THE EFFECT OF ROTATIONAL GRAZING ON THE PERFORMANCE AND GRAZING BEHAVIOR OF COW-CALF PAIRS, AND THE EFFECTIVENESS OF FREQUENT HUMAN INTERACTION IN ALTERING THE TEMPERAMENT OF MATURE BEEF COWS

By

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Abstract: The objective of this study was to evaluate several of the reported benefits attributed to rotational grazing. Rotational grazing (**R**) was compared to continuous grazing (**C**), and grazing behavior, forage and diet quality, and forage production were analyzed. The stocking rate in C was 27% greater than in R. Using GPS collars attached to cows, uniformity of grazing distribution, distance traveled, mean distance to water, time spent near water, daily area explored, and the spatial search pattern was analyzed. Grazing method did not affect grazing distribution ($P > 0.23$). Time spent near water, mean distance to water, and distance traveled per day were also unaffected by grazing method ($P > 0.12$). The daily area explored was greater in the C treatment ($P = 0.02$), and spatial search pattern was greater in the R treatment ($P = 0.01$). Grazing method had no effect on forage utilization ($P = 0.64$), or NDF content of forage ($P > 0.25$). Forage production differed only in May, with C producing more kg/ha of forage ($P = 0.06$). Forage crude protein differed only in July, with C having greater crude protein ($P = 0.05$). Both ADF and lignin differed in May and December, with C having greater values for both ($P < 0.10$). Diet quality was greater in C ($P < 0.07$). No difference was found between grazing treatments in body condition score ($P > 0.13$), calving rate ($P = 0.11$), percentage of weaned calf weight to cow body weight ($P = 0.23$), or kg of calf produced per ha ($P = 0.17$). Calf weaning weights were greater in C ($P = 0.04$). Cow body weights were greater in the continuous treatment in October only ($P = 0.06$). Rotational grazing methods require more frequent human-animal interaction than does continuous grazing, benefiting animals with less excitable temperaments. An additional study was conducted evaluating the effectiveness of acclimating mature Brahman x Angus F-1 cows to human interaction to improve their temperament. No difference was found in chute score ($P = 0.13$) or chute exit velocity ($P = 0.63$) when cows in the positive human interaction treatment were compared to the control treatment. Cows in the positive human interaction treatment tended to have lower alley scores ($P = 0.05$). The specific type of human acclimation implemented did not consistently affect cattle temperament, indicating other traits may be more important in determining temperament or other acclimation procedures may be more effective at altering temperament.

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CHAPTER I

REVIEW OF LITERATURE

1.1 Introduction

Grazing methods have been the subject of many published research experiments. However, little headway has been made in reaching a consensus regarding the potential benefits of various grazing methods among academia, producers, or government agencies (Briske et al., 2008). The purpose of this literature review is to evaluate the large body of literature relating to grazing methods, and to present the results of this research in a concise manner. Additionally, literature will be presented pertaining to the behavior of grazing animals, and the interaction of human handling and beef cattle temperament.

1.2 Overview of Grazing Methods

1.2.1 Introduction

Rangelands and large herbivores are dependent on each other (Teague et al., 2013). The interactions of grazing, fire, and fluctuating climatic conditions create the environmental conditions necessary for rangelands to form (Teague et al., 2013). The coevolution between herbivores and plants has led to the development of various characteristics allowing plants to either tolerate or avoid defoliation (Holechek et al., 2011). Grazing can increase nutrient concentrations available to plants through urination and defecation (Holland et al., 1992), increase photosynthesis potential (Hamilton and Frank, 2001), increase plant aboveground net primary production (Heitschmidt et al., 1982; Bryant et al., 1991; and Frank et al., 1998), and increase palatability of plants (Provenza, 2003b). On the contrary, excess defoliation, or the removal of photosynthetic material, can reduce the ability of a plant to compete in its environment (Caldwell et al., 1981). It has been suggested that the role herbivores play in landscape-scale ecological processes is as great as that of topography and soil type (Frank and Groffman, 1998).

Historically, most global rangelands were characterized by the presence of large herds of migratory herbivores. Although grazing might occur at a high intensity periodically, these transient herds moved on quickly to new feeding grounds, allowing adequate time for plant recovery between defoliation events (Frank et al., 1998). The continual movement of these herds was driven by satiation of water and nutrient requirements, fouling of sites with urine and feces, social organization, seasonal variation in weather, fire, predation, herding, and hunting (Provenza, 2003a; Provenza 2003b; and Bailey and Provenza, 2008). In a few parts of East Africa, large migratory herds of wild herbivores still graze in this transient manner (Mloszewski, 1983; and Estes, 2014). Even non-migratory species of wild bovines such as African buffalo (*Syncerus caffer*) move continually in well-defined grazing circuits while grazing in a tight group (Mloszewski, 1983). Nomadic pastoralists operating in a similar manner as these wild herbivores are often less detrimental to their environment then their sedentary counterparts (Meuret, 2014).

Throughout much of the world, migratory herds of herbivores have been replaced by sedentary herds confined to relatively small areas throughout the grazing season to aid in livestock production (Milchunas and Lauenroth, 1993) and to accommodate the cultural lifestyles of the graziers. This transition occurred in the late 19th century throughout most of North America and was accompanied by widespread degredation of the rangeland resource due to overgrazing (Sayre and Fernandez-Gimenez, 2003). Overgrazing can be defined as occurring when "individual plants are subjected to multiple, severe defoliations without sufficient physiological recovery time" (Briske, 1991). This excessive herbivory can result in the removal of biomass and litter to the extent that the soil is left exposed and subject to erosion and degredation (Thurrow, 1991). Chronic overgrazing can also cause the most palatable plants to perish, enabling species more physically and chemically defended against defoliation to increase in abundance (Bryant et. al., 1983; Briske, 1991; Herms and Mattson, 1992; and Derner et al., 2007). The initial response of range scientists to the chronic overgrazing occurring on American rangelands in the late 19th century was to advocate for a system in which pastures were grazed in rotation, allowing for periods of rest following grazing (Sampson, 1913). This recommendation was made partly based on observations of migratory wild herbivores (Clements, 1920). However, as early as 1951 it was noted that there was a diversity of opinions regarding the merits of rotational grazing (Sampson, 1951).

Currently, a wide range of grazing methods are used by livestock producers. The individual producer can adapt their grazing management to meet their unique objectives and resources. Within the same grazing management unit, grazing methods can vary both spatially across the landscape and temporally as the producer attempts to adapt to changing environmental conditions between seasons and years (Kothmann, 2009). For the purpose of comparison, it is necessary to classify grazing methods into various categories.

Holechek et al. (2011) classifies grazing methods into seven categories. These are continuous or season-long stocking, deferred-rotation grazing, the Merrill three-herd/four-pasture system, seasonal-suitability grazing, the best-pasture system, rest-rotation grazing, high-intensity/low-frequency grazing, and short duration grazing.

The simplest grazing method is continuous or season-long stocking. In this method animals are permitted to graze the entire grazing area throughout the year or growing season (Kothmann, 2009). Deferred-rotation stocking is defined as deferring grazing in a pasture to allow for a specific management goal. The period of deferment can range from as little as 60 days up to one year (Holechek et al., 2011). Originally, it involved only two pastures, with each pasture receiving a period of deferment every other year (Sampson, 1913), although this method has since been adapted to allow for more flexibility (Kothmann, 2009). The Merrill three-herd/four-pasture system, developed in south-central Texas in the 1950's (Merrill, 1954), involves three separate herds of livestock rotated among four pastures. Each pasture is grazed continuously for twelve months, followed by a four-month rest period. After four years, the period of rest has occurred during each quarter of the calendar year in every pasture. At any given point in time, three-fourths of the area is being grazed by livestock (Holechek et al., 2011). In seasonal-suitability grazing, a land area is partitioned by vegetation types. Each vegetation area is grazed based on its suitability for grazing on a seasonal basis (Holechek et al., 2011). An example would be a rancher in the mountain west grazing upper elevation areas in the summer and lower elevation areas during the winter. The best-pasture system, developed in semidesert New Mexico rangelands (Valentine, 1967), resembles seasonal-suitability grazing. In this environment, localized sporadic rainstorms can cause large variations in forage production across a landscape in the same year. The best-pasture system involves following the rains and grazing actively growing areas while they are still in a vegetative state (Holechek et al., 2011). Rest-rotation grazing is like deferred-rotation grazing but differs in that the area being deferred is rested for a full 12 months. The stocking rate is increased in the areas being grazed to accommodate the 12-month rest period in one of the pastures (Holechek et al., 2011). Rotational stocking is defined as a method in which livestock are grouped into one herd and rotated through three or more pastures, increasing stocking density in the pasture where they are currently grazing (Kothmann, 2009). High-intensity/low-frequency grazing and short duration grazing (Holechek et al., 2011) are two forms of rotational grazing.

Many combinations of the above grazing methods are available, and many ranchers combine two or more grazing methods to utilize the unique resources available to them (Kothmann, 2009). A good example of a combination of methods would be a rancher operating in the mountain west who continually grazes valley pastures during the winter, and practices rest-rotation grazing on the mountains during the summer;

combining continuous stocking, seasonal-suitability grazing, and rest-rotation (Dahlgren et al., 2015).

1.2.2 Terminology

It is necessary to define several terms to ensure clarity when discussing grazing methods. A lack of clear definitions for grazing terminology has added to the confusion regarding grazing methods (Kothmann, 2009). For this purpose, Allen et al. (2011) with the International Grassland Congress and the International Rangeland Congress published the *International Terminology for Grazing Lands and Grazing Animals*. The following terms used in this literature review follow the published definitions.

Biomass is defined as the "total dry weight of vegetation per unit area of land above a defined reference level, usually ground level, at a specific time". Litter is an "accumulation of dead detached plant material at the soil surface".

Defoliation is defined as "the removal of plant tissue by grazing animals". Forage selection, or selectivity, is the "removal by animals of specific forages or components of forages rather than other forages or plant parts".

A grazing management unit is the "entire grazing land area used to support grazing animals over a defined time, generally a year". A pasture is a "type of grazing management unit enclosed and separated from other areas by fencing or other barriers and devoted to the production of forage for harvest primarily by grazing". A paddock is defined as a "grazing area that is a sub-division of a grazing management unit and is enclosed and separated from other areas by a fence or other barrier". A pasture can be subdivided into two or more paddocks.

A grazing system is a "defined, integrated combination of soil, plant, animal, social, and economic features, grazing methods and management objectives designed to achieve specific results or goals". A grazing method is a "defined procedure or technique to manipulate animals in space and time to achieve a specific objective".

Deferment is defined as the "postponement or delay of grazing or harvesting to achieve a specific management objective", while rest is defined as "leaving an area of grazing land ungrazed or unharvested for a specific time, such as a year, growing season, or a specified period required within a particular management practice". The rest period is "the length of time that a specific land area is not stocking between stocking periods". The stocking period or grazing period is "the length of time that grazing livestock or wildlife occupy a specific pasture or paddock".

Stocking rate is defined as the "relationship between the number of animals and the total area of the land in one or more units utilized over a specified time; an animal-to-land relationship over time". Carrying capacity is the "maximum stocking rate that will achieve a target level of animal performance, in a specified grazing system that can be applied over a defined time without deterioration of the grazing land". Carrying capacity is site specific and varies from season to season and year to year based on abiotic and biotic factors. The stocking density is the "relationship between the number of animals and the specific unit of land being grazed at any one time; an instantaneous measurement of the animal-to-land area relationship". Grazing pressure is similar to stocking density in that it is measured at a point in time, defined as the "relationship between animal live weight and forage mass per unit area of the specific unit of land being grazed at any one time; an instantaneous measurement of the animal-to-forage relationship". Forage allowance is defined as the "relationship between forage mass and animal live weight per unit area of the specific unit of land being grazed at any one time; an instantaneous measurement of the forage-to-animal relationship. The inverse of grazing pressure."

1.2.3 Stocking Rate Considerations

The Society for Range Management (1989) defines stocking rate as "the amount of land allocated to each animal unit for the grazable period of the year". Stocking rate can be set above or below the carrying capacity of the grazing management unit. Stocking rates have been more extensively studied than have grazing methods (Holechek et al., 1999). These studies have shown that increasing stocking rate consistently results in a linear decrease in individual animal performance and forage biomass production (Holechek et al., 1999).

Stocking rate studies have generally classified grazing pressure as high, moderate, and light. In a summary of 25 grazing studies conducted in North America, Holechek et al. (1999) found that high, medium, and light grazing pressure resulted in 57%, 43%, and 32% use of primary forage species, respectively. Holechek et al. (1999) follow Klipple and Bement's (1961) definitions of heavy grazing as a degree of herbage utilization that does not permit desirable forage species to maintain themselves, moderate grazing as allowing palatable species to maintain themselves but not increase in herbage producing ability, and light grazing as allowing palatable species to maximize their herbage producing ability.

Chronic, high intensity grazing is detrimental to plants (Briske et al., 2008) because it removes leaf area that plants require to perform photosynthesis (Caldwell et al., 1981; and Briske and Richards, 1995). Chronic, high intensity grazing has been shown to reduce root mass, branch number, vertical and horizontal root distribution, and root longevity (Hodgkinson and Bass Becking, 1977). This reduction in root vigor reduces the ability of severely grazed plants to access soil water and nutrients and limits plant growth on rangelands (Briske et al., 2008).

Holechek et al. (1999), in their review of 25 studies, found average forage production (kg/ha) in heavy, moderate, and light grazing intensity to be 1317, 1651, and 1790, respectively. Forage biomass production during drought years averaged 919, 1105, and 1366 (kg/ha). In 92% of studies, heavy stocking resulted in a downward trend in ecological condition of the range, while 52% of moderate stocking studies and 78% of light stocking studies resulted in an upward trend. Calf crop averaged 72%, 79%, and 82%, for heavy, moderate, and light grazing intensity, respectively. Weaning weight in kg averaged 173, 188, and 195. Gain per steer in kg averaged 72, 92, and 103. Average daily gain in kg averaged 0.8, 1.0, and 1.0. Gain per ha, however, averaged 44.8, 37.9, and 25.1 kg per ha. Thus, there is an inverse relationship between gain per ha and individual animal gain.

From an economic standpoint, net return per animal decreased with increasing grazing pressure ($38.06, $51.47, and $58.89, for heavy, moderate, and light). Net return per hectare peaked under moderate grazing pressure ($3.23 for heavy, $6.53 for moderate, and $5.93 for light; Holechek et al., 1999). These 25 studies are consistent in showing that heavy grazing pressure is a losing proposition both financially and ecologically. Holechek et al. (1999) conclude that on a short-term basis, conservative stocking will reduce profits by 10-25% when compared to moderate stocking, but in drought years, conservative stocking will result in 30-60% greater net returns. This is consistent with the bioeconomic grazing model designed by Ritten et al. (2010), who found that 50% utilization consistent with moderate grazing pressure is the economically optimal stocking rate regardless of grain or cattle prices (Ritten et al., 2010).

The consistency and magnitude of differences evident in stocking rates studies is not evident in studies evaluating grazing methods (Holechek et al., 1999; Derner et al., 2008; Briske et al., 2008; and Teague et al., 2013). This has led to the conclusion that setting the stocking rate is the most important decision facing managers that concerns vegetation, livestock, wildlife, and economic returns (Heady, 1961; O'Reagain and Turner, 1992; Ash and Stafford Smith, 1996; and Holechek et al., 2011).

Several studies evaluating grazing method, stocking rate, and the interaction between these have been conducted. Derner et al. (2008 and 2007), reporting on the final 16 years of a 25-year study, compared light, moderate, and heavy stocking rates across two grazing methods (season-long and short-duration rotational grazing). They found a linear relationship between average daily gain and grazing pressure, with heavy stocking rates consistently reducing ADG by 10-16% when compared to moderate stocking rate. The short duration grazing method reduced ADG by an average of 6% across 16 years, although there was no difference in forage biomass production between grazing method. There was no interaction between grazing method and stocking rate. Stocking rate had a greater effect on animal performance than grazing method, which is consistent with Hart et al., 1988; Manley et al., 1997; McCollum and Gillen, 1998; and McCollum et al., 1999. Forage production was 23-29% greater with light stocking rate than with moderate or heavy stocking rates, which did not differ (Derner et al., 2007). Derner et al. (2007) attribute the greater forage production under the light stocking rate to a change in forage species composition that occurred with the greater stocking rates as less-productive blue grama (*Bouteloua gracilis*) replaced more productive grasses after 25 years at the greater stocking rates. Grazing method, however, did not affect forage production or species composition.

Thus, before evaluating various grazing methods, it is of utmost importance to remember that a large body of research shows that stocking rate plays a larger role in grazing management then does grazing method (Holechek et al., 2011). The research indicates that claims of a specific grazing method allowing the stocking rate to be doubled without negatively impacting animal performance, while simultaneously improving range condition and forage production (Savory, 1983), should be viewed with skepticism.

1.2.4 Continuous Grazing

Continuous grazing is defined as a method of grazing livestock on a specific area where animals have unrestricted and uninterrupted access to the entire pasture (Allen et al., 2011), either throughout the year or throughout the growing season (Kothmann, 2009). In this grazing method, animals can graze with maximum selectivity (Kothmann, 2009). Due to the simplicity of this method, this is the method of choice for many ranchers (Teague et al., 2011). Management inputs are minimal, requiring little or no additional investments in infrastructure (Kothmann, 2009). The only grazing variables that the manager can control in this method are the stocking rate, animal species, and animal class.

Since livestock can maximize selectivity, continuous stocking generally results in greater individual animal performance than rotational grazing (Anderson, 1940; Hubbard, 1951; Hyder and Sawyer, 1951; McIlvain and Savage, 1951; Rogler, 1951; Smoliak, 1960; Heady, 1961; Frischknecht and Harris, 1968; Murray and Klemmedson, 1968; Kothmann et al., 1971; Ratliff et al., 1972; Owensby et al., 1973; Ward, 1975; Skovlin et al., 1976; Savory, 1978; Sharrow and Krueger, 1979; Heitschmidt et al., 1982; Ratliff, 1986; Drawe, 1988; Heitschmidt et al., 1990; Pieper et al., 1991; Beck and McNelly, 1993; and McCollum et al., 1999). Briske et al. (2008) found individual animal performance to be greater in continuous stocking in 84% (27 of 32) of grazing experiments they analyzed. The problem with continuous grazing is that livestock will tend to congregate in preferred areas, and even at light stocking rates, these areas may become overgrazed (Holechek et al., 2011). This is because regrowth of previously grazed plants is greater in forage quality than ungrazed areas (Hobbs and Swift, 1988; and Briske et al., 2008), thus livestock will repeatedly graze the same plants. However, in an extensive review of published grazing research, Briske at el. (2008) drew the conclusion that continuous grazing at a moderate stocking level can maintain rangeland productivity. This conclusion has been highly contested, however (Teague et al., 2013; and Savory and Butterfield, 2016). The results of continuous stocking on livestock individual animal performance, gain per land unit, vegetation, soil physical characteristics, and economic profitability will be further discussed in the following sections.

1.2.5 Intensive Early Stocking

Intensive early stocking (IES), or double stocking, was developed in the Kansas Flint Hills by Smith and Owensby (1978). It has since become the most prevalent grazing method practiced by stocker cattle operations in the Flint Hill area (Owensby and Auen, 2018). IES is a modification of season-long stocking that increases stocking density to twice the cattle for half the time on the same land area (Owensby and Auen, 2013). Thus, stocking rate is held constant. For example, a typical stocking rate for season-long grazing would be one ~ 250 kg steer per 1.62 $ha \cdot steer^{-1}$ until October 1, or one ~ 250 kg steer per 0.81 $ha \cdot steer^{-1}$ until mid-July for IES.

IES was developed as a method to utilize tallgrass prairie while at its nutritional peak (Smith and Owensby, 1978). Tallgrass prairie quality declines substantially as the growing season progresses (Pieschel, 1980), accompanied by a corresponding decrease in individual livestock gains (Owensby and Auen, 2013). As plants mature, they begin to accumulate less digestible fiber components, decreasing nutrient concentrations (Owensby et al., 1977). On areas grazed by steers early in the season, regrowth occurs after defoliation, delaying the onset of maturity in these areas (Michunas et al., 2005). Thus, forage quality remains elevated for a longer period on areas that have been grazed. Cattle preferentially graze these areas of greater nutritional quality (Senft et al., 1985), leading to “patchiness”, or uneven utilization, under season-long grazing (Teague et al., 2013). In season-long grazing, this uneven utilization can lead to individual plants being repeatedly defoliated, resulting in patches of overgrazed plants even if the stocking rate is low (Teague et al., 2013). By doubling the stocking rate while allowing for late growing season rest, IES is designed to reduce patchiness of defoliation while concentrating animals temporally during times of greater nutritional quality.

Under IES, cattle are removed from the pasture in the middle of the growing season. This allows perennial grass plants late-season rest from grazing, corresponding to the period when C4 grasses are producing seed and building carbohydrate reserves to last through the dormant season. Smith et al. (1978) found that this late season rest resulted in a greater perennial grass component under IES than under season-long stocking (SLS). Although not evident until the third year after implementing IES, biomass production was greater under IES than SLS, probably due to increased perennial grass component (Smith et al., 1978). Specifically, big bluestem (*Andropogon gerardii*) increased in basal cover under IES at the expense of less productive forage species such as Kentucky bluegrass (*Poa pratensis*) and forbs. Perennial forb cover was greater in the SLS. Smith et al. (1978) propose that this is due to a more continuous fuel source for the annually applied prescribed fire in the IES system. In a 10-year study, Owensby and Auen (2018) found that above-ground grass biomass clipped on October 1 was greater in IES than SLS in one year ($P < 0.10$) but was not statistically different in the other 9 years. Additionally, Smith et al. (1978) found that grazing distribution as measured by forage disappearance across the grazing unit was more uniform under IES than SLS.

IES has been found to increase both individual animal performance and gain per ha when compared to SLS. Smith et al. (1978) found that the three-year average daily gain (ADG) was greater ($P < 0.05$) for IES than SLS when comparing the ADG of both the 75 day period when cattle were in both grazing methods (0.85 vs. 0.79 kg/day), and the entire grazing period (75 days for IES, 154 days for season-long; 0.85 vs. 0.62 kg/day). Gain per ha throughout the grazing period was 93 kg/ha for IES, and 69 kg/ha for season-long stocking. However, total gain per steer was lower with IES since the grazing period was shorter (75 days vs. 154 days). Owensby and Auen (2018) found gain per ha to be greater ($P < 0.10$) in an IES system when compared to SLS in every year of a 10-year study lasting from 2007-2016.

Owensby and Auen (2018) conducted an economic analysis on IES and SLS systems. They found net return per hectare was 49% greater for IES ($99.35) than for SLS ($62.35) when averaged across 10 years. However, net return per steer was 26% greater for SLS ($246.51) than for IES ($183.49). They suggest that in situations where land access is the limiting resource, producers should strive to maximize net return per hectare instead of net return per steer, favoring the IES system (Owensby and Auen, 2018).

Intensive early stocking resembles rotational grazing in that it relies on increased stocking density for a reduced time period to achieve specified goals and has unanimously been shown to be highly effective at increasing gain per hectare while maintaining forage production (Smith et al., 1978; Owensby and Auen, 2018; and Owensby and Auen, 2013).

1.2.6 Rotational Grazing

Rotational grazing is heavily promoted among livestock producers in the United States (Briske et al., 2008). Rotational grazing was first described in Scotland at the end of the 18th century (Voisin, 1959). Throughout the 20th century, rotational grazing has progressed from more simple methods of deferment (Sampson, 1913) to more intensive rotational methods, characterized by more frequent rotations (Savory, 1978; Savory, 1983; Savory, 1988; and Savory and Parsons, 1980).

Rotational grazing can be defined as "reoccurring periods of grazing, rest, and deferment for two or more pastures" (Briske et al., 2011; and Heitschmidt and Taylor, 1991), or as a "method that utilizes recurring periods of grazing and rest among three or more paddocks in a grazing management unit throughout the time when grazing is allowed" (Allen et al., 2011).

The goals of rotational grazing methods are to improve species composition or productivity by ensuring key species have adequate growing season rest to capture adequate resources (Briske et al., 2008), provide adequate post-grazing plant recovery (Teague et al., 2013), increase livestock harvest efficiency (Briske et al., 2008), reduce animal selectivity by increasing stock density (Briske et al., 2008; and Teague et al., 2013), reduce patch grazing (Briske et al., 2008), ensure more uniform animal distribution within large heterogeneous management units (Briske et al., 2008; and Teague et al., 2013), increase primary and secondary productivity (Teague et al., 2013), regulate livestock nutrition and feeding behavior (Teague at el., 2013), and to provide other ecosystem services (Teague et al., 2010; and Teague et al., 2013).

Kothmann (2009) lists the four principal components of rotational grazing as stocking density, number of paddocks per herd, length of rest period, and length of grazing period. Different combinations of these four variables produce different intensities and frequencies of defoliation. For clarity, Kothmann (2009) divides rotational stocking into nine categories based on these combinations of intensity and frequency. These are high-intensity/low-frequency (HILF), high-intensity/medium-frequency (HIMF), high-intensity/high-frequency (HIHF), medium-intensity/low-frequency (MILF), medium-intensity/medium-frequency (MIMF), medium-intensity/high-frequency (MIHF), low-intensity/low-frequency (LILF), low-intensity/medium-frequency (LIMF), and low-intensity/high-frequency (LIHF). Short-duration grazing (SDG), also called Savory grazing, mob grazing, rapid-rotation, or cell grazing, is defined as short grazing periods of intense defoliation, followed by long rest periods (Savory, 1988). SDG is more intensive than HILF in that it requires more than eight paddocks, typically with grazing periods shorter than five days and rest periods longer than four weeks (Holechek et al., 2011).

The effectiveness of rotational grazing in achieving its purposed benefits will be discussed in the following sections based on published literature.

1.3 Effects of Grazing Methods

The following sections will analyze the effect of grazing method on individual animal performance, gain per land unit area, vegetation characteristics, soil, and economic profitability.

1.3.1 Individual Animal Performance

In a review of 28 published peer-reviewed grazing studies comparing rotational and continuous grazing, Briske et al. (2008) found there was no difference in animal production per head in 57% of the experiments when stocking rate was the same. When stocking rate was greater in rotational grazing then in continuous (n=10), 90% of the experiments found either no difference or greater per head production in continuous grazing.

In a review of 15 experiments comparing rotational and continuous grazing at similar stocking rates, Holechek et al. (1999) found average calf crop to be 89.4% for continuous, compared to 85.9% for rotational. Continuous grazing also showed a slight advantage in calf weaning weight (228.9 kg versus 224.1 kg).

1.3.2 Gain per Land Unit Area

In a review of 28 published peer-reviewed grazing studies comparing rotational and continuous grazing, Briske et al. (2008) found no difference for animal production per unit land area in 57% of the experiments when stocking rate was similar between rotational and continuous grazing, and 36% showed greater production per unit land area for continuous grazing. In experiments where stocking rate was greater for rotational grazing (n = 4), rotational grazing showed greater production per unit land area in 75% of the experiments.

1.3.3 Vegetation

In a review of 19 published peer-reviewed grazing studies, Briske et al. (2008) found no difference in plant production between continuous and rotational stocking in 89% of studies with similar stocking rates. In studies where stocking rate was greater for rotational then continuous grazing (n = 4), 75% found that forage production was greater in the continuous method.

