THESIS

A HOLISTIC APPROACH TO ROTATIONAL GRAZING: OPTIMIZED GRAZING SCHEDULE, SMALL-SCALE APPLICATIONS, AND INCORPORATING CARBON CREDITS

Submitted by

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In partial fulfillment of the requirements

For the Degree of Master of Science

Colorado State University

Fort Collins, Colorado

Fall 2025

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ABSTRACT

A HOLISTIC APPROACH TO ROTATIONAL GRAZING: OPTIMIZED GRAZING SCHEDULE, SMALL-SCALE APPLICATIONS, AND INCORPORATING CARBON CREDITS

This paper explores the financial incentives for large- and small-scale cattle producers in Colorado to incorporate rotational grazing into their operation. The financial benefit to rotational grazing is to provide feed for cattle for a longer period of time without purchasing hay by optimizing the rotation schedule according to weather, forage growth, and the changing nutrient requirements of beef cattle during the reproductive cycle. The social and political push towards sustainable practices has resulted in the growth of the carbon credit market, which can act as a secondary source of revenue for large scale cattle producers that are willing to make the switch to rotational grazing. For small acreage producers, the benefit to rotational grazing relies on the ability to stretch pastures and decrease supplemental forage costs. Often times, small acreage operations are raising cattle for their personal beef supply, so every dollar saved from forage costs directly relates to lower beef costs. Longer lasting pastures could offer a producer the option to market calves at a later date for a potentially higher price and carbon credit production diversifies an enterprise, both providing financial incentives for rotational grazing.

TABLE OF CONTENTS

CHAPTER 1: INTRODUCTION

Cattle ranching has been a tradition in American agriculture and an integral part of the economic structure of the United States for over 200 years (Corbett et al. 2014). When the western United States (U.S.) was settled following the Civil War, the cattle industry was a large reason for that western expansion (Corbett et al. 2014). From the time the West was settled up to the present day there has been a large number of technical advances that have improved the environment and efficiency of cattle producers while still preserving the traditions of ranching established by our ancestors. This paper will discuss grazing techniques throughout the western U.S. There are numerous options for how a producer may graze cattle, but every method must be a good fit for each ranching operation. The most important aspect of how to graze cattle is that the practice is beneficial to the livestock, the producer's livelihood, and the environment.

The U.S. is an incredibly diversified country, not just in its population but also in the landscaping, crops, and agricultural practices present across the states. States in the western U.S., such as Montana, Idaho, Wyoming, Colorado, New Mexico, Arizona, Utah, and Nevada, tend to have lower precipitation rates that result in pastures being less productive than the counterpart pastures in the Eastern U.S. (Winters-Michaud 2024). The specific states mentioned above are considered to be part of the Mountain Region in USDA ERS data. The Mountain Region represents 55% of all grazed pastureland in the continental U.S. (Dennis 2021). The Northeast and Appalachian regions have 1.36 grazed pasture acres per beef cow, meaning pastures in these regions are much more productive relative to the rest of the U.S. (Dennis 2021). The Mountain region is on the opposite side of the spectrum of the Northeast and Appalachian regions with 49.02 grazed pasture acres per beef cow (Dennis 2021). This wide range of pasture efficiency across the U.S. has led to the development of many different grazing practices that are personalized to the region's specifications. Cattle grazing is ever evolving and continuously assessing the operation for efficiency while making the necessary adaptations which will ensure resources are being used properly.

Table 1.0. Grazing Techniques

Grazing Technique	Description
Continuous	Uninterrupted Grazing Time
Rotational	Grazing with Rest Periods
Swath	Cut and Windrow Crop then Graze
Corn Residue	Graze Cattle on Leftover Crop
Marginal Planting	Addition High Protein Seed on Pasture

Producers can choose from a variety of different grazing techniques that range from traditional methods to new and innovative practices, as listed in Table 1.0. Continuous grazing involves turning an entire herd of cattle onto a continuous pasture for an uninterrupted amount of time and is considered the traditional method of cattle grazing (*Rotational vs. continuous grazing*). This form of grazing has been a reliable method for generations due to low operating costs and high performance of cattle when the correct stocking rate is used (*Rotational vs. continuous grazing*). Rotational grazing, also known as management intensive grazing, is similar to continuous grazing except that a large pasture is sectioned off into smaller paddocks and cattle are rotated through according to a schedule. Using this method of grazing allows for the smaller paddocks to rest in between grazing periods as well as increase manure spread, increase forage productivity through uniform grazing patterns, sequester carbon, and potentially increase stocking rates (*Rotational vs. continuous grazing*). Windrow or swath grazing is a form of grazing that cuts down on harvesting cost of crops, such as hay, by grazing cattle on a field of cut crop (Berger and Volesky 2022). Skipping the bailing process will not only cut input costs for the hay enterprise but also reduce the feed input costs for the cattle enterprise by providing easily accessible, high-quality forage. Another form of grazing which uses waste for cattle grazing is turning a herd onto corn residue which will help to cut feed costs for cattle producers and benefit corn producers by giving their field a secondary use (Rasby 2020). A more modern and lesser-known approach to cattle grazing is marginal planting, which consists of a producer planting a small section or percentage of a larger pasture with a high protein legume. This gazing system presents an opportunity to increase the protein content and forage availability of a regularly low-quality forage pasture while remaining cost efficient due to a smaller amount of seed needed for planting. These diverse grazing techniques offer producers a variety of options to balance productivity, sustainability, and efficiency which allows them to tailor their approach to the specific needs of their operation and resources.

With the development of ecologically beneficial grazing practices, it is also possible for producers to access additional financial capacity through the use of various grazing practices. This additional revenue generated by regenerative agricultural practices can offset some of the increased costs associated with the transition to these practices and can eventually create a supplemental stream of income. Recently, there has been a significant social, political and financial incentives to pursue reduction of carbon emissions in the food supply chain. This incentive is supported by consumers in that 69% of U.S. adults agree reduction of the carbon footprint of food production is essential (Tyson et al. 2022). Through this push to reduce carbon emissions, the carbon credit market has emerged as a way for large corporations to purchase carbon credits and offset their carbon emissions. Including these practices in a ranching operation can not only help the environment but also potentially increase cattle productivity and open up economic opportunity for producers.

Agriculture as a whole has a plethora of ways to farm and ranch, each personalized to the operation's needs, goals, and available resources. Cattle ranching specifically is remarkably diverse in its applications and methods. A producer can choose to graze cattle in any way that fits their operation best; depending on if their goals are based on environmental conditions, financial gains, animal needs or a combination of all three. This adaptability is one of the strengths of the cattle industry, enabling operations to thrive across diverse climates, terrains, and resource availabilities. Cattle production is a widely spread sector with 55% of beef production consisting of herds under 20 head, with the average herd size being 47 head (Gillespie 2024). Many of the smaller operations are multi-enterprise and incorporation crop production, other livestock, or off-farm income. Given this broad distribution and the unique characteristics of each ranch, developing individualized grazing plans is not just beneficial but essential.

1.1 Objective

The objective of this paper is to develop a rotational grazing model that integrates weather data, forage growth patterns, and livestock nutritional requirements to create an efficient, adaptive schedule for cattle movements. The model aims to optimize pasture usage by reducing overgrazing and allowing for forage regrowth. Using environmental and biological indicators, the model determines ideal timing for cattle movement, which, in theory, can improve pasture conditions and reduce reliance on supplemental forage, therefore increasing the ranch's profit margins.

The model was tested under a variety of scenarios, ranging from large-scale commercial cattle operations to small-acreage hobby cattle farms. For small-acreage producers, a partial budget was included to examine the costs and benefits of raising and processing home-grown beef for personal consumption. Variable costs included within the budget were slaughter and processing fees, mineral supplements, veterinary care and supplies, fencing expenses, cattle price, winter forage, cold storage, and marketing. The variable costs were evaluated against potential savings from home-produced meat.

An enterprise budget was developed to quantify the potential additional value of incorporating carbon credit programs into large-scale operations. To qualify for carbon offset programs, producers must implement or continue management practices that increase carbon sequestration, such as rotational grazing. This provides an opportunity for producers to create a secondary income stream and monetize their efforts towards societal ecological goals.

1.2 Organization of Thesis

Section 1.3 contains an extensive synopsis of characteristics from the Mountain Region, descriptions for ecological sites, and types of grazing. Chapter 2 presents the methodology and findings of an optimized rotational grazing schedule. Chapter 3 alters the model from Chapter 2 in order to better serve the needs of small acreage farms. Using the results from the small acreage model, a partial budget was used to examine the benefits and disadvantages of processing homegrown beef. Chapter 4 uses forage nutritional values and cattle nutritional requirements to further develop the model from Chapter 2. Chapter 5 discusses the potential use of the carbon credit market to develop a secondary stream of revenue for producers that own more than 500 acres of land. This discussion includes enterprise budgets for two types of contracts offered by a carbon credit company. Chapter 6 is the concluding discussion of the thesis.

1.3 Literature Review

Section 1.3.1 Mountain Region Characteristics

The Mountain West region is an expansive land mass in the western United States, consisting of Montana, Idaho, Wyoming, Colorado, New Mexico, Arizona, Utah, and Nevada (Winters-Michaud 2024). Much like the rest of the U.S. the Mountain Region has a distinct landscape, which influences agricultural practices in a region that contains a dry climate with limited precipitation, intense mountain ranges, and large masses of land. There are multiple challenges that this region faces, particularly the relatively low levels of rainfall, but despite this the region boasts a thriving and diverse agricultural economy. All across the U.S. there are thriving agricultural economies, however the methods used to produce crops and livestock differ significantly between contrasting regions of the county due to drastically different climates.

One of the largest impacts on pasture forage availability is the amount of precipitation received each year. In the Mountain Region, New Mexico and Arizona have the lowest precipitation levels with 10.86 inches and 11.07 inches respectively, while Idaho and Colorado have the highest precipitation levels with 22.17 inches and 19.03 inches respectively (Salas 2025). Due to the limited amount of rainfall, the need for irrigated pastures is more prevalent than in the eastern part of the country where water is abundant, and the pastures can sustain a larger number of livestock per acre. In the absence of irrigation, dryland pastures are found in the Western U.S. dryland pastures are less productive and result in lower stocking rates. This lower stocking rate is shown in the Mountain region through the average pasture acres per beef cow which is 49.02 acres and has resulted in 55% of total land being utilized for grazing (Dennis 2021). The high desert climate and limited precipitation of this region has made cattle grazing more challenging for producers, but ranchers have been able to adjust using alternative types of grazing and feeding management.

While every state within the Mountain Region has a diverse agricultural economy, the cattle and calves industry serve a significant role in each state's economy. In 6 out of the 8 states included in the Mountain Region the cattle and calves industry ranks as the 1st or 2nd largest percentage of agricultural sales, driving home the importance of the industry's contribution in each of these states. Colorado and Wyoming have two of the top-ranking cattle and calves industries within the Mountain Region where enterprises are considered in terms of sales (USDA National Agricultural Statistics Service 2022). Cattle and calves account for over 50% of total agricultural sales in Colorado and Wyoming (USDA National Agricultural Statistics Service 2022). The cattle and calves industry ranks as the second largest shareholder of agricultural sales in Montana, Idaho, New Mexico, and Utah (USDA National Agricultural Statistics Service 2022). While the pastures in the West may require more acres to support cattle, the wide-open spaces provide ample space to graze cattle and has led to the creation of a successful industry in each state.

