st determines the number of cattle to be placed on the field. The assumption is that cattle will be placed on the field on April 4th with adequate forage to last until the removal date of April 30th.

Finally, under the charts tab (Figure 1.5, top of picture), a total cost per acre and total head purchased is calculated and displayed in a graph along with another graph that displays a running bank balance of the farm capturing the cash impacts of the different activities related to cereal rye grazing. The total cost per acre in the 2016-2017 sample year, including the purchase of all cattle, is $94,099.01 while the net returns from planting and grazing the cereal rye is a net gain of approximately $92.55 per acre.

Agents within the model have the ability to respond to their environment. Many farm operations may choose to implement cereal rye in different ways than what is presented in this model. The plant date for cereal rye for our on-farm case study averaged November 1st. This date is later than desired to get the best possible stand for a cereal rye before fall dormancy. While we used this date in our model, it can be changed to fit other situations. In fact, each of the following dates could be changed within the model to match any operation: plant date, move cattle on the field, and take cattle off the field. The grazing period that elapses between moving cattle on the field and moving cattle off the field impacts the growth of the cattle and the date at which the main crop can be planted.

IV. Significance of Outcomes and Future Implications

Our model captures a view of operations among machinery, a field, and animal relative to labor productivity. Through an agent-based model approach, the results show the economic returns from grazing cereal rye. Our presentation of crop-livestock integration was developed for grazing cereal rye in rural Nebraska, more specifically costs associated with operations located in the northeastern part of the state. Through testing the profitability and resiliency of cereal rye in a backgrounding operation, we can use the model to develop a better understanding of the interactions between the field, animals, and people within these complex operations. The implications of this work is that an agent-based model has been developed to provide a foundation for determining potential ecological, economic, and social outcomes of integrated crop-livestock farmers under various management and environmental conditions.

The simulation is a base model that can be utilized for future management decisions for farmers. The only decision made by the farmer at this time is a cattle purchase decision based on available forage. An option for future simulation enhancement is adding cattle marketing output decisions to the model. Future simulation enhancements could also analyze the cereal rye planting activity as a decision point for a farmer. For example, when harvest of the main crop is delayed cereal rye planting is also delayed which could result in an inefficient stand of the cereal rye prior to the winter months. With an inefficient stand and a long winter, the result could be catastrophic to the cereal rye crop forage potential in the spring. This would be a worst-case scenario for weather, but could potentially impact a farmer's decision on whether to plant cereal rye in this situation. Within the developed model, the planting period could be expanded and these implications could be simulated for all given years to determine an efficient harvest of the main crop followed by planting of the cereal rye cover crop with weather variation. Farmers deciding if they have ample time to plant a cereal rye cover crop could be studied under this scenario.

Through tracking labor, the AnyLogic model displays actions through a statechart of events. Agents have the ability to make human-like decisions that learn from their environment while other agents select from alternative outcomes (Reilly et al., 2018). With interacting agents, agent-based models can handle uncertainty related to alternative outcomes in agent behaviors. This is different from other modeling approaches as labor is defined specifically for each minute of every day. In the future, models built from this base model can potentially expand the farmer's ability to make decisions within the simulation framework. Marketing and management decisions, as mentioned above, could be expanded within the simulation model to more effectively study the efficiency and resiliency of this production system. This model was built to examine the economic returns of a crop-livestock integrated grazing scenario with cereal rye as a forage crop. Through coordination with farmers, the base model can be enhanced to simulate contemporary integrated crop-livestock production scenarios from multiple viewpoints for further analysis.

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VI. Appendix 1

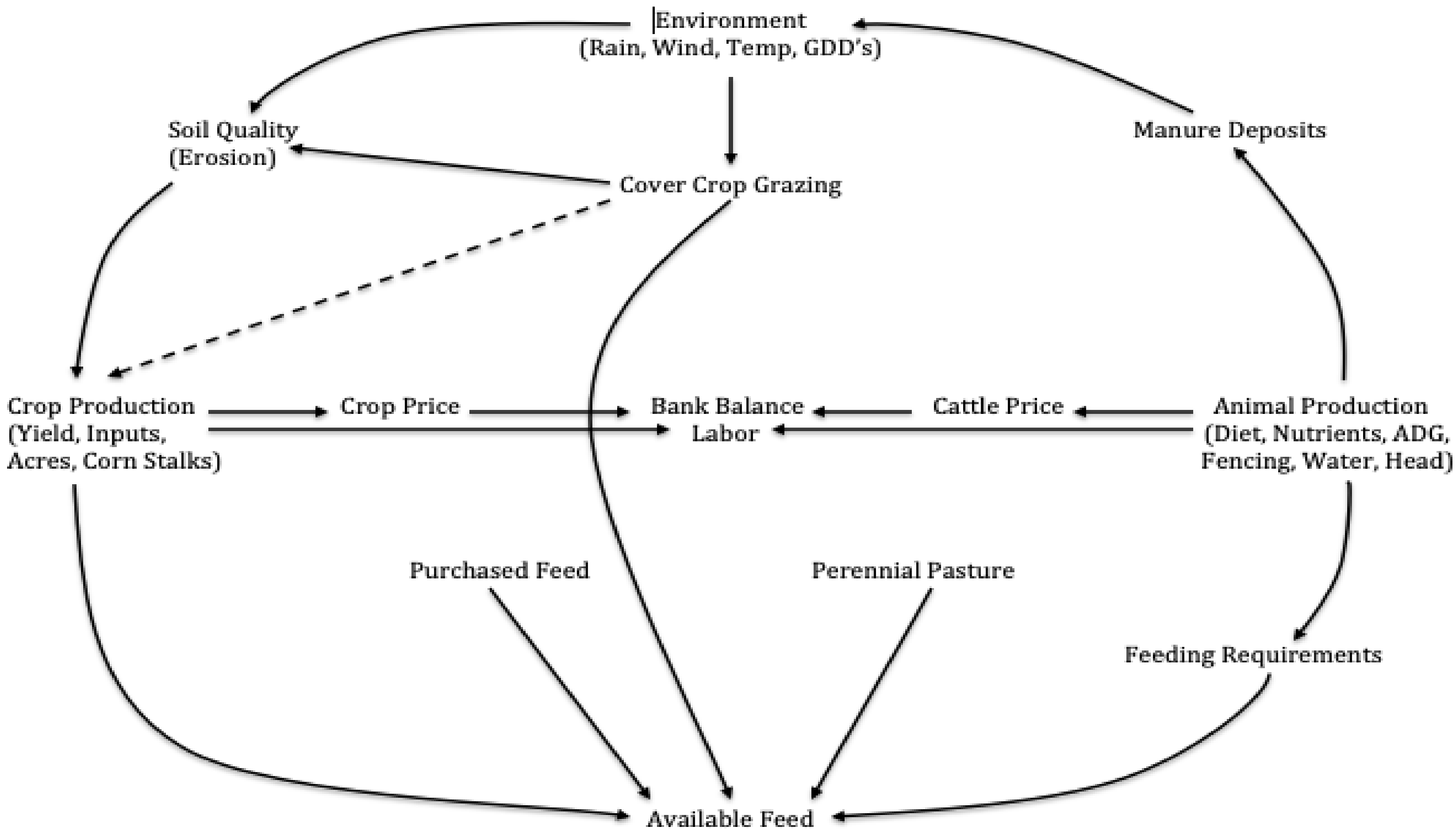

Figure 1.1: Crop-livestock integration used to simulate on farm returns with weather variation. Cereal rye produces forage to graze while impacting future crop production through recycling nutrients.

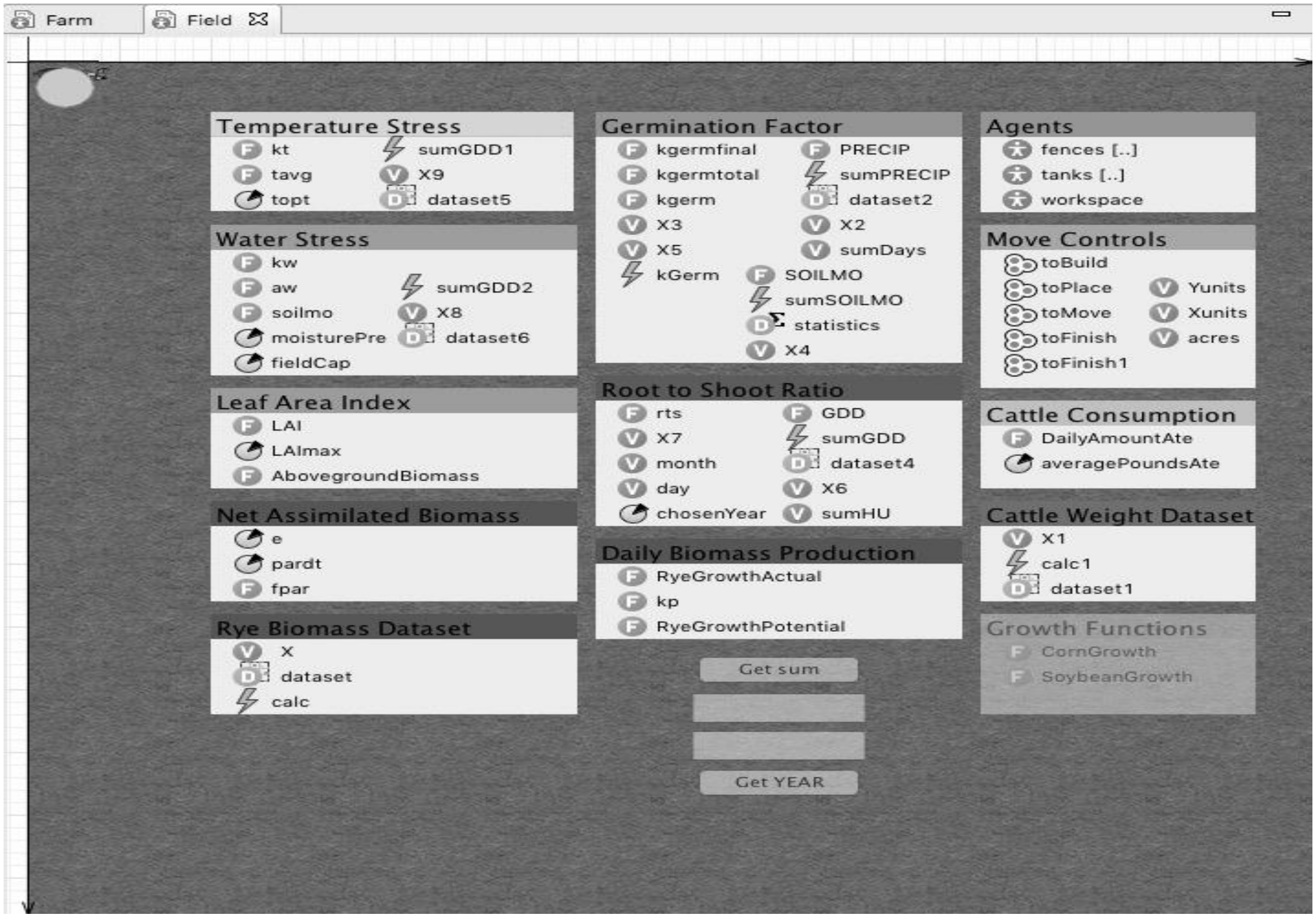

Figure 1.2: A graphical interphase within AnyLogic that displays the functions and parameters used to construct the cereal rye growth model.