In a review of 15 published peer-reviewed grazing studies where stocking rate was the same for continuous and rotational methods, Holechek et al. (1999) found forage production to be 7% greater in the rotational grazing methods when compared to continuous grazing across all 15 studies. Holechek et al. (1999) summarized their review by geographical region and found that in semi-arid and desert range types, rotational grazing methods showed no benefit to forage production over continuous grazing. However, in more humid areas, rotational grazing increased forage biomass production by 20-30% on average.

The differing results of grazing method based on geographical region has often been noted. For post-herbivory rest to be beneficial to the plant, environmental conditions during the rest period must be favorable to plant growth (Wallace et al., 1984; Coughenour et al., 1985; Louda et al., 1990; and Teague et al., 2013). The amount of soil moisture and ambient temperature required for plant growth are species- and plant-specific (Caldwell, 1984). Post-herbivory recovery is slower in drier rangelands; thus, these environments require longer rest periods (Heitschmidt and Taylor, 1991), often a year or more (Cook and Stoddart, 1963; and Trlica et al., 1977). Torell et al. (2008) found that during a 214-day growing season in New Mexico, soil moisture exceeded the 30% threshold needed for plant growth on only 28 non-consecutive days. In environments such as this, improperly designed rotational grazing methods with 60-day rest periods could easily move cattle back into a previously grazed pasture before any re-growth has occurred. This is much less likely to occur in more humid environments with consistent precipitation, where rest periods of 45-90 days have shown desirable results (Gerrish, 2004; Teague et al., 2011; and Teague et al., 2013). Thus, rotational grazing may be more beneficial to vegetation productivity in areas with greater precipitation. Or perhaps rotational grazing can be beneficial in arid environments, but as variability in precipitation increases in arid environments, the importance of flexible management becomes magnified.

Of the 41 experiments cited by Briske et al. (2008) in their review of grazing method studies, only three allowed for flexible management (Teague et al., 2013). The other 38 studies followed a strict rotational protocol, regardless of precipitation, environmental conditions, or annual forage production (Teague et al., 2013). Briske et al. (2008) drew the conclusion that rotational grazing is not superior to continuous grazing, although they concede that "a well-managed rotational system will very likely achieve desired production goals more effectively than poorly managed continuous grazing". Teague et al. (2013) argue that for a rotational method to be well-managed, it must allow for flexible management (Savory and Butterfield, 2016; Norton, 1998; and Diaz-Soliz et al., 2009). Teague et al. (2013) emphasize that for the results of grazing experiments to be valid, rotation schedules must be flexible.

Flexible management has been termed adaptive management (Savory and Butterfield, 2016). The fundamental principle of adaptive management is that since knowledge is incomplete and conditions are constantly changing, management must be flexible and continually modified if desired results are to be achieved (Teague et al., 2013). This adaptability does not fit well into a controlled research protocol, increasing the level of difficulty involved in studying grazing systems.

Of the four principal components of rotational grazing listed by Kothmann (1999), the one with the potential to increase plant productivity when compared to continuous grazing is length of rest period, and therefore will be discussed in this section.

The concept of rest periods is that since chronic, intensive defoliation reduces root number, branch number, vertical and horizontal root distribution, root longevity, and photosynthetic potential (Hodgkinson and Bass Becking, 1977), then periodic cessation of grazing during periods of plant growth will enhance shoot and root growth by promoting the recovery and maintenance of greater leaf area (Holechek et al., 2011). Rest is particularly beneficial to highly palatable plants, which are often chronically intensively grazed even at light stocking rates (Ash and Stafford-Smith, 1996; Earl and Jones, 1996; Teague et al., 2004; 2011; and Teague et al., 2013). It has been suggested that the way to mitigate the damaging effects of repeated selective grazing in continuous grazing is to incorporate periodic growing season rest into the grazing system (Morris and Tainton, 1991; O'Conner, 1992; Norton, 1998; Norton 2003; Provenza, 2008; Teague et al., 2004; and Teague et al., 2011). The length of the rest period is of utmost importance for rest to be effective (Booysen, 1969; Venter and Drewes, 1969; Booysen and Tainton, 1978; Savory, 1983; McCosker, 1994; Norton, 1998; Norton 2003; Gerrish, 2004; and Howell, 2008). The length of time required for plants to recover after defoliation depends on the intensity of defoliation during the grazing period (Trlica, et al., 1977; Mencke and Trlica, 1981; and Mencke and Trlica, 1983), grazing history (Taylor et al., 1993), the stage of plant growth (Mullahey et al., 1990; Mullahey et al., 1991; Cullen et al., 1999), and the post defoliation environmental growing conditions (Thurow et al., 1988). The forage quality of grasses and forbs decreases dramatically when they mature due to the accumulation of lignin and other anti-herbivory compounds (Teague et al., 2013). Thus, animal performance decreases as the length of rest period increases beyond the time it takes grazed plants to recover and plants begin to mature. Well-managed rotational grazing can prolong the period plants stay in vegetative growth, delaying maturity, and can thus increase plant and animal production (Gerrish, 2004; and Teague et al, 2011; and Teague et al., 2013). Therefore, rest periods should be long enough for plant recovery but not so long that plants mature (Teague et al., 2013).

The challenge is the proper rest period to increase vegetative productivity varies from year to year (Diaz-Solis et al., 2009). This is where adaptive management becomes imperative to properly managed rotational grazing methods (Teague et al., 2013).

Several studies have been conducted on commercial ranches where livestock rotations have been managed adaptively in accordance with prevailing environmental conditions (Teague et al., 2013). The results of these adaptively managed studies, conducted using large paddocks, have been contrary to the conclusions made in Briske et al. (2008). In a study conducted in a mesic tallgrass prairie environment of north Texas, Teague et al. (2011) compared neighboring ranches that had practiced either light continuous grazing (LC), heavy continuous grazing (HC), and adaptively managed multi-paddock rotational grazing (MP) for a minimum of nine years prior to the study, as well as an area that had not been grazed since 1867 (EX). The average grazing period for MP was 1-3 days, and the rest period ranged from 30-90 days. They found forage production (kg ha^{-1}) to be statistically significantly different between the HC, LC, and MP grazing methods ($P < 0.05$). Forage production was not different between MP and EX ($P < 0.05$). Forage production for HC was 2696 kg ha^{-1}, 3960 kg ha^{-1} for LC, and 4680 kg ha^{-1} for MP. Percentage bare ground was statistically significantly different between all grazing methods, with 30% in HC, 4% in LC, and 1% for MP. It was not significantly different between MP and EX. They also measured forage species composition, which differed between all methods at $0.05 < p < 0.10$. EX showed the highest percentage tallgrasses at 69%, followed by MP at 45%, LC at 20%, and HP at 7%. Other landscape scale studies comparing adaptively managed multi-paddock grazing methods to continuous grazing have found similar results (Earl and Jones, 1996; Beukes and Cowling, 2003; Teague et al., 2004; Jacobo et al., 2006; Sanjari et el., 2008; Teague et al., 2010a; and Teague et al., 2010b). Based on ranch scale studies, it can be shown that adaptively managed multi-paddock rotational grazing can improve forage production in certain situations.

1.3.4 Soil

Rotational grazing has been promoted as a method to benefit soil in several ways, specifically by increasing organic matter, decreasing bare ground, and decreasing bulk density (Savory and Butterfield, 2016). Excessive herbivory, excessive trampling, extended drought, and fire have been shown to inhibit soil-building processes (Wright and Bailey, 1982; and Thurow, 1991). Soil degredation is indicated by increased bare ground, soil compaction, bulk density, penetration resistance, and a reduction in aggregate stability (Herrick et al., 1999; and Herick and Jones, 2002). Sustainable long-term grazing management should maintain or enhance soil building processes (Teague et al., 2011).

To evaluate the proposed benefits of rotational grazing on soil-building processes, Teague et al. (2011) evaluated the effect of heavy continuous grazing (HC), light continuous grazing (LC), and adaptively managed multi-paddock grazing (MP) on neighboring ranches in North Texas. Each treatment had been managed accordingly for a minimum of 9 years prior to the study. They evaluated the effects of each treatment on bare ground (%), soil aggregate stability (%), bulk density (g cm^{-3}), hydraulic conductivity (K x 10^{-4}), soil water infiltration (cm h^{-1}), penetration resistance (Joules), runoff (cm h^{-1}), sediment loss (g m^{-2}), soil moisture (Volumetric %), soil organic matter (%), various soil nutrient parameters, and ratio of total fungi to total bacteria.

They found statistically significant differences in several physical soil parameters. HC resulted in 30% bare ground, which was statistically significantly ($P < 0.05$) greater than bare ground for LC and MP (4% and 1%, respectively). Aggregate stability percentage was significantly ($P < 0.05$) greater in MP than HC but did not differ between the other treatments. Runoff was significantly less ($P < 0.01$) in LC than in the other treatments, which did not differ. Sediment loss was greater ($P < 0.05$) in HC then the other treatments, which did not differ. Soil moisture was lower in HC ($P < 0.05$) then the other treatments, which did not differ. There were statistically significant ($P < 0.05$) differences in soil organic matter between all three treatments, with MP having the greatest percentage followed by LC, followed by HC.

Differences in soil nutrient parameters were only apparent in magnesium and sodium, with MP having the highest levels of both at $P < 0.10$. There were no differences found in NO_3N, nitrogen, potassium, manganese, copper, phosphorous, zinc, iron, calcium, or pH between grazing treatments. Cation exchange capacity was significant at $P < 0.05$ and was greater for MP than the other treatments.

Greater populations of fungi relative to bacteria are indicative of the soil's ability to store carbon (Bardgett and McAlister, 1999; De Vries et al., 2006; and Teague et al, 2011). Savory has claimed that HILF grazing can mitigate climate change through increased carbon sequestration (Briske et al., 2013; and Savory and Butterfield, 2016). For this to be true, fungal populations might be greater in rotational grazing systems than in continuous grazing systems. Teague et al. (2011) did indeed find both total fungi and the ratio of total fungi to total bacteria to be significantly greater for MP ($P < 0.05$) than the other treatments.

In summary, Teague et al. (2011) found HC has a negative impact on soil parameters, including bare ground, lower aggregate stability, greater penetration resistance and greater sediment loss relative to MP and LC (Teague et al., 2011). However, there is no clear indication of any difference in soil health parameters between LC and MP.

Other research has shown that rotational grazing can result in less bare ground, lower soil temperatures, and greater soil carbon than continuous grazing at the same stocking rate if adaptively managed (Teague et al., 2010b). Working with fescue pasture, Dormaar et al. (1988) stocked a 972-ha, 17-paddock SDG system at 2-3 times the recommended stocking rate, and found that their SDG method decreased soil moisture, increased soil bulk density, decreased hydraulic conductivity, and decreased fungal biomass when compared to a grazing exclosure. Therefore, any positive impacts on soil associated with rotational grazing at the same stocking rate as continuous grazing may not hold true as stocking rate is increased beyond the carrying capacity. Abdel-Magid et al. (1987) compared continuous, rotationally deferred, and SDG and found no consistent relationship when testing for bulk density or water infiltration, but they did find that increasing the stocking rate across all three grazing methods reduced water infiltration during the growing season. Therefore, it is probable that stocking rate has a greater impact on soil parameters than grazing method (Abdel-Magid et el., 1987; Dormaar et al., 1988; and Teague et al., 2011).

1.3.5 Profitability

Rotational grazing requires additional capital expenditures in the form of cross fencing and increased labor costs compared to continuous grazing (Kothmann, 2009;

and Knight et al., 2011). In order to offset the increased costs associated with cross-fencing, profitability must be increased through the implementation of rotational grazing. Knight el al. (2011) conducted a financial analysis where a 4,144.0-hectare pasture in Montana was subdivided into 16 even-sized 259.0-hectare pastures with four-strand barbwire at a cost of $5,181/km. They conclude that for the producer to break-even after 20 years, annual profit would need to be increased by $33,708 ($8.23/ha). Assuming the original pasture was stocked at the NRCS recommended rate of 1.13 Animal Unit Months/ha and several other reasonable economic assumptions, stocking rate would need to be increased by a minimum of 16% in the rotational grazing method to justify the cross-fencing expenditures. They did not include labor costs in their analysis.

In a review of 15 studies comparing rotational and continuous grazing at the same stocking rate, Holechek et al. (1999) found continuous grazing to result in an average net return per ha of $16.50, compared to $15.93 for rotational grazing. Merrill 3 herd/4 pasture showed consistent financial advantage over continuous grazing. Manley et al. (1997) and Hart et al. (1988) found grazing method to have no significant effect on profitability, although stocking rate did.

1.3.6 Other Considerations

Scale is of upmost importance to grazing behavior, and care should be taken when extrapolating small-scale research trials to landscape-scale ranching operations. Hart et al. (1993a, b) reported no difference in grazing impact on vegetation between rotational and continuous grazing when both paddocks were 24 ha, but the impacts were substantially different when compared to a 207 ha continuously stocked pasture.

Teague et al. (2013) criticize the 42 studies reviewed by Briske et al. (2008) as using pastures that are too small and are not comparable to commercial ranch pasture size, stating that only 14% used continuously stocked pastures larger than 240 ha. Grazing patterns are influenced by distribution of water, mineral licks, cover, and intra- and inter-specific social interactions among herbivores (Provenza, 2003b; and Coughenour, 1991). Vegetative heterogeneity increases with increasing size of the grazing paddock (Stuth, 1991; Illius and O'Conner, 1999; and Wallis DeVries et al., 1999). Small experimental continuously grazed paddocks decrease forage heterogeneity and produce more uniform distribution of grazing pressure than would actually occur in larger continuously grazed paddocks, misrepresenting the way that grazing animals at low stocking densities characteristic of continuous stocking would utilize a large landscape (Barnes et al., 2008).

1.4 Grazing Behavior

1.4.1 Introduction

Uniformity of livestock pasture use, or uniformity of grazing distribution, is of vital importance to sustainable livestock production (Bailey, 2005; Holechek et al., 2011; and Valentine, 2001). Overuse of an area within a pasture due to poor grazing distribution can negatively impact vegetation productivity, water quality, wildlife habitat, and other environmental concerns (Fuls, 1992a; and Fuls et al., 1992b). Many environmental concerns regarding livestock grazing of rangelands are the result of poor grazing distribution, not inappropriate stocking rates (Bailey, 2005).

Bailey (2005) recommends that grazing distribution of a pasture be thought of in terms of suitable habitat for livestock. While habitat is a term generally used in reference to wildlife management, it is useful in this case to grazing management. Bailey (2005) defines habitat as the "arrangement of environmental factors, such as food, cover, and water, that a given species needs to survive and reproduce in a given area". By increasing the amount of suitable livestock habitat within a pasture, the uniformity of use by livestock can be maximized.

The ideal habitat for livestock is composed of both biotic and abiotic factors (Bailey, 2005). Abiotic factors include water, slope, terrain attributes, and shade and shelter (Bailey, 2005; and Holechek, 2011). Biotic factors include forage quality, forage quantity, heterogeneity of forage, and pests (Bailey, 2005; and Holechek, 2011).

1.4.2 Factors Affecting Grazing Distribution

The most important factor impacting livestock habitat is water. Water requirements are impacted by physiological state of the animal, ambient temperature, and activity (NASEM, 2016). Horizontal distance from water has long been known to be a major factor impacting livestock grazing distribution; in 1947, Valentine found New Mexican forage utilization to be 50% within 0.8 km of water, 30% at 1.6 km, and 12% at 3.2 km. It has been recommended that the stocking rate be reduced 50% for areas between 1.6-3.2 km from water, and to consider areas further than 3.2 km from water to be unusable for grazing (Holechek, 1988). In areas of uneven terrain, vertical distance from water may be an even greater constraint on utilization than horizontal distance (Bailey, 2005). In Oregon, Roath and Kruger (1982) found that cattle did not graze areas that were at elevations greater than 80 m above water.

Slope is another important factor impacting grazing distribution in rough terrain (Bailey, 2005), although interactions with other factors complicate the relationship (Cook, 1966). As a general guideline, Holechek (1988) recommends a 0% reduction in stocking rate for areas with slopes less than 10%, a 30% reduction for areas with slopes between 11-30%, a 60% reduction in stocking rate for areas with slopes between 31-60%, and to consider areas with slopes greater than 60% to be unusable.

Various attributes of a pasture can influence grazing distribution regarding thermoregulation (Bailey, 2005). The effect of these attributes varies depending on the ambient temperature. Cattle must expand additional energy to maintain homeostasis outside the zone of thermoneutrality (NASEM, 2016). Shade (Harris et al., 2002), soil texture (Senft et al., 1985b), topological features (Senft et al., 1985b), vegetation characteristics (Senft et al., 1985b), and windbreaks (Houseal and Olson, 1995) have been found to impact grazing distribution.

Livestock are attracted to areas with greater forage quality and quantity (Bailey et al., 1996; and Bailey, 2005). Smith et al. (1992) found that cattle in Wyoming spent 80% of their time on plant communities with standing crops of 382 and 730 kg*ha^{-1} that made up only 18% of the pasture, and 20% of their time on a plant community that produced 150 kg*ha^{-1} and composed 82% of the total pasture. Thus, forage quantity plays a role in grazing distribution. Senft et al. (1985a) and Pinchak et al. (1991) found the preference for plant communities was most closely impacted by standing nitrogen (kg N*ha^{-1}). Cattle spend a disproportionate amount of time in riparian areas (Roath and Kruger, 1982; Gillen et al., 1984; Smith et al., 1992; and Parsons et al. 2003), probably since riparian areas provide 1.5-6 times greater quantities of forage with greater concentrations of crude protein than associated upland areas (Bailey, 2005).

Other vegetation characteristics can play a role in grazing distribution in addition to quantity and quality of forage. Heterogeneity of forage allows for a variety of forage in different phenological stages, which may increase animal performance and impact grazing distribution (Rittenhouse and Bailey, 1996).

Grazing distribution within a pasture can be manipulated by managerial practices as well. Managers can change biotic and abiotic characteristics of the pasture to improve the uniformity of livestock habitat, indirectly altering grazing distribution, or they can directly alter the behavior of the livestock themselves (Bailey, 2005). Commonly implemented practices to improve grazing distribution include development of new sources of water, feeding mineral supplements in strategic locations, constructing trails through rough terrain, providing shade and wind shelters, burning and fertilizing to improve forage quality, strategic placement of fencing, using locally adapted animals, using more experienced animals to train younger animals, herding, or a combination of practices (Bailey, 2005; and Holechek et al., 2011).

It has been suggested that implementing a rotational grazing method is a managerial practice that can improve the uniformity of grazing distribution within a pasture (Bailey 2005; and Savory and Butterfield, 2016). The justification for this claim lies in the belief that increasing the stocking density (the number of animals per unit of land at a point in time) for a short period of time (<60 days), followed by a long period of rest where no grazing occurs, will reduce individual animal selectivity of plants while grazing. This should reduce the grazing intensity on the most palatable forage species while increasing the grazing intensity on less desirable species, resulting in more uniform utilization at the individual plant level across the pasture (Savory and Butterfield, 2016). This uniformity in grazing pressure should result in more homogenous plant phenology across the pasture since it has been shown that livestock preferentially select for the most recently grazed plants due to greater nutritional content in regrowth (Briske et al., 2008). This results in repeated defoliation of specific areas while other areas are not grazed. By eliminating the gradient of time since last defoliation by increasing the stocking density to a point where all the plants are grazed, followed by a rest period to allow for plant recovery, it is assumed that grazing distribution will be improved across the pasture since livestock will no longer congregate on repeatedly grazed areas.

1.5 Global Positioning System Collars

Global Positional System (GPS) collar technologies have been used to study various aspects of grazing behavior. Turner et al. (2000) first described a method where light-weight GPS collars could be fitted to cows to assess animal behavior characteristics and pasture utilization, and the data could be analyzed using GIS. Subsequently, Ganskopp (2001) used GPS collars fitted to cows grazing large pastures in the Great Basin to measure the effects of water and salt on grazing behavior. Bailey et al. (2004), Bailey et al. (2006), Bailey et al. (2010), and Bailey et al. (2015) used GPS collars to measure differences in grazing behavior among individual animals due to genetics. Johnson and Ganskopp (2008) tested different sampling frequencies of GPS collars and different methods to determine percentage of pasture visited by cattle, finding that the accuracy of distance traveled increased with increasing sampling frequency. Ganskopp and Bohnert (2009) used GPS collars to test the influence of forage quantity and quality on grazing distribution. Russell et al. (2012) used GPS collars to evaluate the effect of breed of livestock on grazing behavior in the Chihuahuan Desert. Schoenbaum et al. (2017) used GPS collars to measure cattle preference for different levels of woody vegetation in oak woodland in Israel.

Knight et al. (2018) developed a methodology outlining how to use ArcMap to calculate slope utilization and distance from water using GPS coordinates collected from collars attached to livestock. They also included a section on data analysis methodology.

1.6 Cortisol

1.6.1 Introduction

Cortisol is a glucocorticoid hormone released by the adrenal gland continuously into the blood stream (Eiler, 2004). The level of release of glucocorticoids into the blood stream is triggered by activation of the hypothalamic-pituitary-adrenocortical axis (Eiler, 2004). Glucocorticoids play a role in the immune system, muscle maintenance, and regulate carbohydrate, fat, and protein metabolism (Sapolsky, 2002). Elevated cortisol concentrations stimulate body fat and skeletal muscle catabolism (Nelson and Cox, 2005), cause immunosuppression (Kelley, 1988), decrease gonadotropin activity and ovarian steroidogenesis in females (Da Rosa and Wagoner, 1981; and Li and Wagner, 1983), and impair function of the somatotropic axis (Elsasser et al., 1997; and Maciel et al., 2001).

Cortisol concentration is the most frequently used index to measure the level of distress experienced by cattle, with a positive correlation between stress level and cortisol concentration (Moya et al., 2013). Cortisol concentrations have been used as a stress index by Schwartzkopf-Genswein et al. (1997) to compare different methods of branding, Petrie et al. (1996) to compare dehorning with and without local anesthetics, Gonzalez et al. (2009) to compare different methods of castration , and Marti et al. (2017) and Tarrent et al. (1992) to measure stress caused by transport. Montanholi et al. (2010) and Montanholi et al. (2013) tested a potential association between feed efficiency and cortisol. Foote et al. (2017) tested the association of cortisol concentrations and average daily gain and the incidence of bovine respiratory disease. Chase et al. (2017) and Curley et al. (2006) used cortisol concentration as a proxy for temperment in beef cattle. Cortisol concentration can be analyzed using blood, saliva, urine, feces, and hair samples (Moya et al., 2013).

1.6.2 Measuring Cortisol Using Blood Plasma

A common method of assessing cortisol concentration is by measuring cortisol concentration in blood plasma. Plasma cortisol concentration represents the immediate response of the adrenal gland and indicates the cortisol level at the time of sampling (Palme et al., 1999; and Palme et al., 2005).

Cortisol concentration in blood plasma samples is useful to measure the stress response induced by various animal handling practices since it provides an instantaneous measure of cortisol level in the blood stream (Chase et al., 2017). This method was used by Chase et al. (2017) to measure temperament while being handled, by Foote et al. (2017) to test the association between cortisol concentration at weaning with average daily gain and incidence of bovine respiratory disease, and by Montanholi et al. (2010) and Montanholi (2013) to test the association between feed efficiency and cortisol concentration.

A limitation of this method is it cannot separate the stress associated with sample collection from stress associated with the treatment (Moya et al., 2013). Plasma cortisol concentration can change rapidly in minutes (von Holst, 1998). Collecting blood samples induces stress in the animal, causing an increase in the concentration of cortisol in the blood (Moberg and Mench, 2000). Hopster et al. (1999) recommended, based on their study with dairy cows, that cortisol concentration in blood plasma can only be useful if blood collection occurs within one minute of first approaching the animal, which is often unpractical. Montanholi et al. (2013) found that blood plasma cortisol concentration decreased significantly throughout the duration of the trial (P > 0.05) in both of their treatments, indicating that sample collection became less stressful as cattle become acclimated to being handled. Additionally, cortisol concentration in the blood varies according to the circadian rhythm, so variation in collection time should be minimized (Moya et al. 2013).

1.6.3 Measuring Cortisol Using Fecal Samples

Fecal samples can be used to indirectly measure cortisol concentrations. Foote et al. (2016) measured fecal corticosterone concentrations to determine the association of glucocorticoids and feed intake, growth, and feed efficiency. Montanholi et al. (2010) and Montanholi et al. (2013) used fecal cortisol metabolites to test the association between feed efficiency and glucocorticoids. Corticosterone and primary cortisol metabolites in feces can both be used to indirectly measure cortisol concentrations (Foote et al., 2016). The concentrations of corticosterone and primary cortisol metabolites in feces represents the level of cortisol released into the blood stream 12 to 18 hours prior to sampling (Montanholi et al., 2013; Foote et al., 2016). Fecal corticosterone and primary cortisol metabolite concentrations in feces are less influenced by the stress associated with sample collection then blood plasma cortisol concentration (Foote et al., 2016).

1.6.4 Measuring Cortisol Using Hair Samples

Moya et al. (2013) were the first to use hair to test cortisol concentration in beef cattle, although it had been previously used in humans (Sauve et al., 2007), rhesus macaques (Davenport et al., 2006), cats and dogs (Accorsi et al., 2008), and dairy cattle (Comin et al., 2011). Cortisol extracted from hair represents cortisol concentration released over a relatively long period of time, making assessment of cortisol concentration in the hair a good method to assess long-term stress levels (Moya et al., 2013). It is not influenced by circadian rhythms or momentary stress associated with sample collection.

Moya et al. (2013) collected hair samples from five locations on Angus bulls. These locations were the head, the brisket, the shoulder, the hip, and the tail. They collected samples by two separate methods in each location on the animal; by plucking to ensure collection of the hair follicle, or by clipping the hair. Hair samples were ground, extracted, and then assessed for cortisol concentration. The results were compared to cortisol concentration in saliva and feces. They found location and collection method affected cortisol concentration in the hair. Cortisol concentration was greater ($P < 0.01$) in samples collected by clipping then by plucking (2.35 pg/mg vs. 1.75 pg/mg). They found a significant positive association between cortisol concentrations in hair from the hip ($r = 0.52$) and hair from the tail ($r = 0.63$) with cortisol concentrations in saliva samples. They found a trend between cortisol concentrations in hair from the neck ($r = 0.46$) and hair from the tail ($r = 0.47$) with cortisol concentrations in the feces. They recommend clipping hair from the tail as a proxy for long term stress levels in beef cattle.

1.7 Temperament

Any grazing method involving pasture rotations necessitates more frequent livestock handling than continuous grazing. If done properly, increased frequency of livestock handling may not increase livestock stress (Cooke, 2014). If done improperly, increased handling will result in increased animal stress (Ceballos et al., 2018). Increased stress in livestock has been linked to decreased health due to stress-triggered decreased immune function (Mitchell et al., 2007).