Section 1.3.2 Types of Grazing

Over the centuries of cattle ranching, a wide range of grazing techniques have been developed. Every ranching operation is different and some grazing methods that are efficient and effective on one ranch may not be efficient on another ranch. Due to the vast differences between ranches, there are a multitude of ways to graze cattle including: continuous grazing, rotational grazing, swath grazing, corn stalk grazing, and marginal planting grazing.

Continuous grazing is a conventional grazing method where cattle are grazed on a large amount of pasture for the entire grazing season with no interruptions (*Rotational vs. continuous grazing*). With continuous grazing there is no resting time for pastures; however, this method is not labor intensive and is not as costly compared to other grazing systems (*Rotational vs. continuous grazing*). All forage in a pasture is not always palatable for livestock and in continuous grazing systems, livestock choose the most favorable forage available in the pasture often newly grown forage (Rinehart 2008). Overgrazing can be a challenge in continuous grazing systems. In the event of overgrazing, cattle struggle to meet their basic nutritional requirements and often need additional supplementation. As such, establishing and monitoring stock rates for continuous grazing pastures is crucial. Appropriate stocking rates also help prevent negative ecological effects such as rangeland degradation (Redfearn and Bidwell 2017).

One of the most important aspects to consider when using continuous grazing is appropriate stocking rates. Ensuring the correct stocking rates requires calculations that take forage availability into account and the amount of time cattle need to be grazed (Meehan et al. 2018). When grazing on planted and irrigated fields rather than native rangeland, utilization can be higher (Redfearn and Bidwell 2017). This is due to the selection of a high quality and grazing tolerant forage variety at the time of planting (Redfearn and Bidwell 2017). When calculating stock rate on native rangeland, the utilization assumption must be much lower in order to preserve the integrity of the pasture (Redfearn and Bidwell 2017). Optimum grazing allows for an ideal average daily gain, gain per acre, and the best forage utilization (Morgan et al. 2024). Undergrazing leads to increased plant maturity and decrease nutritive value, while overgrazing can lead to soil erosion, increased weeds, and the need to supplement feed (Morgan et al. 2024). The disadvantages of both undergrazing and overgrazing is the reason accurate stocking rate calculations are necessary.

Rotational grazing involves breaking down large areas of pastures into smaller sections and moving cattle according to a schedule. Some researchers argue that rotational grazing is a way to imitate seasonal grazing patterns of ruminants that roamed the United Stated before settlers began fencing livestock (DeRamus 2004). The benefits of rotational grazing from a producer's perspective are optimizing forage production, meeting nutrient requirements of cattle, and feed budgeting (DeRamus 2004). Some ecological benefits from rotational grazing include reducing soil erosion, increased plant persistence, and reduced methane emissions of 22%

(DeRamus 2004). Due to the ecological benefits of rotational grazing, there are a variety of incentives from government programs sponsored by the Natural Resources Conservation Service (NRCS) that could offset additional costs. Rotational grazing has been shown to increase carbon sequestration in the soil (*Rotational Grazing for Climate Resilience* 2025). Experimental research of rotational grazing systems has varied, with some years resulting in sequestered carbon but not all years (Farm 2015). This shows the potential for carbon sequestration but also highlights the need for more experimental research over a longer time frame (Farm 2015). The additional carbon in the soil from rotational grazing creates the potential to access the carbon market. Government incentives and carbon credit sales have the potential to offset the additional costs of rotational grazing and present the possibility to increase profitability.

Rotational grazing is more labor and cost intensive when compared to other grazing types. In Windh's 2019 economic cost analysis of rotational grazing it was determined that the cost of switching to rotational grazing would cost $27,300 for a 3,200 acre study area (Windh et al. 2019). This cost would include permanent cross fencing, additional water sources, and labor needed for weekly cattle checks (Windh et al. 2019). Another option for switching to rotational grazing would be using electric fencing rather than permanent fencing. Electrical fencing, additional water sources, and labor in the study area would cost $17,150 (Windh et al.).

Producers with multiple enterprises, such as hay and cattle production, there is the option to swath graze cattle. This grazing practice refers to a hay producer skipping the baling process of harvesting and instead releasing cattle onto the hay field to graze (Harty and Amundson 2023). This method reduces harvesting costs such as labor and machinery (Harty and Amundson 2023). Other benefits include providing cattle with very high-quality forage and reducing cattle feed costs (Harty and Amundson 2023). A drawback to this method is losing the ability to sell hay in the cash market. However, there is potential to offset the loss of income in the hay enterprise by reducing costs in the cattle enterprise.

Another viable option for multiple enterprise producers is to graze cattle on corn stalks. Following the harvest of corn there is often leftover corn residue that can either be tilled back into the field or left alone. Leftover corn residue can be used to graze cattle and reduce the need to supplement cattle with hay (Rasby 2020). Despite a decreased need to supplement hay, supplements for salt, minerals, Vitamin A, and protein are recommended (Rasby 2020 and Funston et al. 2009). In a study done in Nebraska, cattle were able to be grazed on corn residue from mid-November to mid-February (Rasby 2020). This grazing time frame is dependent on stocking rate, number of acres, and corn yield (Funston et al. 2009). One downside to this method is the reliance on weather to determine grazing days (Rasby 2020). This method capitalizes on reducing waste and adding value to land that would have been otherwise dormant in between corn growing seasons.

The last grazing practice that this paper will explore is marginal planting which is where pastures are supplemented with a high protein legume. Improving the forage quality of a pasture can be done by mixing in a high protein legume seed such as red or white clover or alfalfa or lespedeza (Geist 2025). Only planting a percentage rather than the entire pasture makes this practice cost efficient due to a lower required amount of seed. An improvement in forage quality could lead to increased performance in cattle and can stretch grazing times on pastures (Beckman 2021). The downside of this practice is the additional labor and added expense of legume seeds; however, this cost could potentially be offset by a more productive and higher quality pasture (Geist 2025). Water availability also needs to be considered for this method to be beneficial.

There are many ways to graze cattle beyond the methods mentioned above and not every grazing method will be beneficial to the producer. Personalized grazing methods are important when considering how a rancher should operate and when enterprise decisions are made. Continuous grazing, rotational grazing, swath grazing, corn stalk grazing, and marginal planting grazing are just a few methods a producer can explore to help improve their cattle ranching operation.

CHAPTER 2: OPTIMIZED ROTATIONAL GRAZING SCHEDULE

In many rotational grazing systems, the schedule for rotation is set to a fixed number of days (Filley and Ates 2025). This fixed schedule approach is based on a general rule of thumb revolving around grass height. Since grass height is an observable characteristic, it can be subjective and potentially lead to misuse of a pasture in the form of under-grazing or over-grazing. In either case, there could be negative impacts on pasture health reproductive and forage production.

It is vital that pasture be grazed during the proper stage of development in order to provide the appropriate amount of nutrients and palatability (Moore et al. 1991). The four growth stages of forage grasses are germination, vegetative, elongation, and reproductive. The germination stage is the beginning of the plant cycle; it begins when the seed is planted in the soil and ends when the main tiller is sprouted (Moore et al. 1991). The vegetative stage focuses on development above the soil, beginning with the first leaf and ending with stem elongation (Moore et al. 1991). Grazing should occur at the three-leaf stage within the vegetative stage (Johnston 2018). The elongation stage is when nodes develop and elongate but ends with the boot substage (Moore et al. 1991). The reproduction stage begins when the inflorescence surfaces and starts to flower (Moore et al. 1991). Grazing in between the vegetative and elongation stage is the most effective stage for palatability and regrowth. During the elongation stage, forage matures and begins to have an increase in the number of stems present which is not as palatable to cattle (Peters 2010). The delicate balance of the developmental stages of forage is why accurate grazing must be implemented into a livestock management system.

Growing degree days (GDD) are often used to determine the development stage of the plant by using air temperature to calculate the accumulation of ideal growing days (Woodmansee

2025). GDD is a value that subtracts a specific base number for a crop from the average air temperature per day (Hall 1995). Due to Colorado's climate and common forages used in the region, the model assumption is that the forage is an irrigated cool-season grass with a base temperature of 40ºF (Woodmansee 2025). By understanding and tracking GDD, a producer will have the ability to meet cattle nutrient requirements while maintaining healthy grazing lands.

A fixed rotation schedule that is based on the calendar year rather than air temperature and precipitation does not allow for the flexibility that forage often times requires (Morgan et al. 2024 and Filley and Ates 2025). While a fixed rotation schedule may still work, incorporating weather and soil conditions into a rotation scheduling decision model will optimize pasture availability. This decision model will determine how long a section of pasture should be grazed and how long it should be rested all based on growing conditions. One goal of an optimized grazing schedule is to stretch grazing and avoid purchasing hay earlier in the year. To determine if an optimized grazing schedule will benefit producers by extending the grazing season, then a schedule needs to be made for both scenarios.

2.1 Continuous Grazing Schedule

In this scenario, it is assumed that there are 300 acres of irrigated cool season grass pasture that will be grazed uninterrupted by 100 cow-calf pairs. To ensure that the pasture is in the correct stage of growth when grazing needs to begin, growing degree days (GDD) are calculated and accumulated to a goal of 500 GDD (Ehlert and Johnson 2021). When calculating GDD a base must be determined for the type of seasonal grass, in this case a cool season base of 40ºF was used (Woodmansee 2025). To calculate the GDD per day, the predetermined cool season base was subtracted from the average air temperature (Hall 1995). Daily temperature data from the Soil Climate Analysis Network (SCAN) under the Natural Resources Conservation

Service (NRCS) is the dataset used for the calculation of GDD. Initial available forage at the start of grazing is assumed to be 2,000 pounds per acre for an irrigated pasture of introduced grasses (*Estimating Carrying Capacity of a Pasture* 2025). To avoid overgrazing, a forage threshold must be determined. It is recommended for cool season grasses that 4 inches be left behind to allow for new growth, this converts to a threshold of 800 pounds per acre (*Stand Evaluation* 2025). A set acreage amount was determined to be 300 acres, which is less than the average ranch size in Colorado but more applicable to the assumed scenario of an irrigated pasture. Cattle consumption is assumed to be 26 pounds per cow-calf pair per day (*Livestock Management* 2025).

Table 2.0. Continuous Grazing Schedule Model Parameters for Large Scale Operations

Parameter	Value	Units
Total Acres	300	Acres
Number of Cattle	100	Head
Initial Forage	2,000	Lbs/Acre
Forage Threshold	800	Lbs/Acre
Forage Consumption	26	Lbs/Head/Day
GDD Goal	500	GDD

This continuous grazing model utilizes a daily simulation loop which tracks the accumulation of daily GDD values and decreases the pasture by total daily cattle consumption. When accumulated GDD reaches the goal of 500 GDD, the model will initiate grazing and record the start date. Each day the available forage is decreased by cattle consumption and checked to determine if the forage threshold of 800 pounds per acre is reached. On the day that the threshold is reached, grazing is stopped, and the end date is recorded. Continuous grazing schedules for the years 2018 to 2023 are listed in Table 2.1. Grazing for each year within the dataset began in either the second or third week of May and ended in either the last week of September or the first week of October. If implementing continuous grazing on their operation and if a producer intends to hold cattle for market until December, then supplemental feed would be required. However, a producer can market cattle immediately following the grazing end date and avoid additional supplemental feed costs.