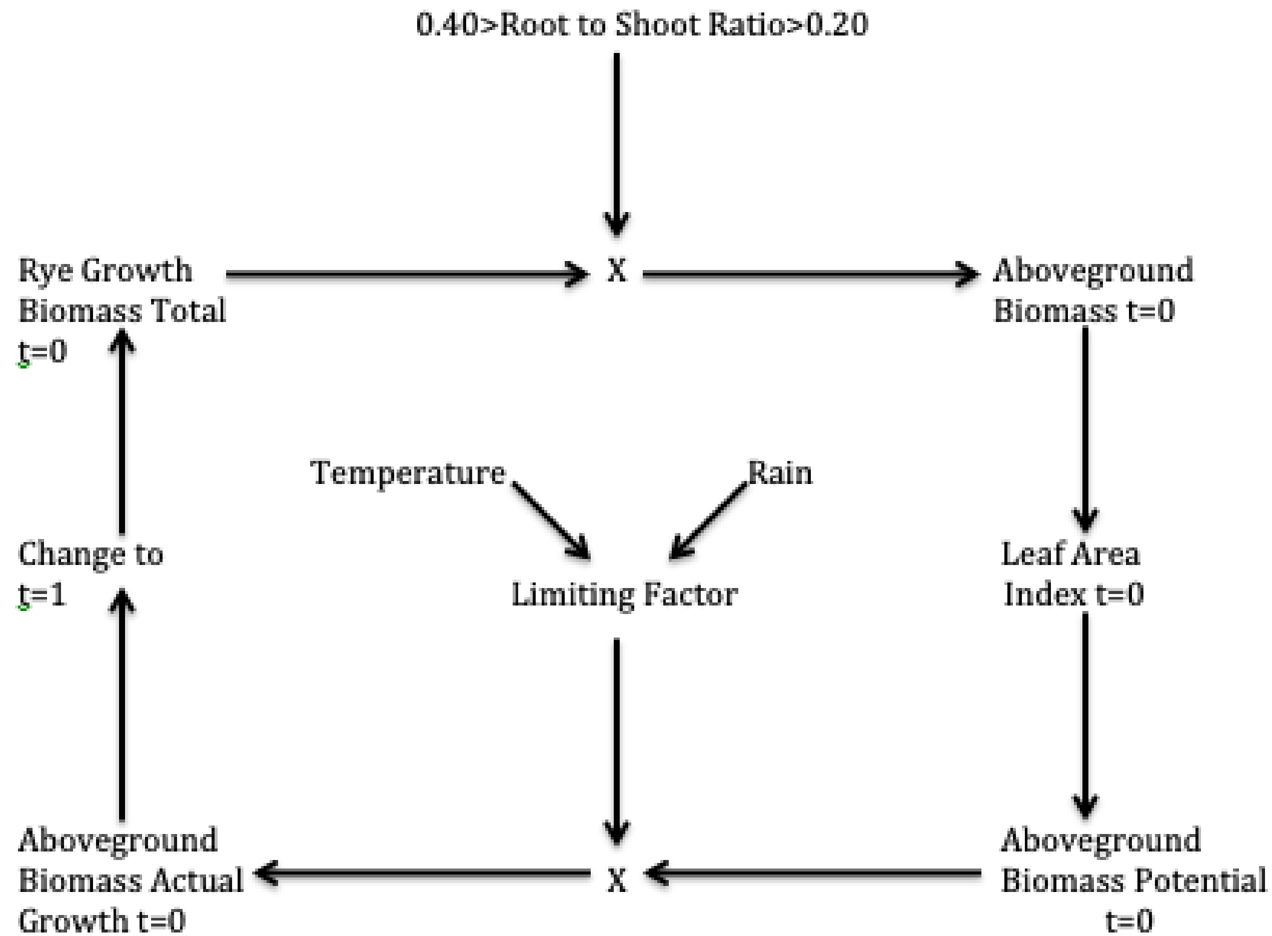

Figure 1.3: The cereal rye growth model used to simulate the total biomass in pounds per acre. Cereal rye begins germination after the plant date of November 1st and on November 15th an initial aboveground biomass is calculated. Growth of the cereal rye crop will continue until April 30th when the rye is terminated in order to plant the main crop.

Figure 1.4: During the simulation, this is the home run screen of AnyLogic used to randomly draw a random year. On model startup, AnyLogic will pick a year from 2006-2017.

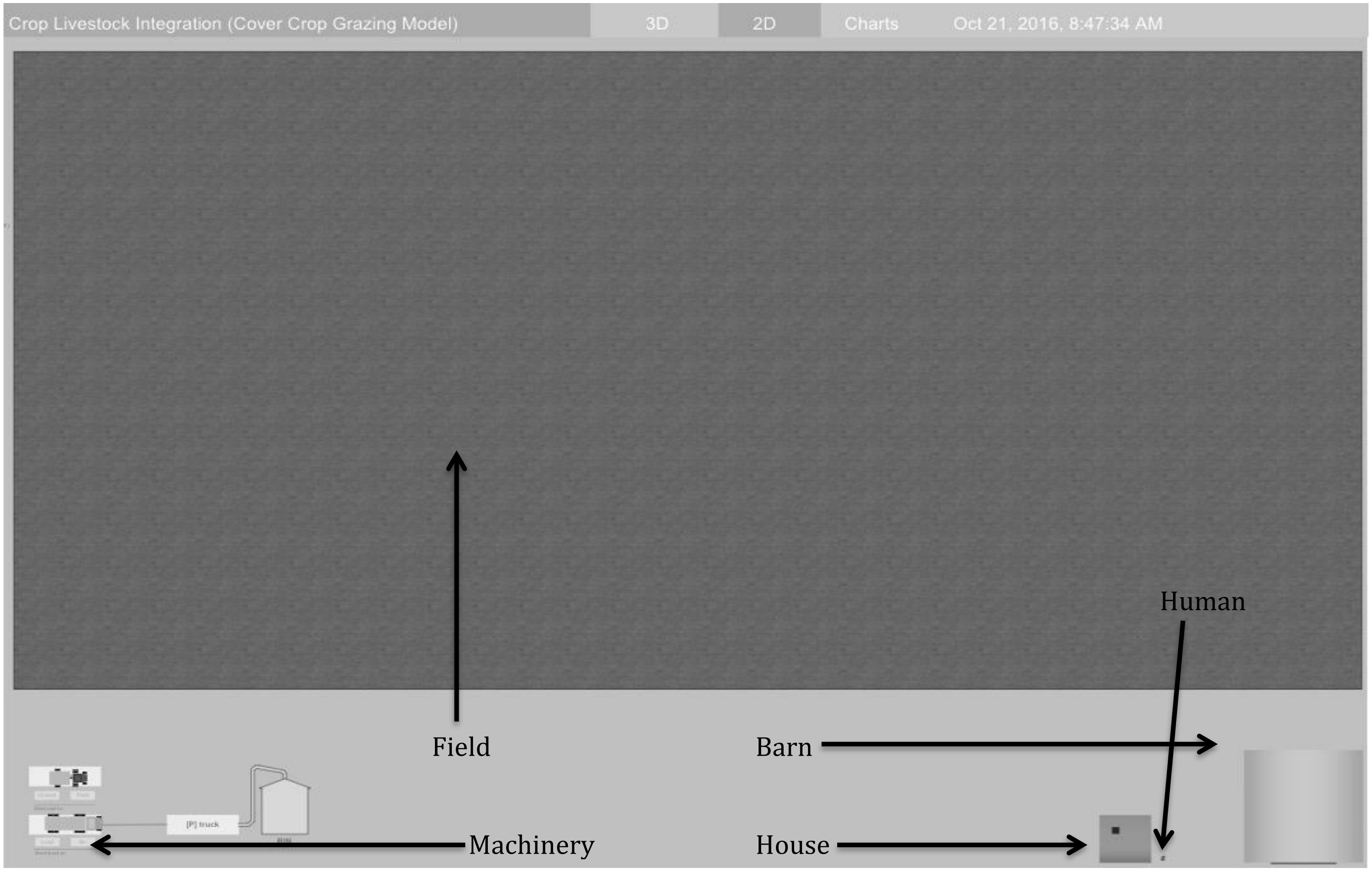

Figure 1.5: After initiating model run, the user can navigate within AnyLogic at the top of the screen. The 3D, 2D, and Charts tabs all can be accessed through clicking the respective control button. The farm is the top-level agent containing all agents found on the 2D and 3D tabs. The charts tab contains total costs and bank balances of costs and revenues.

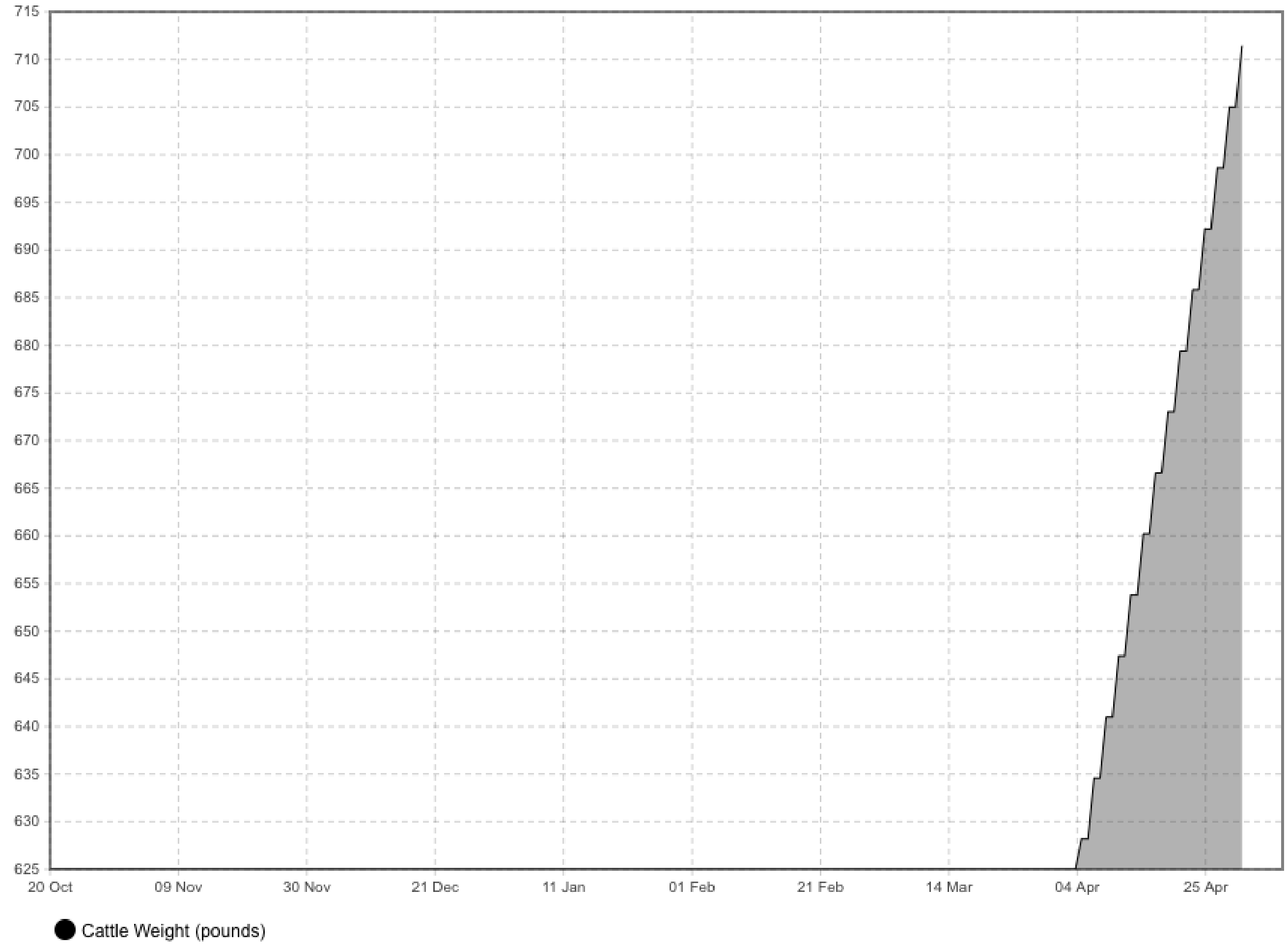

Figure 1.6: This figure is found within the 2D tab next to the farm agent. The cattle weight for a steer is displayed in pounds. If cereal rye biomass of 600 pounds is attained, cattle are purchased on April 1st and placed on the field on April 4th. The cattle gain weight over time while grazing until they are removed on April 30th.

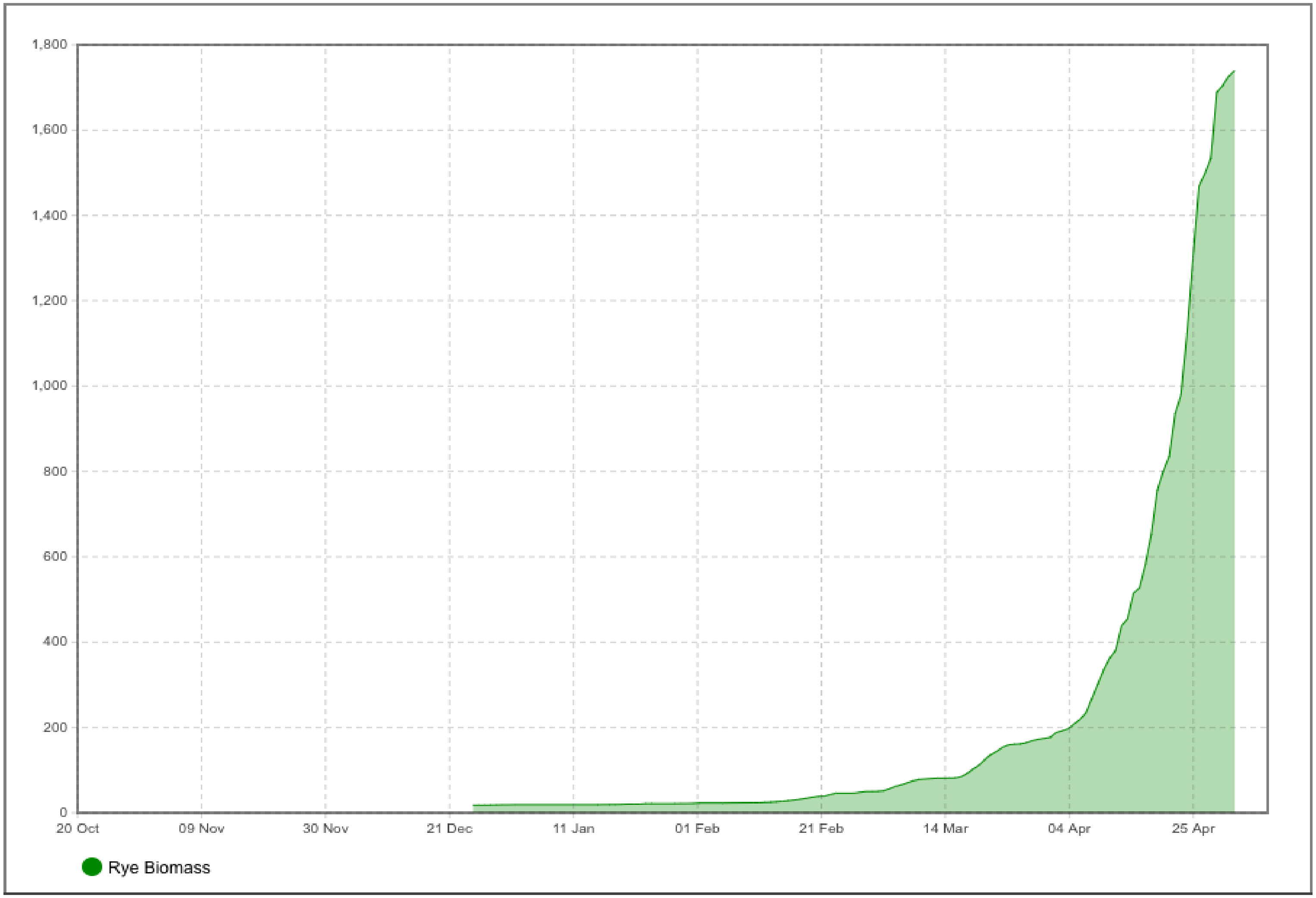

Figure 1.7: This figure is found within the 2D tab next to the farm agent. The cereal rye biomass is displayed in pounds of dry matter per acre. Cereal rye begins growth on November 1st with the KGerm function and continues to grow until April 30th.