Temperament is defined as the fear-related behavioral responses of cattle when exposed to human handling (Fordyce et al., 1988). As the temperament of cattle becomes more excitable, cattle become more fearful and aggressive when handled. Cattle with more excitable temperaments are under more stress when handled then cattle with less excitable temperaments (Cooke, 2014). Temperament in beef cattle is moderately heritable (Shrode and Hammack, 1971; and Fordyce et al., 1988). Cattle with less excitable temperaments pose less risk to personnel and to themselves while being handled than more excitable cattle (Grandin, 1994).

Cattle temperament impacts growth (Voisinet et al., 1997b), immune response (Burdick et al., 2011), carcass quality (Voisinet et al., 1997a), reproduction efficiency (Cooke et al., 2009; and Cooke et al., 2012), and feed intake (Fox et al., 2004; and Nkrumah et al., 2007). Cows with excitable temperaments have decreased probability of pregnancy (Cooke et al., 2009; Cooke et al., 2011; and Cooke et al., 2012), decreased calving rate (Cooke et al., 2012), decreased birth weight (Francisco et al., 2012b) decreased weaning weight (Cooke et al., 2012), and decreased kilograms of calf weaned/cow exposed to a bull (Cooke et al., 2012). Feedlot cattle with more excitable temperaments have reduced dry matter intake (Fox et al., 2004; and Nkrumah et al., 2007), impaired feedlot average daily gain (Voisinet et al., 1997b;

Cafe et al., 2011; Turner et al., 2011; and Francisco et al., 2012a), and reduced feed efficiency (Petherick et al., 2002). Carcasses from cattle with more excitable temperaments have reduced quality as well (Voisinet et al., 1997a; King et al., 2006; and Café et al., 2011).

Several studies have found cattle with excitable temperaments have greater cortisol concentrations during handling then cattle with less excitable temperaments (Stahringer et al., 1990; Fell et al., 1999; Curley et al., 2006; and Cooke, 2014). Cooke (2014) proposes that the elevated cortisol concentration in cattle with more excitable temperaments is the primary mechanism responsible for decreased performance of these cattle due to the neuroendocrine stress reaction.

Cattle temperament is influenced by a variety of factors including breed (Hearnshaw and Morris, 1984; and Fordyce et al., 1988), sex, age, and human interaction (Fordyce et al., 1988; and Voisinet et al., 1997b). Fordyce et al. (1985) found cattle raised in extensive environments had more excitable temperaments due to less frequent human interaction then cattle raised in intensive environments, indicating that temperament in beef cattle can be modified through proper acclimation to human interaction.

1.8 Methods of Quantifying Temperament

1.8.1 Introduction

There are multiple methods of quantifying temperament in beef cattle. These include chute score, pen score, chute exit velocity (Burrow and Corbett, 2000), hair whorl position on the forehead, percentage of eye white exposed (Lanier et al., 2001; and Core et al., 2009), and dam scores (Bailey et al., 2010). Pen scores and chute exit velocity have been found to be repeatable and correlated with serum cortisol concentration (Curley et al., 2006; and Cooke 2014).

1.8.2 Chute Exit Velocity

Chute exit velocity is measured by recording the rate of travel over a set distance immediately after the animal is released from the squeeze chute. It is recorded by an infrared sensor (Cooke 2014; and Burrow et al., 1988).

Chute exit velocity has been positively correlated with blood serum cortisol concentrations ($r = 0.26$, $P < 0.05$) and is repeatable ($r > 0.31$, $P < 0.02$) (Curley et al., 2006). Unlike other methods of assessing temperament, chute exit velocity is an objective method (Curley et al., 2006). Thus, chute exit velocity has been recommended as a valuable tool to assess cattle temperament (Cooke, 2014; and Curley et al., 2006).

1.8.3 Subjective Measures

Chute scores and pen scores are commonly used subjective measures to assess temperament in beef cattle (Cooke, 2014). Chute scores are based on a visual assessment of the animal's behavior while held, but not restrained, in a chute (Cooke, 2014; Curley et al., 2006; and Grandin, 1993). Pen scores are based on a visual assessment of the animal's behavior while confined to a small pen. Hammond et al. (1996) and Curley et al. (2006) took pen scores while small groups of animals ($n = 5$)

were held in a 5x10 m pen. Both chute scores and pen scores use a 5-point scale, with 1 being a quiet animal and 5 being an excitable animal (Cooke, 2014; Curley et al., 2006; and Grandin, 1993).

Curley et al. (2006) compared various methods of temperament assessment with blood plasma cortisol concentrations. They found chute scores, pen scores, and chute exit velocity to be positively correlated to each other ($r > 0.35$, $P < 0.01$) at day 0. Pen scores ($r = 0.29$, $P < 0.05$) and exit velocity ($r = 0.26$, $P < 0.05$) were positively correlated to cortisol concentration in blood plasma, but chute score was not ($r = 0.09$, $P = 0.46$) on day 0. On day 60, only pen and chute scores were positively correlated ($r = 0.4$, $P < 0.01$). On day 120 no measures of temperament measurement were correlated. On day 120, exit velocity ($r = 0.44$, $P < 0.001$) and pen score ($r = 0.25$, $P < 0.05$) were correlated to blood plasma cortisol concentration. The only relationship that held constant throughout the duration of the trial was that between chute exit velocity and blood plasma cortisol concentration. This has led Curley et al. (2006) and Cooke (2014) to recommend chute exit velocity as the most repeatable method of assessing temperament in beef cattle.

1.9 Modification of Temperament in Beef Cattle

1.9.1 Genetic Selection

The simplest method of altering the temperament in beef cattle herds is through direct selection for docile cattle (Cooke, 2014) as temperament is a moderately heritable trait in beef cattle (Shrode and Hammack, 1971; and Fordyce et al., 1988).

Cooke (2014) suggests culling excitable cows and heifers, as this will improve the temperament of the herd and reproductive performance since more excitable cattle generally have lower reproductive efficiency (Cooke et al., 2009; Cooke et al. 2011; Cooke et al. 2012; and Francisco et al., 2012). In some situations, genetic selection is unpractical, however.

1.9.2 Acclimation to Human Interaction

It has been repeatedly shown that acclimation of calves to human interaction improves their temperament while being handled later in life (Jago et al., 1999; Krohn et al., 2001; Curley et al., 2006; and Probest et al., 2012).

Cooke et al. (2009b) and Cooke et al. (2012a) found that acclimating replacement heifers to human interaction by processing them through a chute 3 times a week for 1 month improved their temperament compared to heifers that were not processed. Temperament was assessed via chute scores and chute exit scores. Blood plasma cortisol concentration was also reduced. Similarly, Francisco et al. (2012a) found that feedlot steers acclimated to human interaction had lowered temperament scores and blood plasma cortisol concentrations. Curley et al. (2006) noted that chute exit velocity ($P < 0.001$) decreased throughout the duration of their trial in young bulls, indicating acclimation of the bulls to human handling. Montanholi et al. (2013) likewise found a decrease in blood plasma cortisol concentration ($P < 0.05$) throughout the duration of their trial in all three of their treatments using yearling steers, indicating acclimation to human interaction.

In mature cows, Grandin (1993) found cows with excitable temperaments maintained their excitable temperaments throughout the duration of the trial, indicating a resistance to human acclimation. Similarly, Cooke et al. (2009a) found no impact on cow temperament after a 180-day period during which Brahman x Angus cows were exposed to human interaction twice weekly. It has been suggested that mature cows do not acclimate to human interaction as well as younger animals (Cooke et al., 2009; and Cooke, 2014).

Evidence suggest negative human interaction can have a negative effect on beef cattle temperament (Hemsworth, 2007; and Hemsworth and Coleman, 2011). Cooke et al. (2013) found that simulated wolf presence increased temperament scores and blood plasma cortisol concentrations in cattle herds that had previously been predated by wolves, but not in wolf-naïve cattle, indicating excitable temperament around wolves was learned behavior. Ceballos (2018) found that Brazilian beef farms whose employees had participated in a formal cattle handling skills course had fewer undesirable animal behaviors during handling than farms whose employees had not participated in a formal cattle handling skills course ($P < 0.05$).

1.10 Summary of Literature Review

There are numerous grazing methods available to the livestock producer (Holechek et al., 2011). The effectiveness of the various methods at accomplishing their objectives depends on the skills of the manager, climatic conditions, forage characteristics, and the size of the pastures (Teague et al., 2013). Generally, continuous grazing results in maximum individual animal performance (Briske et al., 2008). Rotational grazing methods may have benefits to forage species composition and biomass production (Teague et al., 2011), and may maximize livestock production per unit area of land (Briske et al., 2008). The increased costs associated with rotational grazing may not have a positive return on investment (Knight et al., 2011). Research has not shown a clear advantage to any grazing method (Briske et al., 2008; and Teague et al., 2013). Stocking rate has universally been found to have a greater impact on livestock performance, forage production, and profitability than grazing method (Holechek et al., 2011).

Grazing distribution within a grazing unit is influenced by various biotic and abiotic factors, such as water availability, forage quality and quantity, location of supplements, topography, and thermoregulation (Bailey, 2005). Grazing distribution has important implications to livestock performance and forage production (Holechek et al., 2011). The effect of grazing method on grazing distribution has not been well studied. Global positioning collars are an excellent new technology to study grazing distribution (Russell et al., 2012).

The glucocorticoid hormone cortisol has various physiological functions (Sapolsky, 2002). Since it is released in response to stress, it can be used as a proxy to measure stress and temperament (Moya et al., 2013). Cortisol concentration can be measured in blood plasma, fecal matter, saliva, and hair samples (Moya et al., 2013). Each method has its unique advantageous and disadvantages.

The temperament of beef cattle has important production and welfare implications (Cooke, 2014). Although temperament is moderately heritable (Shrode and

Hammack, 1971), it can be impacted both positively (Cooke, 2014) and negatively (Ceballos, 2018) by human interaction. There are various methods to measure temperament in beef cattle (Cooke, 2014). The method that has been shown to be most repeatable and most closely correlated to cortisol concentration is chute exit velocity (Curley et al., 2006).

CHAPTER II

EFFECTS OF ROTATIONAL AND CONTINUOUS GRAZING ON THE GRAZING BEHVIOR AND PERFORMANCE OF BEEF CATTLE.

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Abstract: The objective of this study was to determine the effect of grazing method on grazing behavior, forage quality and diet quality, forage production, and animal performance. To achieve this, 75 Angus x Brahman F-1 cows (BW = 642 ± 75 kg; BCS = 6.6 ± 0.4) were randomly allocated to one of two grazing methods, either continuous (**C**) or rotational (**R**). Cattle allocated to C grazed the same 60-ha pasture throughout the duration of the experiment. Cattle allocated to R were rotated among 10 paddocks (7.7 ± 5.5 ha) every 8-31 days. Rest periods averaged 155 days. Each treatment was replicated twice. The stocking rate in the R treatment was 27% greater than the stocking rate in the C treatment (2.4 vs. 3.1 ha/AUE, respectively). Each cow was fitted with a Global Positioning System transmitter on a collar to collect spatial data. Collars were deployed for 77 days during the summer and 61 days during the fall of 2019. Uniformity of grazing distribution was analyzed in ArcMap using the Hotspot Analysis function, the Average Nearest Neighbor function, and the Standard Distance function. None of these analyses found grazing distribution to be affected by grazing treatment ($P > 0.23$). Grazing method did not affect time spent near water ($P > 0.39$) or distance traveled per day ($P > 0.12$). Daily Area Explored was greater in the C treatment ($P = 0.02$), while the Spatial Search Pattern was greater in the R treatment ($P = 0.01$). Daily Area Explored as a percentage of paddock size was greater in the R treatment ($P = 0.03$). Grazing treatment affected forage crude protein in July only ($P = 0.05$), ADF in May and December ($P < 0.06$), and lignin in May and December ($P < 0.10$). Crude protein was greater in C in July only, while R had the advantage in ADF and lignin in all four instances a treatment affect was detected. Diet quality was greater in the continuous grazing treatment ($P < 0.07$). Grazing treatment did not affect NDF ($P > 0.25$). Forage production tended to be greater in the C treatment in May only ($P = 0.06$). Forage utilization was unaffected by grazing treatment ($P = 0.64$). No difference was found between grazing treatments in body condition score ($P > 0.13$), calving rate ($P = 0.11$), percentage of weaned calf weight to cow body weight ($P = 0.23$), or kg of calf weaned per ha ($P = 0.17$). Cow body weights tended to be greater in C in October only ($P = 0.06$). Calf weaning weights were greater in C ($P = 0.04$). This experiment found no consistent differences between rotational and continuous grazing in grazing behavior, forage production, forage quality, forage utilization, or animal performance in this environment at this time.

Key words: Rotational grazing, continuous grazing, grazing distribution

2.1 Introduction

Setting the stocking rate above the ecological carrying capacity of the grazing unit for extended periods of time (Holechek et al., 1999), or improper grazing distribution within the grazing unit (Bailey, 2005), can result in overgrazing. Overgrazing can result in reduced forage vigor (Caldwell et al., 1981), reduced forage production (Holechek et al., 1999), limited plant growth (Briske et al., 2008), an alteration of the plant community (Briske, 1991), reduced root mass and distribution (Hodgkinson and Bass Becking, 1977), exposed soil and increased soil erosion (Thurrow, 1991), and reduced watershed functions (Fuls 1992).

Rotational grazing, defined as reoccurring periods of grazing and rest among multiple paddocks in a grazing management unit (Allen et al., 2011), has been advertised as having the potential to increase the carrying capacity of the grazing unit and to positively alter the grazing behavior within the grazing unit (Savory and Butterfield, 2016). The positive aspects of rotational grazing are achieved by improving the species composition or productivity by ensuring key species have adequate growing season rest to capture adequate resources, providing adequate post-grazing plant recovery, increasing livestock harvest efficiency, reducing animal selectivity by increasing stock density, reducing patch grazing, ensuring more uniform animal distribution within large heterogeneous management units, and increasing primary and secondary productivity (Teague et al., 2013; Briske et al., 2008). However, research results and empirical evidence have not always been in agreement regarding the validity of these claims (Briske et al., 2008; Teague et al, 2013).

The desirability of uniform grazing distribution depends on the objectives of the manager. Many of the environmental concerns associated with livestock grazing of rangelands, particularly on public land, are due to poor grazing distribution (Bailey, 2005) in which livestock congregate on certain areas which can eventually become overgrazed. Encouraging livestock to graze areas further from water or to utilize steeper slopes, with the primary objective of increasing the carrying capacity of a grazing unit (Romo et al., 1997), has been the focus of many experiments (Ares, 1953; Skovlin, 1957; Davison and Neufeld, 1999; Bailey et al., 2008). However, it is recognized that the increased vegetative heterogeneity associated with a gradient of grazing intensities has ecosystem services including benefiting many wildlife species (Fuhlendorf and Engle, 2001). Bobwhite quail managers frequently use cattle as a management tool to increase the heterogeneity of vegetation to improve bobwhite habitat (Hernandez and Guthery, 2012). Additionally, maximizing uniformity of grazing may conflict with the objective of maintaining a high-quality diet for herbivores (Valentine, 2001).

The objective of this study was to determine if rotational grazing results in more uniform grazing distribution compared to continuous grazing and will allow for increased stocking rate. We compared forage production, forage quality, diet quality, and animal productivity between these two grazing methods. Grazing behaviors analyzed included grazing distribution, daily distance traveled, average distance to water, percent of time spent near water, Area Explored, and Spatial Search Pattern.

2.2 Materials and Methods

2.2.1. Study Site

All animal procedures used in this experiment were approved by the United States Department of Agriculture – Agricultural Research Service Grazinglands Research Laboratory Institutional Animal Care and Use Committee (IACUC-GRL-2017-12-15-1-Neel-Cow Temperament). Research was conducted at the United States Department of Agriculture - Agricultural Research Service Grazinglands Research Laboratory (ARS GRL) in Canadian County, Oklahoma, located 10.5 km west of El Reno. The average annual precipitation for Canadian County is 848 mm, with May and June being the wettest months. The average monthly precipitation ranges from a low of 28 mm in January to a high of 148 mm in May. The annual temperature averages 16° C. The growing season averages 209 days (Oklahoma Climatological Survey, 2020).

This experiment was conducted from May through December 2019. The total precipitation during the 8-month duration of this experiment was 833 mm (Oklahoma Climatological Survey, 2020), 25% greater than the 1981-2010 average for this period. Average monthly precipitation is compared to the precipitation received during the duration of the experiment in Figure 2.1.

The research area consisted of 270 ha of native range divided into four pastures. Dominant forage species were big bluestem (*Andropogon gerardii*), little bluestem (*Schizachyrium scoparium*), Indiangrass (*Sorghastrum nutans*) and switchgrass (*Panicum virgatum*). Johnsongrass (*Sorghum halepense*), Old World bluestem (*Bothriochloa ischaemum*), and fescue (*Festuca arundinacea*) were locally abundant in certain areas.

Woody species included roughleaf dogwood (*Cornus drummondii*), buckbrush (*Symphoricarpos orbiculatus*), and black locust (*Robinia pseudoacacia*). Woody species canopy cover ranged from 0% to 17% in the four pastures utilized in our experiment (Rangeland Analysis Platform, 2020).

Two ephemeral streams flowed through the study areas. Both were flowing during the first two months of the trial. Part of the study area was flooded during May and June due to excessive precipitation in May. The dominate soil types were Norge silt loam (57.4%), Pond Creek silt loam (19.6%), and Kirkland-Pawhuska complex (12%; Web Soil Survey Staff, 2020). Other soil types composed less than 5% of the total area.

2.2.2. Study Animals

Seventy-five Angus x Brahman F-1 cows (BW = 642 ± 75 kg; BCS = 6.6 ± 0.4) were randomly assigned to either a rotational or continuous grazing treatment in January 2018. An additional nine first-calf heifers were added in April 2019 to ensure uniform stocking rate within treatments (3.1 ± 0.1 ha/Animal Use Equivalent (**AUE**) for C, 2.4 ± 0.2 ha/AUE for R). Each grazing treatment was replicated in two pastures (herds). Cows ranged in age from 2 to 13 years of age. Eight cows were removed from trial for reasons unrelated to the grazing treatment, including footrot, prolapse, pinkeye, and mortality due to unknown causes.

Calving began 15 March and ended 30 May. From 15 October through 1 March, cows were supplemented with 40% crude protein concentrate supplement consisting primarily of soybean meal and hulls at a rate of 2.3 kg per cow three times per week (mean = (2.3 x 3) ÷ 7 = 1.0 kg/day/cow). From 1 March through 15 May, cows were supplemented with 20% crude protein concentrate supplement consisting primarily of soybean meal and hulls at a rate of 3.2 kg per cow three times per week (mean = (3.2 x 3) ÷ 7 = 1.4 kg/day/cow). No supplemental hay was fed during the duration of this experiment. Calves were weaned on 19 September 2019, averaging 160 days of age at this time.

2.2.3. Grazing Treatment

Our treatments consisted of a continuously grazed treatment (**C**) and a rotationally grazed treatment (**R**). The pastures allocated to C were grazed year-round. The pastures allocated to R were subdivided into 10 paddocks per replicate, and each paddock was grazed from 8-31 days depending on forage availability at the beginning of the grazing period. The average rest period between grazing periods was 155 days in R. Both treatments were replicated in 2 pastures. The pastures had been managed according to the grazing method to which they had been allocated for a minimum of 10 years prior to the initiation of this experiment.

The continuously grazed treatment was divided into two replicates, C1 (60 ha) and C2 (60 ha). Forage production estimates were based on Natural Resource Conservation Service Web Soil Survey Data (Web Soil Survey Staff, 2020) and the estimates were verified with forage clippings taken prior to the beginning of the experiment. We projected C1 to produce 6,766 kg/ha of forage dry matter and C2 to produce 5,662 kg/ha of forage dry matter.

The rotationally grazed treatment was divided into two replicates, R1 (75 ha) and R2 (79 ha). We estimated forage production based on Natural Resource Conservation

Service Web Soil Survey Data (Web Soil Survey Staff, 2020) and verified the results with forage clippings prior to the beginning of the trial. We projected R1 to produce 6,334 kg/ha of forage dry matter and R2 to produce 6,419 kg/ha of forage dry matter.

Forage production was used to calculate carrying capacity. Carrying capacity was calculated using a 25% harvest utilization, and Animal Unit Equivalents (**AUE**) were estimated according to the following formula from Holechek et al. (2011): if BW > 1000 lbs., AUE = (BW - 100) / 1000; if BW < 1000 lbs., AUE = (BW + 100) / 1000. Using estimated forage production, pasture size, and a 25% harvest efficiency, projected usable forage production for C1 was 101,498 total kg of forage, for C2 was 99,615 total kg of forage, for R1 was 118,756 total kg of forage, and for R2 was 126,778 kg of forage. One AUE was defined as 3,318 kg of forage (Holechek et al, 2011). Thus, C1 was estimated to have a carrying capacity of 30.6 AUE, C2 was estimated to have a carrying capacity of 25.6 AUE, R1 was estimated to have a carrying capacity of 35.8 AUE, and R2 was estimated to have a carrying capacity of 38.2 AUE (Table 2.1)

The stocking rate for the R treatment was 27% greater than for the C treatment, averaging 2.4 ± 0.2 ha/AUE for R and 3.1 ± 0.1 ha/AUE for C. R1 was stocked with 26 cows totaling 33 AUE, R2 was stocked with 23 cows totaling 30.7 AUE, C1 was stocked with 15 cows totaling 19.8 AUE, and C2 was stocked with 16 cows totaling 19.3 AUE. Thus, the C treatment was stocked at 70% of the estimated carrying capacity, with the R treatment was stocked at 87% of the estimated carrying capacity. R1 had a stocking rate of 2.3 ha/AUE, R2 had a stocking rate of 2.6 ha/AUE, C1 had a stocking rate of 3.0 ha/AUE, and C2 had a stocking rate of 3.1 ha/AUE. Carrying capacity, stocking rate, and the relationship of stocking rate to actual carrying capacity is shown in Table 2.1.

The rotational schedule in R was managed adaptively throughout the experiment. The grazing periods ranged from 8-31 days, with rest periods averaging 155 days. Forage was clipped the day cattle entered a new paddock to determine forage biomass availability at that time. Two grazing exclosures were built in each paddock. Inside each exclosure, three 0.96-m^2 quadrats were clipped. Outside the exclosure, four 0.96-m^2 quadrats were clipped 10-m from the edge of the exclosure in the four cardinal directions. This was repeated at each grazing exclosure, resulting in a total of 14 forage clippings in each paddock taken the first day of the grazing period. All plant biomass was clipped to the ground inside the 0.96-m^2 ring. Woody vegetation (primarily buckbrush) was sorted out and discarded. Forage samples were then dried at 60° C for a minimum of 72 hours and weighed. The grazing period for each paddock was calculated using this forage biomass data. The initial target utilization was 12.5% per grazing period. Forage disappearance was estimated to be 4% of animal body weight per day based on previous unpublished research conducted at the ARS GRL (Neel, personal communication, 2019). The target utilization was adjusted throughout the experiment based on actual forage disappearance.

Actual forage disappearance was calculated to measure forage utilization. At the end of the grazing period, forage samples were clipped again in the same manner as prior to the grazing period. Three samples were clipped inside the grazing exclosure, and four were clipped outside the grazing exclosure. This was repeated at each grazing exclosure, resulting in 14 forage clipping per paddock after the grazing period. Forage disappearance was calculated as the difference in standing forage biomass inside the exclosure and outside the exclosure at the end of the grazing period.

2.2.4. Animal Production Parameters

Cow body weight and body condition scores were measured in May, August, October, and December 2019. Additionally, calving rate, calf weaning weight, and percentage of calf weaning weight to cow body weight were also measured. Weight of weaned calf per ha was calculated as the weaning weight of the calves (kg) divided by the land area of their pasture (ha). Body condition scores (**BCS**) were taken on a 1-9 scale (NASEM, 2016). The same trained observer scored all the cows at each collection period.

Measures of reproductive performance included calving rate, calf weaning weight, ratio of calf weaning weight to cow body weight, and kilograms of weaned calf produced per hectare. Kilograms of weaned calf produced per ha was analyzed on an opens in basis, with cows that did not calve recorded as weaning a calf that weighed 0 kg. Calf weaning weight and percentage of calf weaning weight to cow body weight were analyzed on an opens out basis, where cows that did not calve were removed from the dataset prior to analysis. Calves were weaned on 19 September 2019, averaging 160 days of age at this time.

2.2.5. Vegetation Measurements

We measured forage production, forage utilization, and forage quality. Forage production was calculated based on forage clippings and reported in kg/ha. Forage utilization was calculated based on the difference in forage production (kg/ha) inside and outside the grazing exclosures. Forage quality was determined using near infrared spectrometry. Forage acid detergent fiber (ADF), neutral detergent fiber (NDF), crude protein, and lignin are reported

The C treatment had 16 grazing exclosures constructed per replicate, for a total of 32 exclosures. A grid was overlaid on a map of the C pastures, and the grazing exclosures were distributed evenly across the pastures at the rate of one exclosure per 3.8 ha. The R treatment had two grazing exclosures constructed per paddock, resulting in 20 exclosures per replicate, and 40 exclosures total. Exclosures were distributed across the R treatment at a rate of one exclosure per 3.9 ha.

Forage production (ha/kg) was measured in the C treatment in May, July, and December. Both replicates in C were clipped at the same time. Forage rings (0.96 m^2) were used. All vegetation inside the ring was clipped to ground level. Non-herbaceous vegetation (primarily buckbrush) was sorted out and discarded. The remaining vegetation was dried for a minimum of 72 hours and then weighed. Three forage rings were clipped inside each exclosure. Four were clipped outside each exclosure in each of the four cardinal directions (N, S, E, W) 10-m from the edge of the exclosure. This resulted in 112 forage samples at each clipping per replicate.

In the R treatment, forage production (kg/ha) was measured at the beginning and end of each grazing period in every paddock. Three forage rings were clipped inside, and four outside, both grazing exclosures at this time. Thus, a total of 14 forage clippings were taken before and 14 after each grazing period in every paddock. The clippings taken before the grazing period were clipped on the day cattle were rotated into that paddock, and the clippings taken after the grazing period were taken the day cattle were rotated out of that paddock.

Forage utilization was calculated as the difference between forage production outside and inside the exclosures. In the C treatment, forage utilization was calculated three times, in May, July, and December. In the R treatment, forage utilization was calculated every time cattle were rotated (n = 12 and n = 10 for R1 and R2, respectively).

Sixteen forage samples from each replicate (C1, C2, R1, and R2) were clipped in May, July, and December; ground; and tested for forage quality. Thus 32 forage samples from each treatment were tested in May, July, and December, for a total of 192 forage samples. These forage samples were clipped to ground level outside the grazing exclosures to best represent the forage available to the cattle. In the R treatment, they came from paddocks that had not yet been grazed that year, indicating the diet that would be available to the cows once rotated into that paddock. Cattle were rotated in the R treatment several hours after sampling for forage quality.

After clipping, forage samples were dried for a minimum of 72 hours at 60° C. Samples were then ground (Fritsch 11.15550 Funnel P-19) and passed through a 1-mm screen. Testing was done using near-infrared spectroscopy (Foss NIRS DS 2500F). The results from the near-infrared spectroscopy were validated by duplicate testing of three samples at the Soil, Water, and Forage Analytical Laboratory (SWFAL) at Oklahoma State University (Appendix A). The NIRS results were deemed acceptably accurate for our purpose since the standard deviation comparing the results from NIRS and SWFAL was 1.5%.