Table 2.1. Continuous Grazing Schedules for Large Scale Cattle Operations

Year	Start Date	End Date
2018	5/13/2018	9/28/2018
2019	5/26/2019	10/11/2019
2020	5/14/2020	9/29/2020
2021	5/24/2021	10/9/2021
2022	5/17/2022	10/2/2022
2023	5/23/2023	10/8/2023

2.2 Rotational Grazing Schedule

Rotational grazing offers a way for producers to manage their pastures effectively and sustainably while simultaneously extending their grazing season to be able to hold calves longer if they wish. This rotational grazing model simulates an optimized grazing schedule using growing degree days (GDD), which estimates plant growth based on air temperature. Using the same SCAN daily temperature data as in the continuous grazing model from NRCS, the model determines when pastures can begin grazing, the amount of time cattle remain in each pasture before reaching the forage threshold, and when pastures recover enough to be grazed again. The goal of this model is to optimize pasture usage, prevent overgrazing, and maximize forage availability.

Traditional continuous grazing does not allow for this critical resting period that allows for healthier plants that can recover faster from less than ideal environmental conditions (*Rotational vs. continuous grazing*). Continuous grazing allows cattle to be selective when choosing what forage to eat, by using rotational grazing techniques cattle are forced to eat forage more uniformly (Filley and Ates 2025). Due to the benefits of rotational grazing, some producers have decided to utilize this type of management system. However, many management intensive grazing systems rely on fixed schedules based on the number of calendar days in between cattle movements rather than pasture growth and weather (Filley and Ates 2025). The approach used in our model accounts for climate variability and provides a more accurate schedule for moving cattle. By using a dynamic model that accounts for GDD accumulation and forage consumption rates, decision-making is more informed and decreases the chances of inaccurate grazing patterns. Implementing a structured grazing model will increase pasture efficiency.

Section 2.2.1 Model Assumptions

This optimized rotational grazing model is in its most simple form which leads to assumptions that allow it to function. There are 10 pastures on this simulated ranch, each of which are 30 acres meaning the simulation ranch encompasses 300 acres. As established in the continuous grazing model, the number of cattle are a set parameter of 100 cow-calf pairs. Cattle consumption is assumed to be fixed in this scenario and based on cow-calf daily nutrient requirements, which is assumed at 26 pounds per cow-calf pair per day (*Livestock Management* 2025).

Growing degree days (GDD) is calculated using the minimum and maximum air temperatures from NRCS SCAN data and a species-specific cool season base temperature of 40ºF (Woodmansee 2025). Adding minimum and maximum air temperatures together, then dividing by 2, and subtracting the base will result in the daily GDD values (Hall 1995). Using daily GDD values, accumulated GDD can be calculated to determine starting dates and recovery periods for each pasture. The GDD goal to initiate grazing is set to 500, which means that the pasture grass will be in the elongation stage and in the ideal stage for grazing cattle (Ehlert and Johnson 2021 and Moore et al. 1991). The recovery GDD goal to initiate re-grazing is set to

1000, which is assumed to result in only 1 inch of growth since cool-season grass growth slows dramatically during the warmer months (*Cool-Season or Warm-Season Grasses* 2025).

Initial available forage at the start of grazing, when the GDD goal is met, is 2,200 pounds per acre for an irrigated pasture of introduced grasses (*Estimating Carrying Capacity of a Pasture* 2025). The continuous grazing model assumed that initial forage would be 2,000 pounds per acre. Rotational grazing decreased cattle selectivity of forage which leads to more available forage at the start of grazing (Filley and Ates 2025). The forage threshold remains the same as it was in the continuous grazing model at 4 inches of growth left ungrazed to allow for proper root and stem recovery, which is 800 pounds of forage per acre per acre (*Stand Evaluation* 2025).

Table 2.2. Rotational Grazing Schedule Model Parameters for Large Scale Operations

Parameter	Value	Units
Total Acres	300	Acres
Number of Cattle	100	Head
Initial Forage	2,200	Lbs/Acre
Forage Threshold	800	Lbs/Acre
Forage Consumption	26	Lbs/Head/Day
GDD Goal	500	GDD
Number of Paddocks	10	Paddock

This rotational grazing model utilizes a daily simulation loop which tracks the accumulation of daily GDD values and decreases the pasture by total daily cattle consumption. When accumulated GDD reaches the goal of 500 GDD, the model will initiate grazing on pasture 1 and record the start date. Each day the available forage is decreased by total daily cattle consumption and checked to determine if the forage threshold of 800 pounds per acre is reached. On the day that the threshold is reached, grazing is stopped, the end date for pasture 1 is recorded, and cattle are moved to pasture 2. This process is continued for all 10 pastures. It is important to note that the start date of the next pasture is also the end of the previous pasture to ensure that there are no grazing gaps in the model. A model that has a grazing gap would not be a good representation of actual ranch practices.

Once an end date for a pasture is established, the model will begin to calculate accumulated GDD which represents a recovery period. We assume that each pasture needs 1,000 accumulated GDD before it is replenished enough to graze (Ehlert and Johnson 2021). When the recovery GDD is met, the model assumes the pasture has an additional 1 inch of growth and is available for re-grazing (*Cool-Season or Warm-Season Grasses* 2025). To ensure that pastures are regenerated properly, GDD accumulation begins right after the end of grazing. The end date for each repeated grazing period of a pasture is recorded when that pasture meets the established grazing threshold. The final end date for grazing occurs and is recorded when a pasture has reached the grazing threshold, but the next pasture has not met the GDD goal. Through this simulation loop, a dynamic rotational grazing schedule is created.

Section 2.2.2 Model Implementation

This model is implemented through R software and contains a daily simulation loop. This simulation loop tracks and updates pasture conditions using temperature data, forage consumption, and pasture recovery status. The temperature data and recovery status are dependent upon NRCS SCAN data that was used to calculate daily GDD values which is accumulated and tracked through the simulation loop. Accumulated GDD values are the driving factor of initiating pasture grazing and recovery.

To begin the simulation, the model reads minimum and maximum air temperature values from a NRCS SCAN dataset and calculates daily GDD values. The model will then track accumulated GDD and initial grazing once GDD reaches the predetermined goal of 500 GDD.

The pasture set up is a rotational grazing system that is divided into 10 pastures of equal size stretching across a total of 300 acres.

At the core of this model is a daily loop that has key functions and checks key questions that occur on every iteration. The functions and questions work together as part of a systematic flow which allows the model to run smoothly. The first function that occurs is to retrieve the daily GDD amount and add it to the GDD accumulation variable for every pasture. The next occurrence is a check that determines if a pasture has been grazed and if it has reached the goal GDD. If the pasture has not been grazed and has not reached the goal GDD then it will continue to rest and accumulate GDD. If the pasture has not been grazed but has met the GDD goal, then grazing is initiated. The next key function that happens is a simulation of cattle forage consumption. If a pasture is being grazed, then the forage level will be decreased by the daily cattle consumption of 2,600 pounds. After this function is performed, a threshold check occurs. When a pasture is being grazed, the loop will check when the grazing threshold of 800 pounds per acre is met, grazing will stop for the current pasture and move to the next. As soon as grazing ends in a pasture the recovery period will begin by tracking GDD accumulation once again. Each day the model tracks GDD accumulation for the pastures in the recovery phase and alerts when the pasture has reached the recovery GDD goal. When the recovery GDD goal is met, the initial forage levels are assigned, and grazing can initiate again. This simulation loop is repeated every day in the dataset. The model output is a grazing schedule that includes pasture ID, start date, and end date.

A rotational grazing schedule was created for the past 5 years, 2018 to 2023, as seen in Table 2.3 to Table 2.8. Each year resulted in grazing that extended into the third or fourth week of November. Which allows for a producer to market calves at a later date or to at least reduce feed costs for cows kept on the operation. Since the model has a daily calculation of GDD accumulation and forage consumption, it can be used as a production tool that would alert the producer that it is time to move cattle. However, further development of this tool would be beneficial before the model is presented to producers in an extension setting. Next steps to further develop the model would include adding precipitation variables, changing cattle nutrient requirements depending on the time of year, and grazing on warm and cool season grasses rather than assuming all pastures are cool season grasses. Converting the model from R to an excel decision making tool would allow for a wider reach of producer users. Further research can be done to gather more accurate Colorado forage production data, using the systems that are already in place in the CoAgMET network. With these next research steps, this simple model could become a valuable decision making tool for cattle producers in Colorado.

Table 2.3. Rotational Grazing Schedule (2018) for Large Scale Cattle Operations

Paddock	Start Date	End Date	Start Date	End Date
1	5/13/2018	5/29/2018	10/29/2018	11/1/2018
2	5/29/2018	6/15/2018	11/1/2018	11/4/2018
3	6/15/2018	7/2/2018	11/4/2018	11/7/2018
4	7/2/2018	7/19/2018	11/7/2018	11/10/2018
5	7/19/2018	8/5/2018	11/10/2018	11/13/2018
6	8/5/2018	8/22/2018	11/13/2018	11/16/2018
7	8/22/2018	9/8/2018	11/16/2018	11/19/2018
8	9/8/2018	9/25/2018		
9	9/25/2018	10/12/2018		
10	10/12/2018	10/29/2018		

Table 2.4. Rotational Grazing Schedule (2019) for Large Scale Cattle Operations

Paddock	Start Date	End Date	Start Date	End Date
1	5/26/2019	6/11/2019	11/11/2019	11/14/2019
2	6/11/2019	6/28/2019	11/14/2019	11/17/2019
3	6/28/2019	7/15/2019	11/17/2019	11/20/2019
4	7/15/2019	8/1/2019	11/20/2019	11/23/2019
5	8/1/2019	8/18/2019	11/23/2019	11/26/2019
6	8/18/2019	9/4/2019	11/26/2019	11/29/2019
7	9/4/2019	9/21/2019		
8	9/21/2019	10/8/2019		
9	10/8/2019	10/25/2019		

10	10/25/2019	11/11/2019		

Table 2.5. Rotational Grazing Schedule (2020) for Large Scale Cattle Operations

Paddock	Start Date	End Date	Start Date	End Date
1	5/14/2020	5/30/2020	10/30/2020	11/2/2020
2	5/30/2020	6/16/2020	11/2/2020	11/5/2020
3	6/16/2020	7/3/2020	11/5/2020	11/8/2020
4	7/3/2020	7/20/2020	11/8/2020	11/11/2020
5	7/20/2020	8/6/2020	11/11/2020	11/14/2020
6	8/6/2020	8/23/2020	11/14/2020	11/17/2020
7	8/23/2020	9/9/2020	11/17/2020	11/20/2020
8	9/9/2020	9/26/2020		
9	9/26/2020	10/13/2020		
10	10/13/2020	11/30/2020		