Chapter 2: Crop-Livestock Grazing Systems Vs. Mechanical Removal of Cereal Rye

VII. Introduction

Across the Midwest, farmers have developed an understanding of the benefits of implementing cover crops into their crop rotations. However, recovering investment costs in a long-term strategy can lead to alternative methods of managing the cover crop. Cover crops are grown to reduce erosion while maintaining soil health for the long-term productivity of the land. Farmers are using cover crops to maintain soil structure, which impacts yield productivity of the following crop depending on the type of cover crop (Larson et al., 2001). This environmental footprint may impact the long-term infrastructure of the farm and farm succession planning. Additional benefits of cover crops include weed suppression, pest suppression, and reduced soil compaction (Snapp et al., 2005; Franzluebbers and Stuedemann, 2008). Alternative conservation practices such as cover crops can reduce the environmental footprint of farming.

Cereal rye has many benefits when grown as a cover crop within a row crop system. Cereal rye has the ability to grow quickly in early spring versus other winter hardy small cereals. As a winter hardy cover crop, cereal rye traps the soil over the winter keeping the soil from losing precious nutrients while holding moisture from snowfall (Clark, 2010). This enables cereal rye to fit many row crop rotations that could use a winter soil cover to provide extra protection from the wind.

Several research papers have examined the net returns of adding cover crops to an operation (Mine et al., 2017; Bergtold et al., 2017). Bergtold et al. (2017) examines the direct, indirect, and opportunity costs of implementing cover crops and found that in time cover crops could provide profitability and viability. Plastina et al. (2018) used a partial budget to assess cover crops after soybeans and corn. They found that herbicide terminated cover crops following a corn crop had negative returns while soybeans had a positive net return. The variability in net returns was driven by yields, planting costs, and cost-share program payments. A case study done by the USDA in Illinois used a partial budget to analyze the year-by-year changes in income attributed to cover crops (Mine et al., 2017). With a corn – cover crop mix (tillage radish, cereal rye, crimson clover, oats, annual rye, and brassicas) – soybean rotation, after three years of implementing cover crops, the case study farm had a positive net return from implementing the conservation program with increased yields, reduced fertilizer application, and reduction in erosion repairs (Mine et al., 2017).

Grazing of cover crops can be analyzed through a partial budget examining material costs (fencing and water), transportation costs, purchasing animal costs, and interest costs (Higgins, 2017). However, this approach fails to fully address the integration of multiple social and physical components relating to soil characteristics and environmental sustainability. In livestock and cropping systems, an integration of animals and land provide the opportunity to address the interaction of social and physical scenarios of specific farms (Hendrickson et al., 2008). Therefore, models used to analyze these systems should include the entire system and must encapsulate the diverse tradeoffs between animal and crop production. Agricultural systems' modeling incorporates the weather, policies, markets, and technologies needed to analyze tradeoffs and responses among multiple variables.

For the integration of crops and livestock, agriculture modeling could be presented through a process and an action based model. However, in order to capture real world trade offs and outcomes, simulation software can be used to better understand the factors farmers must consider. Using simulation software called AnyLogic (AnyLogic, 2018), an agent-based model was developed. Agent based modeling can analyze the multiple tradeoffs and responses to certain situations (Borshchev, 2013). AnyLogic's framework has the ability to manipulate decisions under uncertain circumstances through using an agent's behaviors. AnyLogic contains an agent-based model approach while having the capabilities to program discrete event modeling and systems dynamics. Systems modeling involving land, animals, plants and people must depict the discrete events, such as grazing of cover crops along with system dynamics to capture the interactions between the individual components.

Agent-based modeling provides an environment that enables agents to interact with one another while providing the economic results of an integrated crop-livestock production model or the mechanical harvesting of the crop. The objectives of this paper are to examine the economic difference between mechanically harvesting cereal rye in the spring out of a cover crop situation versus grazing the cereal rye with steers. The system being evaluated is a corn and soybean rotation with a winter cereal rye crop planted in the fall. The rye crop is planted following harvest of either corn or soybeans and sprayed in the spring before planting of the main crop. Through researching these two alternative management methods of mechanical harvesting or grazing, the profitability of each process will help evaluate management decisions for farmers to use in the future.

VIII. Literature Review

Through an initiative to find ways of preventing soil erosion, some farmers have adopted cover crops to help manage runoff while building soil organic matter (Drewnoski et al., 2015). The implementation of cover crops as a conservation practice due to the depletion of soil productivity and social pressures to decrease agricultural externalities have played a role in the adoption of cover crops (Bergtold et al., 2017). During winter throughout the Midwest, inserting cover crops into fallow periods can achieve multiple soil management goals (Kasper and Singer, 2011). While improving soil quality, cover crops serve as a ground cover to suppress weeds and pests (Altieri and Nicholls, 2004) during the spring months before planting the main crop (corn or soybeans).

While solving environmental problems, cereal rye is a good choice for an overwintering cover crop in corn-soybean rotations (Moore et al., 2014). Winter rye has an extensive growing range with robust germination and establishment, frost tolerance, and the ability to accumulate large amounts of biomass during the cool spring weather (Feyereisen et al., 2013). Cover crops provide options to row crop farmers during the lag period between harvest and planting. Moore et al. (2014) reported when adding a rye winter cover crop within a corn silage-soybean cropping system resulted in higher soil organic matter, particulate organic matter, and nitrogen mineralization relative to treatments without a rye cover crop. They also found that soybean yields increased relative to the no cover crop treatment (Moore et al., 2014). Cereal rye is considered a winter energy crop, or a double crop, since the aboveground biomass can be harvested rather than left as soil cover (Feyereisen et al., 2013).

Farmers can use cereal rye as a feedstock if managed properly in the spring (Feyereisen et al., 2013). Whether being removed mechanically or grazed, cover crops such as cereal rye provide ample nutritional value that can be used for feeding all types of livestock (Clark, 2010). With many feedlot systems throughout Nebraska, some farmers remove cereal rye mechanically to enhance rations for their farm. Using rye as a double crop has the potential to become a major energy resource for producers within a corn-soybean rotation (Feyereisen et al., 2013).

Management of rye is dependent upon a farmer's preference and situation. Time of planting, killing, and the beginning of grazing are all management decisions. Weather, soil type, equipment, and labor resources ultimately determine the strategy used by a farmer to incorporate rye into their row crop system. Cereal rye is typically planted following the main crop in October or November. If the management system allows, planting rye in early October gives the crop time to absorb nutrients and become established before the harsh winter months (Clark, 2010). Rye can establish and germinate in temperatures as low as thirty-four degrees Fahrenheit (1.11 degrees Celsius) (Sarrantonio, 1994). Germination typically occurs within fourteen days or when fifty heat units accumulate following sowing (Feyereisen et al., 2006).

There are two main ways to plant the cereal rye seed. The first is through aerial application and the second is by drilling the seed directly into the soil. Aerial application allows for the rye to be planted prior to the main crop being harvested. This provides an early plant date to accumulate more heat units before winter and more growth in the spring before harvest of the main crop. Drilling the seed directly into the soil would require the main crop harvest to be completed and result in a later plant date. Better soil contact could result in better germination with drilling but the tradeoff is less time to accumulate heat units and growth before winter. All winter crops require substantial water resources (Feyereisen et al., 2013). Without suitable weather conditions, aerial seeding may result in poor germination rates (Snapp et al., 2005). Soil moisture is crucial to the germination of rye during the late fall months (Feyereisen et al., 2006). With the proper stand, rye will go dormant during the winter period until spring weather reaches temperatures greater than thirty-eight degrees Fahrenheit (3.33 degrees Celsius) (Sarrantonio, 1994).

A primary risk in planting rye is production risk. Harvesting of the main crop and weather variability may impact the establishment of rye in the fall. By putting a greater importance on the main crop (corn/soybeans), producers make decisions that impact the production of rye. If a producer decides to plant the main crop at an earlier date in the spring, the rye is terminated at an earlier date shortening the growth period and negatively impacting the production results of cereal rye. During a two-year study at the University of Nebraska-Lincoln, one year of results yielded little rye for harvesting or grazing (Conway and Drewnoski, 2018). The analysis accrued fixed costs for the year while seeing no income from forage production. This risk must be considered when evaluating future strategies of implementing rye.

In the spring, rye will grow quickly with the appropriate soil moisture and temperature giving time for a grazing period before planting of the main crop. Cereal rye has the ability to produce large amounts of biomass in the spring, which produces a residue base for feedstock (Feyereisen et al., 2013). However, the window in which cereal rye can be grazed may be short due to the desired planting of the corn or soybean crop following termination. The forage could be grazed by background calves or mechanically harvested as ryelage to feed to calves in a dry lot.

Terminating rye is important to an operation due to the planting of the main crop. For crop rotations, corn is typically planted earlier than soybeans. Therefore, when a corn crop follows rye, the deadline to terminate rye is on a much tighter schedule. Cereal rye can be tilled or sprayed with herbicide to terminate the crop (Werle et al. 2017).

Devising a management plan for rye requires not only an understanding of the rye crop but, more importantly, having a set of objectives and knowledge to coordinate harvest and planting dates. For example, personal experiences on the author's family farm in Nebraska incorporate an early corn harvest for silage, which provides an earlier planting date for the establishment of a cereal rye cover crop in the fall. The earlier planting date increases the chances of developing an effective forage crop for spring grazing (Bastidas and Elmore, 2017). However, the author's family uses this strategy to produce harvested feedstock to implement into feed rations for feedlots.

In this paper, a system is examined where cereal rye is incorporated into a no-till corn grain and soybean rotation. A scenario is examined where cattle are purchased for grazing the rye in April as a short backgrounding enterprise. This enterprise is compared to a control enterprise where the rye is mechanically harvested at the end of April for ryelage. Every farming operation must diagnose which strategy is best for their situation. Farm specific machinery and labor costs can have a big impact in the decision between the two types of management. However, there are multiple benefits in common between the two scenarios including erosion prevention and weed suppression to consider when implementing a cereal rye cover crop.

IX. Data & Methods

As described below, the simulation model used in this analysis incorporates a variety of data including weather, market, and cost data. Conway and Drewnoski (2018) worked in partnership with a local farmer to incorporate rye production for spring grazing into a traditional crop rotation. This on-farm study near Mead, Nebraska began two years ago. All information pertaining to markets and weather were specific to that area. The on-farm trial involved using a cereal rye cover crop as a feed resource, which was rented by the University of Nebraska to graze growing calves (Conway and Drewnoski, 2018). The grazing enabled the collection of data on average daily gain for feeder steers on a cereal rye crop grazed during April. The biomass of the rye on the field was collected before grazing on April 3rd and after grazing on April 29th (Conway and Drewnoski, 2018).

The University of Nebraska-Lincoln Climate Center provided weather data for the modeling and analysis presented here (High Plains Regional Climate Center, 2018). Data used within the model incorporates daily precipitation, temperature, and soil moisture records from 2006 to 2017. All temperature data was converted to degrees Celsius for the production function of rye. If any days were missing records, the average of the previous and following day were used to fill in missing data. After transforming the temperature records, a growing degree-day function was constructed using the following equation:

2.1 $$GDD = \left(\frac{(High\ Temperature + Low\ Temperature)}{2}\right) - \text{Plant base temperature}$$

This equation was developed for general use with a specific base temperature used for each specific species of plant (Feyereisen et al., 2006). The plant base temperature for cereal rye is one degree Celsius (Table 2.1).

For this study, a simple rye growth model developed from a field study in Minnesota (Feyereisen et al., 2006) was used to model rye biomass production.

This model uses a germination function that incorporates fourteen-day cumulative precipitation and average soil moisture to calculate initial biomass following germination. A simple rye production function is then used to calculate daily biomass growth using the previous day's biomass total along with the current day's temperature and precipitation data. The production function for rye has the following parameters (Table 2.1) implemented into the model:

Table 2.1: The respective values for rye crop growth.