2.2.6 Diet Quality

The diet quality of livestock grazing native range often exceeds the forage quality results achieved from clipped forage samples due to the ability of livestock to select a high-quality diet (Holechek et al., 1982; Theurer et al., 1976). Proponents of rotational grazing claim that rotational grazing can alter the forage selectivity of grazing livestock by forcing livestock to consume plants they would otherwise avoid (Savory and Butterfield, 2016). For this to be true, diet quality must differ between grazing treatments, with continuous grazing having greater diet quality. In this experiment diet quality was analyzed indirectly through the analysis of fecal samples.

Fecal samples were collected ten times throughout this experiment, once in May, once in June, once in July, once in August, twice in September, once in October, twice in November, and once in December. Fecal samples were collected on the day the cattle in the rotational treatment were rotated to the next paddock in their rotation. Fecal samples were collected in the pasture from 20 separate fecal pads. Fecal samples from the same replicate collected at the time were composited. A subsample of this composite was dried at 60° C for 48 hours, then ground through a 1 mm screen. Diet quality assessment was performed at the Texas A&M Grazing Animal Nutrition Lab in Temple, Texas, using near-infrared spectroscopy (**NIRS**) technologies (Lyons and Stuth, 1992). Fecal samples were analyzed for dietary crude protein and dietary digestible organic matter, as well as for fecal nitrogen and fecal phosphorus content.

2.2.7. Spatial Data

Each cow in our experiment was fitted with a collar and GPS coordinate transmitter to collect data to be used in spatial analysis. The collars were constructed in our lab based on the methods of Knight et al. (2018a and 2018b). The collars were deployed from 15 May through 31 July 2019, and again from 2 October through 2 December 2019. The first deployment will hereafter be referred to as the summer deployment, and the second as the fall deployment.

We used Mobile Action i-gotU GT-600 GPS units (New Taipei City, Taiwan). We replaced the factory installed 3.7V 750mAh Li-ion battery with two Tenergy 3.7V 5200mAh Li-ion battery packs (Fremont, CA) wired in parallel to extend the battery life of the GPS units. The unit and attached batteries were then placed in a polycarbonate box (Polycase; Avon, OH) and attached to a 3.8 cm x 111.8 cm nylon collar (Valhoma Corporation; Tulsa, OK). A steel plate was fabricated and attached to the nylon collar to serve the purpose of a weight so the GPS unit would sit on the top of the cow's neck. The units were programmed to record a GPS position every 5 minutes.

After the collar was removed from the cow at the end of the deployment period, the data was uploaded to the @trip PC software provided by Mobile Action. Data was then exported as a csv file. GPS data was filtered to remove erroneous data using R (R Core Team, 2020; RStudio Team, 2015; Wickham et al., 2019; Wickham, 2016). Data that fell outside the desired date range was removed. The first and last day collars were deployed was also removed. We filtered data according to the methods outlined in Knight et al. (2018b). Data with altitude values that fell outside the range of possible altitude values at our site (250 m < x <600 m) was removed. Additionally, if speed was greater than 500 meters/hr, the rate was greater than 84 meters/minute, the course difference was less than -100 or greater than 100, or the distance traveled was greater than 420 meters, the data was removed as recommended in Knight et al., 2018a.

Data was then uploaded into ArcMap 10.7.1 (ESRI, 2019). Data points that fell outside of the pasture boundaries were clipped using the Clip command in the Arc Toolbox Extract function, with a polygon of the pasture outline as the clip feature. Using the Select by Attributes command, a shapefile was made for each individual animal. Spatial data analyzed included distance traveled, mean distance to water, time spent within a specified radius of water, evenness of pasture use, Nearest Neighbor, Standard Distance, Area Explored, and Spatial Search Pattern.

Distance traveled was calculated in meters using the Statistics function in the attribute table. Daily distance traveled was calculated by dividing the total distance traveled by the number of days the unit recorded data. To calculate daylight distance traveled, the Select by Attribute command was used. For the summer deployment, daylight hours were based on sunrise at 0615 and sunset at 2048, the average day length for the deployment period. For the fall deployment, daylight hours were based on sunrise at 0751 and sunset at 1835, the average day length for the deployment period.

Mean distance to water was calculated using the Near command in the Arc Toolbox Proximity function. Water sources were marked using the Draw command in the Geoprocessing function. Pastures with multiple water sources had the water sources joined into one shapefile using the Merge command in the Arc Toolbox Data

Management Tools function prior to running the Near command. The distance to the closest water source was used as the mean distance to water, reported in meters.

The percentage of time spent within 50 m and 100 m of water was calculated by creating a 50- or 100-meter buffer, respectively, around the water sources using the Buffer command in the Arc Toolbox Proximity function. The individual animal spatial data that fell within the desired radius of water was clipped using the Clip command in the Arc Toolbox Analysis Tools Extract function with the buffer around the water used as the clip feature. The percentage of GPS fixes that fell within the desired radius of water was divided by the total number of GPS fixes to determine the percentage of GPS fixes that fell within 50 or 100 meters of water.

The number and type of water source varied between treatments and replicates. C1 had three cement water tanks. C2 had one cement water tank and one pond. The paddocks grazed during the summer deployment of collars in the R1 replicate had two cement water tanks, while those grazed during the fall had only one cement water tank. The paddocks grazed during the summer deployment of collars in the R2 replicate had two cement water tanks and a creek which was flowing at this time, and those grazed during the fall had two cement tanks and two ponds.

The evenness of grazing distribution across the pasture was analyzed using the Optimized Hot Spot Analysis (Getis-Ord Gi*) command in the Arc Toolbox Spatial Statistics Tool Mapping Clusters function. The bounding polygon was the pasture outline, and the cell grid size was 9 meters by 9 meters. The output of the hotspot analysis shows the Z-score, P-value, and Gi_bin calculated on the number of GPS points per polygon. The Gi_bin is the confidence interval. To determine the uniformity of pasture use, the number of polygons within one standard deviation of the mean (Gi_bin = 0) was divided by the total number of polygons for that pasture. This resulted in the percentage of the pasture where the number of GPS points per 81 m^2 was within one standard deviation of the mean number of GPS points per polygon for the pasture. Inversely, areas of the pasture identified as within one standard deviation of the mean were not hot or cold spots. Pastures with greater percentage of either hot or cold spots had lower uniformity of pasture use when compared to pastures with a greater percentage falling within one standard deviation of the mean. Output examples from the Hot Spot Analysis can be seen in Figure 2.16 and Figure 2.17.

Because the rotational schedule was based on forage/AUE, not hectares/AUE, the data had to be further filtered to prevent the creation of artificial hotspots in the rotational pastures prior to performing the hotspot analysis. These artificial hotspots could occur if paddocks with more animal days per ha were compared to paddocks with fewer animal days per ha, since each day should have generated 288 GPS coordinate fix positions. To prevent this, data from the first X days a paddock was grazed was analyzed so that days/ha = 1.37. This number was chosen since it was the fewest days/ha that occurred during the experiment. This data was used for the hotspot analysis only.

Additionally, grazing distribution was measured using the Average Nearest Neighbor and Standard Distance functions in the Arc Toolbox. To correct for differential numbers of GPS fixes across treatments and seasons, for these analyses the minimum number of GPS fixes per ha was randomly selected for every animal in accordance with the methodology of Venter et al. (2019). The minimum number of GPS fixes per ha in our experiment was 78. Thus 78 GPS fixes per ha were randomly selected and used in these analyses. The pasture size in the two continuous replicates in both the summer and the fall was 60 ha, so 4680 GPS fixes (78 x 60) were randomly selected. In the rotational replicates, the paddocks grazed ranged in size from 21 to 39 ha, so between 1628 and 3042 (21 x 78; 39 x 78) GPS fixes were randomly selected. These randomly selected GPS fixes for each animal were used in the Average Nearest Neighbor and Standard Distance analysis.

The Average Nearest Neighbor function in Arc Map is a measure of the dispersion of the GPS points across the pasture. The results of this analysis include the mean distance between points (Average Nearest Neighbor), and the ratio of the observed mean distance between points and the expected mean distance between points if the points were equally spaced across the pasture (Nearest Neighbor Ratio). A Nearest Neighbor Ratio less then one indicates clustering, while a Nearest Neighbor Ratio greater than one indicates dispersion.

The Standard Distance function in Arc Map analyses the degree to which points are concentrated or dispersed around a geometric mean center. A circle polygon is drawn around the mean center with a radius equal to the standard distance. All points that fall within this polygon are within one standard deviation of the geometric mean center. A larger value thus represents more dispersed data, while a smaller value indicates the points are grouped closer around the mean.

The Area Explored was calculated using the Minimum Bounding Geometry function in Arc Map. For this analysis, a separate shapefile was made of GPS points for each cow on each day. This was repeated for four separate days per cow per deployment. Thus 224 (56 cows x 4 days) days were analyzed for the summer deployment and 280 (70 cows x 4 days) days were analyzed for the fall deployment. The output of this analysis is a polygon encompassing all GPS coordinate fixes. The area of the polygons was calculated to determine the area in which cattle had been present on each day. A larger Area Explored indicates that the animal was present in a larger part of the pasture on that day. A smaller Area Explored indicates that the animal stayed in the same general area throughout the day.

The Spatial Search Pattern was calculated using the 24-hour distance traveled and the Area Explored. The 24-hour distance traveled in meters was multiplied by 1 meter to calculate the 24-hour grazeable area. One meter was chosen because it was assumed a cow could graze 0.5-meter perpendicular from her present location due to lateral neck movement. Thus, 24-hour grazeable area was presented in meters^2 when the 24-hour distance traveled (m) was multiplied by areas within reach of grazing (m). To calculate Spatial Search Pattern, the 24-hour grazeable area (m^2) was divided by the Area Explored (m^2). The result was the percentage of the Area Explored that could have been grazed by that animal. A larger Spatial Search Pattern indicates that the animal thoroughly covered the Area Explored on that day. A smaller Spatial Search Pattern indicates that the animal did not thoroughly cover the Area Explored on that day. For example, a cow that walked the perimeter of the pasture but never strayed from the perimeter fence would have a Spatial Search Pattern close to 0%. A cow that was present in every square meter of the Area Explored would have a Spatial Search Pattern of 100%. Spatial Search Pattern is illustrated in Figure 2.21.

Additionally, the Area Explored as a percentage of the paddock the animal had access to on that day was calculated. If this value was high, then the animal used the entire paddock on that day. If this value is small, then there was a large part of the paddock the animal did not access on that day.

Area Explored, Spatial Search Pattern, and the Area Explored as a percentage of the paddock the animal had access to on that day were calculated for each animal on a given day, then averaged across days for each animal.

2.2.8 Statistical Analysis

Statistical analysis was performed in R (R Core Team, 2020, Kassambara, 2020; Wickham et al., 2019; Wickham, 2016). All variables were analyzed using analysis of variation (**ANOVA**). The dependent variables were cow body weight, cow body condition score, calving rate, calf weaning weight, the ratio of calf weaning weight to cow body weight, forage production, forage utilization, forage quality, diet quality, distance traveled, proximity to water, Hotspot Analysis, Standard Distance, Average Nearest Neighbor, Spatial Search Pattern, and Area Explored. Grazing treatment was a fixed independent variable. Pasture replicate was the experimental unit. For the distance traveled analysis, fix frequency was a covariate with distance traveled.

Calving rate, calf weaning weight, the ratio of calf weaning weight to cow body weight, and kg of calf weaned per ha were measured only once. Cow BW and BCS were recorded four times throughout the experiment and are reported and analyzed at each of these four collections. All the spatial data was measured during the summer and fall and is reported and analyzed for the summer and fall separately, as well as the summer and fall combined. Forage production, forage utilization, and forage quality (CP, ADF, NDF, and lignin) were measured in May, July, and December. These variables are reported and analyzed for each collection, as well as overall in which the data from each collection is combined.

2.3 Results and Discussion

2.3.1 Animal Productivity

Grazing method did not affect BCS in May, August, October, or December ($P > 0.13$; Table 2.2). The continuous grazing treatment tended to have greater BW in October ($P = 0.06$), but there was no difference in May, August, or December ($P > 0.22$). Calving rate, the percentage of the cow herd that produced a calf, was not affected by grazing treatment ($P = 0.11$). Calf weaning weight was greater in the C treatment ($P = 0.03$). The ratio of calf weaning weight to cow body weight was not affected by grazing treatment ($P = 0.23$). The kg of weaned calf produced per hectare was not affected by grazing treatment ($P = 0.17$).

Although calving rate was not statistically affected by grazing treatment ($P = 0.11$), there was a large numerical difference in calving rate. The rotational treatment had a calving rate that was 18% greater than the calving rate in the continuous treatment (82% vs. 64%, respectively). Both calving rates are lower than expected. Mean cow age in this experiment was 8 years, which may account for the low conception rates. Cows were randomly assigned to grazing treatment, so there was not a significant interaction between age and treatment ($P = 0.43$). One bull serviced each herd/replicate, so the bull to cow ratio for C1 was 1:15, for C2 was 1:16, for R1 was 1:26, and for R2 was 1:23.

Most grazing experiments have found individual animal performance to be greater in continuous grazing then in rotational grazing (Briske et al., 2008). This is especially true when the stocking rate in the rotational grazing treatment exceeds that of the continuous grazing treatment, as was the case in our experiment. The pastures in the rotational grazing treatment of our experiment were stocked 27% greater than those in the continuous grazing treatment (2.4 vs. 3.1 ha/AUE; Table 2.1). Thus, the greater weaning weights in the continuous grazing treatment are in accordance with the literature.

The stocking rate was 27% greater in the rotational grazing treatment than in the continuous grazing treatment in this experiment. It must be remembered that even with the 27% increase in stocking rate in the rotational grazing treatment, both treatments were stocked below the estimated ecological carrying capacity of this site. The continuous grazing treatment was stocked at 70% of the estimated carrying capacity, while the rotational grazing treatment was stocked at 86% of the estimated carrying capacity. So even though the rotational grazing treatment had a greater stocking rate, it was still below the estimated ecological carrying capacity. The estimated carrying capacity was based on projected forage production for this site from the NRCS Web Soil Survey (Web Soil Survey Staff, 2020). Above average precipitation during the experiment magnified the difference between stocking rate and carrying capacity. Based on forage clippings, the continuous grazing treatment was only stocked at 48% of the actual carrying capacity, and the rotational grazing treatment was only stocked at 70% of the actual carrying capacity (Table 2.1). Forage utilization in this experiment averaged 22% and was not affected by grazing treatment ($P = 0.64$).

Thus, although we found that an increased stocking rate in the rotational grazing treatment did not adversely affect all the individual animal performance variables analyzed, this may not have been true had the stocking rate in our experiment been at or above the ecological carrying capacity. These results should not be interpreted as meaning that in all cases rotational grazing will allow for an increase in stocking rate without adversely affecting animal performance. There is a point at which this ceases to be the case (Briske et al., 2008; Holechek et al., 1999).

Most grazing experiments have found greater production per land area in rotationally grazed then continuous grazed systems when the stocking rate is greater in the rotationally grazed treatment (Briske et al., 2008, Mott, 1960). We did not find this to be the case. We found no difference between treatments in kg of calf produced per ha.

2.3.2 Forage Production and Utilization

Forage production was measured in May, July, and December 2019 (Table 2.3 and Figure 2.2). The continuous grazing treatment showed a tendency to produce more kg of forage per ha in May only ($P = 0.06$). In July, December, and overall ($P > 0.13$), forage production in kg/ha was unaffected by grazing treatment. Forage utilization (Table 2.3 and Figure 2.3) was not affected by grazing treatment ($P = 0.64$).

It is logical that a treatment effect would be detected in May, since the greater stocking rate in the rotational grazing treatment (27% greater) should have resulted in greater forage disappearance during the dormant season. Little biomass production would have occurred over the dormant season. Thus, the greater stocking rate in the rotational treatment would have resulted in a quicker depletion of the forage resource during the dormant season, resulting in more standing biomass in May in the continuous treatment. Once the growing season began, however, the treatment difference in forage production disappeared ($P > 0.20$) despite the difference in stocking rates.

Briske et al. (2008) report that most grazing experiments have found equal forage production between rotational and continuous grazing when the rotational system is stocked greater. Teague et al. (2011) found greater forage production in a rotational grazing system compared to a continuous grazing system, even though the rotational grazing system was stocked 52% greater.

Teague et al. (2011) attribute the greater forage production they found in the rotational grazing system to a greater percentage of the forage consisting of tall- and mid-grasses in their treatment. They attribute the greater percentage of tall- and mid-grasses in the rotational grazing treatment to the ability of these more desirable forage species to recover during the rest period in this treatment. The continuously grazed treatment did not allow them to recover following defoliation, resulting in a shift in the plant community towards short grasses.

The rotationally grazed pastures in our experiment had less standing forage at the beginning of the growing season (May) but this difference in forage production was eliminated by July. This indicates that they grew more forage during the growing season to compensate, despite being stocked 27% heavier. We found no difference in forage utilization ($P = 0.64$) between treatments. Thus, our results may support Teague et al. (2011). Alternatively, the low stocking rates in both our treatments may have simply not affected forage production due to unusually high precipitation during our experiment.

Further research should be conducted at the same location as our experiment looking at the difference in forage species composition to determine if grazing treatment really affects forage production.

2.3.3 Forage Quality

We used forage crude protein percentage, NDF percentage, ADF percentage, and lignin percentage as a proxy for forage quality (Table 2.4). Forages with the highest ratio of cell soluble components (amino acids, proteins, lipids, and starch) to cell structural components (hemicellulose, cellulose, lignin, and silica) are considered to be the highest quality, and are preferentially selected by grazing animals (Briske et al., 2008). Cellulose, hemicellulose, and lignin comprise NDF (Van Soest, 1963). In forage-based diets, NDF is the primary source of digestible energy and stimulates rumination, salivation, reticulorumen motility, and increases ruminal pH (NASEM, 2016). Cellulose and lignin comprise ADF (Van Soest, 1963). Cellulose and lignin are cell structural components with anti-quality properties (Briske et al., 2008). Lignin increases with plant maturity, and negatively effects digestibility of forage since lignin itself is indigestible (Himmelsbach, 1993; Moore and Hatfield, 1994).

Lignin content of the forage in our experiment was greater ($P = 0.10$) throughout the duration of the experiment in the continuous grazing treatment, as well as in May and December ($P < 0.10$). Similarly, ADF percentage was greater in the continuous grazing treatment in May and December ($P < 0.06$). These results indicate that in May and December, a greater portion of the forage consisted of mature, poor quality forage in the continuous grazing treatment then in the rotational grazing treatment. This supports the claim that rotational grazing prolongs the period that forage remains in the vegetative state and thus increases forage quality. However, the only difference in crude protein was observed in July ($P = 0.05$), with the continuous grazing treatment having greater crude protein content ($10.0 \pm 0.2\%$ for the continuous vs. $8.9 \pm 0.3\%$ for the rotational treatment). NDF percentage was unaffected by treatment throughout the experiment ($P > 0.25$).

In summary, continuous grazing showed a tendency to have greater crude protein in July. ADF tended to be greater in the continuous grazing treatment in May and December. Lignin tended to be greater in the continuous grazing treatment overall, in May, and in December. Thus, the rotational grazing treatment generally tended to have greater forage quality.

2.3.4 Diet Quality

The results from the NIRS analysis of the fecal samples found diet quality to be greater overall in the continuous grazing treatment, as indicated by greater overall dietary crude protein ($P = 0.01$), greater overall digestible organic matter ($P = 0.02$), greater overall fecal nitrogen ($P = 0.07$), and greater overall fecal phosphorus ($P = 0.02$). These results are shown in Table 2.4 and Figures 2.23-2.26.

The consistently greater diet quality of the continuous grazing treatment shows that the cows in the C treatment were consistently selecting a higher quality diet than the cows in the rotational grazing treatment. This may indicate that grazing treatment did alter forage selectivity in this experiment, as is one of the objectives of rotational grazing.

Alternatively, the forage species present for cattle to select from may have differed between treatments.

2.3.5 Grazing Behavior

The I-got-U 600 GPS units performed differently in this experiment than in Knight et al. (2018) and Craun et al. (2018). The average number of GPS fixes per cow in this experiment was 45,319, with a mean fix frequency of 3.4 minutes. This was unexpected since we programmed our GPS units with a fix frequency of 5 minutes. Fix frequency (Table 2.5) was unaffected by grazing treatment ($P = 0.25$) or season ($P = 0.30$). Number of GPS fixes per cow was unaffected by grazing treatment ($P = 0.54$) or season ($P = 0.93$). All of the GPS position fixes recorded per cow were used in the spatial analysis unless otherwise noted. It was unexpected that the GPS units recorded more fixes then they were programmed to do. The default program for these units is to record a fix every two minutes. Perhaps our attempt to program these units to record a position every 5 minutes failed, and the units reverted to the factory setting of recording a position every 2 minutes. Knight et al. (2018) found the units to record a successful fix position 66% of the time. If our units had reverted to the factory setting of recording a fix every 2 minutes, and then succeeded in recording a position 66% of the time in accordance with Knight et al. (2018), a mean fix rate of 3.4 minutes would be reasonable. Units programmed to record a fix every 2 minutes that did so every 3.4 minutes would be successful at recording a position 59% of the time.

An increase in fix frequency resulted in an increase in the estimate of daily distance traveled ($P < 0.01$; Figure 2.8). This is because cattle do not travel in a straight line. Thus, recording more frequent fixes of their position will capture more sinuosity in the line traveled, closer to the actual distance traveled. Fewer fixes will cause the line traveled to appear artificially straighter, since some sinuosity will not be recorded. To account for this, fix frequency was used as a covariate in all distance traveled analysis.

There is error associated with the locations of the GPS coordinates recorded by the Mobile Action i-gotU GT-600 GPS units. Previous experiments using these GPS units found the standard error for the GPS coordinate points to be 10 meters (Husz et al., 2019). These errors accumulate and increase the estimated distance traveled beyond the actual distance traveled. A test was performed in which seven of the GPS units used in this experiment were placed in a stationary location and turned on for three days. Daily distance traveled was calculated as the distance between consecutive GPS coordinate locations, summed for all the points recorded that day. The estimated daily distance traveled in this test was 4,224 meters. The actual daily distance traveled was 0 since the units were stationary. In this test, the accuracy error associated with the GPS coordinates over estimated daily distance traveled by 4,224 meters. To prevent this exaggeration of distance traveled, 4,224 meters was subtracted from the daily distance traveled data in this experiment.

Grazing treatment did not affect daily distance traveled (Figure 2.9), distance traveled during daylight (Figure 2.10), distance traveled from sundown until midnight (Figure 2.11), or distance traveled from midnight until sunrise (Figure 2.12; $P > 0.80$). Likewise, grazing treatment did not affect the mean distance from water (Figure 2.13), time spent within 50 meters of water (Figure 2.14), or time spent within 100 meters of water (Figure 2.15; $P > 0.26$). These results can be seen in Table 2.6.

In both seasons and overall, the Area Explored was greater in the continuous grazing treatment ($P < 0.02$; Table 2.6). Spatial Search Pattern showed a tendency to be greater in the rotational treatment in the fall and overall ($P < 0.07$), but not in the summer ($P = 0.12$). The Area Explored as a percentage of the paddock size was greater in the rotational treatment in the summer, fall, and overall ($P < 0.04$). Larger daily Area Explored was expected in the continuous treatment because the paddock size in the rotational grazing treatment was 12.8% ± 0.4% (mean ± standard deviation) the size of the pastures in the continuous grazing treatment. The size of the paddocks in the rotational grazing treatment was probably limiting daily Area Explored, evidenced by the fact that on 56.5% of days the Area Explored in the rotational treatment was the entire paddock. This indicates that on these days, if the paddocks were larger in the rotational treatment, the Area Explored would also have been larger. The Area Explored in the continuous treatment was never larger than 85.09% of the pasture and averaged 73.3% of the pasture. The Area Explored in the rotational treatment averaged 97.4% of the paddock.

The greater values for Spatial Search Pattern in the rotational treatment is also likely an effect of smaller paddock size in the rotational treatment. When paddock size limits the size of the daily Area Explored, which occurred on 56.5% of days analyzed in the rotational treatment but never in the continuous treatment, cattle are forced to revisit areas they visited previously in the day. These revisits greatly increase the Spatial Search Pattern values.

Thus, it is probable that the results found in grazing behavior are due to differences in paddock size between the treatments. Paddock size and Area Explored were positively correlated ($R^2 = 0.88$; $P < 0.01$), and paddock size and Spatial Search Pattern were negatively correlated ($R^2 = -0.66$; $P < 0.01$). Season did not significantly affect Area Explored ($P = 0.25$), Spatial Search Pattern ($P = 0.40$), or Area Explored as a percentage of the paddock size ($P = 0.37$).

GPS collars have been used in many experiments to evaluate the effect of a variety of traits on grazing behavior and distribution (Russell et al., 2012). However, this may be the first experiment to use GPS collars to evaluate the effect of grazing method on grazing distribution. Most experiments evaluating the effect of grazing method on grazing distribution were conducted prior to the introduction of GPS collars as a viable method of studying grazing behavior, and thus used other methods.

Walker and Heitschmidt (1986) used the density of cattle trails to study the effect of grazing system on grazing behavior, finding that rotational grazing resulted in an increase in the number of cattle trails. Walker and Heitschmidt (1989) used vibracorders, pedometers, and visual observations to study the effect of grazing system on grazing behavior. They found distance traveled increased as the frequency of rotation increased. Walker et al. (1989) used visual observations to measure the effect of grazing system on preference for plant communities, finding that grazing system had no effect on relative selectivity of plant communities.

2.3.6 Grazing Distribution

The uniformity of pasture use was measured using the Optimized Hot Spot Analysis (Getis-Ord Gi*) function, the Average Nearest Neighbor function, and the Standard Distance functions in Arc Map 10.7.1 (ESRI, 2019). The results from the Hot

Spot Analysis were correlated to the results from the Average Nearest Neighbor function (R^2 = -0.93, P < 0.01) and the Standard Distance function (R^2 = 0.81, P < 0.01). The results from the Average Nearest Neighbor analysis and the Standard Distance Analysis were correlated as well (R^2 = -0.88; P < 0.01). Figure 2.16 shows an example output for the Optimized Hot Spot Analysis for one animal from each replicate from the fall deployment. Figure 2.17 shows the results of the Optimized Hot Spot Analysis for a single cow in the rotational grazing treatment, replicate R1, during the summer. Uniformity of pasture use was analyzed for the summer, fall, and across both deployments (Table 2.7).

Rotational grazing is often claimed to improve livestock grazing distribution within a pasture (Savory and Butterfield, 2016; Teague et al., 2013; Teague et al., 2011; Walker et al., 1989; Malechek and Dwyer, 1983; Kothmann, 1980). However, several experiments have found that this is not the case (Teague et al., 2013; Walker et al., 1989; Kirby et al., 1986; Gammon and Roberts, 1978).

We found the uniformity of grazing distribution across the pasture based on the Hotspot Analysis was more even in the continuous grazing treatment in the summer only (P = 0.06). This is the inverse of the claims about rotational grazing made in Savory and Butterfield (2016). In the fall and overall, grazing treatment did not affect uniformity of grazing distribution (P > 0.23) as measured by the Hotspot Analysis. The Average Nearest Neighbor Analysis and the Standard Distance Analysis did not detect a treatment effect (P > 0.23) in either season or overall. Thus, our results indicate that rotational grazing did not improve the uniformity of grazing distribution across the pasture in our experiment.