Table 2.6. Rotational Grazing Schedule (2021) for Large Scale Cattle Operations

Paddock	Start Date	End Date	Start Date	End Date
1	5/24/2021	6/9/2021	11/9/2021	11/12/2021
2	6/9/2021	6/26/2021	11/12/2021	11/15/2021
3	6/26/2021	7/13/2021	11/15/2021	11/18/2021
4	7/13/2021	7/30/2021	11/18/2021	11/21/2021
5	7/30/221	8/16/2021	11/21/2021	11/24/2021
6	8/16/2021	9/2/2021	11/24/2021	11/27/2021
7	9/2/2021	9/19/2021	11/27/2021	11/30/2021
8	9/19/2021	10/6/2021		
9	10/6/2021	10/23/2021		
10	10/23/2021	11/9/2021		

Table 2.7. Rotational Grazing Schedule (2022) for Large Scale Cattle Operations

Paddock	Start Date	End Date	Start Date	End Date
1	5/17/2022	6/2/2022	11/2/2022	11/5/2022
2	6/2/2022	6/19/2022	11/5/2022	11/8/2022
3	6/19/2022	7/6/2022	11/8/2022	11/11/2022
4	7/6/2022	7/23/2022	11/11/2022	11/14/2022
5	7/23/2022	8/9/2022	11/14/2022	11/17/2022
6	8/9/2022	8/26/2022	11/17/2022	11/20/2022
7	8/26/2022	9/12/2022	11/20/2022	11/23/2022
8	9/12/2022	9/29/2022		
9	9/29/2022	10/16/2022		
10	10/16/2022	11/2/2022		

Table 2.8. Rotational Grazing Schedule (2023) for Large Scale Cattle Operations

Paddock	Start Date	End Date	Start Date	End Date
1	5/23/2023	6/8/2023	11/8/2023	11/11/2023
2	6/8/2023	6/25/2023	11/11/2023	11/14/2023
3	6/25/2023	7/12/2023	11/14/2023	11/17/2023

4	7/12/2023	7/29/2023	11/17/2023	11/20/2023
5	7/29/2023	8/15/2023	11/20/2023	11/23/2023
6	8/15/2023	9/1/2023	11/23/2023	11/26/2023
7	9/1/2023	9/18/2023	11/26/2023	11/29/2023
8	9/18/2023	10/5/2023		
9	10/5/2023	10/22/2023		
10	10/22/2023	11/8/2023		

2.3 Comparison Between Continuous and Rotational Models

The most significant differences between these two models is the multi-pasture tracking and the recovery period. The assumptions for both models are the same in many instances such as forage threshold, cattle consumption, total acreage, head of cattle, and GDD goal. Splitting the continuous pasture into 10 different pastures requires creating additional loops that track each pasture's GDD accumulation and consumption reduction. Tracking the recovery period requires adding more checks into the model that are similar to the initiation checks that start grazing at the beginning.

Initial forage is the only parameter that changes from the continuous to the rotational grazing model. Available forage at the start of the continuous grazing model is assumed to be 2,000 pounds per acre, while the initial forage for the rotational grazing model is 2,200 pounds per acre. This change in available forage is to account for the reduction of selectivity of forage among cattle when grazed under rotational grazing conditions (Filley and Ates 2025). Initial forage production does not increase because of rotational grazing; the parameter increases only due to cattle being forced to eat plants that they may find less palatable.

The results for these two models show that using rotational grazing with proper recovery periods allows for a longer overall grazing season. During the 2018 dataset, grazing starts on May 13th for both the continuous grazing model and the rotational grazing model. However, grazing ends September 28th under continuous grazing conditions and November 19th under rotational grazing conditions. Similar results are yielded for all other years in the dataset. Extending the grazing season gives producers the option to hold onto calves and wait for higher selling prices at a better weight. Keeping calves longer is a question often considered by producers and the price of hay is usually one of the deciding factors. Eliminating the need to purchase hay could potentially increase the revenue of each calf sold.

2.4 Economic and Ecological Considerations

Creating an optimized grazing schedule that focuses on efficiency can potentially result in reduced supplemental feed costs. A GDD-based model takes a step towards an accurate model that incorporates weather into grazing decisions in a quantitative way. Using GDD to initiate grazing allows for forage to develop adequately at the beginning of the growing season and during recovery periods. Grazing pastures when there is adequate forage helps prevent plant stress, soil erosion and overgrazing. An overgrazed pasture will not be as productive in future years and therefore using a model to prevent overgrazing will benefit a producer in the long run.

Year after year, a major expense for cattle producers is purchased feed when pastures have run out of available forage. By implementing an optimized grazing system, pastures can have proper recovery and regrowth which extended the grazing season in the simulated model. However, this model is heavily assumed and the ability to extend the grazing season is considered theoretical until further research and experimental studies are performed. Future field trials would be necessary to validate these findings under real-world conditions. These conditions could include, but are not limited to, weather variability, soil health, and forage composition.

Implementing a rotational grazing system also has additional costs associated with fencing materials. The upfront costs of adding fencing to your property will significantly outweigh the costs of hay for one year; however, over a longer period of time yearly fencing maintenance costs may be lower than yearly feed costs. Further analysis of costs and savings would provide more reliable guidance for producers seeking to transition to rotational grazing.

In recent years, there has been a push for agricultural producers to incorporate sustainable management practices into their operations. Rotational grazing is often considered a sustainable land management practice due to the development of deeper root systems which leads to less soil erosion (*Rotational Grazing for Climate Resilience* 2025). In some cases, rotational grazing has been seen to improve carbon sequestration, soil health, and drought resilience (*Rotational Grazing for Climate Resilience* 2025). Under proper pasture management, rotational grazing could lead to increased forage and higher quality feed (Beetz and Rinehart 2010). When a single pasture is overgrazed, this can lead to a variety of problems including weed invasion, decreased soil health, and decreased cattle health (Ehlert et al. 2025). When cattle have the option to only eat the desirable forage, they will leave weeds to grow uncontrolled which could lead to an unhealthy pasture in the future (Ehlert et al. 2025). Allowing pastures to rest in between grazing periods aims to incorporate regenerative agricultural principles that focus on maintaining soil health, increase organic matter, and promote pasture biodiversity (*Rotational Grazing for Climate Resilience* 2025).

The grazing schedule determined by this model provides a data-driven approach to rotation grazing which incorporates daily temperatures that are used to determine optimal growing conditions for cool season grasses. Tracking GDD accumulation helps determine current pasture conditions, it allows for accurate and efficient decision making in regard to livestock rotation and forage utilization. Using a model that adapts to environmental changes results in a dynamic model that is more accurate than grazing decisions based on objective pasture conditions. By increasing the accuracy of pasture management, producers are able to extend their grazing season which in turn will reduce supplemental feed costs and promote sustainable land management techniques. This model offers the ability to adjust parameters and analyze scenarios with different amounts of cattle, pasture sizes, and forage type. An adaptable and flexible tool provides a decision-making tool for producers on a multitude of different scales. Through the use of plant growth principles, this model results in a solution for livestock producers to implement rotation grazing. Implementing rotational grazing could result in long term reduced costs and ecological benefits for the pasture acreage. Integrating both economic and ecological considerations ensures that environmental parties and the producers are served in a positive light.

CHAPTER 3: SMALL ACRE APPLICATIONS

A majority of this paper has focused on cow-calf operations on a large scale, but only 22% of Colorado farms are over 500 acres (USDA National Agricultural Statistics Service 2022). The substantial portion of cattle producers that reside on small acreage shows that these producers are not operating to provide themselves with a full-time income from cattle ranching. Often, smaller producers raise cattle as a way to maintain a certain type of lifestyle that aligns with the traditions of agriculture or to provide their families with homegrown beef or to diversify their enterprise. While both large- and small-scale producers usually operate on close margins, management decisions differ between the two due to resource availability, economic goals, and production goals. Consequently, the models and decision-making tools for both types of operations should be adjusted to better fit the unique challenges they face.

In the rural mountains of Fremont County, Colorado, over 70% of farms are under 50 acres, with 41% percent of farms being less than 10 acres (USDA National Agricultural Statistics Service 2022). While a portion of these small farms are dedicated to fruit tree production and other crops prevalent in Fremont County, farms under 10 acres have cattle as a means of personal consumption (USDA National Agricultural Statistics Service 2022). No matter what the scale of production, profit margins are still important but small farms tend to have other goals relating to food security, self-sufficiency, and sustainable land management practices. While small farms may not meet the acreage requirements to participate in carbon credit programs, there are other subsidized programs that are available to them (Grassroots Carbon 2023). Programs such as the Environmental Quality Incentive Program (EQIP) do not have minimum acre requirements and provide subsidies for producers implementing sustainable agricultural practices. Even with limited land and resources, small producers are often motivated to implement regenerative agricultural practices that reduce input costs, optimize land use, and maintain soil health.

In this section, the theoretical rotational grazing schedule model is altered to better serve the needs of a small acreage cattle producer. Small acreage producers are often limited by their resources such as land, capital, and other livestock inputs (Manono 2025). Large-scale producers will also face similar challenges in these areas but how to manage these problems will change because of the different herd sizes. A small acreage producer, especially in the scenarios created for this paper, will only have 2 to 3 head of cattle and cannot afford death loss in their operation. Each grazing system is unique in order to best serve the operation which is why systems for small acreage ranches will differ greatly from large acreage ranches. The results presented from the optimized rotational grazing schedule section of this paper revealed that the use of pastureland could, in theory, be increased under certain circumstances. When strategically moving cattle through paddocks, forage is allowed to rest and regrow which can lead to more efficient forage use (Beetz and Rinehart 2010).

In order to adapt this model for a small acreage operation with just a few acres of pasture supporting a limited number of cattle, the model was adjusted to test whether supplemental hay feeding could be reduced or eliminated altogether, with pasture forage taking on a greater share of the nutritional burden. Rotational grazing will limit forage selection and introduces scheduled rest periods in each paddock (Filley and Ates 2025). These key changes from conventional grazing practices will increase forage availability, sustainability, and long-term ecological benefits (Beetz and Rinehart 2010). The theoretical results of the model suggest that the grazing season can extend into the first parts of the winter under rotational grazing conditions. By extending the grazing season into the early winter months the need to supplement forage with hay decreases and improves feed efficiency.

Using the output from the theoretical model, a partial budget analysis was conducted to determine the economic impacts and value of transitioning from purchasing beef at the grocery store to raising cattle for personal consumption. The purpose of a partial budget is to examine the additional costs and savings associated with a decision. The partial budget analysis revealed a net gain when substituting from store-bought beef to home grown beef. However, this financial gain is present due to the extended grazing season replacing supplemental feed costs.