Rye Plant Parameter Values		
Parameter	Range of Values	Selected Value
Plant base temperature (ºC)	0[a] to 4[a]	1
Plant optimum temperature (ºC)	15[a] to 20[a]	17
Heat units to emergence (ºC)	100[a]	50
Heat units to maturity (ºC)	1700[a] to 2200[a]	2050
LAI_{max} (m^2m^{-2})	7[a]	7
e (Radiation use efficiency, kg DM ha^{-1} MJ^{-1} m^2)	2.8[a]	3.0
par (Fraction photosynthetically active radiation, MJ per time unit)	0.5[a]	0.5
Initial shoot BM (kg DM ha^{-1})	30[a]	30
Moisture Pressure	0.16[b] to 0.195[a]	0.18
Field Capacity	0.32[a] to 0.36[b]	0.35

[a] Feyereisen et al. (2006)
[b] Blanco-Canqui et al. (2017)

The case study is dependent on a November 1st plant date of cereal rye similar to the on-farm trial that was conducted (Conway and Drewnoski, 2018). An earlier plant date would have provided better growth for rye before the winter months occur and the crop enters dormancy. However, to match our on-farm trial, the study uses the November 1st plant date. The rye crop is harvested or cattle are removed from the field by the end of April to allow adequate time for planting of the main crop. The main crop (corn or soybeans) is typically a priority for row crop farmers across Nebraska. Therefore, in this case study an early termination date for the cereal rye crop was chosen to maximize production of the main crop.

Coupled with the weather data, Nebraska feeder cattle market data was obtained from the Livestock Marketing Information Center (LMIC) for the years 2006-2017 (LMIC, 2018). Using the cattle market and weather data for the years of 2006-2017, the costs and revenues associated with grazing and mechanically harvesting rye can be constructed. In table 2.2, the price of acquiring cattle on April 1st is shown along with a sale date price on April 30th. The study acquires cattle at 625 pounds by April 1st and sells them at the price listed under April 30th. Using weekly data, an initial purchase price was calculated using the average price for 600-650 pound steer calves in the two weeks nearest April 1st (LMIC, 2018). To calculate a selling price at the end of the grazing period, prices for 700-750 pound steers were averaged for the two weeks nearest April 30th. Prices for these dates were used to portray buying cattle for utilizing effective rye biomass growth for grazing purposes during the month of April.

Table 2.2: The Nebraska average steer auction market price per hundredweight as it was reported by the USDA. April 1st is the average price paid for 600 to 650 pound steers while April 30th is the average price received for 700 to 750 pound steers (Source: LMIC, 2018).

Year	**April 1st**	**April 30th**
2007	122.605	112.560
2008	114.070	107.615
2009	102.330	104.445
2010	126.670	117.865
2011	154.205	141.0075
2012	174.265	155.395
2013	161.225	145.710
2014	214.945	191.090
2015	272.370	237.435
2016	183.020	150.590
2017	163.420	161.690

The on farm-trial near Mead, Nebraska contributed data pertaining to the speed of the tractor and sprayer while planting and spraying the cereal rye crop. This information was combined with the University of Nebraska-Lincoln (UNL) crop budgets (Klein et al., 2018) to construct a representative farm with assets and acres for a common farmer in Nebraska. For this study, an 80-acre field was selected as planted to cereal rye and either grazed or mechanically harvested. Costs were broken down between grazing and mechanical removal. Each enterprise included machinery, labor, seeding, and herbicide costs. For the grazing scenario, additional costs accrued from fencing materials, extra labor costs, a daily watering schedule, cattle interest expense, and electricity cost. Schedules of operations for grazing and mechanically removing rye are essential to process design and implementation (Figure 2.1).

Three initial factors contribute to the incorporation of cereal rye into a farming operation. Capital, labor requirements, and machinery infrastructure regulate the optimal management method.

1. Capital: In this analysis, initial investment in fencing and calves for grazing can limit any operation due to the increase in risk exposure from the capital investment.
2. Labor Requirements: For the implementation of grazing, committing to a long-term plan of checking livestock and water supplies during the spring grazing period can sway farmers from this strategy. In addition, grazing requires a commitment to scouting rye as it emerges from winter dormancy and making an assessment of possible spring biomass. In comparison, mechanical removal involves an intense commitment of labor for harvest of the rye crop near the end of April before spring planting.
3. Machinery infrastructure: Grazing on cropland requires a water source for the livestock. In our scenario, this was accomplished with the use of a water truck to transport water on a daily schedule. Some farms have the capability to use a pivot well to water cattle. Although the planting and production of rye are similar in grazing and mechanically harvesting, the method of removing the rye is altered. A farm needs access to a chopper to remove the rye. If not available, renting the machinery or hiring custom operators are other options to meet an operation's needs.

The parameters for input costs associated with wage rate, taxes, etc. were obtained from the 2018 UNL cover crop budget (Klein et al., 2018) and are stated below (Table 2.3). The static 2018 UNL crop budget was used for every year of the simulation. Using estimated hours per year, total tachometer hours, and estimated life for the power unit, depreciation was calculated for each unit. Each operation is unique in terms of machinery used and approximated costs. Therefore, the enterprises may be different in calculating costs for a particular power unit. The only manipulation done to the UNL cover crop budgets was increasing the diesel price to $2.49 per gallon as displayed in Table 2.3. The diesel price was changed to represent the current fuel price when this study was conducted.

Table 2.3: The input costs related to machinery

Year	2018	
Wage Rate	$20.00	/ Hour
Diesel Price	$2.49	/ Gallon
Lube Factor	1.15	Multiplier
Diesel & Lube	$2.86	/ Gallon
Electricity Price	$0.1050	/ Kilowatt hour
Taxes, Insurance, Housing Factor	2.00%	/ Year
Investment Interest Rate	4.00%	/ Year
Operations Borrowing Rate	5.50%	/ Year
Operations Borrowing Time	6.00	Months
Real Estate Tax Rate	1.00%	/ Year
Overhead Cost	$20.00	/ Acre

The Nebraska crop budgets are built using assumptions of the typical producer, but every farming operation is unique in its own way. The Nebraska cover crop budgets were developed to have the ability to modify them by adding additional activities for cover crop grazing or mechanical harvesting. Adding additional crop enterprises to an existing farm will lower ownership costs per hour of use on equipment by adding additional hours of annual use to the machinery cost calculations. The two different scenarios studied here added hours of annual use to machinery that decreased relative machinery ownership costs per acre for the relevant farm operations. Based on the model assumptions, the formulated budgets are relative to a farm of this size with these specific power units, operations, and materials. The services used are state averages determined and discussed on the UNL crop budget website for 2018 (https://cropwatch.unl.edu/budgets).

AnyLogic provided a simulation platform to establish a decision model incorporating humans interacting with cattle, machinery, and crops (AnyLogic, 2018). Agents in the simulation model include machinery, land, calves, and a person. All agents interact with one another while providing reactions to events triggered by statecharts. Statecharts contain messages that enable agents in the model to react to their surroundings. A statechart consists of states and transitions used to define events that are time-driven based on the behavior of various objects (Borschchev, 2013). In the simulation software, the agents are displayed with their respective icon on the farm level. The model agents interact to perform the tasks of cover crop grazing or mechanical removal of rye. Tables and charts within the model include cattle weight over time as the cattle graze on the field, costs for machinery, rye biomass growth, and a running balance of money spent on grazing activities or mechanically removing the rye crop through chopping.

X. Results

A partial budget for the farming operation was constructed pertaining to the eighty acres of rye, which is harvested or grazed. The machinery used for harvesting or grazing can be found in the schedule of operations (Figure 2.1). Key dates in the model match the on-farm rye grazing trial near Mead, Nebraska. The spray dates to terminate the rye crop prior to planting the primary crop will match for either management method.

Cost Calculation: Grazing Scenario

Breaking down the costs of cover crop grazing can be outlined through the schedule of operations (Figure 2.1). The UNL no-till cover crop budget (Klein et al. 2018) was used as a baseline for all calculations. All machinery speed data was adjusted to match our case study (Conway and Drewnoski, 2018). The UNL budgets for corn, soybean, and cover crop include a medium and large tractor with an assumed hours of annual use of 500 hours per year for the medium tractor and 300 hours per year for the large tractor. Under the assumption that adding a cover crop is an additional cropping activity, the change in total hours of annual use on the medium tractor is an increase of 11 hours to 511 hours since the medium tractor is used for both planting and spraying the cover crop. The added additional hours were calculated using the acres per hour formula found in Chapter 1 (Formula 1.2). By adding additional hours of annual use to the tractor, fixed ownership costs for the medium tractor are distributed across more acres. Therefore, by adding the rye cover crop to the farm, the medium tractor has a reduced ownership cost of approximately $0.04 per acre for planting and $0.02 per acre for spraying compared to the original UNL cover crop budget. The costs presented in Table 2.4 are per acre costs for the machinery associated with cover crop grazing and total cost added to the farm. These specific activities are used for cover crop grazing.

Table 2.4: Field operations and materials/services for rye cover crop grazing that are adjusted from the 2018 UNL Crop Budgets (Klein et al., 2018).

Field Operations	Times or Qty	Labor @ $20.00 /Hr	Fuel @ $2.49 and Lube	Repairs Power	Repairs Imp.	Ownership Power	Ownership Imp.	Total
1 No-Till Drill	1	1.83	1.45	0.72	1.57	2.21	3.21	10.99
2 Fencing	1	2.40	0.00	0.00	0.00	0.00	0.00	2.40
3 Water Truck	1	3.38	0.17	0.15	0.00	0.41	0.00	4.11
4 Truck Cattle (Custom)	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5 Spray Herbicide	1	1.00	0.30	0.35	0.29	1.06	0.04	3.04
Total for Field Operations		8.61	1.92	1.22	1.86	3.68	3.25	20.54

Materials & Services		Operation Index	Percent Acres	Application	Unit	Applied Price	Total
Cover Crop	Seed	1	100%	1	acre	15.00	15.00
Fencing Supplies	Other	2	100%	1	acre	2.00	2.00
Tank	Other	3	100%	1	acre	1.56	1.56
Truck Cattle	Custom	4	100%	1	acre	5.00	5.00
Glyphosate w/Surfactant	Herbicide	5	100%	32	ounce	0.12	3.75
Total Materials & Services							27.31

Total listed costs for Field Operations and Materials and Services					47.85
Interest on Operations Capital	40.92	cash expense @	5.50%	for 6.0 mo.	1.13
Total Operating and Use Related Ownership Costs					48.98

The first step is to plant the rye crop by drilling the seed into the soil. The medium tractor and implement cost around $10.99 per acre while taking 8 hours to plant the rye crop (Table 2.4). Fencing labor costs $2.40 per acre (Drewnoski et al., 2018). A means to transport water was not provided within the UNL crop budgets. Therefore an assumption was made that the tanker accumulated approximately 30 minutes of labor use per day over a 27-day grazing period. Using a standard mileage rate of $0.545 (IRS, 2018) for 4 miles round trip per day, the total cost on a per acre basis was $4.11 while contributing a total of 13.5 hours to the enterprise. ($0.545 x 4 miles) + ($20 (labor) x 0.5 (half hour)) = $12.18 per day x 27 days = $328.86 /80 acres = $4.11 per acre. With a medium tractor and boom sprayer, herbicide application costs were $3.04 per acre while taking about 3 hours to spray an 80-acre field (Klein et al. 2018).

The materials and services are included in Table 2.4 for cover crop grazing. The rye seed cost for planting was $15 per acre (Klein et al. 2018). The fence costs include labor of $2.40 per acre and $2.00 per acre (Table 2.4) for depreciation, maintenance supplies, and interest on investment for the initial investment of $600 per mile for fencing supplies (Drewnoski et al., 2018). The initial purchase cost for a water tank was $500. The water tank is assumed to have a useful life of 4 years. Since the tank was used for the grazing enterprise, its cost was split among eighty acres resulting in an annual cost of $1.56 per acre. For trucking cattle, a per acre charge is calculated based on $4 per loaded mile (McClure, 2019). The trucks (50,000 pound capacity) deliver cattle approximately twenty-five miles to market. Through the eleven-year study, the average cattle purchased for grazing was resolved to 106 head over the 80 acres. A total of four loads were needed to transport the 106 head with two loads to the field and two loads to market. Four loads times twenty-five miles at $4 per loaded mile divided by 80 acres equals $5 per acre for trucking costs. To spray the crop, a glyphosate with surfactant was used to terminate the rye (Klein et al., 2018).

Cost Calculations: Mechanical Harvesting Scenario

The costs presented in Table 2.5 are per acre costs for the scenario with mechanically removing rye. Similar to the grazing scenario, the planting and spraying operations add 11 hours of annual use to the medium tractor. In addition, the medium tractor accumulates 20 hours of annual use during harvesting activities while the large tractor accumulates 22. The total annual hours for the medium tractor for the mechanically harvesting rye scenario are 531 hours. The large tractor accumulates 322 hours of use for the year in this scenario.

Table 2.5: Field operations and materials/services for mechanically harvesting rye that are adjusted from the 2018 UNL Crop Budgets (Klein et al., 2018).