Despite these results, many land managers successfully practicing rotational grazing can provide anecdotal evidence that rotational grazing improves the uniformity of pasture use. Teague et al. (2013) attributes this discrepancy to inadequate pasture size in many experiments. They suggest that it is probable that small continuously grazed pastures are grazed more uniformly than large continuously grazed pastures. When large continuously grazed pastures are subdivided into paddocks, there is probably an improvement in the uniformity of grazing distribution (Teague et al., 2013). Hart et al. (1993a, b) found no difference between grazing treatment when both treatments had a pasture size of 24 ha but did find differences when 24 ha rotationally grazed paddocks were compared to a 207 ha continuously grazed paddock. Compared to many pastures in Western North America and globally, 207 ha is still a small pasture.

The continuously grazed pastures used in this experiment averaged 60 ha, and the rotationally grazed pastures averaged 77 ha with an average paddock size of 7.7 ha. None of the pastures used in this experiment had areas greater than 900 meters from water, and the vegetation in all four replicates was relatively homogenous within replicates. If the pastures used in this experiment had been larger with more variable vegetative communities, the results for uniformity of grazing distribution may have been different.

2.3.7 Regression Analysis

A Pearson correlation test was conducted using R (R Core Team, 2020; Kassambara, 2020; Harrell, 2020) to analyze the correlations between the variables analyzed in this experiment. The results of the correlation test are shown in Table 2.8 and Figure 2.22. Cow body weight and BCS were averaged across the experiment prior to performing the correlation test. Grazing behavior and grazing distribution variables were averaged between the summer and fall collections prior to performing the correlation test. Cow body weight and BCS were so closely correlated ($R^2 = 0.98$; $P < 0.01$) that BCS was not included in the correlation test. The results from the Average Nearest Neighbor Ratio were not correlated with any other variable ($P > 0.22$) and therefore are not shown in Table 2.8 or Figure 2.22.

Cow body weight was correlated with calf weaning weight ($R^2 = -0.73$; $P < 0.01$), daily distance traveled ($R^2 = -0.57$; $P = 0.04$), Hotspot Analysis ($R^2 = 0.49$; $P = 0.09$), and Average Nearest Neighbor ($R^2 = -0.51$; $P = 0.07$). This indicates that larger cows had smaller calves, traveled less distance per day, and had more uniform grazing distribution across the pasture when compared to smaller cows.

Calf weaning weight was correlated with the results from the Hotspot Analysis ($R^2 = -0.58$, $P = 0.04$) and the results from the Average Nearest Neighbor ($R^2 = 0.57$, $P = 0.04$). This indicates that the cows that produced larger calves at weaning had less uniform grazing distribution.

Daily distance traveled was negatively correlated to time spent within 50 meters ($R^2 = -0.67$; $P = 0.01$) and 100 meters of water ($R^2 = -0.71$; $P < 0.01$). This indicates that cows that traveled greater distances each day spent less time near water.

Time spent within 50 meters of water and time spent within 100 meters of water were both correlated to the results from the Standard Distance analysis ($R^2 = 0.54$; $P = 0.06$; and $R^2 = 0.59$; $P = 0.03$, respectively) and the results from the Average Nearest Neighbor analysis ($R^2 = -0.51$; $P = 0.07$; and $R^2 = -0.55$; $P =0.05$).

The results from the Hotspot Analysis function were correlated with the results form the Standard Distance analysis ($R^2 = 0.81$; $P < 0.01$) , the Average Nearest Neighbor analysis ($R^2 = -0.93$; $P < 0.01$), Area Explored ($R^2 = 0.57$; $P = 0.04$), Spatial Search Pattern ($R^2 = -0.66$; $P = 0.01$), and Area Explored as a percentage of the paddock available ($R^2 = -0.51$; $P = 0.08$). The results from the Standard Distance analysis were correlated to results from the Average Nearest Neighbor analysis ($R^2 = -0.88$; $P < 0.01$) , Area Explored ($R^2 = 0.59$; $P =0.03$) , Spatial Search Pattern ($R^2 = -0.72$; $P = 0.01$), and Area Explored as a percentage of the paddock available ($R^2 = -0.66$; $P = 0.01$). The results from the Average Nearest Neighbor analysis and the Spatial Search Pattern were correlated ($R^2 = 0.49$; $P = 0.09$). The correlations between these variables confirm that these analyses measure the uniformity of grazing distribution.

Area Explored was correlated with Spatial Search Pattern ($R^2 = -0.89$; $P < 0.01$) and Area Explored as a percentage of paddock ($R^2 = -0.87$; $P < 0.01$). Spatial Search Pattern was correlated with Area explored as a percentage of paddock ($R^2 = 0.96$; $P < 0.01$). This indicates that as Area Explored decreases, Spatial Search Pattern and Area Explored as a percentage of paddock size increase. Since Area Explored and paddock size are positively correlated ($R^2 = 0.88$, $P < 0.01$), these correlations show that paddock size influences Area Explored and Spatial Search Pattern.

2.3.8 Summary of Results

In summary, calf weaning weight was greater in the continuous grazing method ($P = 0.04$). The other parameters of animal performance did not differ between treatments ($P > 0.11$). Similarly, forage production and forage utilization were not affected by grazing method significantly throughout the experiment ($P > 0.13$). Forage lignin content tended to be greater in the continuous grazing treatment ($P = 0.10$) throughout the experiment, but other forage quality parameters were not affected by treatment ($P > 0.23$). Dietary crude protein, digestible organic matter content, fecal nitrogen content, and fecal phosphorus content were greater in the continuous grazing treatment ($P < 0.07$). Distance traveled and proximity to water was not affected by grazing method ($P > 0.45$), and neither were the three indicators of grazing distribution analyzed ($P > 0.23$). Daily Area Explored and Spatial Search Pattern were affected by grazing method ($P < 0.03$), most likely due to differences in paddock size between treatments.

In this experiment, we found stocking rate could be increased 27% without affecting forage quality, forage production, or forage utilization. Weaning weights were suppressed in the rotational grazing treatment with the heavier stocking rates, but the other measures of cow performance did not differ ($P > 0.11$). Both stocking rates were conservative, well below the ecological carrying capacity of the study site. Thus, both treatments had an excess of forage beyond the forage requirements needed. If the stocking rate had been increased above the carrying capacity threshold, resulting in limited forage availability per AUE, the results may have been different. The results of this experiment should not be interpreted to mean that in all cases the stocking rate can be increased in rotational grazing. The relationship between stocking rate and carrying capacity probably plays a role in determining the degree to which the stocking rate can be increased in rotational grazing. Future research conducted assessing the effects of grazing method on animal production should compare rotational and continuous grazing at the same stocking rate, replicated at different stocking rates, to separate the effect of stocking rate and grazing method.

Grazing distribution did not appear to be affected by grazing method. Any differences in grazing behavior appear to be the result of differences in paddock size rather than the grazing method itself. In this experiment, paddock size and Area Explored were positively correlated ($R^2 = 0.88$; $P < 0.01$), and paddock size and Spatial Search Pattern were negatively correlated ($R^2 = -0.66$; $P < 0.01$). The results of this experiment indicate that Area Explored increases with increasing paddock size, and Spatial Search Pattern decreases with increasing paddock size. Since the rotational paddocks were smaller than the continuous treatments in this experiment, the effects of grazing method and paddock size cannot be separated. Future research should be conducted to further test the effect of grazing method on grazing behavior. Paddock size should be held constant across treatments to separate the effect of paddock size and the effect of grazing method.

CHAPTER III

EFFECTS OF ACCLIMATION ON CATTLE RESPONSE TO HUMANS WHILE BEING HANDLED.

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Abstract: The objective of this study was to evaluate the impact of previous human interaction on the behavior of beef cows when handled. To achieve this, 61 F-1 Angus x Brahman cows were randomly assigned to one of two human interaction treatments. The positive human-animal interaction group (**P**) was subjected to contact with a herdsman (on foot) for 15 minutes and was fed supplement by the herdsman. The control group (**N**) was checked and fed from a vehicle, with no direct human interaction. Each acclimation procedure was replicated in 2 pastures/herds (n = 8 to 25 cows in each herd). During routine processing times for these herds (d = 0, 306, 563, 623, and 687), herds were gathered from their pastures and temperament was assessed. Chute and alley scores were assigned to individual animals by the same trained observer and ranged from 1 (calm) to 5 (aggressive). Chute exit velocity was also measured. Temperament variables were evaluated with ANOVA as a split plot with acclimation procedure in the whole plots and replicate as the whole-plot experimental unit, and processing time in the split plot. Neither human interaction (P = 0.63) nor time (P = 0.85) affected chute exit velocity. Chute scores increased through time (P < 0.01) but were not affected by human interaction (P = 0.13). Alley scores tended to be lower in P (P = 0.04), but alley scores were not affected by time (P = 0.31). Neither time nor the specific type of human acclimation we implemented consistently affected cattle temperament, indicating other traits may be more important. Alternatively, different acclimation procedures may be more effective at improving cattle temperament.

Keywords: Livestock handling, Livestock temperament, Stockmanship

3.1 Introduction

Temperament is defined as the fear-related behavioral response of cattle when exposed to human handling (Fordyce et al., 1988). Cattle with more excitable temperaments are under more stress when handled, often exhibited in the form of aggressive behaviors (Cook, 2014). The aggressive nature of cattle with excitable temperaments poses increased risk to their handlers and themselves (Grandin, 1994).

The elevated cortisol concentrations in cattle with more excitable temperaments (Cooke, 2014) has been linked to a variety of negative production traits. This includes reduced growth (Voisinet et al., 1997b), reduced immune response (Burdick et al., 2011), reduced carcass quality (Voisinet et al., 1997a), reduced reproduction efficiency (Cooke et al., 2009; and Cooke et al., 2012), and impaired feed intake (Fox et al., 2004; and Nkrumah et al., 2007). Cows with excitable temperaments have decreased probability of pregnancy (Cooke et al., 2009; Cooke et al., 2011; and Cooke et al., 2012), decreased calving rate (Cooke et al., 2012), decreased birth weight (Francisco et al., 2012b) decreased weaning weight (Cooke et al., 2012), and decreased kilograms of calf weaned/cow exposed to a bull (Cooke et al., 2012). Feedlot cattle with more excitable temperaments have reduced dry matter intake (Fox et al., 2004; and Nkrumah et al., 2007), impaired feedlot average daily gain (Voisinet et al., 1997b; Cafe et al., 2011; Turner et al., 2011; and Francisco et al., 2012a), and reduced feed efficiency (Petherick et al., 2002). Carcasses from cattle with more excitable temperaments have reduced quality grades as well (Voisinet et al., 1997a; King et al., 2006; and Café et al., 2011).

Due to the negative impact of excitable temperament on a variety of production traits, temperament is an economically important trait in beef cattle production. The temperament of beef cattle herds can be altered through genetic selection or through acclimating cattle to frequent positive human interaction (Cooke, 2014).

The effectiveness of acclimating cattle to human interaction has been varied. Research has supported the commonly held belief that negative human handling can negatively impact cattle temperament (Ceballos et al., 2018). Frequent human interaction has been shown to effectively reduce the excitability of temperament in adult cows when exposed to frequent human interaction as calves (Jago et al., 1999; Krohn et al., 2011; Curley et al., 2006; and Probest et al., 2012). Likewise, frequent human interaction has been shown to effectively reduce the excitability of temperament in replacement heifers (Cooke et al., 2009b; and Cooke et al., 2012a), in yearling steers (Montanholi et al., 2013; and Francisco et al., 2012a), and yearling bulls (Curley et al., 2006). However, research has shown the temperament of adult cows to be unaltered by frequent human interaction

(Cooke et al., 2009a). Age of the animal may play a factor in the effectiveness of altering cattle temperament by human interaction (Cooke, 2014).

A plethora of anecdotal evidence suggests cattle temperament is impacted by stockmanship, including animal handling practices (Williams, 2012), indicating the type of human interaction is of importance in its effectiveness at altering temperament. Stockmanship is defined as the knowledgeable and skillful handling of livestock in a safe, efficient, effective, and low-stress manner (Hibbard, 2020). Stockmanship is a multifaceted discipline that is influenced by low-stress livestock handling, facilities design, and many other factors including feed delivery, horsemanship, dog handling, and method of doctoring (Hibbard, 2020). The essential components of stockmanship, however, are low-stress livestock handling methods.

Cortisol concentration is frequently used as a proxy to measure stress levels in beef cattle (Moya et al., 2013). Cortisol is a glucocorticoid hormone released by the adrenal gland into the bloodstream in response to stimulation of the hypothalamic-pituitary-adrenocortical axis (Montanholi et al., 2013; and Eiler, 20014). Stress triggers a release of cortisol into the bloodstream, causing elevated cortisol concentrations in the blood (Moya et al., 2013). Blood plasma cortisol concentration can be used to measure short-term stress (Palme et al., 2005), fecal cortisol metabolite concentration can be used to estimate the concentration of cortisol in the blood 12 hours prior to collection (Montanholi et al., 2013), and hair cortisol concentration can be used to measure long-term stress levels (Moya et al, 2013).

The objective of this study was to evaluate the effectiveness of more frequent human interaction on altering the temperament of mature *Bos indicus* influenced cows. It was hypothesized that the method of feed delivery in the positive interaction group would acclimate the cows in this treatment group to human interaction, resulting in lower temperament scores during routine processing. The aspect of stockmanship that was altered in this experiment was the method of feed delivery.

3.2 Materials and Methods

3.2.1. Study Site

All animal procedures used in this experiment were approved by the United States Department of Agriculture – Agricultural Research Service Grazinglands Research Laboratory Institutional Animal Care and Use Committee (IACUC-GRL-2017-12-15-1-Neel-Cow Temperament). This experiment was conducted at the United States Department of Agriculture -Agricultural Research Service Grazinglands Research Laboratory (USDA ARS-GRL) in Canadian County, Oklahoma, located 10.5 km west of El Reno.

The cows in this experiment were raised in an extensive forage-based production system. The four pastures used ranged in size from 60-79 ha, averaging 69 ha. Cattle spent the entire year turned out to pasture. The pastures consisted of a native range forage base. From 15 October through 1 March, cattle were supplemented with a 40% crude protein concentrate pellet consisting primarily of soybean meal and hulls at the rate of 2.3 kg per cow three times a week (mean = (2.3 x 3) ÷ 7 = 1.0 kg/day/cow). From 1 March through 15 May, cattle were supplemented with a 20% crude protein concentrate pellet consisting primarily of soybean meal and hulls at the rate of 3.18 kg per cow three times per week (mean = (3.2 x 3) ÷ 7 = 1.4 kg/day/cow).

3.2.2. Study Animals

In January 2018, 62 Brahman x Angus F-1 mature cows were randomly assigned to one of two treatments, a positive interaction treatment (P) and a control treatment (C). The experiment lasted for 687 days. The average body weight of the cows used in this experiment was 663 ± 34 kg (mean ± standard deviation). Body condition scores averaged 6.5 ± 0.7. The cowherd consisted of spring calving cows, with a 75-day calving window. Calving began 15 March and ended 30 May. Calving percentage was 72.5% in 2019. Calves born in 2019 were weaned 19 September 2019, averaging 160 days of age at this time. Cows ranged in age from 2.5 to 13 years old at the beginning of the experiment.

3.2.3. Temperament Treatment

The treatments in the experiment consisted of a positive human interaction group (**P**) and a control group (**C**). Both treatments were replicated in 2 herds. The P group was replicated as P1 and P2, and the C group was replicated as C1 and C2. The number of cows per replicate in P1 was 8 cows, P2 was 19 cows, C1 was 9 cows, and C2 was 25.

Cattle in the P treatment group were subjected to a minimum of 15 minutes of contact with a herdsman on foot when supplemented. This was achieved when they were fed the concentrate supplement from October through May. Thus, cattle in the P group were subjected to 15 minutes of contact with the herdsman 3 times a week from October through May. While they were eating, the herdsman would get out of the feed truck and walk amongst them. Cattle in the C treatment only had contact with a herdsman on foot while they were being worked.

Except for human presence during feed delivery in the P treatment, all other aspects of stockmanship were the same between treatments. Cattle were gathered and handled in the same manner in both treatments. Cattle were gathered with 4-wheelers to the pens, where they were then handled on foot.

3.2.4. Temperament Variables Analyzed

Chute scores, chute exit velocity, and alley scores were taken to analyze temperament. These variables were taken on day 0, 306, 563, 623, and 687 during routine processing. Dam scores were recorded once when calves were tagged shortly after birth. The period during which dam scores were recorded ranged from day 438 to day 513.

Chute scores were assigned by the same trained observer throughout the experiment. The animal was restrained but not squeezed in a chute for 3 seconds, during which time her behavior was assessed. The chute was not squeezed, and her neck was not caught in the head catch, to prevent the inhibition any behavior. The scale ranged from 1-5, with a score of 1 indicating she stood calmly in the chute, a score of 2 indicating she showed some agitation while in the chute, a score of 3 indicating she moved about the chute and was unsettled while restrained, a score of 4 indicating she jumped and hit the sides of the chute while restrained, and a score of 5 indicating she showed excessive aggression while restrained in the chute.

Chute exit velocity was measured as the rate of travel over 3 meters, taken immediately after being released from the chute. Chute exit velocity was recorded in seconds; thus, a greater score indicated a slower chute exit velocity.

Alley scores were assigned by the same trained observer throughout the experiment. Alley scores were assigned based on the behavior exhibited as the cow traveled up the alley back towards the rest of the cows after being released from the chute. A cow was assigned a score of 1 if she walked down the alley, a 2 if she exhibited a slight gait, 3 if she trotted down the alley, 4 if she ran down the alley, and 5 if she run down the alley and showed aggression.

Dam scores were assigned once during the experiment. Dam scores were based on the behavior exhibited by the cow while her calf was tagged shortly after birth. A cow was assigned a score of 1 if she stood quietly while her calf was tagged, a score of 2 if she showed slight excitement while her calf was tagged, a score of 3 if she exhibited excessive movement and pawing, a score of 4 if she attempted to interfere with the procedure, and a score of 5 if she succeeding at inhibiting the procedure and it was deemed excessively dangerous to tag her calf. This scoring system was adapted from the methodology of Hoppe et al. (2008). Only cows that produced a calf were evaluated for dam scores. Seven dam scores were recorded from P1, 17 from P2, 5 from C1, and 21 from C2.

3.2.5. Statistical Analysis

Chute scores, chute exit velocity, and alley scores were evaluated with ANOVA in R (R Core Team, 2020, Kassambara, 2020; Wickham et al., 2019; Wickham, 2016) as a split plot with acclimation procedure in the whole plots and replicate as the whole-plot experimental unit, and processing time in the split plot. Dam scores were evaluated with ANOVA with dam score as the dependent variable, acclimation procedure as the independent variable, and replicate as the experimental unit.

3.3 Results and Discussion

3.3.1. Temperament Variables

The human interaction treatment did not affect chute scores ($P = 0.13$; Table 3.1). There was no difference ($P > 0.21$) in chute scores between treatment groups on any collection day. There was not an interaction between collection day and treatment ($P = 0.56$). However, chute scores increased through time from day 0 in both treatment groups ($P < 0.01$; Figure 3.2). The human interaction did not affect chute exit velocity ($P = 0.63$; Table 3.1). There was no difference ($P > 0.32$) in chute exit velocity on any collection day. There was not an interaction between collection day and treatment ($P = 0.63$), and chute exit velocity did not change through time ($P = 0.85$; Figure 3.3). The P group had lower alley scores at $P = 0.05$ (Table 3.1). There was no difference ($P > 0.14$) in alley scores on any collection day, however. There was not an interaction between collection day and treatment ($P = 0.37$), and alley scores did not change through time ($P = 0.31$; Figure 3.4). Dam scores were not affected by the human interaction treatment ($P = 0.90$; Table 3.1; Figure 3.5).

Based on the temperament variables we analyzed, our method of acclimating cattle to human interaction did not appear to significantly affect cow behavior either in the working facilities (chute scores, chute exit velocity, alley scores) or when calves were tagged in the pasture (dam scores). Other experiments have found the temperament of mature cows unaltered by human interaction (Cooke et al., 2009a). The method of acclimating cattle to human interaction used by Cooke et al. (2009a) was very similar to the method used in this experiment. Both methods lasted for two years and consisted of human contact when cows were supplemented 3 times per week. Neither experiment found that human interaction altered the temperament scores of the cows in the experiment. Cooke et al. (2009a) reported mean chute scores of 1.98 and 1.96 for acclimated and control groups, respectively. In our experiment chute scores averaged 2.09 and 1.87 for the acclimated and control groups, respectively ($P = 0.13$). Thus, the chute scores in our experiment were similar to the chute scores reported in Cooke et al. (2009a).

The subjective measures (chute scores and alley scores) could have been taken by an individual blinded to treatment group. The increase of chute scores through time may be due to this observer bias.

An abundance of anecdotal evidence exists showing that low-stress livestock handling results in cattle with calmer temperaments. Some particularly skilled practitioners of low-stress livestock handling who have produced material and clinics on the topic include Bud Williams, Dr. Ron Gill, Dr. Whit Hibbard, and Curt Pate. Although the method of acclimating cattle to human interaction used in this experiment did not alter the temperament of the cows in this study, other methods of acclimating cattle to human interaction may be effective at calming the temperaments of mature cows.

3.4.2. Implications

The two methods available to producers to alter the temperament of the beef cattle herd are genetic selection and good stockmanship. The method we used to acclimate cattle to human interaction did not significantly alter their temperament, measured by chute scores, alley scores, chute exit velocity, and dam scores.

However, these results should not be interpreted to mean that the temperament of mature cattle is not affected by stockmanship. The aspect of stockmanship altered in the treatment methods of this experiment was feed delivery. The other components of stockmanship were not addressed. Other aspects of stockmanship may be more important than feed delivery methods in determining the temperament of mature cows. In this experiment, human presence during feed delivery did not alter the temperament of mature beef cattle.

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APPENDICES

APPENDIX A

Comparison of Laboratory Methods of Analyzing the Crude Protein Content of Dormant Native Range

The results of two laboratory methods of analyzing crude protein are compared. Samples were clipped in December 2019. They were clipped outside grazing exclosures using a 0.96-m^2 ring. Forage was clipped to ground level, dried for a minimum of 72 hours at 60° C, and ground. Sample A came from replicate R1 in the rotational grazing treatment, while samples B and C came from replicate C1 in the continuous grazing treatment. C1 had been grazed continuously since 2009. R1 had been rotationally grazed since 2009. At the time sample A was clipped, the paddock from which sample A was clipped had been rested for 166 days following a 13-day grazing period. These three samples were chosen because they had the highest crude protein of the 64 forage samples analyzed from December. We compared the results of the NIRS machine (Foss NIRS DS 2500 F) in the Ruminant Nutrition Laboratory in the Animal Science Department at OSU with the results from the Soil, Water, and Forage Analytical Laboratory (SWFAL) at OSU.

	Crude Protein (%)		
Sample Number	SWFAL	NIRS	Standard Deviation
1	10.0	13.1	-
2	11.7	12.7	-
3	9.2	11.4	-
Mean	10.3	12.4	1.5

APPENDIX B

Instructions for the Construction of Inexpensive GPS Collars for Studying Grazing Behavior

The experiment conducted in Chapter I utilized GPS collars attached to all 75 cows in the study. It was possible to attach collars to all 75 cows due to the construction of inexpensive GPS collars by our lab. This appendix will detail instructions for the construction of these collars. Our methods are an adaptation of the methods used in Knight et al. (2018) and Craun et al. (2018).

The following table includes all materials needed for the construction of 100 of these collars.

Item	**Item Description**	**Quantity Needed**
Nylon collar	Cow Collar 1.75 x 44 in.	100
GPS units	i-gotU GT-600 USB GPS Travel and Sports Data Logger	105
Batteries	Tenergy Li-Ion 18650 3.7V 5200mAh PCB Protected Rechargeable Battery Module with Bare Leads	210
Polycarbonate enclosure	WC-22 WC Series Outdoor Enclosures	120

Rivets	3/16” Dia .376-.500” Grip Range ABL68A Aluminum Rivets – W/Drill Bit; n=500	**1**
Washers	13/64” ID x 3/32” x ½” OD (#10) Nominal Size Stainless Steel Component Flat Washer	200
Bolts	¼”-20 x 5/8” Grade 18-8 Stainless Steel Hex Cap Screw, n=50	4
Loctite	Red 271 Loctite	4
Soldering Iron	Sywon 60W ESD Soldering Iron Station Kit	1
Solder	Alpha Fry AT-31604 60-40 Rosin Core Solder (4 oz)	2
Epoxy	Two-Part Marine Epoxy Adhesive Paste	2
Zip ties	10” zip ties	100
Silica packets	Silica packets (1oz); n=100	1
Rubber coating	Flex Seal 32-oz Clear Dip Rubberized Coating	4
Shrink Wrap	6” Black Single Wall Shrink Tubing, 1/16” (10 MIN)	10
Weights	50’ ½” thick steel strap	100
USB multi-port charger	Sabrent 60 Watt (12 Amp) 10-Port Family-Sized Desktop USB Rapid Charger	10
Spray primer	Flat white spray paint primer	2
Spray paint	Flat black spray paint	2

Using an electrical drill, drill four holes in the bottom of the polycarbonate enclosure. Using the soldering iron, melt four corresponding holes in the nylon cow collar. The polycarbonate enclosure should be situated 14 inches from the end of the tail of the collar. Rivet the polycarbonate enclosure to the nylon collar. To seal the holes in the bottom of the polycarbonate enclosure, pour a layer of Flex Seal in the bottom. In our experiment we found Flex Seal to do an excellent job of sealing these holes and preventing water damage inside the polycarbonate box.

The lids of these polycarbonate boxes tend to break easily when attached to a cow. In our first deployment, we had 40% of the lids break. To solve this problem, we turned the lid upside down and poured a thick layer of Flex Seal into the lid. This provided added structural support for the lid. After pouring Flex Seal into the lid, we did not have a single lid break during the second deployment of collars.

Melt additional holes in the tail of the collar so there are more options to adjust the collar size. Large cows may require additional holes in the end of the tail, while heifers might require additional holes closer to the polycarbonate box to shorten the collar.

A 6-inch segment of ½-inch thick steel strap was cut to length and bent into a 90° angle to serve as a counterweight so that the box and GPS unit remained on the top of the cow's neck. Two holes were drilled and threaded in the steel strap. The steel weights were then painted to prevent rust. Two holes were melted in the nylon cow collar corresponding to these two holes. The steel strap was then bolted to the collar using the bolts and washers. Loctite was applied to the bolts to ensure they did not come loose. This weight was attached to the buckle end of the collar.

We successfully extended the battery life of the GPS units used in our experiment by wiring in two 3.7V 5200mAh batteries in parallel. By doing so, most of the GPS units in our experiment were still recording coordinate fixes when removed after a 62-day deployment. It is unknown how long these batteries will last being recharged, but it is longer than 62 days.