3.1 Small Acreage Rotational Grazing Model

To better serve the needs of small-acreage cattle operations, the theoretical model for an optimized rotational grazing schedule can be adjusted by modifying key parameters. The parameters that must be reduced to accommodate a small-scale operation are total acreage, herd size, and daily forage consumption. Total acreage and herd size must be decreased in order to portray a more accurate picture of the operations grazing system. It is assumed that the pasture in this scenario is 2 acres of irrigated, introduced cool season grass. Many farm properties under 10 acres may be comprised of more than 2 acres; however, not all of the acreage is grazable. Assuming that the property has at least one house, a small shop, and driveways, 2 acres of irrigated pasture is a reasonable assumption for a small acreage producer. In the case of a small-scale producer only wishing to raise beef for family consumption, there is not a need for more than one steer. Forage consumption is reduced because it is assumed that this operation will be feeding a feeder steer which will consume less per day than a cow-calf pair (*Livestock Management* 2025). The daily forage consumption is assumed to be 15.6 pounds per day for a yearling feeder steer (*Livestock Management* 2025). This model will determine strategic rotational grazing practices that could improve pasture productivity and reduce feed costs by simulating grazing patterns, recovery periods, and seasonal variations.

Table 3.0. Rotational Grazing Schedule Model Parameters for Small Scale Operations

Parameter	Value	Units
Total Acres	2	Acres
Number of Cattle	1	Head
Initial Forage	2,200	Lbs/Acre
Forage Threshold	800	Lbs/Acre
Forage Consumption	15.6	Lbs/Head/Day
GDD Goal	500	GDD
Number of Paddocks	3	Paddock

The model implementation was established in Chapter 2 and remained unchanged when applied to a small-scale operation. Using the adjusted parameters, a small-scale rotational grazing schedule is created for the years 2018 to 2023, as seen in Table 3.1 to Table 3.6. Each year, the grazing season was able to be extended into the last week of November or the first week of December. Additional days on pasture will allow the producer to finish their steer on grass before sending them to be processed.

Table 3.1. Rotational Grazing Schedule (2018) for Small Scale Cattle Operations

Paddock	Start Date	End Date	Start Date	End Date
1	5/13/2018	7/11/2018	11/8/2018	11/17/2018
2	7/11/2018	9/9/2018	11/17/2018	11/26/2018
3	9/9/2018	11/8/2018		

Table 3.2. Rotational Grazing Schedule (2019) for Small Scale Cattle Operations

Paddock	Start Date	End Date	Start Date	End Date
1	5/26/2019	7/24/2019	11/21/2019	11/30/2019
2	7/24/2019	9/22/2019		
3	9/22/2019	11/21/2019		

Table 3.3. Rotational Grazing Schedule (2020) for Small Scale Cattle Operations

Paddock	Start Date	End Date	Start Date	End Date
1	5/14/2020	7/12/2020	11/9/2020	11/18/2020
2	7/12/2020	9/10/2020	11/18/2020	11/27/2020
3	9/10/2020	11/9/2020		

Table 3.4. Rotational Grazing Schedule (2021) for Small Scale Cattle Operations

Paddock	Start Date	End Date	Start Date	End Date
1	5/24/2021	7/22/2021	11/19/2021	11/28/2021
2	7/22/2021	9/20/2021	11/28/2021	12/7/2021
3	9/20/2021	11/19/2021		

Table 3.5. Rotational Grazing Schedule (2022) for Small Scale Cattle Operations

Paddock	Start Date	End Date	Start Date	End Date
1	5/17/2022	7/15/2022	11/12/2022	11/21/2022
2	7/15/2022	9/13/2022	11/21/2022	11/30/2022
3	9/13/2022	11/12/2022		

Table 3.6. Rotational Grazing Schedule (2023) for Large Scale Cattle Operations

Paddock	Start Date	End Date	Start Date	End Date
1	5/23/2023	7/21/2023	11/18/2023	11/27/2023
2	7/21/2023	9/19/2023	11/27/2023	12/6/2023
3	9/19/2023	11/18/2023		

3.2 Small Acreage Partial Budget

Partial budgets are often used to make business decisions on a multitude of different operation sizes. Some instances where a partial budget would be preferred to a whole farm budget or an enterprise budget would be exploring different enterprises, alternative production practices, or buying equipment (Dalsted and Gutierrez 1990). In the case of the scenario small farm in Fremont County, the partial budget will be used to determine the economic impacts of raising your own cattle for beef or buying beef at the grocery store. A partial budget will consist of two columns: one measuring the positive effects of the proposed change and the other measuring the negative effects (Dalsted and Gutierrez 1990). The positive effects column consists of increased revenue and reduced costs (Dalsted and Gutierrez 1990). The negative effects column consists of decreased revenue and additional costs (Dalsted and Gutierrez 1990). Subtracting the total negative effects from the total positive effects will result in the net effect, also called the net gain or loss (Dalsted and Gutierrez 1990). Using the results from the partial budget will help the consumer make an informed decision about raising their own beef.

The first element of the positive effects column in the partial budget analysis represents the increased revenue generated by the proposed change in consumer patterns. In the evaluated scenario, the increased revenue is the monetary value of home-raised, grass-fed and grass-finished beef. To calculate the value of beef on a small acreage operation, an average of local direct to consumer prices were used. The quantity was determined based on the average processed weight of a grass-finished steer. The average hanging weight of a grass-finished steer is 500 pounds, which is 60% of live weight (Tracy 2025; Buseman and Saner 2024). Due to trimming and deboning, 30% of hanging weight is lost (Tracy 2025). The final quantity in pounds of processed and packaged beef is 350 pounds that came from an 850 pound live steer. Thus, the total revenue generated from raising and processing a steer, based on direct to consumer market prices and butcher shop quantities, was estimated at $2,275.00.

Table 3.7. Positive Effects: Increased Revenues

Item	Quantity (lbs)	Value ($/lbs)	Total
Full Processed Beef	350	$6.50	$2,275.00
		Total Increased Revenue	$2,275.00

The second element of the positive effects column in the partial budget analysis represents the decreased costs by no longer purchasing beef from a grocery store. The cuts analyzed in this section were determined because of their popularity among consumers. These cuts of beef include ribeye steak, New York strip steak, sirloin steak, top roast, bottom roast, chuck roast, brisket, tri-tip, stew meat, and ground beef. For each cut, the estimated annual household consumption quantities are based on estimations of factors which would affect beef consumption (Davis and Lin 2005). People living in rural populations eat 75.38 pounds per capita of beef per year (Davis and Lin 2005). This means rural populations eat 12.2% more beef than people living in Urban populations and 16.8% more beef than people living in Suburban populations (Davis and Lin 2005). The categories of beef cut types are broken down to processed, ground, stew, steak, beef dishes, and other cuts, with the largest category being stew meat (Davis and Lin 2005). Rural areas are the highest in every category except for processed beef and steak (Davis and Lin 2005). The quantities in pounds of each cut of beef was determined by multiplying the category total by four to represent an average family of four and then dividing that number by the number of line items in that category. The quantities of common steak cuts can be seen in the second column of Table 3.8. To calculate the value of each cut of beef, the quantities were multiplied by retail prices for USDA choice beef that were listed in the 2024 Beef Retail Price Report (United States Department of Agriculture, Agricultural Marketing Service 2024). It is important to note the reason for the price differences between the increased revenue and decreased cost portion. This is due to the use of direct to consumer prices in the increased revenues portion and USDA Retail prices in the decreased cost section. The combination of this data resulted in an estimated total grocery store cost savings of $1,733.09 for the average family of four.

Table 3.8. Positive Effects: Decreased Cost

Item	Quantity (lbs)	Value ($/lbs)	Total
Ribeye Steak	15.16	$11.00	$166.76
New York Steak	15.16	$8.06	$122.19
Sirloin Steak	15.16	$5.98	$90.66
Top Roast	8.28	$6.49	$53.74
Bottom Roast	8.28	$5.49	$45.46
Chuck Roast	8.28	$6.87	$56.88
Brisket	24.22	$5.29	$128.12
Tri-Tip	24.22	$7.99	$193.52
Stew Meat	49.4	$6.99	$345.31
Ground Beef (80%-89%)	133.28	$3.98	$5330.45
		Total Decreased Cost	$1,733.09

On the negative effects side of the partial budget, two categories are typically evaluated: decreased revenues and increased costs. In the scenario presented in this paper, excess beef supply is the only decreased revenue. The fully processed steer yields 350 pounds of packaged beef while a rural family of four will consume a total of 301.44 pounds of beef (Tracy 2025; Davis and Lin 2005). By subtracting the total beef consumption from the total beef production, the quantity of excess beef is 48.56 pounds. The value of this excess beef is determined by multiplying the quantity by the same price of $6.50/lb used to value the homegrown beef in the increase revenues portion of the partial budget. The total decreased revenue for this proposed change is $315.64.

The second component of the negative effects column is increased cost which includes several necessary expenditures associated with raising and processing a steer. These costs consist of a slaughter fee, processing fee, mineral supplements, vet supplies, pasture expenses, cattle purchase cost, winter hay, cold storage, and marketing. The slaughter fee is a flat fee of $100 per head and the processing fee is $1.10 per pound of hanging weight (Tracy 2025). Mineral supplement costs are $219.99 which is calculated using the retail price of commonly available mineral tubs and dosage recommendation appropriate for growing beef cattle (*Big R Mineral Tub Prices* 2025). A typical mineral tub is 225lbs with a daily consumption rate of 0.5lbs, meaning one mineral tub will provide a single steer with minerals for 450 days (*Purina Wind and Rain Mineral Tub* 2025). Vet supplies are estimated to be $31.41 and pasture expenses are estimated to be $145.83 from the most recent 2022 Colorado Cow-Calf Business Benchmark publication from Colorado State University Extension (Rhodes and Mooney 2022). The purchase price of the steer was based on Colorado auction prices for a 500 pound steer, reported in dollars per hundredweight for the month of October (Livestock Marketing Information Center 2025). The price for hay to feed in the winter months is $600.00 total and was determined using the USDA Colorado Direct Hay Report and a calculation for daily feed intake (United States Department of

Agriculture, Agricultural Marketing Service 2025). A processed whole beef will require larger cold storage space, assuming the small acreage producer already owns a chest or standing freezer, the increased electricity cost to run that freezer would be $54.78 (Farrelly 2024). If a producer chooses to market their excess beef directly to consumers, then those marketing costs would be $0.17/lb of live weight, which would equal $144.50 for an 850 pound steer (Kientzy et al. 2024). The total increased cost of raising a steer at home would be $3,081.11.

Table 3.9. Negative Effects: Increased Cost

Item	Quantity	Value ($/unit)	Total
Slaughter Fee	1	$100.00	$100.00
Processing Fees	500	$1.10	$550.00
Mineral Supplements	1	$219.99	$219.99
Vet Supplies	1	$31.41	$31.41
Pasture Expenses	1	$145.83	$145.83
Cattle Price	5	$246.92	$1,234.60
Winter Hay	3	$200.00	$600.00
Cold Storage	1	$54.78	$54.78
Marketing	850	$0.17	$144.50
		Total Increased Cost	$3,081.11

By combining total increased revenues and total decreased costs, the total positive effects resulted in $4,008.09. The negative effects column is $3,396.75, which represents the combined total of decreased revenues and increased costs. The difference between negative and positive effects is $611.34, which is the annual net gain. This suggests that transitioning to home-raised beef production under a rotational grazing system can provide both financial and food security benefits to small-acreage producers and rural families.