	Field Operations	Times or Qty	Labor @ $20.00 /Hr	Fuel @ $2.49 and Lube	Repairs Power	Repairs Imp.	Ownership Power	Ownership Imp.	Total
1	No-Till Drill	1	1.83	1.45	0.72	1.57	2.14	3.21	10.92
2	Windrow Grain	1	2.00	1.43	2.32	0.00	2.86	0.85	9.46
3	Chop Silage	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	Haul Rye (Medium Tractor)	1	1.10	0.57	0.43	0.14	1.28	1.33	4.85
5	Haul Rye (Large Tractor)	1	1.10	0.57	0.17	0.14	2.09	1.33	5.40
6	Spray Herbicide	1	1.00	0.30	0.35	0.29	1.03	0.04	3.01
	Total for Field Operations		7.03	4.32	3.99	2.14	9.40	6.76	33.64

Materials & Services		Operation Index	Percent Acres	Application	Unit	Applied Price	Total
Cover Crop	Seed	1	100%	1	acre	15.00	15.00
Chop	Custom	3	100%	1	acre	10.00	10.00
Glyphosate w/Surfactant	Herbicide	6	100%	32	ounce	0.12	3.75
Total Materials & Services							28.75
Total listed costs for Field Operations and Materials and Services							62.39
Interest on Operations Capital	46.23	cash expense @		5.50%	for 6.0 mo.		1.27
Total Operating and Use Related Ownership Costs							63.66

For the 80-acre field, the medium tractor and planter accumulate a $10.92 per acre charge while still adding 8 hours to the annual use of the power unit (Klein et al., 2018). A medium tractor and boom sprayer provides three more annual hours to the medium tractor while costing $3.01 per acre (Klein et al., 2018). A windrower that is present on the farm began with 120 annual hours of use. While windrowing the rye, the machine gains 20 additional hours of annual use with a per acre cost of $9.46 (Klein et al., 2018). Since most operations don't have a chopper, the current custom rate of $10 per acre is used (Klein et al., 2018). The hauling rate for rye was $4.85 per acre for the medium tractor while adding 20 additional annual hours (Klein et al., 2018). The large tractor added an additional 22 annual hours for hauling and packing rye at a rate of $5.40 per acre (Klein et al., 2018). The no-till drill and spray herbicide field operations (Table 2.4) are cheaper per acre than the grazing scenario. By adding additional hours, the medium tractor spreads power ownership costs across more acres resulting in a decrease in per acre costs.

An operation was added to the cover crop budgets named haul rye. The implement was a forage wagon. The two forage wagons were preexisting on the farm with a purchase price of $35,000 each. Both were used for this and other enterprises, which accumulated 2000 tons of annual use. The average tons per hour hauled were 20. Since the assumption is the farm has only two power units (medium and large tractor), the remaining help and labor needed to haul rye is contracted out at $5 per ton if needed. It must be noted that within the UNL crop budgets, there is a custom rate for chopping, hauling, and packing at $10.75 per ton (Klein et al., 2018). Therefore if an average yield on a wet matter basis were applied at 4 tons per acre, the total cost would be $43.00 per acre for chopping, hauling, and packing. In the budgets provided below, the total cost for these activities was $20.25 per acre.

The materials and services are included in Table 2.5 for mechanically harvesting cereal rye. The rye seed cost for planting is $15 per acre (Klein et al., 2018). The above crop budgets for mechanically harvesting are different from year to year based on the yield of rye. The costs for windrowing and hauling rye will change depending upon the amount of rye biomass produced. The simulated dry matter biomass accumulation is displayed in Figure 2.2 for each year from 2006-2017. The acreage from year to year is assumed constant at 80 acres. The costs accrued independent of crop yield include the no till drill to plant the cover crop seed. Establishment costs for the drilling and spraying rye are fixed costs in comparing the two management strategies.

The highest simulated rye dry matter biomass was 13.93 tons on April 30th, 2012. Shao et al. (2015) reported a rye dry matter basis of 19.3% of total biomass on May 4th in his study while UNL animal scientists reported 17% (Conway, 2018). Based on these studies, an 18% dry matter content was used to calculate the wet weight of rye for mechanically harvesting and hauling the rye (Ex. 5015 lbs. dry matter / 0.18 dry matter = 27861 lbs. wet rye biomass = 13.93 tons/acre).

Determining the price of ryelage as a feed crop from mechanically harvesting can be based on the price of other hay-crop silages. Hendrix (2002) states to use a good price for hay while adjusting for dry matter content of the crop to find a fair price for high quality forages. Through obtaining the USDA Hay Reports (2019), a good hay market price at the end of April from 2007-2017 was used to help find a value for harvested cereal rye. The averaged good alfalfa hay market price from the high and low bids in Nebraska was determined in Table 2.6.

Table 2.6: The Nebraska state average hay market price data per bale from the USDA Hay Reports (2019). The average high bid for large round bales over the last week in April and first week in May with a grade description of good alfalfa was used to determine a value for high quality harvested forage.

Year	Last Week in April	First Week in May	Average Bid
2007	90	90	90
2008	100	80	90
2009	85	85	85
2010	100	100	100
2011	100	100	100
2012	150	150	150
2013	230	230	230
2014	130	130	130
2015	95	110	102.5
2016	95	85	90
2017	75	75	75

The process of obtaining a price for ryelage uses the price of hay. With 13% moisture, a ton of hay has a dry matter content of 1740 lbs. If the value of hay were \$100, each one hundred pounds of hay would then have a value of 100/17.40 = \$5.75 on a dry matter basis. For ryelage, a dry matter content of 18% is assumed in this study. The net revenue of harvested rye is calculated through each prospective year based on wet matter tons produced per acre. Figure 2.3 (Appendix) displays the total tons per acre of wet rye. For harvesting rye, the crop is harvested and transported immediately after harvest. Therefore, the wet biomass is configured in Figure 2.3.

If hay is worth \$100 per ton (\$5.75 per 100 pounds on a dry matter basis), a ton of silage is worth approximately \$20.70 as shown below:

2000 x 0.18 = 360; 3.6 x 5.75 = \$20.70/ton

Grazing Calculations: Head Per Acre

In the appendix, Figure 2.4 displays the average cost of each production strategy if grazing or harvesting were performed. Figure 2.4 does not present the interest cost of purchasing cattle since it is variable from year to year based on the cost of the cattle.

According to Higgins (2017), timely termination of a cereal rye crop is important for the production of the main cash crop. The grazing period for this analysis totaled 27 days to allow time for rye termination and planting of the main crop. From our case study, the cattle averaged 3.2 pounds of growth per day (Conway and Drewnoski, 2018). The full set of cattle parameters are presented in Table 2.7.

Table 2.7: Cattle parameters presented in the model.

Cattle Parameter Values	
Parameter	Selected
Initial Weight Before Grazing	625 lbs.
Final Weight After Grazing	711 lbs.
Average Daily Gain	3.2 lbs./day
Grazing Period (April 4th – April 30th)	27 days
Leftover Biomass	500 lbs.
Pounds Dry Matter per AUM	780 lbs.
AUM per Head per Month	0.60 AUM's

The stocking rate of cattle can be adjusted depending on the available forage. For modeling purposes, the stocking rate was determined based on predicting forage in the future. The rye biomass from the rye growth model was recorded on April 4th. This biomass of rye was used to predict growth from April 4th to April 30th using daily average heat units from 2007-2017 to project daily growth. Using the predicted biomass and a targeted leftover biomass on April 30th of 500 pounds per acre (Drewnoski, 2019), the head per acre and AUM's per head was calculated as follows:

2.2 $$Head\ per\ Acre = \left(\frac{(Predicted\ Biomass - Leftover\ Biomass)}{2 * Pounds\ per\ AUM * AUM\ per\ Head}\right)$$

2.3 $$AUM's/Head/Month = \left(\frac{(Initial\ Weight + Final\ Weight)}{2}\right) * \frac{Grazing\ Period}{Days\ in\ Month}$$

The case study done at UNL used a stocking rate of 2 head per acre, but used a rotational grazing strategy to retain biomass (Conway and Drewnoski, 2018). Rotational grazing was not an assumption in our simulation model. Therefore, the assumption of half grazed and half trampled was used to calculate head per acre. The total head calculated for each year was variable depending upon the predicted biomass from our production function for rye (Figure 2.5). Implementing the costs from the partial budgets and biomass growth into our model, the net returns from each strategy can be examined.

Our production function calculated the initial dry matter biomass on April 1st. The end dry matter biomass was recorded on April 30th. From our production results we determined that dry matter biomass less than 100 pounds on April 1st would be inadequate for grazing. After analyzing the results from April 30th, a dry matter biomass of less than 1000 pounds would also lead to insufficient grazing levels. Through examining our functions simulating rye production, spring years of 2008, 2010, and 2013 didn't reach the dry matter biomass limit (Figure 2.2). The dry matter growth threshold was created to maximize transportation efficiency. The gross weight for freight is maximized when a full truckload is utilized.

Net Return Calculations:

Net return is calculated using the positive impacts of final animal revenue and reduced hourly ownership cost on equipment charged to the corn and soybean crops minus animal purchase costs and total expenses related to grazing activities including interest. Price on April 30th (P1), final animal weight (W1), and number of head (N) are used to determine the final animal value. Reduced hourly ownership costs (S) due to increases in annual use on equipment have a positive marginal impact on the partial budget results. Price on April 1st (P2), initial animal weight (W2), and number of head (N) are used to calculate initial animal value. Interest costs for purchasing cattle are determined based on initial animal value. The total operating and use related ownership costs (O1) found at the bottom of Table 2.4 and total acres (A) account for grazing activity costs with interest.

$$2.4 \qquad Net\ Return\ (Grazing) = (P1 * W1 * N) + S - (P2 * W2 * N) - I - (O1 * A)$$

While calculating mechanical removal of cereal rye, the price of ryelage (P3) times our yield (Y) plus savings on ownership costs is our total positive effects. The total operating and use related ownership costs (O2) found at the bottom of Table 2.5 and total acres (A) account for mechanical harvesting scenario expenses with interest.

$$2.5 \qquad Net\ Return\ (Mechanically\ Harvesting) = (P3 * Y) + S - (O2 * A)$$

RightRisk Risk Scenario Planning tool:

Using the RightRisk Risk Scenario Planning tool and AnyLogic, the net returns of cover crop grazing rye can be discovered. The partial budget for the year 2018 can be found in the appendix (Figure 2.6). The RightRisk Risk Scenario Planning tool was developed to help determine risk scenario planning in analyzing simple changes where a partial budget analysis was applicable (Hewlett and Parsons, 2013). The partial budget shows the costs per acre for adding the enterprise of cover crop grazing to a corn-soybean rotation. Added costs are counted within the negative effects of adding grazing and they include the field operations, materials, and supplies. The initial purchase cost for cattle is also displayed in the negative effects as an added cost while the selling value of the cattle is displayed in the positive effects as an added return. Also, under the positive effects as a reduced cost, is the cost savings for machinery ownership costs per acre by adding a rye grazing enterprise. A cost savings for ownership costs associated with the power unit (medium tractor) over the initial 500 hours of annual use is configured at $0.56 per hour for a savings of $280. Ownership costs were paid over the first 500 hours to configure an initial base cost. Within the partial budget of the Risk Scenario Planning tool, an initial static case displays the net benefit of implementing cover crop grazing with average rye growth and average total head that graze. The net benefit of grazing rye is -$416.07 or -$5.20 per acre. The risk scenario presented in Figure 2.7 is the difference in prices that a farmer may experience for cattle. This risk scenario displays the probability of a positive or negative return based on varying cattle prices and will be discussed in more detail below.

The net returns for grazing and for mechanically harvesting rye for any year from 2007-2017 is provided in the appendix (Figure 2.8). The profitability of grazing rye over the eleven year period resulted in an average return of -$19.56 throughout those years (Figure 2.9) while the maximum ($147.04) cover crop grazing returned was in year 2017. In years 2015 and 2016, the spreads between the April 1st (600-650 lb. weights) and April 30th (700-750 lb. weights) price had considerable drops of $34.94 and $32.43 per hundredweight, respectively. This led to negative returns for purchasing cattle for grazing a rye cover crop. The years 2009, 2011, and 2017 were the only profitable years for the cover crop grazing strategy.

The profitability of mechanically harvesting rye over the eleven-year period resulted in an average return of $70.70 (Figure 2.9) while the maximum ($368.67) for mechanically harvesting rye returned was in 2012. Mechanically harvesting rye performed well throughout the eleven-year study, producing a consistent return with wet matter yields ranging from 1.28 to 13.93 tons per acre.

Risk Scenario 1: Basis Change in Cattle Price for Grazing Cereal Rye

A risk scenario on the change in the price basis from April 1st to April 30th was conducted. The average price over an eleven-year period was $162.65 for purchasing cattle on April 1st for grazing. Between April 1st and April 30th, the average price change between incoming 600-650 pound steers and outgoing 700-750 pound steers was a decrease of $14.88 per hundredweight. Therefore, the price of selling cattle would be $147.77 and net benefit within the partial budget for this average scenario would be a loss of $416.07 or $5.20 per acre. Over the eleven-year period, the basis between the cattle purchase price on April 1st and the cattle selling price on April 30th had a maximum loss of $34.94 per hundredweight as a worst-case scenario and a gain of $2.12 per hundredweight as a best-case scenario. A risk scenario analysis over this range of possible basis price changes under the assumption of a fixed purchase price of $162.65 resulted in a 57% chance of negative returns to grazing the cereal rye and a 43% chance of positive returns. A breakeven basis was calculated at -$14.31 with a fixed purchase price of $162.65.