To wire in these batteries, carefully open the GPS units by drilling a small hole into the side of the unit. Using an awl, gently pry open the GPS unit. Inside, there will be a blue battery. Cut the wires connecting this battery to the unit as close to the battery as possible. Carefully strip the coating off these wires. Likewise, strip the coating off the wires connected to the two Tenergy batteries. Solder the black wires from the two Tenergy batteries to the black wire attached to the GPS unit. Similarly, solder the red wires from the two Tenergy batteries to the red wire attached to the GPS unit. Cover the exposed copper wire with shrink wrap. Charge for seven days prior to deployment.

Place the GPS unit in the polycarbonate box with a silica packet and screw the lid down. The collars are now ready for deployment. It is imperative that a zip-tie be used to secure the tail of the collar to the buckle. Otherwise, many cows will be successful at removing the collars by rubbing the tail out of the buckle and the collars will be lost in the pasture.

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APPENDIX C

GPS Spatial Data Management

GPS collars attached to grazing livestock for extended periods of time generate a lot of data. This experiment generated 2.897 gigabytes of spatial data. This appendix details how to manage spatial data generated from grazing behavior studies according to the methods used in our experiment. Our methods are based on those of Knight et al., (2018), with some alterations. The primary alteration made was the use of R Studio (RStudio Team, 2015) instead of Microsoft Excel. This was done due to the capability of R Studio to handle greater quantities of data more efficiently.

First, Mobile Action @trip PC should be downloaded to a computer. This is the software developed by Mobile Action to be used with their i-gotU GT-600 GPS Units (New Taipei City, Taiwan). Other software utilized includes Microsoft Excel (Excel Version 2001), R Studio (RStudio Team, 2015), and Arc Map 10.7.1 Desktop (ESRI 2019). These software programs should all be downloaded to one computer that will be used in the analysis.

Remove the Mobile Action i-gotU GT-600 GPS units from the polycarbonate box in which they are housed during data collection. Connect them to the computer via the USB cord provided with the GPS unit. Mobile Action @trip PC will open automatically.

A pop-up message will appear with the message “GPS device detected. Download GPS log data now?”, with the option to select yes or no. After selecting yes, a second pop up window will open titled “Downloading Track Data”. Once complete, the option to “Create a trip” or “Geotag photos” is provided. Select “Create a trip”. The next window allows for the selection of the correct time zone and the selection of the GPS coordinate fixes. By sorting by date, the desired GPS coordinate fixes are easily selected. Uploading the desired GPS coordinate fixes often takes a long time (in some cases several hours). Once complete, the option is given to name the trip and select the desired style. Select “Classic Style” and name the trips in a manner that indicates which animal the GPS unit had been attached to. The next window gives the option of adding photos, which we did not do. The next window gives the message of “Trip Completed”. By selecting “Finish”, the spatial data is overlaid on a map in @trip PC, and the file is added to @trip PC.

After uploading data from each animal to @trip PC, download the data to Excel. This is done by highlighting the desired files and exporting them as csv files. The files created in @trip PC often exceed the maximum file size in Excel. This results in multiple files being created per animal in Excel. In this case, the download process will denote multiple files by automatically numbering them (1), (2), (3), etc. The maximum number of csv files created for one animal in our experiment was 7. Files from @trip PC were downloaded into separate folders designated for each deployment (summer and fall in our experiment).

At this point, we had 239 csv files in Excel from the summer deployment of GPS collars, and 453 csv files in Excel from the fall deployment of GPS collars. Bailey et al.

(2018) performed data analysis in Excel. However, due to the large number of Excel files in our experiment, it was more efficient to perform data management in R Studio.

Our files were named in the format of "StudySite_Replicate_TagNumber_GPSUnitNumber". Data was imported into RStudio using the following code:

```
data_dir <- list.files(".", pattern = "*.csv*")

data <- (NULL)

for(file in data_dir) {

  this.data <- read_csv(file)

  this.data$tag <- sapply(strsplit(file,"\\_"), `[`, 3)

  this.data$replicate <- sapply(strsplit(file,"\\_"), `[`, 2)

  ifelse(file != data_dir[1], names(this.data) <- names(data), names(this.data))

  data <- rbind(data, this.data)

}

rm(this.data, data_dir, file)

data_original <- data

summary(data_original)

data<- data %>% filter(tag %in% unique(data$tag)[1:2])
```

```
unique(data_original$tag)
```

The above code was used to upload the GPS spatial data into R Studio in its entirety so it could be filtered prior to performing analysis in Arc Map. We filtered the data in several ways. In order to reduce the file size, we filtered the data by replicate. The GPS units record date and time as one variable titled “datetime”. We separated “datetime” into “date” and “time”. We then filtered out any data that fell outside the range of dates when cattle were collared. Additionally, we filtered out the first and last day that cattle were collared. We then filtered out data that recorded unrealistic altitudes based on the range of altitudes present at our experiment site. We then created a value titled “Time_Difference_Minutes” as the difference in time divided by 60. We then created a value called “Rate”, calculated as “Distance/Time_Difference_Minutes”. We filtered out unrealistic rate, speed, and distance traveled values as well. This was done with the following code:

```
C1 <- data_original %>%
  filter(replicate=="C1") %>%
  mutate(datetime = as.POSIXct(paste(Date, Time, sep=" "))) %>%
  filter(Date >= as.Date("2019-05-15"),
         Date <= as.Date("2019-07-29"),
         Altitude > 250,
         Altitude < 600,
```

```
      Speed < 500)%>%
  group_by(tag) %>%
  mutate("Time_Difference_Minutes"= (datetime - lag(datetime))/60)%>%
  mutate(Time_Difference_Minutes = as.numeric(Time_Difference_Minutes))%>%
  mutate("Rate"=Distance/Time_Difference_Minutes)%>%
  filter(Rate<84)%>%
  mutate("Course_Difference"=Course-lag(Course))%>%
  filter(Course_Difference<100)%>%
  filter(Course_Difference>-100)%>%
  filter(Distance<420)
write.csv(C1,file="C1_Summer.csv")
```

The data can then be uploaded to ArcMap as csv files. This is done by selecting File, then Add Data, then Add XY Data in ArcMap. The desired csv file is then selected. Arc Map correctly identified the X and Y Fields as longitude and latitude automatically in our experiment. It is necessary to select the correct XY Coordinate System at this point. This is done by clicking the Edit button near the Coordinate System of Input Coordinates. Geographic Coordinate System is then selected, then World, then WGS 1984. WGS 1984 is the coordinate system used by the i-GotU GPS Units. Select OK, and the data will be added as a layer to the Table of Contents. If an incorrect coordinate system is selected, the data will either not project in Arc Map, or will project in the wrong location. Also, make sure the X field is longitude and the Y field is latitude, or the data will be projected in the wrong global location.

The csv layer then needs to be converted to a shapefile for analysis to be performed. This is done by right clicking on the csv file, then selecting data, then exporting the data, and saving the file in a designated folder. The csv file can then be removed.

It is necessary to create a shapefile for each animal prior to analysis. This is done in the following manner. First, the shapefile for the replicate is added to the Table of Contents by dragging it from the Catalog to the Table of Contents. Open the Attribute Table by right clicking on the shapefile and then clicking Open Attribute Table. Next, select the data for each individual animal by opening the Select by Attributes tool at the top of the attribute table, then use the code "tag" = "Animal Tag Number" to select data for an individual animal. Once this is selected, close the attribute table. Right click on the shapefile name in the Table of Contents, click Selection, then "Create Layer from Selected Feature". A new layer will be added to the Table of Contents. To save this new layer as a new shapefile, right click on the layer name and then select Data>Export Data. This process should be repeated until a shape file is created for each cow.

At this point, a base map of the study area should be added to Arc Map. This can be done by downloading National Agriculture Imagery Program (NAIP) imagery from USGS for the desired study site. NAIP imagery uses a different coordinate system then the i-GotU GPS units, so it may be necessary to convert either the NAIP image or the i-

GotU GPS coordinate data to another coordinate system. This is done by Arc Toolbox > Data Management Tools > Projections and Transformations > Batch Project. It is important that all layers used have the same coordinate system. In this experiment, the NAIP image was projected to the WGS 1984 geographic coordinate system.

Prior to performing any further analysis, it is necessary to clip each cow's shapefile to the pasture outline. This eliminates any erroneous GPS coordinate fixes that fall outside the bounds of the pasture. First, the pasture boundary should be drawn by Customize > Toolbars > Draw > Polygon > Convert Graphic to Features, then in the Table of Contents, Data > Export Data. The pasture boundaries should be named appropriately and stored in a properly labeled folder as they will be needed again in the Hotspot Analysis and other functions. To clip the individual cow's GPS coordinates shapefile by the pasture outline, select Arc Toolbox > Analysis Tools > Extract > Clip. For the Input Feature, select the GPS coordinate shapefile. For Clip Feature, select the pasture outline. Name the output feature class appropriately in a designated folder for clipped shapefiles. The XY Tolerance is optional; we added an XY Tolerance of 9 meters since that is the error of our GPS units. This means that GPS coordinates that fell less then 9 meters outside the pasture boundary were included. This process should be repeated for each cow. It may be faster to clip the shapefile for each replicate by the pasture outline, rather than each individual cow's shapefile. However, in our experiment the files containing the GPS coordinates for the entire replicate were too large and tended to crash the program when the Clip function was performed, making it necessary to separate the replicate shapefile into smaller shapefiles for each individual cow prior to clipping them.

We used Arc Map to calculate distance traveled, proximity to water, evenness of grazing distribution, standard distance, average nearest neighbor, area explored, and spatial search pattern. Instructions for using Arc Map to calculate these variables will be explained in the following sections.

To calculate daily distance traveled, first open the attribute table for the individual cow on which the analysis will be performed. Right click on “Distance”, then “Statistics”. “Sum” shows the total distance traveled, in meters. Record this value in a spreadsheet. Then divide this value by the number of days the collar was deployed to determine the daily distance traveled. To calculate the distance traveled during a specified time frame, such as from sunrise to sunset, use the following sequence: Select by Attributes> ““Time”>= ’07:51:00’ AND “Time” <= ’18:35:00’” >Apply. This code selects all the coordinate fixes that fall between 0751 and 1835. This time frame can be adjusted as desired. By clicking “Show Selected Features”, the attribute table for just the desired features is shown. The distance traveled during this period can be determined by right clicking “Distance”, then “Statistics”. Record this value in a spreadsheet. This process can be repeated for each individual cow. Once this is done, the spreadsheet is ready for statistical analysis. In our experiment, Arc GIS was not used for statistical analysis; rather, it was used to generate data from the GPS coordinate fixes, which was recorded in a spreadsheet and then analyzed in R Studio.

Mean Distance to Water can be calculated via Arc Toolbox > Analysis Tools > Proximity > Point Distance. The Input Feature is the shapefile for that animal, and the Near Feature is a shapefile created for the water sources. Water sources can be drawn via Customize > Toolbars > Draw. Drawing a point may be applicable for a water tank, while a polygon is more applicable for a pond or river. In instances where each pasture has multiple water sources, they must be joined into one shapefile prior to analysis. If a pasture has multiple water sources, draw each water source, create a layer for each water source, then export the layer as a shapefile via “Export Data”, then join the two shapefiles into one via Arc Toolbox > Data Management Tools > General > Merge. Merge can only join two shapefiles of the same type, such as two polygons or two points. It cannot join a point and a polygon. Make sure all water sources are either drawn as a point or a polygon, but do not use both if they need to be merged into one file. Use the shapefile including both water sources as the Near Feature in the Proximity analysis.

It is also possible to calculate the percent of GPS coordinate fixes within a specified distance from water. This is done by creating a buffer around the water, then clipping the animal’s shapefile by the buffer. We did this for areas within 50-meter and 100-meters of water. To create a buffer around the water sources, use Arc Map > Analysis Tools > Buffer. For the Input Feature, select the water sources. Then add the value for the desired radius of the buffer. For Dissolve Type, select All. Leave the other settings as default. Once the buffer is created, Clip the GPS coordinate fix shapefile by Arc Map > Analysis Tools > Clip. The number of fixes within the buffer divided by the total number of fixes gives the percentage of coordinate fixes recorded within that distance of water. Repeat this process for each animal’s GPS coordinate fix shapefile. This process can be done for other features of interest if desired, such as shade or supplementation areas.

We used Optimized Hot Spot Analysis, Standard Distance, and Nearest Neighbor to measure the evenness of grazing distribution across the pasture. These analyses were used as a proxy for grazing distribution in our experiment. Each tool has its strengths and weaknesses. Each provides unique data. Average Nearest Neighbor probably provides the best data to indicate clustering or dispersion of GPS coordinate fixes, as it compares the actual spatial distribution of points to the projected spatial distribution of points if the coordinates were evenly distributed across the area. The results of this analysis include the mean distance between points (average nearest neighbor), and the ratio of the observed mean distance between points and the expected mean distance between points if points were equally spaced (nearest neighbor ratio). A nearest neighbor ratio less than 1 indicates clustering, while a nearest neighbor ratio greater than 1 indicates dispersion. However, Average Nearest Neighbor does not provide information showing where clustering occurs. The Hot Spot Analysis alone shows the locations of clustering. The Standard Distance draws a geometric circle around the geometric center of the data points so that all points within this circle fall within one standard deviation of the center of the points. The output is the radius of the circle. A smaller radius indicates the data is more closely grouped around the center, while a larger radius indicates the data is spread more widely.

The hotspot analysis can be performed by Arc Toolbox > Spatial Statistics Tools > Mapping Clusters > Optimized Hot Spot Analysis. The input feature should be the individual cow's GPS coordinate shapefile. The Analysis Field should be left blank. The Bounding Polygons Defining Where Incidents Are Possible should be the pasture outline. The Polygons for Aggregating Incidents Into Counts, and the Density Surface should be left blank. In the Override Settings, the Cell Size should be entered so that the polygon size is the same for each animal's analysis. We used a cell size of 9 meters by 9 meters since that was the error of our GPS units. The attribute table of this analysis gives the GiZScore, GiPValue, and Gi_bin. To calculate the percentage of polygons that fall within one standard deviation of the mean (i.e., are not hot or cold spots), use the Select by Attributes tab to select for Gi_bin values that are 0. Dividing the number of polygons with a Gi_bin of 0 by the total number of polygons gives the percentage of the polygons where the number of GPS coordinate fixes is within one standard deviation of the mean number of GPS coordinate fixes per polygon. Standard distance can be performed by Arc Toolbox >Spatial Statistics Tool > Measuring Geographic Distributions > Standard Distance. The Average Nearest Neighbor function can be performed by Arc Map > Spatial Statistics Tool > Analyzing Patterns > Average Nearest Neighbor.

We also calculated Daily Area Explored and Spatial Search Pattern in Arc Map. Prior to performing these analyses, it is necessary to create a separate shapefile for data from each day for each cow. Open the attribute table of the shapefile for an individual animal, then Select by Attributes using the code “Date” = “X”. Once the desired day is selected, create a layer of this data by right clicking on the file name in the Table of Contents, then Selection> Create Layer from Selected Features. Then right click on this layer and export the layer as a shapefile via Data>Export Data. Repeat this process for each day. The area explored can be calculated for any given day by Arc Toolbox > Data Management Tools > Features > Minimum Bounding Geometry. Select Convex Hull as the polygon type. The output of this analysis is a polygon encompassing all GPS coordinate fixes. To calculate the area of this polygon, open the attribute table. Click on Table Options, then Add Field. Name the field area, and select float for type, then OK. Right click on Area, then click on Calculate Geometry. Select the desired units, then OK.

Record this value in a spreadsheet for future analysis. A larger area explored indicates that the animal was present in a larger part of the pasture on that day. A smaller area explored indicates that the animal stayed in the same general area throughout the day. The spatial search pattern can be calculated using the 24-hour distance traveled and the area explored. The 24-hour distance traveled can be determined by opening the attribute table for the animal and day in question and right clicking on Distance. The sum is the total distance traveled that day. The 24-hour distance traveled in meters should be multiplied by 1 meter to calculate the 24-hour grazeable area in square meters. We chose one meter because it was assumed a cow could graze 0.5-meter perpendicular from her present location due to lateral neck movement towards both the right and the left. Thus, 24-hour grazeable area is presented in meters^2 when the 24-hour distance traveled (m) is multiplied by areas within reach of grazing (m). To calculate spatial search pattern, the 24-hour grazeable area (m^2) is divided by the area explored (m^2). The result is the percentage of the area explored that could have been grazed by that animal. A larger spatial search pattern indicates that the animal thoroughly covered the area explored on that day. A smaller spatial search pattern indicates that the animal did not thoroughly cover the area explored on that day. For example, a cow that walked the perimeter of the pasture but never strayed from the perimeter fence would have a spatial search pattern close to 0. A cow that was present in every square meter of the area explored would have a spatial search pattern of 1. Spatial search pattern is illustrated in Figure 2.19.

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APPENDIX D

Data by Replicate

Experiment 1 Data by replicate, with standard error (SE)										
Grazing Treatment		Continuous				Rotational				P-value
Replicate		C1	SE	C2	SE	R1	SE	R2	SE	-
Mean Cow Age		7	1	9	1	8	1	9	1	0.43
Body Weight (kg)	May	663	7	654	18	618	16	651	15	0.32
	Aug.	691	7	689	20	625	18	670	15	0.24
	Oct.	688	7	680	22	615	17	638	15	0.06
	Dec.	712	6	701	25	638	17	683	17	0.22
BCS	May	6.8	0.1	6.7	0.1	6.4	0.1	6.6	0.1	0.13
	Aug.	7.2	0.1	6.9	0.1	7.2	0.1	6.9	0.1	0.29
	Oct.	7.2	0.1	6.6	0.2	6.8	0.1	6.9	0.1	0.77
	Dec.	5.2	0.3	5.7	0.2	4.0	0.3	5.0	0.3	0.20
Calving Percentage		69	-	56	-	80	-	85	-	0.11
Calf Weaning Weight (kg)[1]		238	4	249	2	208	8	199	8	0.04
Ratio of Calf WW to Cow BW[1]		37	1	38	1	35	1	32	1	0.23
Kg of Calf Weaned per Ha[2]		36	-	21	-	55	-	43	-	0.17
Forage Production (kg/ha)	May	6132	-	6669	-	4406	-	3134	-	0.06
	July	12344	-	9827	-	7739	-	9017	-	0.20
	Dec.	9987	-	8007	-	6654	-	9700	-	0.70
Forage Utilization		36	16	13	3	19	11	20	19	0.64
Forage Crude Protein	May	11.4	0.9	10.4	0.5	9.7	0.7	9.9	0.5	0.15
	July	9.9	0.7	10.1	0.5	9.11	0.6	8.7	0.4	0.05
	Dec.	9.4	0.8	8.3	0.9	9.5	0.9	7.5	0.5	0.81
	Overall	10.3	0.9	9.6	0.9	9.4	0.8	8.7	0.7	0.23
Forage ADF	May	46.2	2.8	47.5	2.6	43.8	1.7	42.5	1.9	0.06
	July	41.8	1.8	45.4	2.3	47.2	1.9	42.7	0.8	0.70
	Dec.	57.1	1.5	57.1	2.2	42.4	1.2	50.3	1.6	0.03
	Overall	48.4	4.3	50.0	3.4	47.8	2.6	45.2	2.6	0.23
Forage NDF	May	71.3	3.3	75.4	2.8	72.7	2.9	71.6	2.6	0.62
	July	68.3	3.2	74.2	2.9	78.3	2.4	69.9	1.6	0.64
	Dec.	83.0	2.4	85.5	2.0	85.9	1.7	88.5	1.4	0.25
	Overall	74.2	4.8	78.4	3.9	79.0	3.9	76.7	5.3	0.59

Forage Lignin	May	11.7	1.9	11.0	1.5	7.9	0.7	8.0	0.8	0.01
	July	9.7	1.1	10.1	0.8	10.6	1.0	7.4	0.4	0.63
	Dec.	15.1	2.0	13.8	1.2	12.1	0.9	10.2	0.6	0.10
	Overall	12.1	2.1	11.6	1.5	10.2	1.3	8.5	0.1	0.10
Daily Distance Traveled (m)	Summer	5762	1827	1360	551	12112	1810	4245	1182	0.25
	Fall	8925	2171	15676	3012	13016	2299	5931	1340	0.52
	Overall	7549	1469	8995	2080	12629	1510	5200	911	0.81
Sunrise-Sunset Distance Traveled (m)	Summer	5031	1051	1341	380	8613	1220	2971	766	0.25
	Fall	5353	1379	10388	1865	8349	1344	3641	740	0.48
	Overall	5213	886	6166	1301	8462	919	3351	529	0.86
Sunset-Midnight Distance Traveled (m)	Summer	332	118	0	49	1266	201	314	133	0.26
	Fall	2099	663	2780	562	2592	473	1206	285	0.64
	Overall	1330	416	1450	397	2024	299	820	187	0.88
Midnight-Sunrise Distance Traveled (m)	Summer	1183	330	89	121	2194	395	961	284	0.10
	Fall	1768	492	2507	586	2075	486	1083	315	0.46
	Overall	1514	313	1379	385	2126	322	1030	213	0.80
Mean Distance to Water (m)	Summer	179	0.4	606	1.1	231	0.3	141	1.2	0.39
	Fall	201	0.4	490	0.7	319	0.2	106	0.4	0.53
	Overall	191	2.3	544	10.8	281	7.0	120.8	3.3	0.45
Time Spent < 50 m from Water	Summer	12.5	0.2	5.0	0.1	9.7	0.1	23.4	0.3	0.46
	Fall	16.5	0.3	15.6	0.2	3.4	0.1	32.7	0.4	0.99
	Overall	14.6	0.5	10.6	1.0	6.1	0.5	28.6	0.9	0.81
Time Spent < 100 m from Water	Summer	32.6	0.4	6.3	0.1	16.9	0.1	44.5	0.7	0.63
	Fall	40.5	0.4	21.4	0.1	6.6	0.2	57.0	0.6	0.95
	Overall	36.8	0.9	14.3	1.4	11.1	0.8	51.6	1.2	0.89
Hotspot Analysis % of Pasture within 1 SD of Mean	Summer	87.5	0.1	76.2	3.6	54.8	6.8	44.8	1.7	0.06
	Fall	96.2	0.2	83.9	6.0	94.0	0.5	93.9	0.3	0.51
	Overall	92.4	0.9	80.3	3.6	77.2	4.1	72.6	4.6	0.23
Standard Distance (m)	Summer	296.5	0.6	324.5	0.7	254.0	3.6	282.1	0.6	0.14
	Fall	377.5	0.4	371.6	1.0	312.85	4.2	370.1	1.0	0.35
	Overall	342.3	8.4	349.7	4.4	287.6	5.4	332.0	8.1	0.23
Average Nearest Neighbor (m)	Summer	2.5	0.0	2.8	0.0	4.7	0.0	3.3	0.1	0.19
	Fall	0.8	0.0	1.4	0.4	0.7	0.0	0.7	0.0	0.26
	Overall	1.5	0.2	2.0	0.2	2.4	0.3	1.8	0.2	0.47
Average Nearest Neighbor Ratio	Summer	0.38	0.00	0.43	0.00	0.60	0.00	0.50	0.01	0.11
	Fall	0.12	0.01	0.22	0.06	0.10	0.00	0.08	0.00	0.20
	Overall	0.23	0.03	0.32	0.04	0.31	0.04	0.26	0.04	0.81
Area Explored (m^2)	Summer	233047	5876	321880	5209	78830	7489	79412	1991	0.04
	Fall	428243	14559	452284	11373	157013	10125	64421	1277	0.02
	Overall	334888	22248	391429	14025	120929	8344	70917	2220	0.02

Spatial Search Pattern (%)	Summer	4.4	0.4	1.8	0.2	19.4	1.9	10.3	1.1	0.12
	Fall	3.1	0.5	5.5	1.7	11.0	1.0	14.7	1.7	0.07
	Overall	3.7	0.4	3.8	1.0	14.9	1.2	12.8	1.1	0.01
Area Explored as a Percentage of Paddock (%)	Summer	38.6	0.9	53.8	0.8	99.2	1.2	86.6	0.5	0.04
	Fall	70.4	2.4	75.6	1.9	98.8	1.0	95.6	1.8	0.02
	Overall	55.2	3.6	65.4	2.3	99.0	0.6	91.7	1.6	0.03

[1] Cows that did not wean a calf were removed from the dataset prior to analysis
[2] Cows that did not wean a calf were included in the analysis as having weaned a calf that weighed 0 kg.

Experiment 2 Data by replicate, with standard error										
Treatment Group		Positive				Control				P-value
Replicate		P1	SE	P2	SE	C1	SE	C2	SE	-
Variable	Day									
Chute Scores	0	1.5	0.3	1.7	0.3	1.2	0.2	1.7	0.2	0.75
	306	1.5	0.3	1.7	0.2	1.6	0.4	1.4	0.2	0.22
	563	2.4	0.5	2.0	0.2	1.9	0.5	1.8	0.2	0.21
	623	2.6	0.4	2.3	0.3	2.2	0.3	2.1	0.2	0.24
	687	3.1	0.5	2.5	0.3	2.8	0.6	2.3	0.3	0.53
Chute Exit Velocity	0	1.5	0.2	1.3	0.1	1.5	0.2	1.3	0.1	0.95
	306	1.3	0.2	1.3	0.1	1.4	0.2	1.2	0.1	0.71
	563	1.2	0.1	1.4	0.1	1.4	0.1	1.4	0.1	0.48
	623	1.6	0.3	1.6	0.1	1.6	0.2	1.3	0.1	0.32
	687	1.3	0.1	1.3	0.1	1.3	0.1	1.3	0.1	0.62
Alley Scores	0	2.3	0.3	2.2	0.3	1.8	0.4	2.2	0.2	0.70
	306	1.5	0.3	1.9	0.3	1.9	0.4	2.0	0.3	0.30
	563	2.3	0.6	1.7	0.3	2.1	0.5	1.7	0.2	0.86
	623	2.0	0.5	1.6	0.3	1.9	0.4	1.9	0.2	0.37
	687	1.5	0.4	1.9	0.3	2.4	0.5	2.2	0.3	0.14
Dam Scores		1.1	0.1	1.8	0.3	1.2	0.2	1.6	0.2	0.903

TABLES

Table 2.1 Carrying Capacity, Stocking Rates, and Forage Allowance

Pasture		**Forage Production (kg/ha)**		**Total Forage Production (kg)**		**Carrying Capacity (AUE/year)**	
Replicate	Size (ha)	Estimated[1]	Actual[2]	Estimated[1]	Actual[2]	Estimated[1]	Actual[2]
C1	60	6767	9989	405996	599196	31	45
C2	60	5662	8007	339744	480396	26	36
Ra	75	6334	6654	475050	499020	36	38
Rb	79	6419	9701	507101	766340	38	58

Pasture		**Actual Stocking Rate**				**Forage Allowance**
Replicate	Size (ha)	Cows	AUE	Ha/AUE	Stocking Rate as % of Actual Carrying Capacity[3]	Kg forage/AUE
C1	60	15	20	3.0	44%	30262
C2	60	16	19	3.1	53%	24891
Mean		**16**	**20**	**3.1**	**49%**	**27577**
R1	75	26	33	2.3	88%	15122
R2	79	23	31	2.6	53%	24962
Mean		**25**	**32**	**2.5**	**71%**	**20042**

[1] based on NRCS WSS (Web Soil Survey Staff, 2020)
[2] based on December 2019 forage clippings
[3] actual stocking rate divided by the actual carrying capacity

Table 2.2 Cow Performance				
Variable	**Continuous**	**Rotational**	**Standard Error**	**P-value**
Body Condition Score				
May	6.8	6.5	0.04	0.13
August	7.1	7.2	0.04	0.29
October	7.0	6.8	0.07	0.77
December	5.4	4.4	0.16	0.20
Body Weight (kg)				
May	659.3	632.7	9.2	0.32
August	690.2	644.8	10.0	0.24
October	684.5	625.5	10.1	0.06
December	707.4	658.0	10.5	0.22
Calving Percentage	63.6	82.2	5.2	0.11
Calf Weaning Weight (kg)[1]	241.9	203.4	7.3	0.04
Ratio of Calf WW to Cow BW, %[1]	37.4	33.8	1.3	0.23
Kg of Weaned Calf per ha[2]	28.2	49.1	7.2	0.17

[1] Cows that did not wean a calf were removed from the dataset prior to analysis.
[2] Cows that did not wean a calf were included in the analysis as having weaned a calf that weighed 0 kg.