Now that we have considered a partial budget for switching to home grown beef, it is important to examine at which price point a consumer will consider becoming a producer. When the marginal cost of producing beef is less than the market price of beef, a small-acreage producer will switch to producing their own beef. However, this would only apply to consumers that already have access to land and the knowledge of raising beef or a resource to gain knowledge. If some existing factors are not in place, then the elasticity of substitution is low. The marginal cost of producing beef is calculated by dividing the sum of costs by the total weight of processed beef, as shown in the formula below. Table 3.10 defines and values the variables in the marginal cost formula.

$$Marginal\ Cost\ of\ Home\ Grown\ Beef = \frac{(S + PF + M + V + PE + CP + W + CS + M)}{PW}$$

Table 3.10. Marginal Cost Variables

Variable	Definition	Value
S	Slaughter Fee	$100.00
PF	Processing Fees	$550.00
M	Mineral Supplements	$219.99
V	Vet Supplies	$31.41
PE	Pasture Expenses	$145.83
CP	Cattle Price	$1234.60
W	Winter Hay	$600.00
CS	Cold Storage	$54.78
M	Marketing Costs	$144.50
PW	Processed Weight	350

Using the same costs from the partial budget, the marginal cost of raising beef for home use is $7.39/lb of processed beef. Using the same 2024 Beef Retail Prices from USDA as was used in the partial budget, the average cost across cuts of beef is $6.81/lb. According to the marginal cost calculation, it is not rational to switch from buying beef in the grocery store to raising beef at home. However, local Fremont County grocery store prices are much higher for certain cuts of beef than what USDA reports. For example, 80% lean ground beef in a 2025 grocery store is $7.23/lb (*Walmart Ground Beef Prices* 2025). An added benefit without a numeric value is knowing exactly what was put into your steer prior to being processed. When making a personal decision such as switching where your families' beef comes from, it is important to adjust a partial budget to fit the local scenario and personal needs of a producer.

CHAPTER 4: NUTRIENT CONTENT OF GRAZING FORAGES

The cattle industry revolves around a large number of cycles ranging from the market cycle that impacts prices to the reproduction cycle that directly influences production to the plant growth cycle that affects forage production. The reproduction cycle is broken down into five stages that influences the required amount of Total Digestible Nutrients (TDN), Crude Protein (CP), Calcium (Ca), Phosphorus (P), and Net Energy for Maintenance (NeM). Forage nutrient content also changes in a cycle according to which of the four stages of plant growth the forage is in (Moore et al. 1991). By analyzing the different cycles in the cattle industry, management practices can be refined to increase the efficiency of an enterprise. The model discussed earlier in this paper can be altered to include data related to cattle nutrient requirements and forage nutrient production. Adding this data will provide a more accurate rotational grazing schedule that is tailored to the needs of a cow-calf pair during different times of the year.

The five stages of the reproductive calendar are calving with lactation (stage 1), breeding with lactation (stage 2), early gestation with lactation (stage 3), mid gestation with weaning (stage 4), and late gestation (stage 5). If a producer decides on a spring calving, then the respective time frame for each stage would be January through March, April through June, July through August, September through October, and November through December. Under the assumption that the cow is 1,000lbs, the average dry matter intake throughout the year is 19.76lbs but the amount of dry matter required fluctuates depending on which stage of the reproductive cycle she is in (George et al. 2001). During stage 1, dry matter intake should be 20.60lbs, protein intake should be 12.14% dry matter, and Total Digestible Nutrients (TDN) should be 66.99% dry matter (George et al. 2001). During stage 2, dry matter intake should be 21.00lbs, protein intake should be 12.38% dry matter, and TDN should be 66.67% dry matter

(George et al. 2001). During stage 3, dry matter intake should be 19.50lbs, protein intake should be 10.26% dry matter, and TDN should be 58.97% dry matter (George et al. 2001). During stage 4, dry matter intake should be 18.10lbs, protein intake should be 7.18% dry matter, and TDN should be 48.62% dry matter (George et al. 2001). During stage 5, dry matter intake should be 19.60lbs, protein intake should be 8.16% dry matter, and TDN should be 53.57% dry matter (George et al. 2001). Once the nutrient requirements of the cow are obtained, the nutrient requirements of calves throughout the year are needed to gain a comprehensive understanding of cow-calf pair nutrition.

During the first 10 months of a calf's life their nutrient requirements change depending on their weight and pounds of average daily gain (ADG). For the purpose of this paper, the goal ADG is 2.0lbs. At this level of ADG, dry matter intake requirements tend to steadily increase while the percent of TDN remains constant and the percent of crude protein decreases (Beck et al. 2024). From January to October, the percent dry matter of TDN is 69% (Beck et al. 2024). From April to June, dry matter intake is 8.6lbs/day and protein intake is 16.2% dry matter (Beck et al. 2024). From July to August, dry matter intake is 10.7lbs/day and protein intake is 14.1% dry matter (Beck et al. 2024). From September to October, dry matter intake is 12.7lbs/day and protein intake is 12.8% dry matter (Beck et al. 2024). Having nutrient requirements for cows and calves allows for holistic analysis of the amount of forage needed based on protein and TDN values rather than just pounds of feed.

To accurately determine if the nutrient contents of forage meet or exceed the nutrient requirements of cattle, dry matter, crude protein, and total digestible nutrients for 3 common types of pasture forages are used for analysis. Bermuda, fescue, and native range are commonly grazed grasses, with readily available data, that have changing nutrient content throughout the growing and grazing seasons. For each of the three forages, TDN and crude protein spike during April and June which correlates to the beginning of the grazing season (Lalman and Holder 2024). Throughout every time frame of the year native range has the lowest crude protein content, even if TDN is not the lowest (Lalman and Holder 2024).

Table 4.0. Forage Nutrient Contents

	Dry Matter	Total Digestible Nutrients	Crude Protein
Bermuda (Jan-March)	90	47	7
Bermuda (April-June)	30	65	16
Bermuda (July-Aug)	35	60	13
Bermuda (Sept-Oct)	35	57	13
Bermuda (Nov-Dec)	85	54	11
Fescue (Jan-March)	60	40	11
Fescue (April-June)	29	64	18
Fescue (July-Aug)	33	57	12
Fescue (Sept-Oct)	70	49	8
Fescue (Nov-Dec)	40	52	13
Native Range (Jan-March)	85	49	4
Native Range (April-June)	30	70	14
Native Range (July-Aug)	35	64	10
Native Range (Sept-Oct)	46	59	7
Native Range (Nov-Dec)	75	55	5

Beck et al. 2024

To analyze nutrient content of forage versus the nutrient requirements of cattle, the data was plotted into line graphs. Cattle requirements for TDN are exceeded by all three forage types in July through August and November through December. In September through October, native range and Bermuda exceed cattle TDN requirements, while fescue falls short. Only native range meets the cattle TDN requirements in January through March. In April through June, cattle TDN requirements exceed the TDN availability in all three forage types. Cattle requirements for crude protein far exceed the available protein in forage from January until November. During November and December, fescue and Bermuda grasses exceed cattle protein requirements, but native range protein levels are still significantly below the needs of the cow-calf pair.

Chart 4.0. Yearly Change of Total Digestible Nutrients in Forage with Cattle Requirements

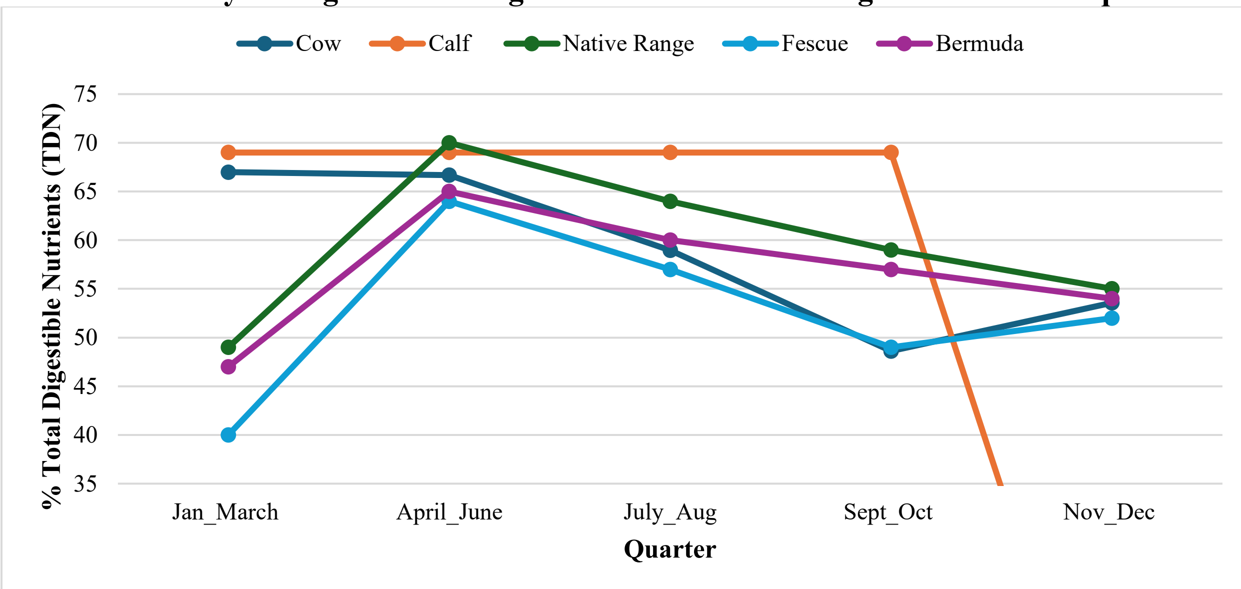
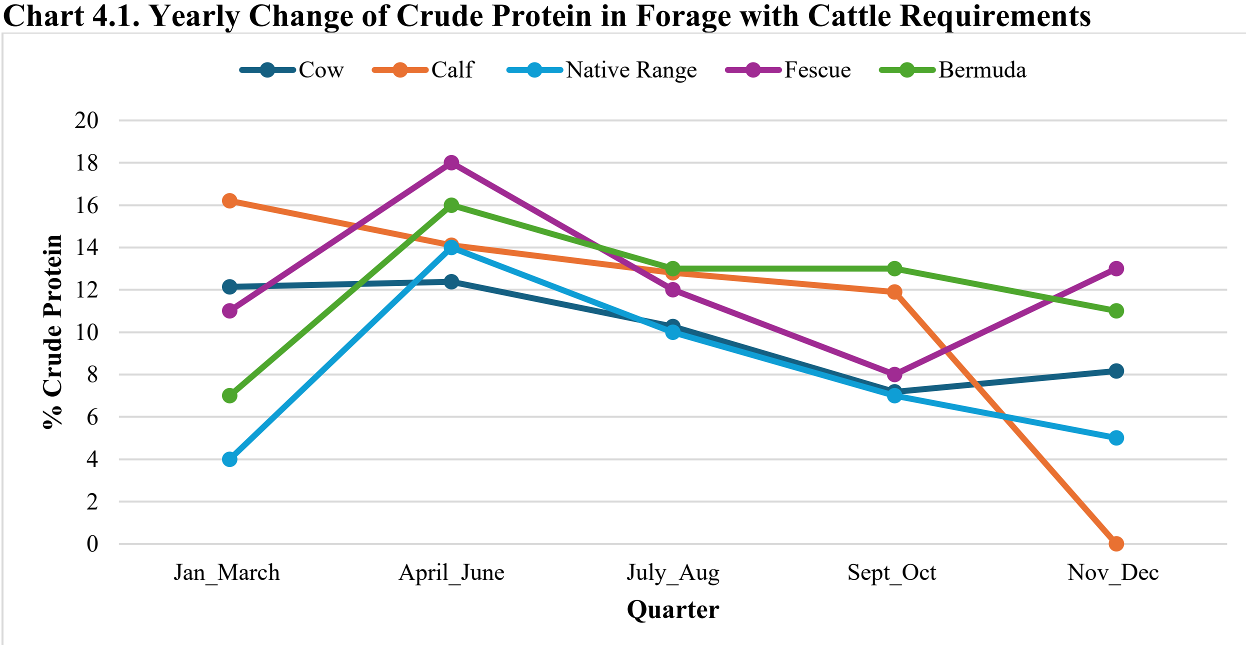