Risk Scenario 2: Changes in Initial Cattle Purchase Price for Grazing Cereal Rye

A risk scenario analysis on the purchase price of cattle on April 1st was also conducted. The average purchase price over the eleven years was $162.65 per hundredweight. The initial purchase price ranged from a low price of $102.33 per hundredweight to a high price of $272.37 per hundredweight. The average drop was $14.88 per hundredweight from April 1st to April 30th. A risk scenario analysis over the range of possible purchase prices assuming a fixed basis of -$14.88 was conducted for grazing cereal rye and resulted in a 46% probability of negative returns and a 54% probability of positive returns.

Risk Scenario 3: Changes in Basis and Initial Cattle Purchase Price for Grazing Cereal Rye

A joint risk analysis was conducted on the basis price and initial purchase price. As stated in the previous scenarios, the high and low pricing scenarios of $272.37 per hundredweight and $102.33 per hundredweight with an average of $162.65 per hundredweight were used for cattle purchase price on April 1st. Using the basis price scenario from Risk Scenario 1 and the purchase price scenario from Risk Scenario 2, a risk scenario analysis with two uncertain variables was conducted (Figure 2.7). This joint risk analysis resulted in a 50% chance of returning positive returns and a 50% chance of negative returns.

Risk Scenario 4: High Cattle Price scenario for the Last Seven Years Grazing Cereal Rye

For cover crop grazing, the last seven years (2011-2017) have seen higher prices in respect to purchasing calves. The last seven years had an average steer purchase price of $189.06 per hundredweight with an average steer-selling price of

\$168.99 per hundredweight during the April 1^{st} to April 30^{th} time period. This is a much larger drop of \$20.08 during this period than the average drop of \$14.88 for the full eleven years of the study. The first four years of the data set (2007-2010) showed a much lower price environment with an average purchase price of \$116.42 and an average selling price of \$110.62. The average price drop over those years was only \$5.80 which is significantly lower (p-value = 5%) than it was over the last seven years. Therefore, a risk scenario analysis based on the seven-year period from 2011-2017 was conducted. Over that period, the basis between the cattle purchase price on April 1^{st} and the cattle selling price on April 30^{th} had a maximum loss of \$34.94 per hundredweight as a worst-case scenario and a loss of \$1.73 per hundredweight as a best-case scenario. From 2011-2017, the maximum purchase price on April 1^{st} was \$272.37 and the minimum purchase price was \$154.205.

Profitability for grazing rye is highly dependent on cattle price. Using the average cattle purchase price of \$189.06 and the average basis of -\$20.08 for the high priced years of 2011-2017, the expected net return is -\$1,932.72. This expected loss is more than four times larger than the expected loss for the full eleven year period from 2006-2017. A joint sensitivity analysis of the high price risk scenario with cattle purchase price ranging from \$154.205 to \$272.37 and the basis ranging from -\$34.94 to -\$1.73, showed approximately a 57% chance of failure (negative profits). The analysis must point out that the three years with the highest prices for purchasing cattle, 2014-2016, also had the three largest negative price basis values between purchasing and selling prices. Therefore, at a higher initial purchase price, producers must realize the risk in purchasing cattle in the April time period.

Risk Scenario 5: Low Cattle Price scenario for the First Four Years Grazing Cereal Rye

In a low price scenario, the first four years (2007-2010) present an average purchase price for cattle of $116.42 per hundredweight with a selling price of $110.62 per hundredweight. The difference between these prices is $5.80 per hundredweight. For the low price risk scenario analysis from 2007-2010, the maximum purchase price on April 1st was $126.67 and the minimum purchase price was $102.33. The maximum basis loss throughout these years was -$10.045 per hundredweight as a worst-case scenario and a gain of $2.12 per hundredweight as a best-case scenario. Using these values, the risk scenario analysis showed the risk of purchasing and selling the cattle is much lower in this low price scenario than it was in the high price scenario. The sensitivity analysis showed that 96% of the time cover crop grazing is profitable under this scenario with only a 4% chance of negative net returns. Purchasing cattle for grazing at lower prices more than doubles your chances to have a profitable enterprise compared to high price scenarios. Therefore, it must be noted that farmers would be more successful with grazing cereal rye under lower but more stable cattle price conditions. The expected net returns given the average low price scenario purchase price of $116.42 and basis of -$5.80 is $2,222.33. The added cost of the grazing scenario excluding the cost of purchasing cattle is $48.93 per acre (Figure 2.4) or $3,918.40 for the 80 acre field. Coupled with a 3.2 pound per day gain for 103 steers over 27 days of grazing, this equates to only a $44.03 per hundredweight cost of gain.

Table 2.9: Risk scenarios done on the RightRisk Risk Scenario Planning tool to determine probability of profitability for grazing cereal rye.

Risk Scenarios			
	Uncertain Values	Probability of Positive Net Returns	Probability of Negative Net Returns
Risk Scenario 1	Basis Price Change in Cattle Price	43%	57%
Risk Scenario 2	Purchase Price for Grazing Rye	54%	46%
Risk Scenario 3	Basis Price and Initial Purchase	50%	50%
Risk Scenario 4	Price of cattle over last seven years	43%	57%
Risk Scenario 5	Price of cattle over first four years	96%	4%

Two-Sample T-test: For Mechanically Removing and Grazing Rye

A two-sample t-test was conducted on the net returns for mechanically removing and grazing rye assuming equal variances. The t-test concluded a two-tailed p-value of 0.056. The results show that it is not significant at the 5% level. Despite having better average returns to mechanically harvesting (Figure 2.9), a two-tailed t-test revealed there was not a significant difference in net returns at the 5% level when comparing mechanically removing the rye to grazing the rye with growing cattle.

XI. Conclusions

The results between cover crop grazing and mechanically harvesting rye show that both options are viable under a stable cattle market. If the cattle price between April 1st and April 30th stays relatively close (+/-$6 per hundredweight), grazing cereal rye could be profitable. Cereal rye grazing is highly dependent on the cattle purchase and sell price. Between the two alternatives, mechanically harvesting rye has a better probability to be profitable as shown in Figure 2.8. Eight out of the ten years, mechanical harvesting rye outperformed cover crop grazing based on net returns. However, the difference between the means was not statistically significant at the 5% level. Mechanical harvesting rye was highly dependent on the rye produced for any given year.

The two alternatives of grazing or mechanical harvesting rye have their advantages and disadvantages. A big disadvantage of mechanical harvesting cereal rye is an enterprise still accrues depreciation, interest, taxes, housing, and insurance costs for the forage wagons and a windrower that are owned with the intent to be used for mechanically removing rye. Grazing cereal rye has an advantage in this respect, as a farmer wouldn't purchase cattle with no forage available for grazing and, thus, fixed costs are lower in that scenario. Grazing cereal rye is exposed to a large amount of cattle market risk if cattle are purchased. At higher initial purchase prices on April 1st, grazing cattle on rye resulted in negative profits due to cattle market risk. If lower prices persist, grazing cattle on cereal rye can lead to greater returns while managing feed expenses for the enterprise.

The implications of these results demonstrate that mechanically removing rye as forage in the spring or grazing the rye with growing cattle can each return positive net returns to an operation. This examination of grazing doesn't provide a financial assessment of the manure returned as fertilizer to the field. The nutrients provided from cover crop grazing are important to soil health. Being able to quantify these positive returns toward fertilizing the next crop should be considered in future studies.

The objectives of this study were to examine the net benefits of grazing versus mechanically harvesting rye in cropping systems. Data was extracted from multiple sources including Livestock Marketing Information Center and University of Nebraska at Lincoln Climate Center. However, the main data used for grazing rye was developed in collaboration with University of Nebraska at Lincoln Animal Science department (Conway, 2018; Drewnoski, 2018). Crop budgets from the University of Nebraska at Lincoln (Klein et al., 2018) were manipulated to match each management strategy. Results were calculated and manipulated within the RightRisk Risk Scenario Planning tool (Hewlett & Parsons, 2013) and AnyLogic software to provide a comparative analysis. This analysis didn't support either mechanically harvesting or grazing cereal rye. During certain cattle market conditions, grazing cereal rye can be the better altnernative. Under consistent dry matter biomass production results, mechanically harvesting rye may be the better option. This economic analysis provides additional management strategy considerations for farmers adding a cereal rye cover crop.

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XIII. Appendix 2

Schedule for Cover Crop Grazing

Date	Operations
November 1st	Plant Rye
April 1st	Build Fence, Purchase Cattle
April 2nd	Place Water Source
April 4th	Move Cattle On
April 30th	Remove Cattle, Sell Cattle
May 1st	Remove Fence and Tank
May 2nd	Spray Rye

Schedule for Mechanically Harvesting Cover Crops

Date	Operations
November 1st	Plant Rye
April 30th	Harvest Rye Forage
May 2nd	Spray Rye

Figure 2.1: This is the schedule of operations for grazing cereal rye and mechanically harvesting rye. Each management strategy has different operations used to remove the cereal rye crop.

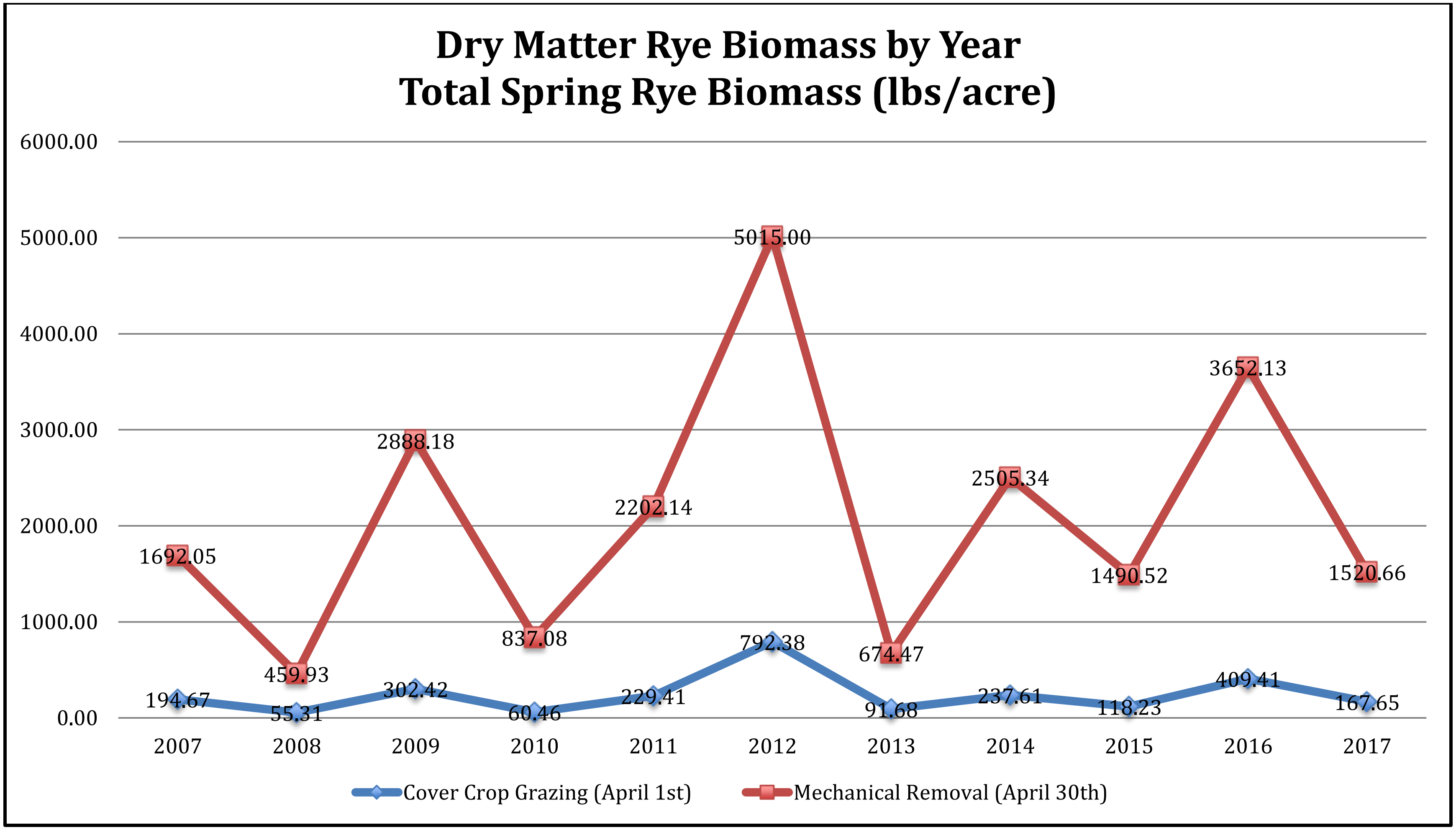

Figure 2.2: From 2007-2017, this is the spring simulated dry matter biomass growth of cereal rye in pounds per acre. The blue line represents cereal rye biomass growth on April 1st, which is recorded to predict the number of cattle to purchase. The red line represents simulated cereal rye biomass on April 30th that was removed through mechanically harvesting cereal rye.