Table 2.3 Forage Production, Utilization, and Quality				
Variable	**Continuous**	**Rotational**	**Standard Error**	**P-value**
Forage Production (kg/ha)				
May	6400.5	3770.0	810.0	0.06
July	11085.4	8378.3	970.9	0.20
December	8996.6	8177.1	778.5	0.70
Forage Utilization (%)	24.5	19.5	4.7	0.64
Forage Quality				
Crude Protein				
May	10.9	9.8	0.17	0.15
July	10.0	8.9	0.14	0.05
December	8.8	8.5	0.20	0.81
Overall	9.9	9.1	0.11	0.23
ADF				
May	46.9	43.2	0.55	0.06
July	43.6	44.9	0.46	0.69
December	57.1	51.4	0.51	0.03
Overall	49.2	46.5	0.44	0.23
NDF				
May	73.3	72.1	0.65	0.62
July	71.2	74.1	0.73	0.64
December	84.3	87.2	0.50	0.25
Overall	76.3	77.8	0.57	0.59
Lignin				
May	11.3	7.9	0.36	0.01
July	9.9	9.0	0.24	0.63
December	14.5	11.2	0.35	0.10
Overall	11.9	9.4	0.22	0.10

Table 2.4 Diet Quality

Variable	Continuous	Rotational	Standard Error	P-value
Crude Protien				
Nov. 2018	8.6	5.4	1.1	0.15
May 2019	10.5	7.7	0.9	0.02
June 2019	10.5	7.1	1.0	0.00
July 2019	9.9	6.1	1.2	0.07
Aug. 2019	9.5	7.8	0.9	0.07
Sept. 5, 2019	7.8	5.3	0.7	0.00
Sept. 26, 2019	6.9	6.7	0.6	0.91
Oct. 2019	8.7	6.3	0.8	0.12
Nov. 2019	7.8	4.8	0.9	0.06
Dec. 2019	4.3	3.3	0.5	0.36
Overall	8.6	6.0	0.3	0.01
Digestible Organic Matter				
Nov. 2018	60.6	57.0	1.1	0.05
May 2019	62.7	59.5	1.1	0.16
June 2019	63.4	60.1	1.0	0.01
July 2019	63.3	58.2	1.5	0.04
Aug. 2019	64.5	60.3	1.3	0.03
Sept. 5, 2019	62.2	58.3	1.2	0.03
Sept. 26, 2019	60.4	59.2	0.4	0.18
Oct. 2019	60.3	58.1	0.7	0.03
Nov. 2019	59.1	57.1	0.7	0.18
Dec. 2019	57.2	55.9	1.2	0.38
Overall	61.4	58.4	0.4	0.02
Fecal Nitrogen				
Nov. 2018	1.5	1.2	0.2	0.31
May 2019	2.0	1.5	0.2	0.07
June 2019	1.9	1.4	0.2	0.11
July 2019	1.8	1.3	0.2	0.06
Aug. 2019	1.8	1.5	0.1	0.23
Sept. 5, 2019	1.4	1.0	0.1	0.00
Sept. 26, 2019	1.2	1.1	0.1	0.70
Oct. 2019	1.5	1.1	0.1	0.23
Nov. 2019	1.4	1.1	0.1	0.25
Dec. 2019	1.4	1.3	0.2	0.51
Overall	1.6	1.3	0.1	0.07

Table 2.4 Continued				
Variable	**Continuous**	**Rotational**	**Standard Error**	**P-value**
Fecal Phosphorus				
Nov. 2018	0.1	0.0	0.0	0.31
May 2019	0.4	0.2	0.0	0.06
June 2019	0.3	0.2	0.0	0.02
July 2019	0.3	0.1	0.1	0.03
Aug. 2019	0.4	0.2	0.0	0.03
Sept. 5, 2019	0.2	0.1	0.0	0.00
Sept. 26, 2019	0.1	0.1	0.0	0.71
Oct. 2019	0.2	0.1	0.0	0.21
Nov. 2019	0.1	0.1	0.0	0.16
Dec. 2019	0.0	0.0	0.0	0.27
Overall	0.2	0.1	0.0	0.02

Table 2.5 GPS Collar Performance			
Variable	**Continuous**	**Rotational**	**Standard Error**
Summer Mean Fix Frequency (min)[1]	5.7	2.9	0.5
Fall Mean Fix Frequency (min)[1]	3.1	2.9	0.4
Summer Mean Fix Number[2]	19705.9	40882.3	2413.8
Fall Mean Fix Number[2]	60014.6	52794.5	4453.7

[1] The mean time elapsed between GPS position fix recordings (min).
[2] The mean number of GPS position fixes recorded per cow. The actual number of GPS position fixes recorded per cow was used in the spatial analysis unless otherwise noted.

The interaction of season and fix frequency was not significant (P = 0.30).
The interaction of grazing treatment and fix frequency was not significant (P = 0.25).

Table 2.6 Grazing Behavior				
Season	**Summer**		**Standard Error**	**P-value**
Grazing Treatment	**Continuous**	**Rotational**		
Number of Cows	**25**	**31**	**-**	**-**
Daily Distance Traveled (m)	3194	8813	924	0.25
Sunrise-Sunset Distance Traveled (m)	2879	6247	616	0.25
Sunset-Midnight Distance Traveled (m)	97	867	103	0.26
Midnight-Sunrise Distance Traveled (m)	545	1677	189	0.10
Mean Distance to Water (m)	428	193	25	0.39
Time Spent <50 m from Water (%)	8	16	1	0.46
Time Spent <100 m from Water (%)	17	28	1	0.63
Area Explored (m^2)	282793	79074	14448	0.04
Spatial Search Pattern (%)	3	16	1	0.12
Area Explored as a Percentage of Paddock (%)	47	94	3	0.04
Season	**Fall**		**Standard Error**	**P-value**
Grazing Treatment	**Continuous**	**Rotational**	-	-
Number of Cows	**29**	**41**	-	-
Daily Distance Traveled (m)	12649	10078	1223	0.52
Sunrise-Sunset Distance Traveled (m)	8131	6397	751	0.48
Sunset-Midnight Distance Traveled (m)	2475	2017	255	0.64
Midnight-Sunrise Distance Traveled (m)	2176	1663	247	0.56
Mean Distance to Water (m)	360	230	17	0.53
Time Spent <50 m from Water (%)	16	16	1	0.99
Time Spent <100 m from Water (%)	30	28	1	0.95
Area Explored (m^2)	441981	115591	20459	0.02
Spatial Search Pattern (%)	4	13	1	0.07
Area Explored as a Percentage of the Paddock (%)	73	97	2	0.02

Table 2.6 Continued				
Season	**Summer + Fall Combined**		**Standard Error**	**P-value**
Grazing Treatment	**Continuous**	**Rotational**	**-**	**-**
Number of Cows	**54**	**72**	**-**	**-**
Daily Distance Traveled (m)	8368	9534	820	0.81
Sunrise-Sunset Distance Traveled (m)	5753	6333	508	0.86
Sunset-Midnight Distance Traveled (m)	1398	1522	167	0.88
Midnight-Sunrise Distance Traveled (m)	1437	1669	163	0.80
Mean Distance to Water (m)	391	214	14	0.45
Time Spent <50 m from Water (%)	12	16	1	0.81
Time Spent <100 m from Water (%)	24	28	2	0.89
Area Explored (m^2)	366892	99185	13458	0.02
Spatial Search Pattern (%)	4	14	1	0.01
Area Explored as a Percentage of the Paddock (%)	61	96	2	0.03

Table 2.7 Grazing Distribution				
Season	**Summer**		**Standard Error**	**P-value**
Grazing Treatment	**Continuous**	**Rotational**	**-**	**-**
Number of Cows	**25**	**31**	**-**	**-**
Hotspot Analysis: Percentage of Paddock within 1 Standard Deviation of the Mean (%)	80.1	50.6	3.1	0.06
Standard Distance (m)	312.8	265.8	3.8	0.14
Average Nearest Neighbor (m)	2.7	4.1	0.1	0.19
Average Nearest Neighbor Mean Ratio	0.4	0.6	0.0	0.11
Season	**Fall**		**Standard Error**	**P-value**
Grazing Treatment	**Continuous**	**Rotational**	**-**	**-**
Number of Cows	**29**	**41**	**-**	**-**
Hotspot Analysis: Percentage of Paddock within 1 Standard Deviation of the Mean (%)	89.4	94.0	1.5	0.51
Standard Distance (m)	374.3	336.6	3.7	0.35
Average Nearest Neighbor (m)	1.1	0.7	0.1	0.26
Average Nearest Neighbor Mean Ratio	0.2	0.1	0.0	0.20
Season	**Summer + Fall Combined**		**Standard Error**	**P-value**
Grazing Treatment	**Continuous**	**Rotational**	**-**	**-**
Number of Cows	**54**	**72**	**-**	**-**
Hotspot Analysis: Percentage of Paddock within 1 Standard Deviation of the Mean (%)	85.6	75.3	0.02	0.23
Standard Distance (m)	346.4	306.1	4.0	0.23
Average Nearest Neighbor (m)	1.8	2.1	0.1	0.48
Average Nearest Neighbor Mean Ratio	0.3	0.3	0.0	0.81

Table 2.8 Pearson Correlation Test

The R^2 values are shown.
A P-value $0.05 < P < 0.10$ is indicated by *.
$P < 0.05$ is indicated by **.

	BW[1]	WW[2]	DDT3	< 50 m[4]	< 100 m[5]	HOA[6]	SD[7]	ANN[8]	AE[9]	SSP[10]	AEPP[11]
BW[1]	1.00	-0.37 **	-0.21 *	0.18	0.23	0.23 *	0.20	-0.27 *	0.02	-0.15	-0.08
WW[2]	-0.37 **	1.00	0.10	-0.07	-0.07	-0.30 *	-0.15	0.24 *	-0.03	0.11	-0.06
DDT[3]	-0.21 *	0.10	1.00	-0.35 **	-0.34 **	-0.05	-0.10	0.02	0.18	0.39	0.29
< 50 m[4]	0.18	-0.07	-0.35 **	1.00	0.95 **	0.03	0.51 *	-0.33	-0.32	0.14	0.07
< 100 m[5]	0.23	-0.07	-0.34 **	0.95 **	1.00	0.10	0.47 *	-0.35 *	-0.28	0.08	-0.5
HOA[6]	0.23 *	-0.30 *	-0.05	0.03	0.10	1.00	0.48 **	-0.78 **	0.30 *	-0.38 **	-0.21
SD[7]	0.20	-0.15	-0.10	0.51 *	0.47 *	0.48 **	1.00	-0.69 **	0.51 **	-0.42 **	-0.40 **
ANN[8]	-0.27 *	0.24 *	0.02	-0.33	-0.35 *	-0.78 **	-0.69 **	1.00	-0.19	0.21	0.02
AE[9]	0.02	-0.03	0.18	-0.32	-0.28	0.30 *	0.51 **	-0.19	1.00	-0.70 **	-0.70 **
SSP[10]	-0.15	0.11	0.39	0.14	0.08	-0.38 **	-0.42 **	0.21	-0.70 **	1.00	0.76 **
AEPP[11]	-0.08	-0.06	0.29	0.07	-0.05	-0.21	-0.40 **	0.02	-0.70 **	0.76 **	1.00

[1] BW = cow body weight, averaged across the experiment.
[2] WW = calf weights taken at weaning. Calves averaged 160 days of age at this time.
[3] DDT = daily distance traveled, averaged across the experiment.
[4] < 50 m = percentage of GPS fixes that fell within 50 meters of water.
[5] < 100 m = percentage of GPS fixes that fell within 100 meters of water.
[6] HOA = the results from the Hot Spot Analysis.
[7] SD = the results from the Standard Distance Analysis.
[8] ANN = the results from the Average Nearest Neighbor Analysis.
[9] AE = the results from the Area Explored Analysis.
[10] SSP = the results from the Spatial Search Pattern Analysis.
[11] AEPP = Area Explored as a percentage of the paddock available to the cow.

Table 3.1 Temperament Variables					
Treatment		**Positive**	**Control**	**Standard Error**	**P-value**
Number of Cows		**27**	**34**	**-**	**-**
Chute Scores					
Collection Day	**0**	1.6	1.6	0.1	0.75
	306	1.6	1.4	0.1	0.22
	563	2.1	1.8	0.1	0.21
	623	2.4	2.1	0.1	0.24
	687	2.7	2.4	0.2	0.53
There was not a significant interaction between treatment and chute score (P = 0.13). There was not a significant interaction between collection day and treatment (P = 0.56). The interaction between collection day and chute score was significant (P < 0.01).					
Chute Exit Velocity					
Collection Day	**0**	1.4	1.4	0.1	0.95
	306	1.3	1.3	0.1	0.71
	563	1.3	1.4	0.1	0.48
	623	1.6	1.4	0.1	0.32
	687	1.3	1.3	0.1	0.62
There was not a significant interaction between treatment and chute exit velocity (P = 0.63), collection day and chute exit velocity (P = 0.85), or collection day and treatment (P = 0.63).					
Alley Scores					
Collection Day	**0**	2.2	2.1	0.1	0.70
	306	1.8	2.0	0.2	0.30
	563	1.9	1.8	0.2	0.89
	623	1.7	1.9	0.2	0.37
	687	1.8	2.2	0.2	0.14
There was a significant interaction between treatment and alley score (P = 0.05). The interaction between collection day and alley score was not significant (P = 0.31), nor was the interaction between collection day and treatment (P = 0.39).					
Dam Scores					
Number of Cows		**24**	**26**	**-**	**-**
Dam Score		1.6	1.5	0.1	0.90

FIGURES

Figure 2.1. 2019 Monthly Precipitation Compared to 1981-2010 Monthly Precipitation Average

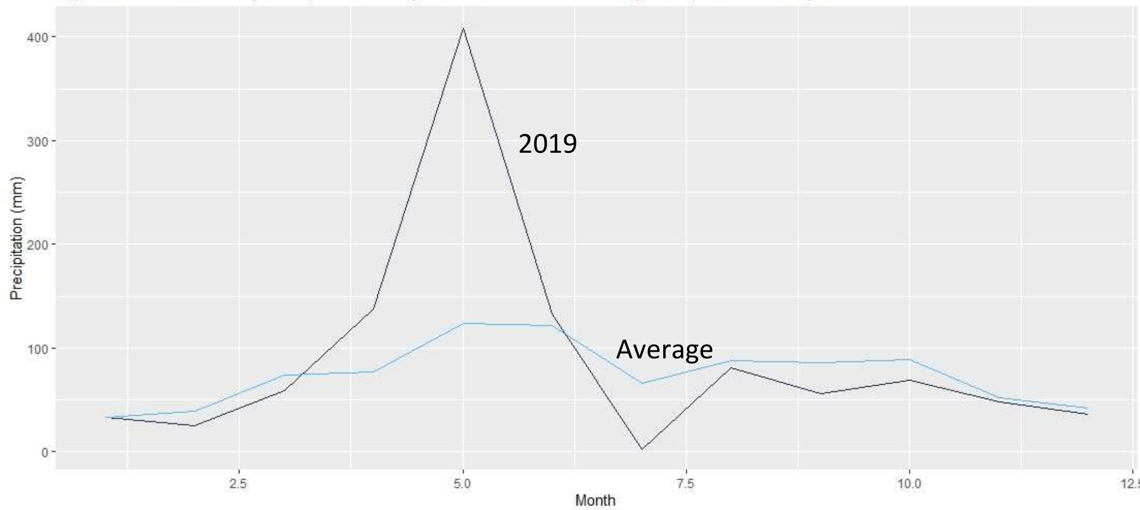


Figure 2.2. Forage Production (kg/ha)

Grazing treatment affected forage production in May (P = 0.06) only.

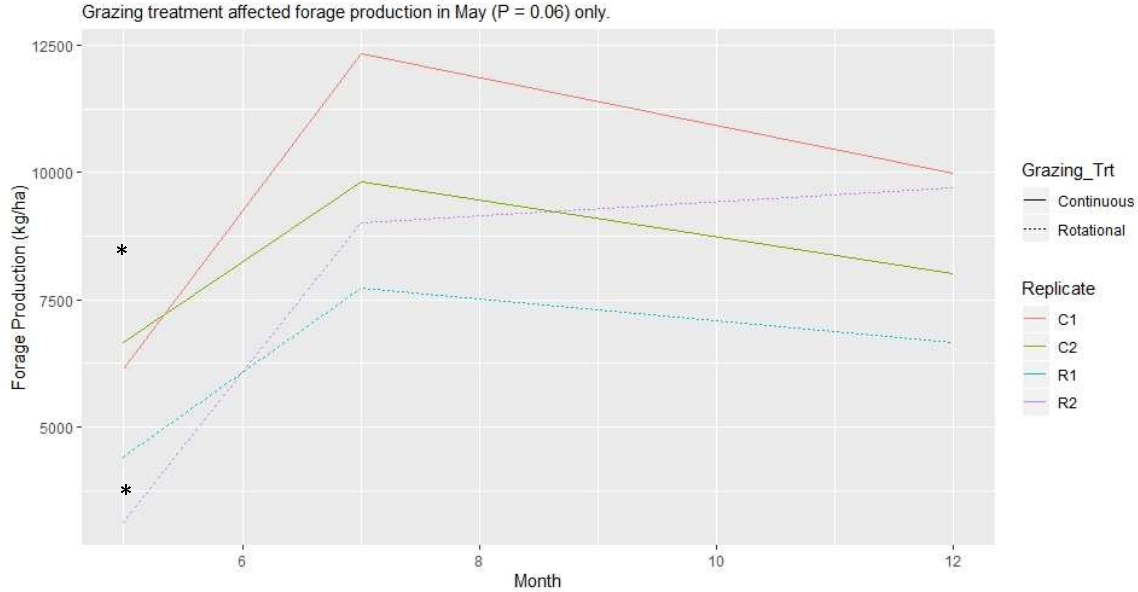


Figure 2.3. Forage Utilization (%)
Forage Utilization was not affected by grazing treatment (P = 0.64).

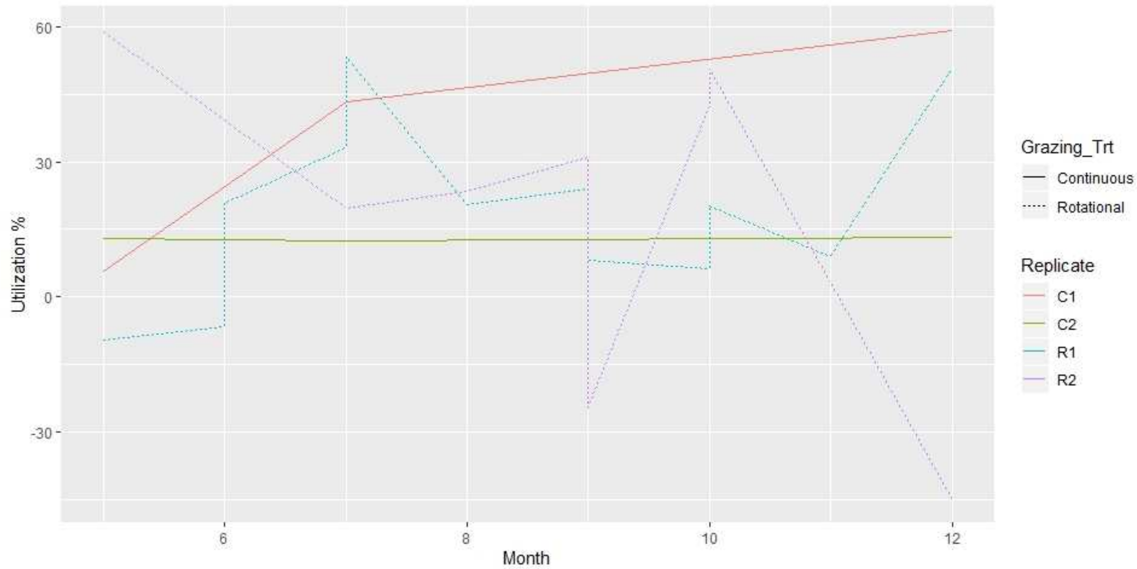


Figure 2.4. Forage Crude Protein
The continuous grazing treatment had greater CP in July only (P = 0.05).

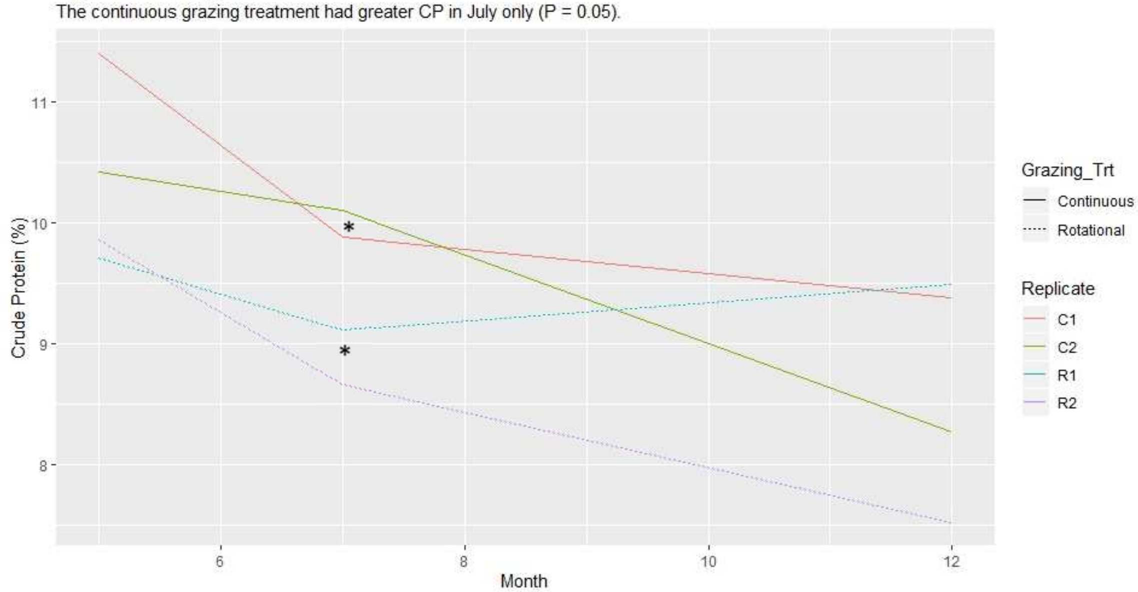


Figure 2.5. Forage ADF

The continuous grazing treatment had greater ADF in May (P = 0.06) and December (P = 0.03).

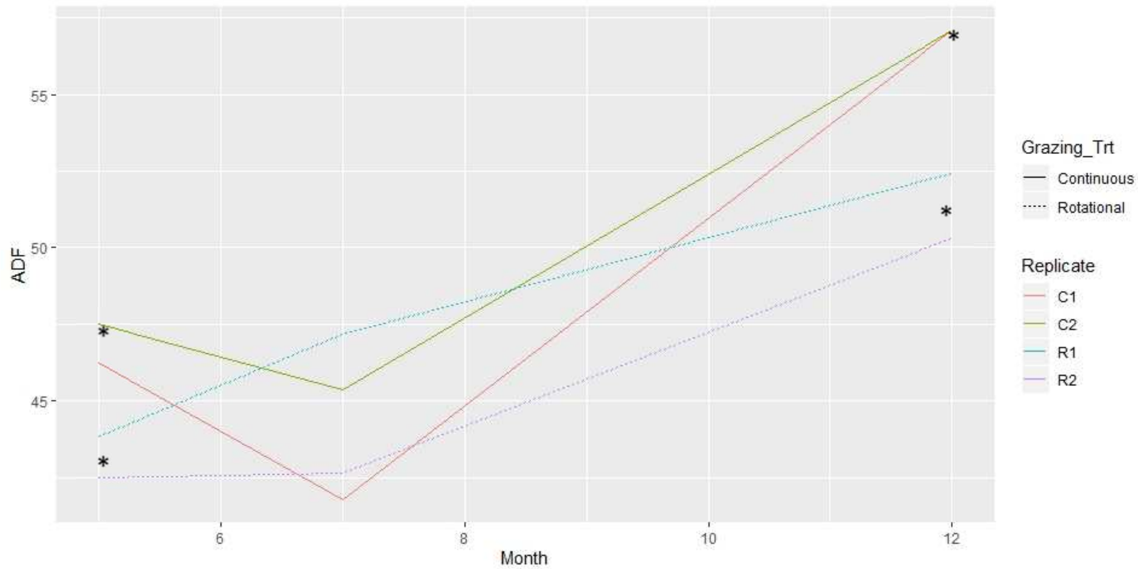


Figure 2.6. Forage NDF

NDF was unaffected by grazing treatment (P > 0.25).

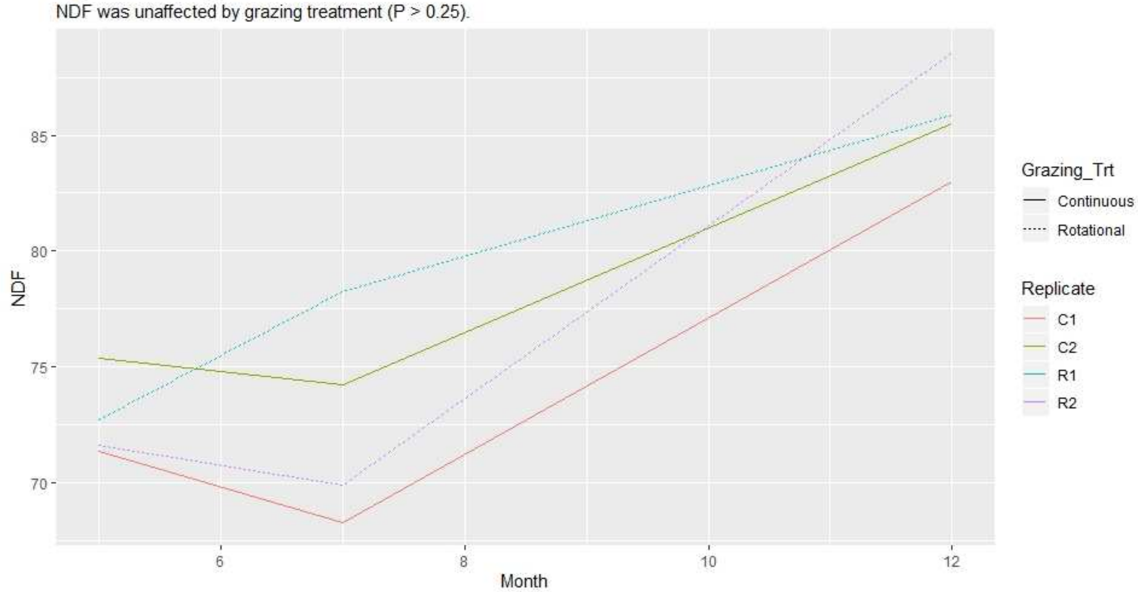


Figure 2.7. Forage Lignin

Lignin content differed overall (P = 0.10), in May (P = 0.01), and in December (P = 0.10); with C having greater lignin.