Chart 4.1. Yearly Change of Crude Protein in Forage with Cattle Requirements



It is important to note that the forage nutrient content data is from Oklahoma State University Extension Services. While introduced and irrigated forages are similar from state to state, there are still differences in nutrient content, forage production, and forage quality. Native range also differs drastically from Oklahoma to Colorado, where this paper is focused. The Colorado Climate Center has a network of weather data collecting stations across the state called the CoAgMET (CoAgMET 2025). These weather stations can lend a helping hand to future research that would involve analyzing the relationship between air temperature, precipitation levels, and soil temperature with forage growth. The CoAgMET has stations located in irrigated fields and rangeland (CoAgMET 2025). Data collection from CoAgMET paired with forage production data could create a unique dataset which could be related back to cattle nutrient requirements and provide Colorado producers a clearer understanding of their forage availability.

CHAPTER 5: GENERATING CARBON CREDITS THROUGH ROTATIONAL GRAZING

In recent years, there has been a large push for countries and corporations to reduce their carbon footprint. This push has led to international agreements and domestic policies that encourage companies and citizens to prioritize environmental goals, with a large focus on reducing carbon emissions. Carbon emissions add to greenhouse gases in the atmosphere which has led to global warming and the purpose of the Paris Agreement is to encourage countries to work together on this issue (Lindsey 2025). The 2015 Paris Agreement is established between nations and aims to limit the increase in global warming to 1.5°C (*The Paris Agreement* 2015). The Paris Agreement not only serves as global policy but also inspiration for countries to enact their own legislation to fight to reduce their carbon emissions.

In response to the push towards net zero carbon emissions, the carbon credit market has grown substantially. Carbon market currency consists of a credit that certifies a decrease in one metric ton of carbon dioxide that would have been contributed to atmospheric greenhouse gases (Grassroots Carbon 2023). Some companies produce significant carbon emissions and due to the nature of their operations are unable to decrease their emissions on their own, which leads to the need to purchase carbon credits to achieve net-zero emissions (*The Ultimate Guide to Understanding Carbon Credits* 2025). Since the only solution for certain companies to reach net-zero emissions is through the carbon market, there has been an increase in demand for carbon credits. The carbon market is expected to be 50 times as large in 2030 as it was in 2022, the value of the market changing from $2 billion to $100 billion (*Where the Carbon Offset Market is Poised to Surge* 2023). To meet this demand, any organizations that have the ability to reduce carbon emissions are encouraged to do so through social or financial incentives. Rotational grazing practices is one of the effective ways to reduce carbon emissions and generate carbon credits (*Rotational Grazing for Climate Resilience* 2025).

Regenerative agriculture practices, such as rotational grazing, is how cattle ranchers can gain a piece of the carbon market metaphorical pie. Switching from traditional continuous grazing to rotational grazing will store more carbon in the soil, reduce greenhouse gases, and thus generate carbon credits. Soil carbon levels in the soil can be measured, certified as a credit, and sold on the carbon market (Grassroots Carbon 2023). This process provides a financial incentive for ranchers to use the carbon market. Ranches that begin to measure their soil carbon levels before implementing rotational grazing may take longer to see the benefits of the carbon market, while ranches with existing rotational grazing systems will see more immediate results with generating carbon credits (Grassroots Carbon 2023).

Given the complex nature of the carbon market, it is more efficient for a producer to utilize a carbon company that can streamline and simplify the process. Companies such as Grassroots Carbon or Agoro Carbon Alliance assist with the measurement, certification, and selling of carbon credits which allows producers to focus on what is important to them, their operation. Carbon companies also provide resources for regenerative practices that could potentially help producers with questions they may have about their new systems. By partnering with carbon companies, ranchers are able to ensure that their carbon market ambitions are effective.

Grassroots Carbon works with entities in Colorado, such as the Colorado Cattlemen's Agricultural Land Trust, to provide information to help ranchers enter into the carbon market. Grassroots Carbon offers two different plans with opportunities for ranches under different scenarios. A 15-year program is offered for ranches that have existing regenerative practices in place while a 30-year program is offered to ranches planning to implement regenerative practices (Coit 2024). Both program options also include resources that indirectly affect profit, such as Grassroots' PastureMap which is an online management tool (Grassroots Carbon 2023).

The 15-year program consists of a 5-year selling period and a 10-year storage period. Payments are made in yearly increments where years one through four payments are based on a standard model and year five is a payment based on actual soil carbon (Coit 2024). Collaborating with a company has many advantages but one drawback is that a percentage of profit goes towards the carbon company; in this case the rancher receives 80% and Grassroots Carbon receives 20% (Coit 2024). Despite not all profit going directly to ranchers, using a company to sell carbon credits cuts down on other associated costs such as soil testing and allows access to management tools that are exclusively for Grassroots' partners. Ranchers that participate in the 15-year program typically profit $16.00 to $17.00 per credit (Coit 2024). In Colorado, rotational grazing practices can generate about 1 ton or less of soil carbon which equates to 1 credit or less per acre (Coit 2024).

The 30-year program is aimed at operations that do not already have regenerative agricultural practices in place. This program consists of a 10-year selling period and a 20-year storage period. Similarly to the 15-year plan, payments are made yearly but based on a dynamic baseline using historical data rather than a standardized model (Coit 2024). In the case of the 30-year program, ranchers receive 70% and Grassroots Carbon receives 30% of the profit generated from carbon credit sales (Coit 2024). An added benefit that accompanies the 30-year program is a Razor Grazer which will cut down on upfront fencing costs by providing an electrical fencing tool for pastures (Coit 2024). Pricing per credit also differs for this program with ranchers profiting $23.00 to $29.00 per credit (Coit 2024).

5.1 Enterprise Budget Incorporating Carbon Credits

The two enterprise budgets included with this paper are based on scenarios for a 50 head cow-calf operation located in Colorado where pastures are managed using rotational grazing. The two scenarios considered for this budget are an established rotational grazing ranch and a ranch that is implementing rotational grazing for the first time. The established ranch will begin the 15-year program through Grassroots Carbon, and the newly regenerative ranch will begin the 30-year program through Grassroots Carbon.

Section 5.1.1 Scenario Parameters

This sample ranch contains 50 head of cows that were bred by 2 bulls in the summer for a spring calving. Calf crop is assumed to be 90%, which leads to a 45 head calf herd with 23 steers and 22 heifers. With a 20% replacement heifer retention rate, 10 of the heifer calves will be retained to be bred next year. At a 15% cow replacement rate, 2 yearling heifers and 8 cull cows will be sold. The ranch established in the scenario for this enterprise budget is 800 acres of rotationally grazed pasture broken down to 20 paddocks that are 40 acres each.

Cattle will be fed on native dryland pasture from May to December under a rotational grazing system. All cattle, including cull cows and calves, will be marketed during the first week of December. From January to May cattle will be supplemented with high quality grass hay. Protein tubs are also provided for 3 months during the winter months with the worst weather. Mineral tubs are provided year-round so that cattle will meet their nutrient requirements.

Section 5.1.2 Data

Prices for cattle are a 5-year average (2019-2024) from the Livestock Marketing Information Center (LMIC) data spreadsheets. Colorado Feeder Cattle Auction Prices data sheet was used for per hundredweight steer and heifer calf prices. Colorado Slaughter & Replacement

Cow/Bull Prices was used for per hundredweight cull cow and bull prices, as well as bred heifer prices.

Section 5.1.3 Revenue from Cattle and Carbon Credit Production

Carbon credit production is assumed to be 1 credit per acre which is based on past data of other Colorado ranches from Grassroots Carbon. Using a median price per credit of $16, the total revenue per year for a 15 year contract period is $8,000. For the 30 year contract period, a median price per credit of $25 is used. The total revenue per year for a 30 year contract period is $12,500.

The first 4 years of the 15 year contract period will be a yearly payment of $8,000 which results in an estimated contract value of $32,000. This total contract value does not include the 5th payment year that will be based on the actual carbon levels in the soil. The first 9 years of the 30 year contract period will be a yearly payment of $12,500 which results in an estimated contract value of $112,500. This total contract value also does not include the 10th payment year that is based on actual carbon levels.

The revenue from cattle production is equivalent between the budgets for the 15 year contract and the 30 year contract. Animals planned to be sold are 45 steer calves, 25 heifer calves, 3 yearling heifers, 15 cull cows, and 1 cull bull for a total of 89 animals to be marketed in December. Average weights are assumed to be 600lbs, 550lbs, 800lbs, 1,100lbs, and 1,800lbs respectively. Per hundredweight prices are based on a 5 year average for Colorado auction feeder prices which are shown in Table 5.0.

Table 5.0. Revenue from Cattle Production

Item	Head	Average Market Weight (lbs)	Sale Price ($/cwt)	Per Head Value	Total Value
Steer Calves	45	600	$249.55	$1,497.30	$67,378.50
Heifer Calves	25	550	$237.67	$1,307.19	$32,679.63
Yearling Heifers	3	800	$2,680.79	$2,680.79	$8,042.37

Cull Cows	15	1,100	$104.29	$1,147.19	$17,207.85
Cull Bulls	1	1,800	$110.57	$1,990.26	$1,990.26
		Total Revenue from Cattle Production			$127,298.61

Section 5.1.4 Operating Expenses

Calves will receive a 7-way blackleg and Pasteurella vaccine at 4 months, a 7-way booster at weaning and a 5-way respiratory vaccine at weaning (*Recommended Vaccinations for Large Animals*). Cows will receive an annual 5-way respiratory vaccine that fights against IBR, BVD Types I and II, P13, and BRSV (*Recommended Vaccinations for Large Animals*). All cattle will receive a pour on Ivermectin treatment. All adult cattle, including replacement heifers, bulls, and cows will be wormed twice a year in the fall and the spring (*Recommended Vaccinations for Large Animals*). Calves will be wormed with pour on Ivermectin at weaning (*Recommended Vaccinations for Large Animals*). A vet service fee of $9.50 per head is included in the budget to account for calf dehorning and castration, as well as pregnancy testing and bull health testing.