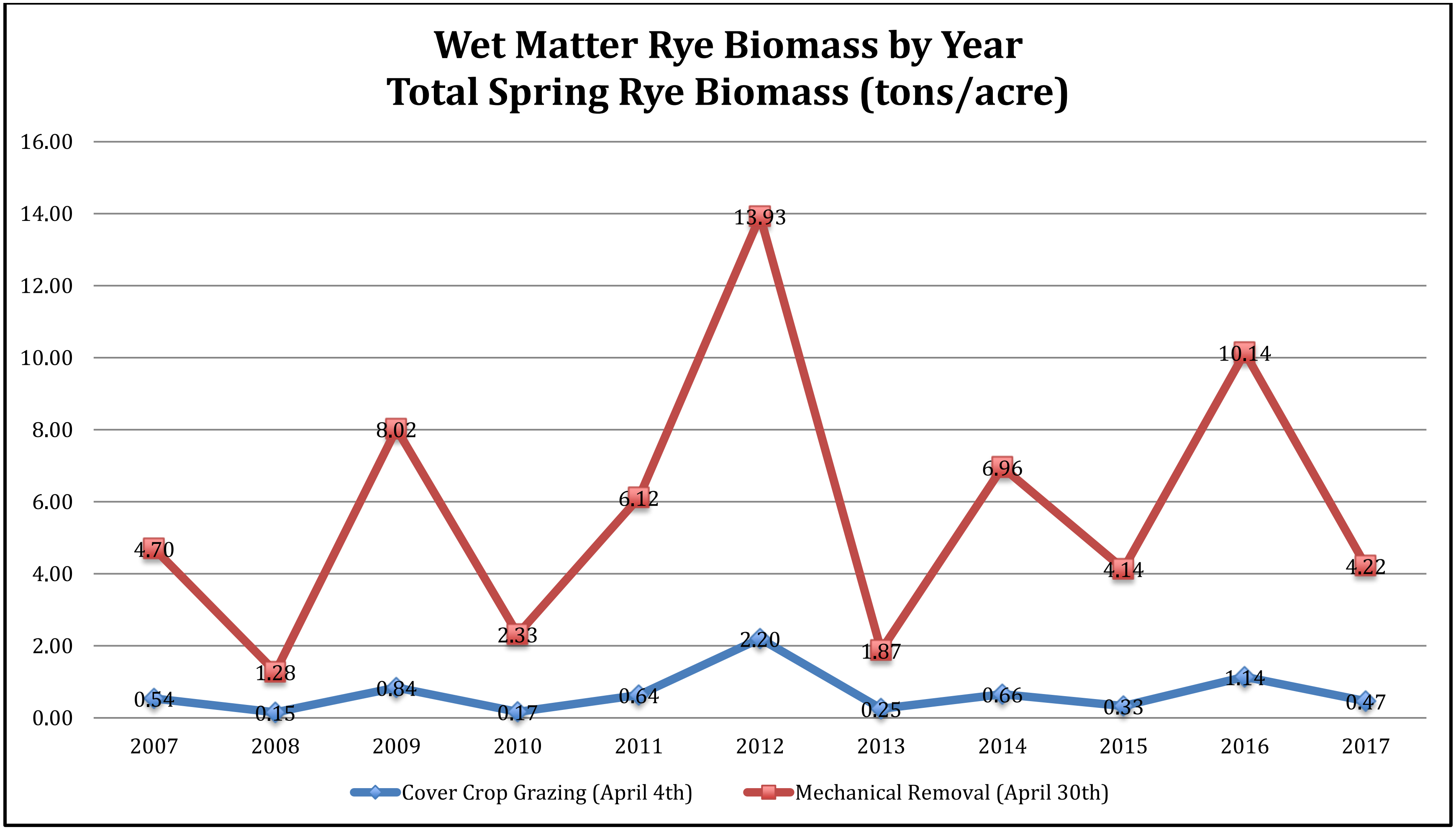

Figure 2.3: From 2007-2017, this is the spring simulated wet matter biomass growth of cereal rye in tons per acre. The blue line represents cereal rye biomass growth on April 1st, which is recorded to predict the number of cattle to purchase. The red line represents simulated cereal rye biomass on April 30th that was removed through mechanically harvesting cereal rye.

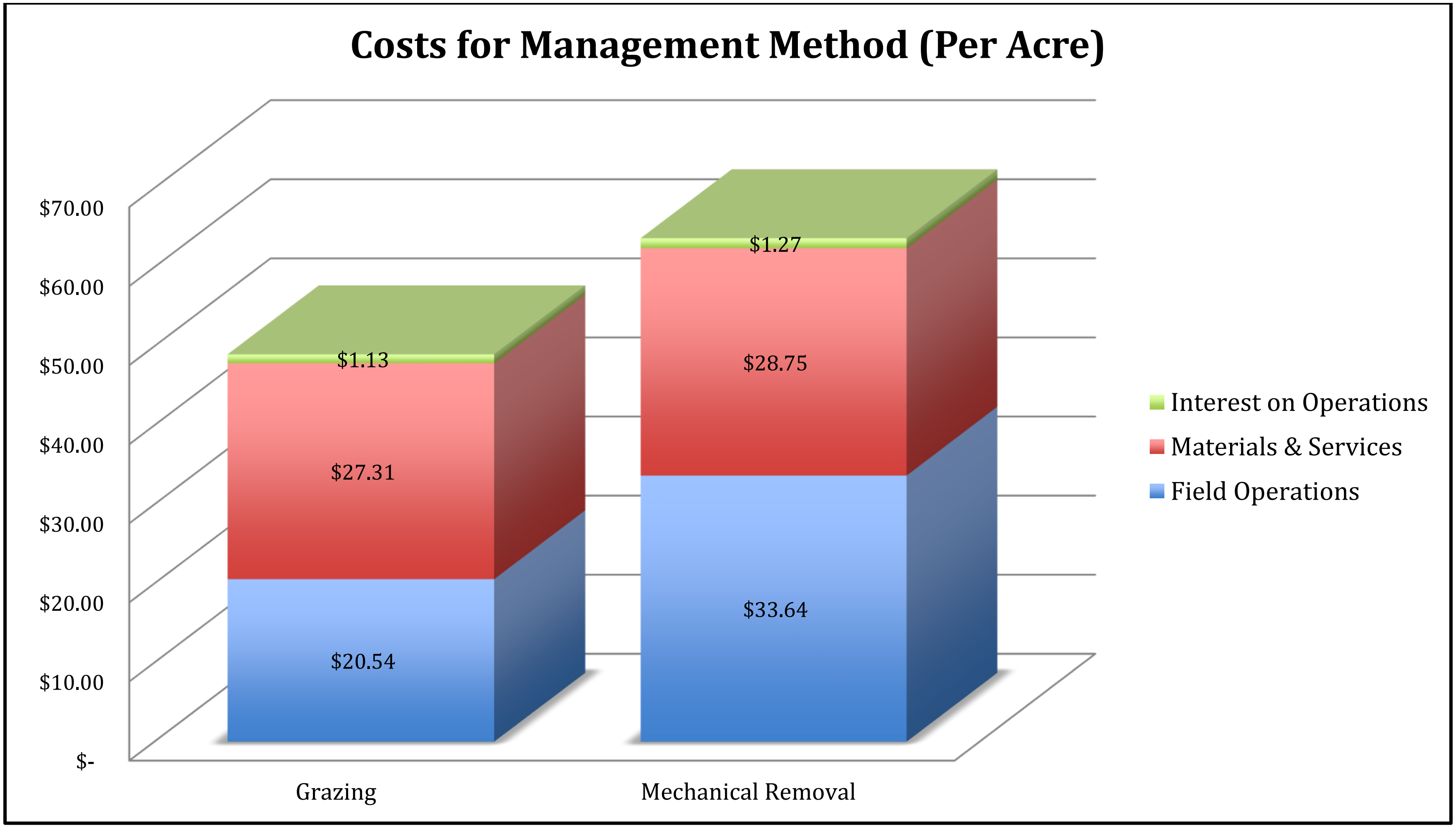

Figure 2.4: The total costs of grazing and mechanical removing cereal rye within a row crop system. The following costs were determined within the University of Nebraska-Lincoln cover crop budgets (Klein et al., 2018).

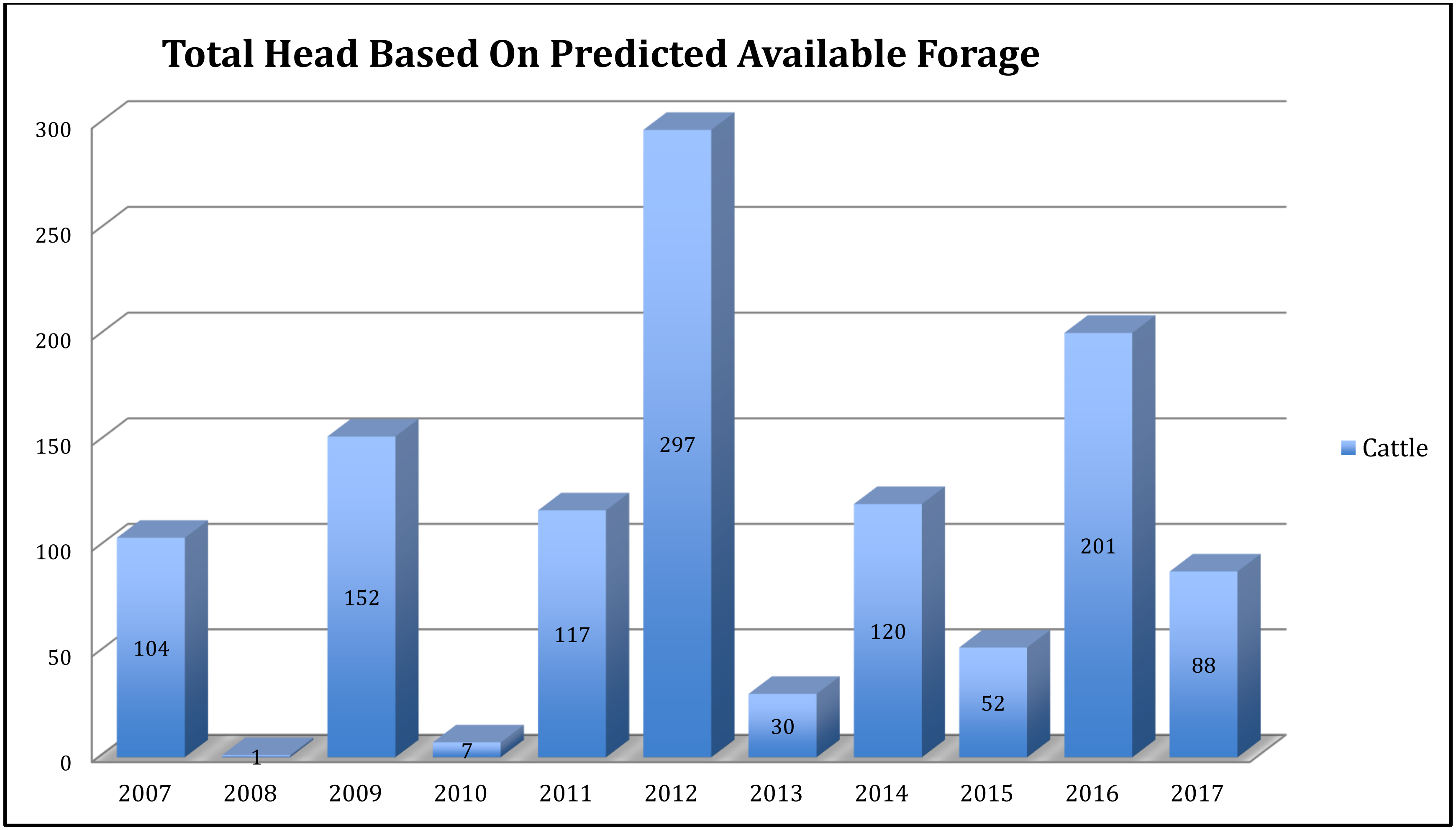

Figure 2.5: Using the April 1st simulated dry matter biomass, total number of head purchased per year to graze cereal rye is displayed above. For three years (2008, 2010, & 2013), a decision was made to forfeit buying cattle due to low cereal rye production.

RightRisk			Partial Budget For:	Implementing Cover Crop Grazing			
Positive Effects				**Negative Effects**			
Added Returns	**Quantity**	**Value**	**Total**	**Added Costs**	**Quantity**	**Value**	
Sell Cattle (Total Head * per head cost)	103	$ 1,051.24	$ 108,277.29	Tractor/Drill (Cost/acre)	80	$ 10.99	$ 879.20
Per Head Cost	1051.23578		$ -	Fencing (Cost/acre)	80	$ 4.40	$ 352.00
Per Cwt. Value	147.77		$ -	Water Trucking (Cost/acre)	80	$ 4.11	$ 328.80
Weight/100	7.114		$ -	Tractor/Sprayer (Cost/acre)	80	$ 3.04	$ 243.20
Total Head	103		$ -	Move Cattle/Check Cattle (Labor Cost/acre)(10 hours)	80	$ 5.00	$ 400.00
			$ -	Glyphosate w/Surfactant (Cost/acre)	80	$ 3.75	$ 300.00
			$ -	Seed Cost (Cost/acre)	80	$ 15.00	$ 1,200.00
			$ -	Tank Initial Cost (Amortized cost/acre)	80	$ 1.56	$ 124.80
Basis between Input & Output Cattle Prices	-14.88		$ -	Interest on Operations	80	$ 1.13	$ 90.40
			$ -	Purchase Cattle (Total Head *Per Head Cost)	103	$ 1,016.56	$ 104,705.94
			$ -	Interest	0.04	$ 8,725.49	$ 349.02
			$ -				$ -
			$ -	Per head Cost	1016.5625		$ -
			$ -	Per Cwt. Value	162.65		$ -
			$ -	Weight/100	6.25		$ -
			$ -	Purchase Cost / 12 months (1 month interest)	$ 8,725.49		$ -
			$ -				$ -
			$ -				$ -
Total Added Returns			$ 108,277.29	**Total Added Costs**			$ 108,973.36
Reduced Costs	**Quantity**	**Value**		**Reduced Returns**	**Quantity**	**Value**	
Tractor/Planter/Sprayer (Cost Saved/acre)	500	$ 0.56	$ 280.00				$ -
			$ -				$ -
			$ -				$ -
			$ -				$ -
Total Reduced Costs			$ 280.00	**Total Reduced Returns**			$ -

Total Positive Effects (Added Returns + Reduced Costs)	$ 108,557.29	**Total Negative Effects** (Added Costs + Reduced Returns)	$ 108,973.36
		Net Benefit of: Implementing Cover Crop Grazing	$ (416.07)

Figure 2.6: The partial budget for the RightRisk Scenario Planning tool displays costs associated with implementing cattle into a cereal rye grazing scenario. The cattle costs presented are averages of all scenarios across eleven years using market data from Livestock Marketing Information Center for weekly and monthly combined Nebraska auction cattle prices.

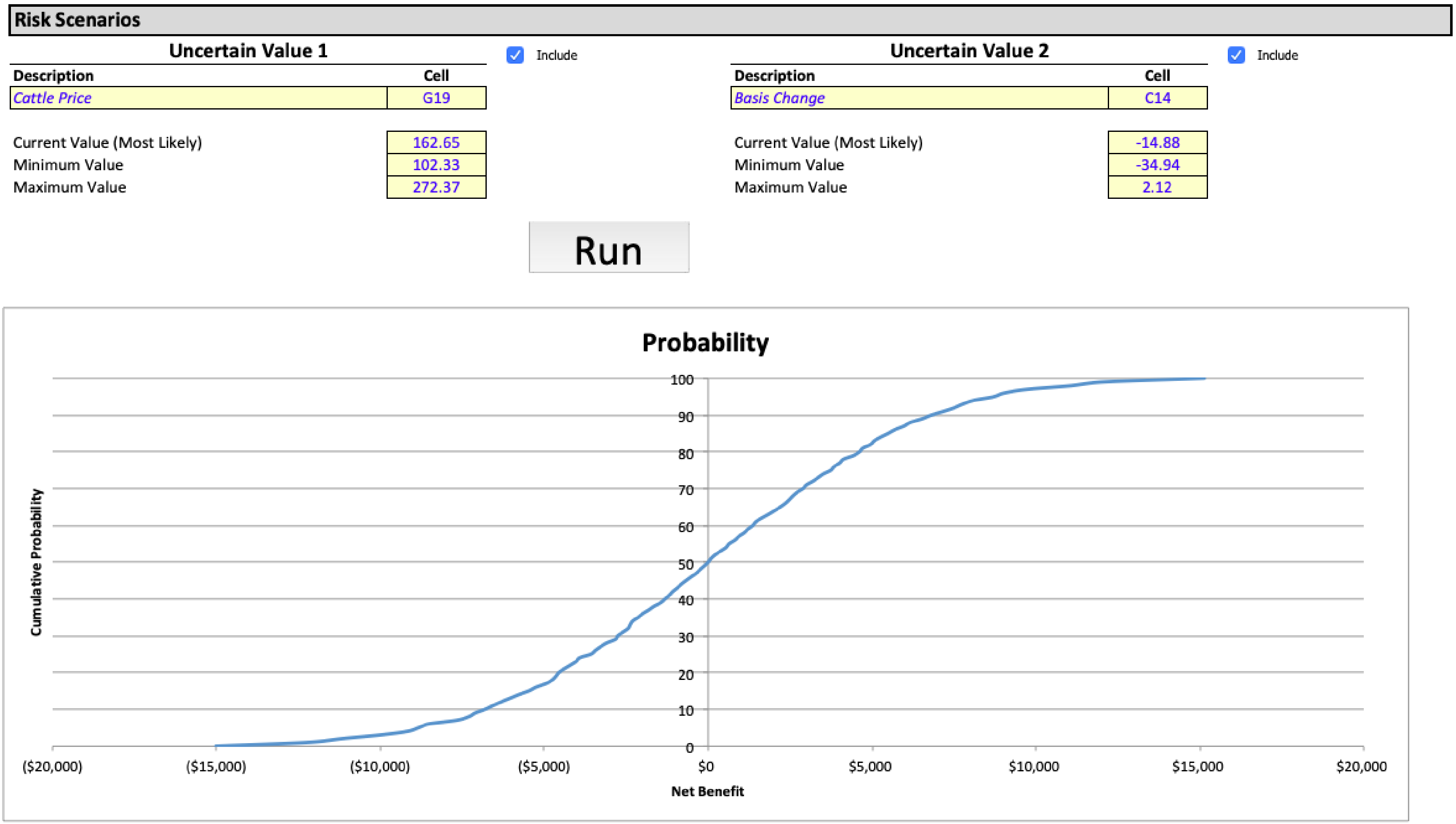

Figure 2.7: The risk scenarios within the RightRisk Risk Scenario Planning tool analyze the probability of the net benefit being positive or negative. The uncertain values that were varied include cattle price, interest rates, and number of cattle.

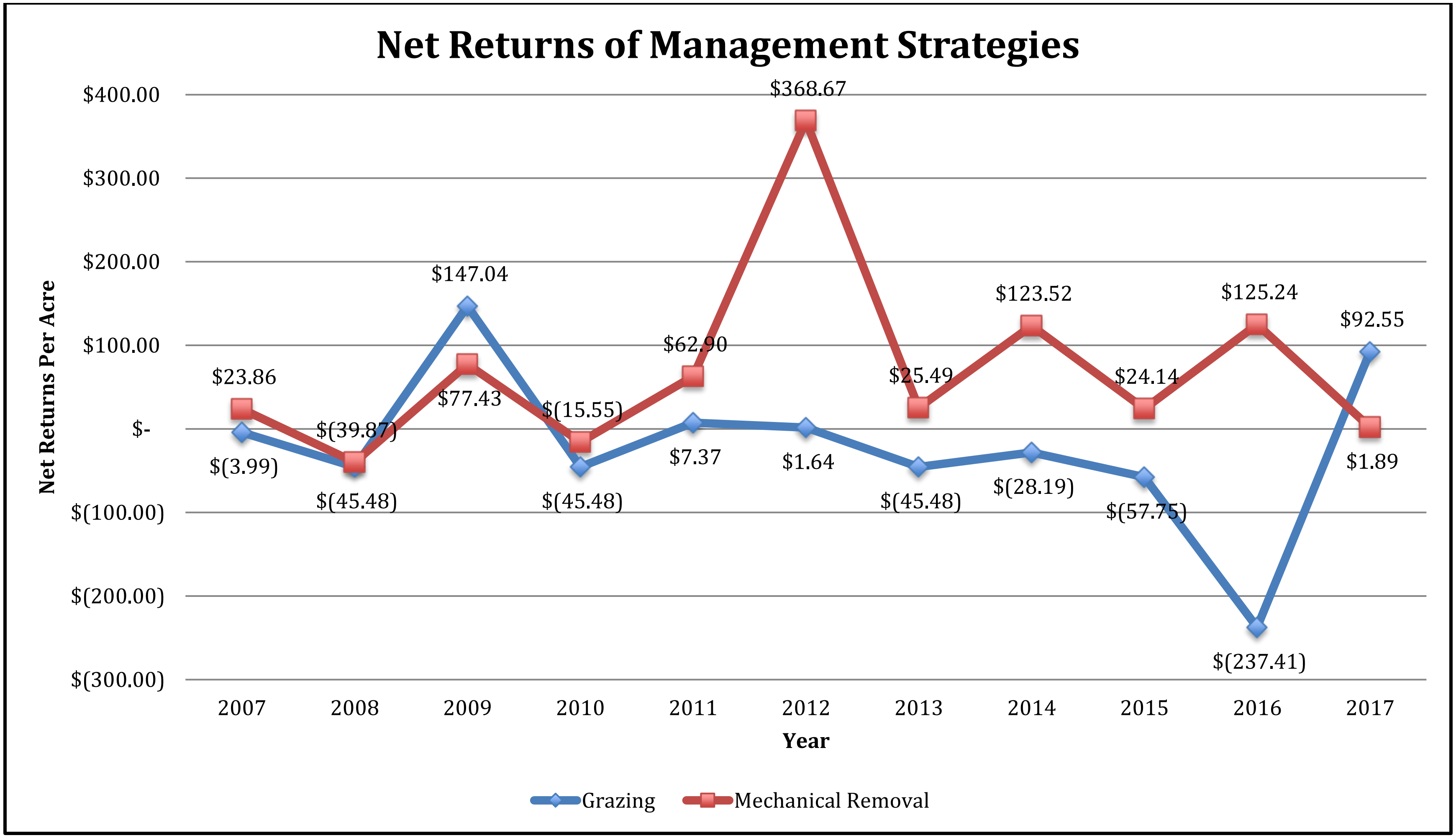

Figure 2.8: The net returns for grazing and mechanically removing cereal rye are presented for each given year. The blue line represents net returns for grazing cereal rye with cattle while the red line represents selling mechanically harvested cereal rye.

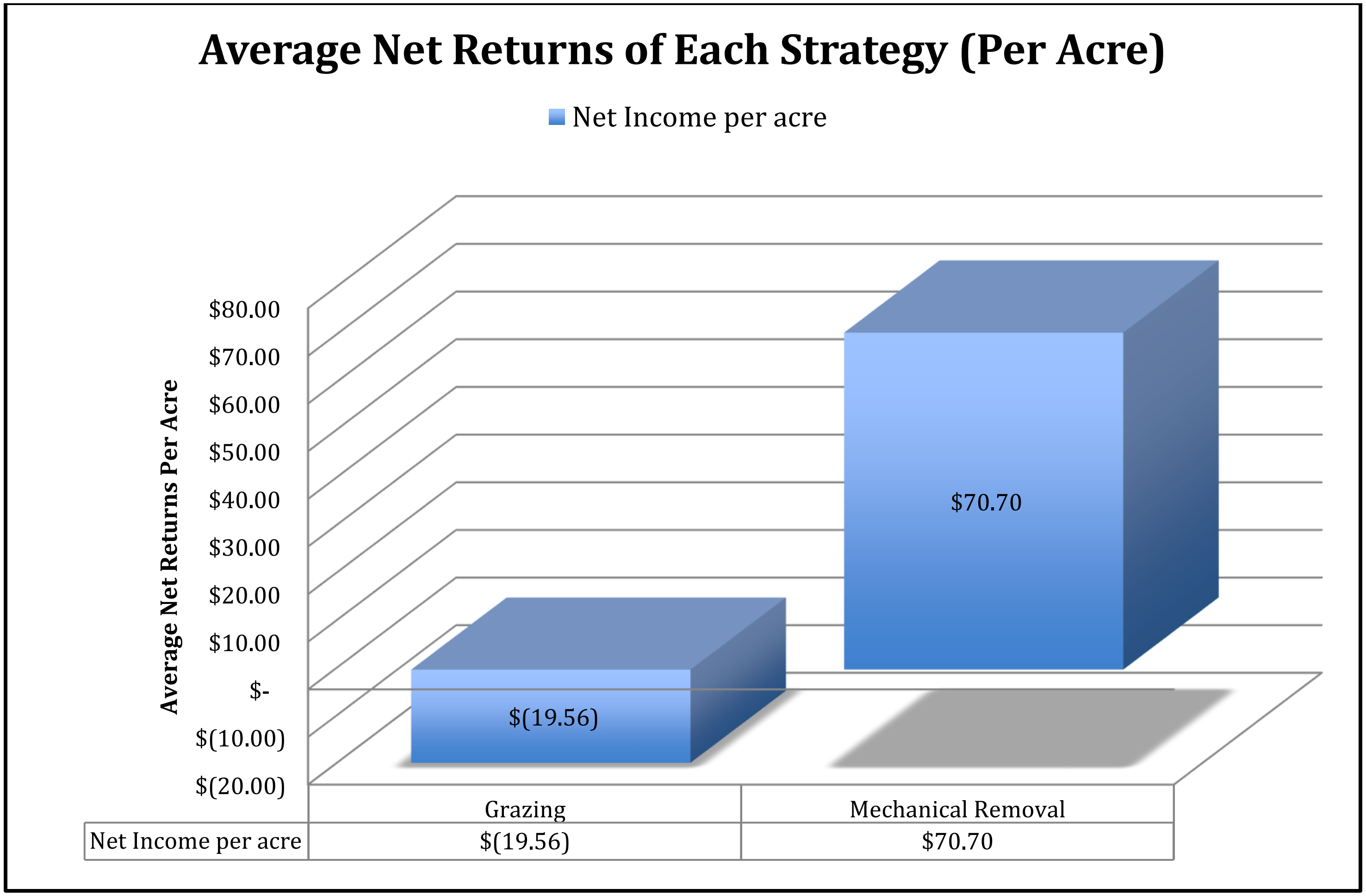

Figure 2.9: Using the values from Figure 2.8, the average net returns of each strategy across eleven years of experiments. Using cattle to graze cereal rye resulted in a loss of $19.56 over eleven years. Mechanically harvesting rye produced an average return of $70.70 over eleven years.