The 35 calves will be marketed through an online video auction which reduces trucking costs due to cattle ownership being transferred once cattle are loaded on the truck from the ranch (Bastian et al. 2017). Costs associated with online marketing include a taping fee, beef checkoff fee, brand inspection, and health inspection (Bastian et al. 2017). Commission on the sale of cattle through video auction ranges based on the company used, some companies choose to charge a flat rate per head and others charge a percentage of the gross sale. In the scenario used for the enterprise budget, it is assumed that a 2% gross sales commission will be charged (Bastian et al. 2017).

In order to calculate taxes, the value of the land is needed first. Land value is calculated by multiplying the size of the ranch by the value of the land. The average value of pastureland in Colorado in 2024 was $1,830 per acre (*Land Values 2024 Summary* 2024). By multiplying the land value by a 1% tax rate, the total property taxes are estimated (Dyer et al. 2018). It is assumed that half of the operating capital is from an operating loan at a 4.875% interest rate (*Current FSA Loan Interest Rates* 2025). The average cash rent of pastureland in Colorado was $8.28 per acre in 2025 and was used to determine land costs for the budget (Beiermann et al. 2025).

Section 5.1.5 Summary of Enterprise Budget

The enterprise budget for the 15 year contract length resulted in total net receipts of $37,395.17 and per cow net receipts of $432.54. Which is a 78.6% and 81.5% increase, respectively, from net receipts without revenue from carbon credit marketing. The enterprise budget for the 30 year contract length resulted in total net receipts of $30,048.71 and per cow net receipts of $479.27. Which is a 58.4% and 73.9% increase, respectively, from net receipts without revenue from the carbon market.

CHAPTER 6: CONCLUDING DISCUSSION AND FUTURE WORK

In this study an optimized rotational grazing schedule was modeled to create and analyze an enterprise budget with carbon credit revenue, a partial budget for home-raised beef, and beef cattle nutrient requirements throughout the reproductive cycle. There is a large amount of research on the ecological benefits of rotational grazing, but the financial incentives have not been explored thoroughly. The theoretical work done in this paper shows that there can be financial benefits to implementing rotational grazing into both large- and small-scale ranching operations. For a large-scale producer, the use of the carbon market can diversify revenue and add a passive income to a ranch. For both size producers, rotational grazing can be used to stretch pasture, reduce supplemental feed costs, and potentially lead to late marketing of calves for a higher price.

While this model provides more informed and accurate decision making, there is potential to expand the model and increase accuracy. This model does not account for precipitation or soil temperature. Soil temperature and precipitation contribute to optimal grass growth and including them in the model will result in an even more accurate grazing schedule (Heckman and Krichels). Many of the forage assumptions in this paper were assumed using data from other states with similar climates. Future research to analyze forage production in Colorado in relation to weather conditions would be beneficial for more robust models to be created.

Comparison of optimized grazing schedules across several types of forage would be additional beneficial information for producers. Forage assumptions for this model are uniform for all 300 acres of the simulated ranch; it is assumed that all pastures consist of irrigated, introduced cool season grasses. Pastures that are a mix of cool season and warm season grasses could also help extend the growing season (Duiker and Williamson 2025). Different types of grass will allow a portion of the pasture to grow better in the spring and fall, while the other portion grows better in the heat of the summer (Pearson et al. 2011). Adding a separate warm season GDD tracker into the model will result in a more encompassing picture of actual Colorado grazing land. Forage quality can differ across types of forage. A model altered for higher quality forage will have a higher initial forage level and cattle consumption will also be higher (Little and Wiseman 2024). A model altered for a lower quality forage will have a lower initial forage level and cattle consumption will be less (Little and Wiseman 2024). Incorporating data for higher and lower quality forage into the model will give a wider view of the distinct types of forage in Colorado, how grazing changes with each type of forage, and allow more producers to have access to more accurate rotational grazing models.

It is important to note that the optimized grazing model in this paper provides a theoretical framework for creating a grazing schedule. The model is based on informed assumptions and is a simplified representation of grazing management. While this model attempts to account for climate variability and livestock consumption, real world conditions would introduce factors that were not originally accounted for in this model. Further case studies and experimental research could be conducted to provide real world data and provide the most accurate model. Field studies would provide empirical data that would serve to potentially validate predictions, identify discrepancies, and refine the chosen parameters. Integrating empirical data into the theoretical model would provide researchers with a way to create more robust decision-making tools that better reflect applicable grazing management strategies.

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APPENDIX A

1 Year Small Acreage Partial Budget
Colorado 2025
Proposed Change: Raise your own beef
Bought a 500lbs calf to feed to 850lbs

Positive Effects

Increased Revenues			
Item	Quantity (lbs)	Value ($/lb)	Total
Full Processed Beef	350	$ 6.50	$ 2,275.00
Total Increased Revenues			$ 2,275.00

Decreased Cost			
Item	Quantity (lbs)	Value ($/lbs)	Total
Ribeye Steak	15.16	$ 11.00	$ 166.76
New York Steak	15.16	$ 8.06	$ 122.19
Sirloin Steak	15.16	$ 5.98	$ 90.66
Top Roast	8.28	$ 6.49	$ 53.74
Bottom Roast	8.28	$ 5.49	$ 45.46
Chuck Roast	8.28	$ 6.87	$ 56.88
Brisket	24.22	$ 5.29	$ 128.12
Tri-Tip	24.22	$ 7.99	$ 193.52
Stew Meat	49.4	$ 6.99	$ 345.31
Ground Beef (80%-89%)	133.28	$ 3.98	$ 530.45
Total Decreased Cost			$ 1,733.09

Negative Effects

Decreased Revenues			
Item	Quantity (lbs)	Value ($/lbs)	Total
Excess Beef	48.56	$ 6.50	$ 315.64
Total Decreased Revenues			$ 315.64

Increased Cost			
Item	Quantity	Value ($/unit)	Total
Slaughter Fee	1	$ 100.00	$ 100.00
Processing Fees	500	$ 1.10	$ 550.00
Mineral Supplements	1	$ 219.99	$ 219.99
Vet Supplies	1	$ 31.41	$ 31.41
Pasture Expenses	1	$ 145.83	$ 145.83
Cattle Price	5	$ 246.92	$ 1,234.60
Winter Hay	3	$ 200.00	$ 600.00
Cold Storage	1	$ 54.78	$ 54.78
Marketing Costs	850	$ 0.17	$ 144.50
Total Increased Cost			$ 3,081.11

Total Positive Effects	$ 4,008.09
Total Negative Effects	$ 3,396.75
Annual Net Gain or Loss	$ 611.34

APPENDIX B

Beef Cow/Calf Rotational Grazing and Carbon Credit Enterprise Budget
Colorado 2025

Production Assumptions

Exposed Females		100
Cows per Bull		50
Cow Death Loss		2%
Cow Replacement Rate		15%
Bull Replacement Rate		25%
Weaned Calf Crop		90%
Percentage Steers	50%	
Replacement Heifers Retained		20%
Land		500

Production Summary

Total Calves Weaned	90
Steers	45
Heifers	45
Heifers Retained	20
Heifers Sold	25
Bred Heifers Sold	3
Number of Bulls	2
Total	192

Revenue from Cattle Production

Animal Type	Head	Avg. Mkt. Weight lbs	Net Sale Price $/cwt	Value Per Head $/hd	Total $	Per Cow $
Steers	45	600	$ 249.55	$ 1,497.30	$ 67,378.50	$ 673.79
Heifers	25	550	$ 237.67	$ 1,307.19	$ 32,679.63	$ 326.80
Bred Heifers	3	800	$ 2,680.79	$ 2,680.79	$ 8,042.37	$ 80.42
Cull Cows	15	1100	$ 104.29	$ 1,147.19	$ 17,207.85	$ 172.08
Cull Bulls	1	1800	$ 110.57	$ 1,990.26	$ 1,990.26	$ 19.90
Subtotal	89			$ 8,622.73	$ 127,298.61	$ 1,272.99

Revenue from Carbon Credit Production

	Credits /acre	Price $/credit	Value Per Acre $/acre	Total $	Per Cow $
Carbon	1	$ 16.00	$ 16.00	$ 8,000.00	$ 80.00
Subtotal			$ 16.00	$ 8,000.00	$ 80.00

Total Gross Revenue

	Total	Per Cow
Total	$ 135,298.61	$ 1,352.99

Operating Expenses

	Total	Per Cow
Feed and Supplements	$ 54,765.00	$ 447.94
Livestock Medical	$ 2,678.65	$ 17.90
Marketing	$ 3,062.17	$ 34.41
Labor	$ 16,000.00	$ 179.78
Pasture Expenses	$ 9,140.00	$ 102.70
Farm Expenses	$ 12,257.62	$ 137.73
Total Operating Expenses	$ 97,903.44	$ 920.45

Net Receipts

	Total	Per Cow
Net Receipts	$ 37,395.17	$ 432.54

APPENDIX C

Beef Cow/Calf Rotational Grazing and Carbon Credit Enterprise Budget
Colorado 2025

Production Assumptions

Exposed Females		100
Cows per Bull		25
Cow Death Loss		2%
Cow Replacement Rate		15%
Bull Replacement Rate		25%
Weaned Calf Crop		90%
Percentage Steers	50%	
Replacement Heifers Retained		20%
Land		500

Production Summary

Total Calves Weaned	90
Steers	45
Heifers	45
Heifers Retained	20
Heifers Sold	25
Bred Heifers Sold	3
Number of Bulls	4
Total	194

Revenue from Cattle Production

Animal Type	Head	Avg. Mkt. Weight lbs	Net Sale Price $/cwt	Value Per Head $/hd	Total $	Per Cow $
Steers	45	600	$ 249.55	$ 1,497.30	$ 67,378.50	$ 673.79
Heifers	25	550	$ 237.67	$ 1,307.19	$ 32,679.63	$ 326.80
Bred Heifers	3	800	$ 2,680.79	$ 2,680.79	$ 8,042.37	$ 80.42
Cull Cows	15	1100	$ 104.29	$ 1,147.19	$ 17,207.85	$ 172.08
Cull Bulls	1	1800	$ 110.57	$ 1,990.26	$ 1,990.26	$ 19.90
Subtotal	89			$ 8,622.73	$ 127,298.61	$ 1,272.99

Revenue from Carbon Credit Production

	Credits /acre	Price $/credit	Value Per Acre $/acre	Total $	Per Cow $
Carbon	1	$ 25.00	$ 25.00	$ 12,500.00	$ 125.00
Subtotal			$ 25.00	$ 12,500.00	$ 125.00

Total Gross Revenue

	Total	Per Cow
Total	$ 139,798.61	$ 1,397.99

Operating Expenses

	Total	Per Cow
Feed and Supplements	$ 54,765.00	$ 447.94
Livestock Medical	$ 2,678.65	$ 17.90
Marketing	$ 3,062.17	$ 34.41
Labor	$ 16,000.00	$ 179.78
Pasture Expenses	$ 20,350.00	$ 93.82
Farm Expenses	$ 12,894.07	$ 144.88
Total Operating Expenses	$ 109,749.89	$ 918.72

Net Receipts

	Total	Per Cow
Net Receipts	$ 30,048.71	$ 479.27