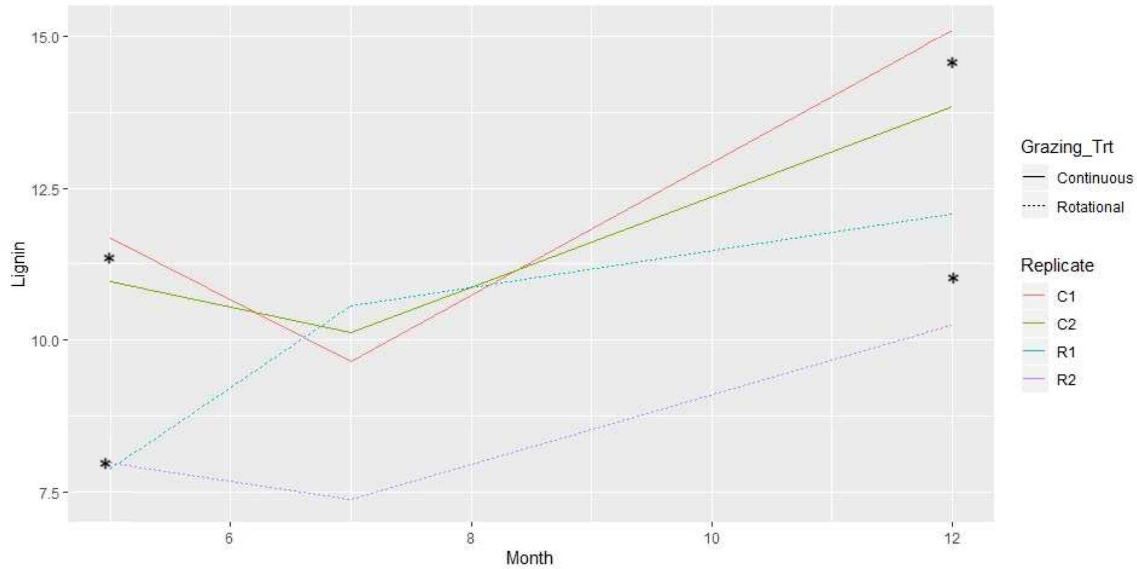


Figure 2.8. Relationship between Fix Frequency and Distance Travelled

Increased time between fixes resulted in decreased daily distance travelled (P < 0.001).

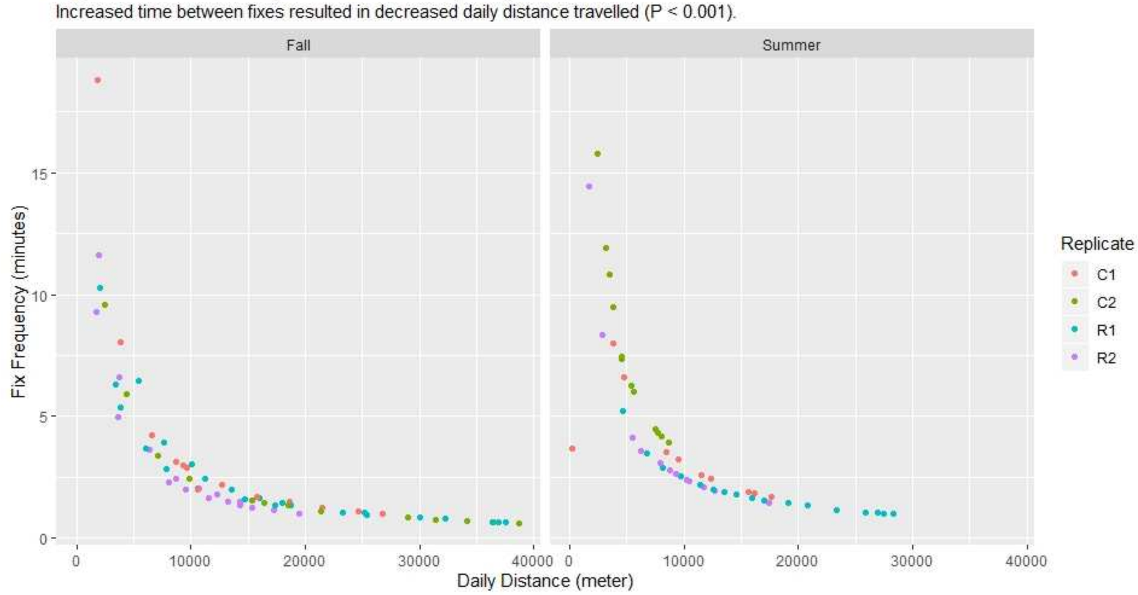


Figure 2.9. Daily Distance Traveled (m).

Grazing method did not affect daily distance traveled in either season (P > 0.25).

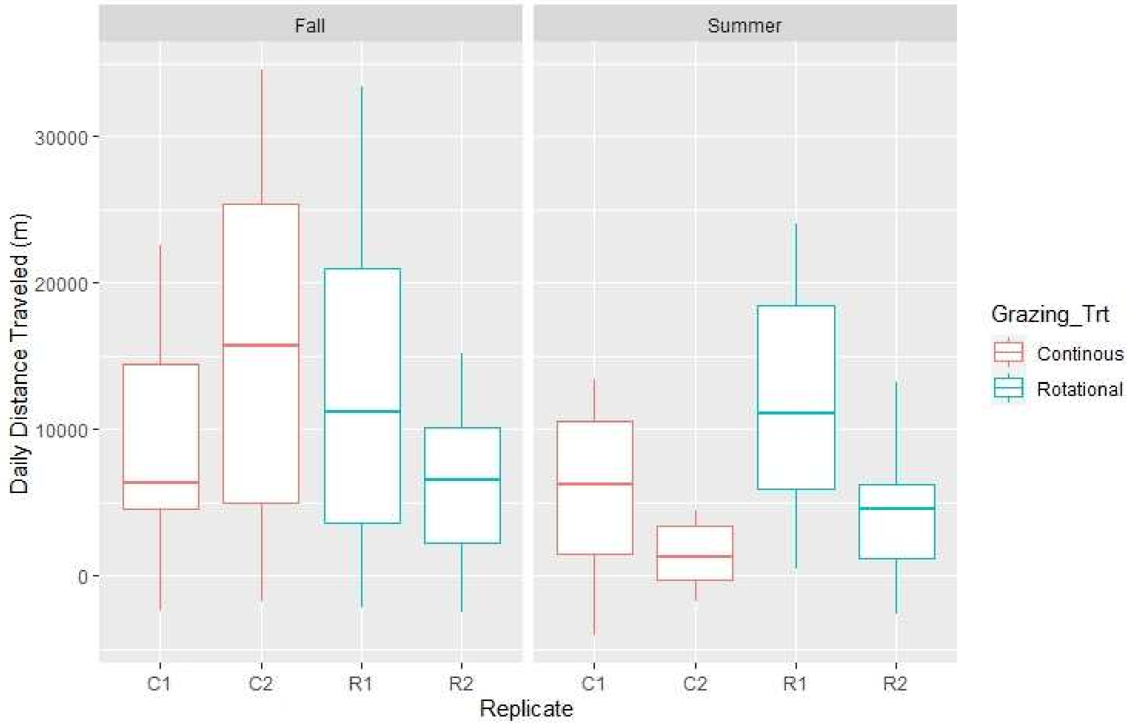


Figure 2.10. Distance Traveled During Daylight (m)

Grazing treatment did not affect the daily distance traveled during daylight in either season (P > 0.25).

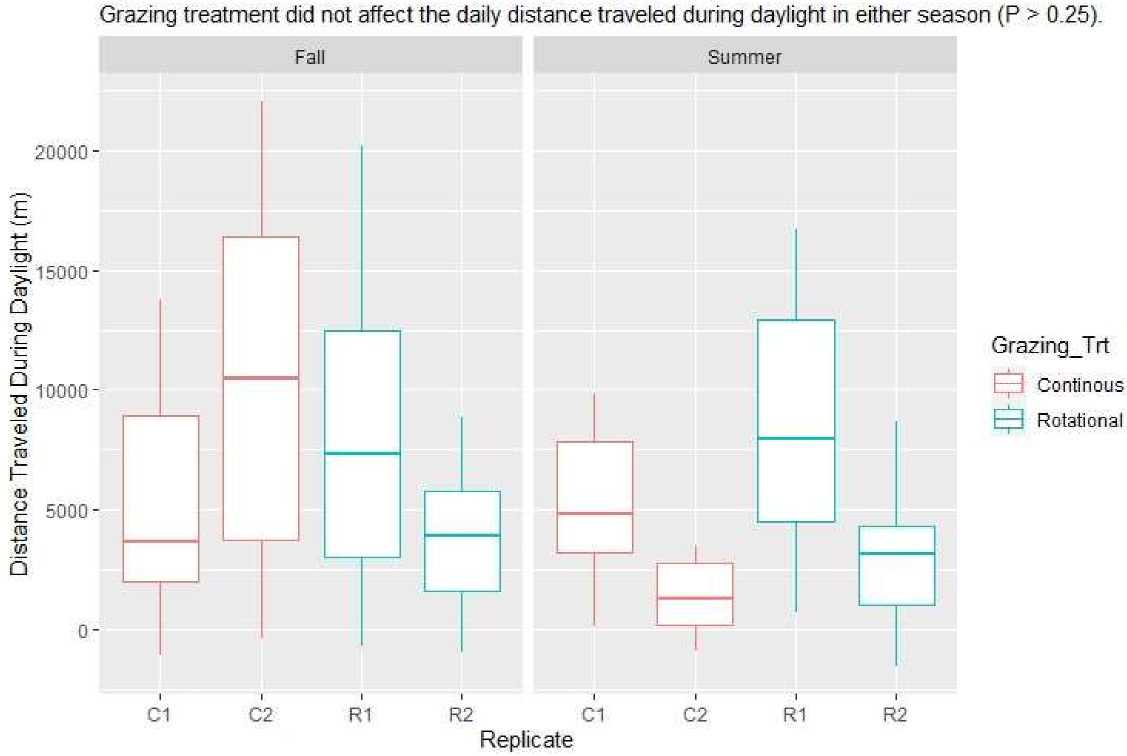


Figure 2.11. Distance Traveled from Sunset to Midnight (m)

Grazing treatment did not affect the distance traveled from sunset to midnight in either season (P > 0.26).

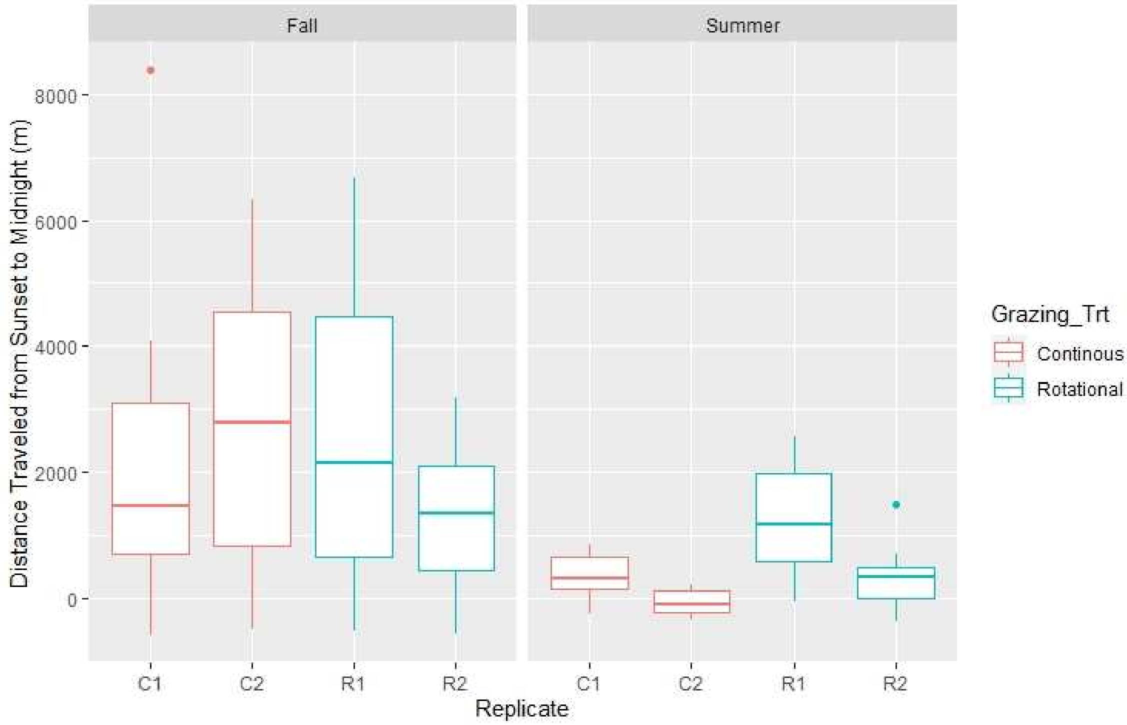


Figure 2.12. Distance Traveled from Midnight to Sunrise (m)

Grazing treatment did not affect the distance traveled from midnight to sunrise in either season (P > 0.10).

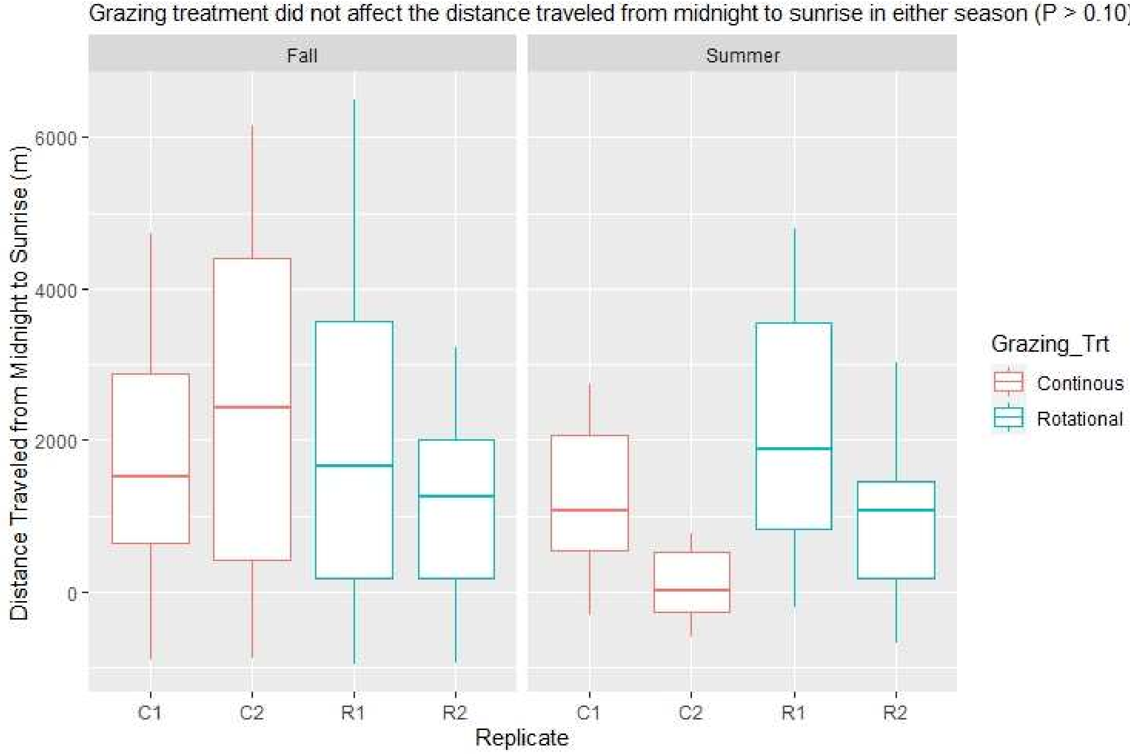


Figure 2.13. Mean Distance to Water (m)

Grazing treatment did not affect mean distance to water (P = 0.45).

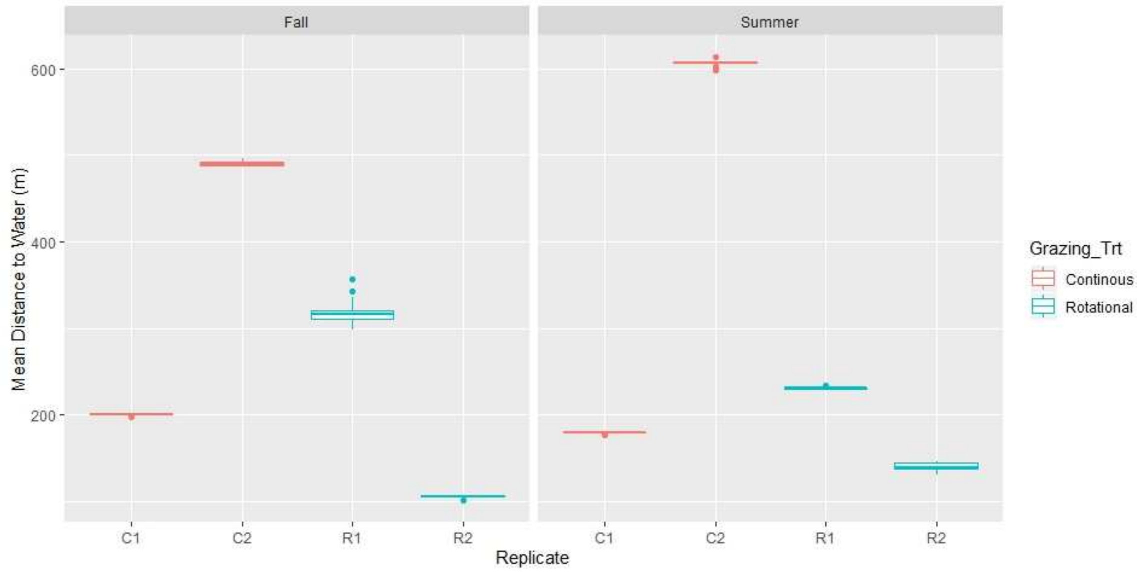


Figure 2.14. Time Spent within 50m of Water (%)

Grazing treatment did not affect time spent within 50m of water (P = 0.81).

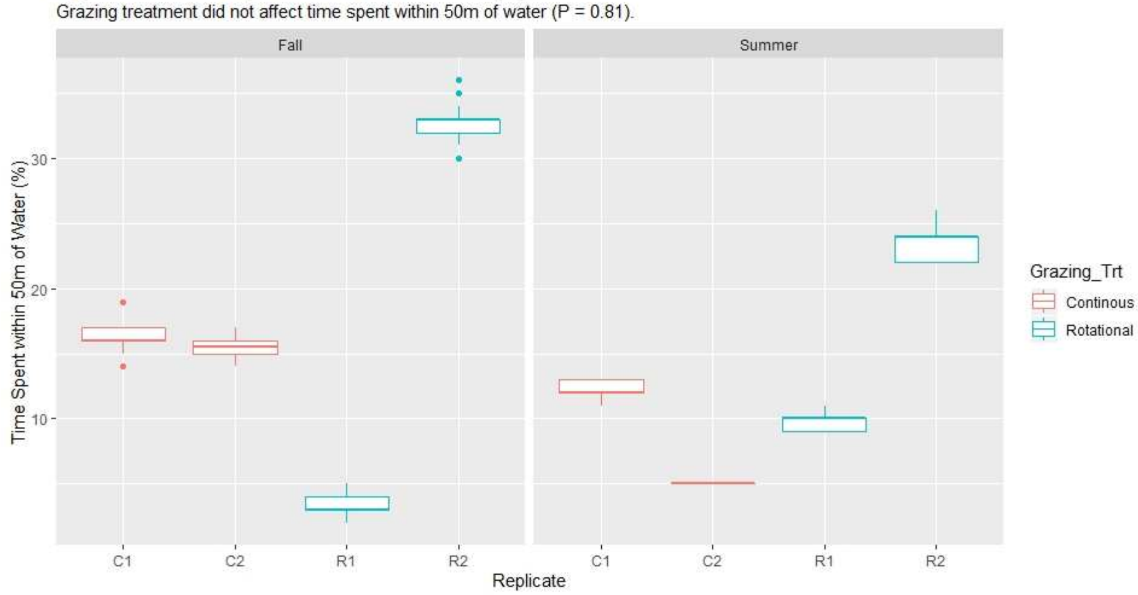


Figure 2.15. Time Spent within 100m of Water (%)

Grazing treatment did not affect time spent within 100m of water (P = 0.89).

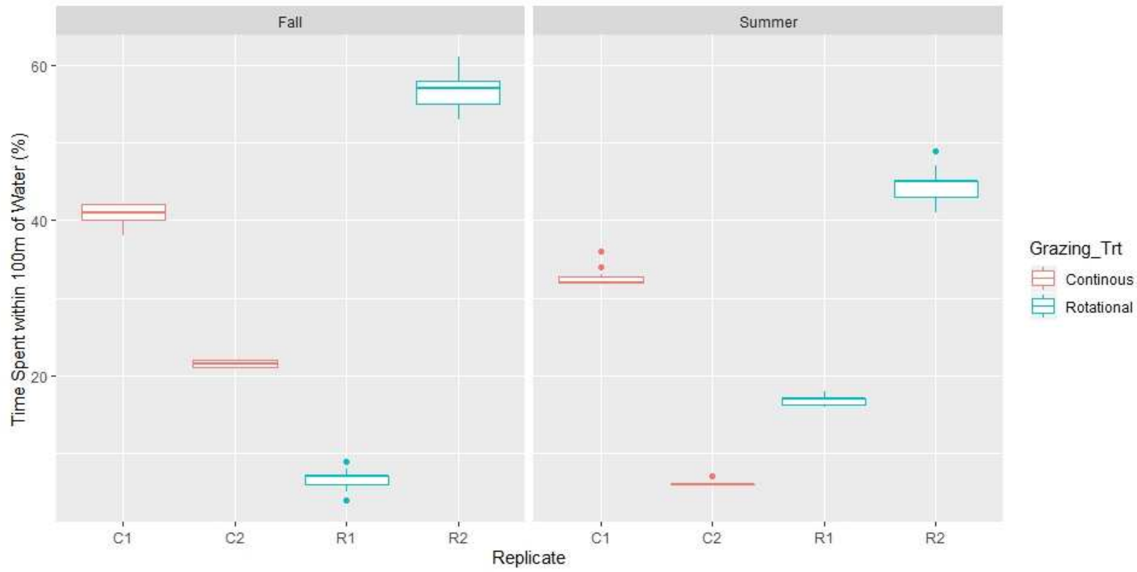


Figure 2.16 Hotspot Analysis

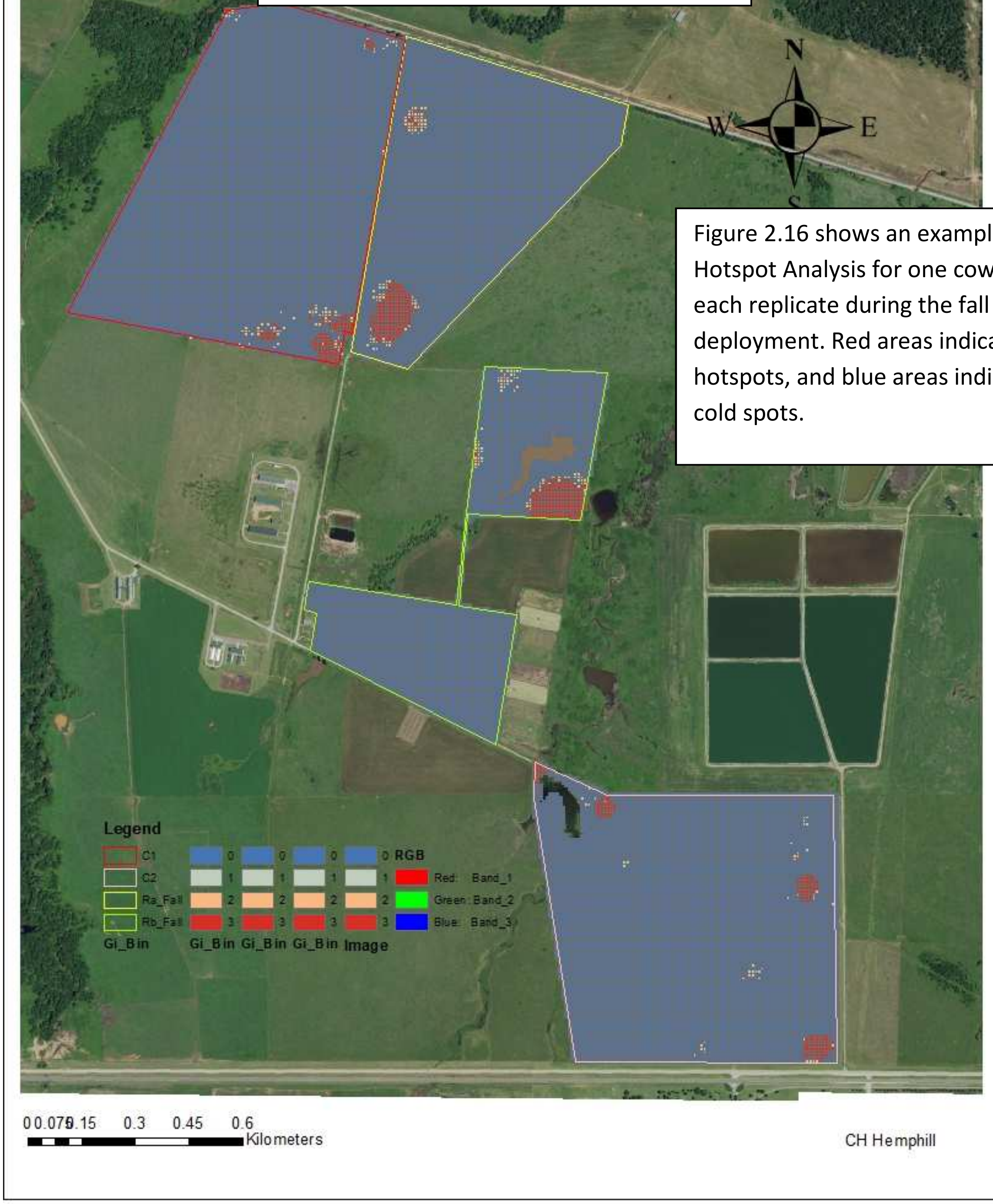


Figure 2.16 shows an example Hotspot Analysis for one cow from each replicate during the fall deployment. Red areas indicate hotspots, and blue areas indicate cold spots.

Figure 2.17 Example Hotspot Analysis

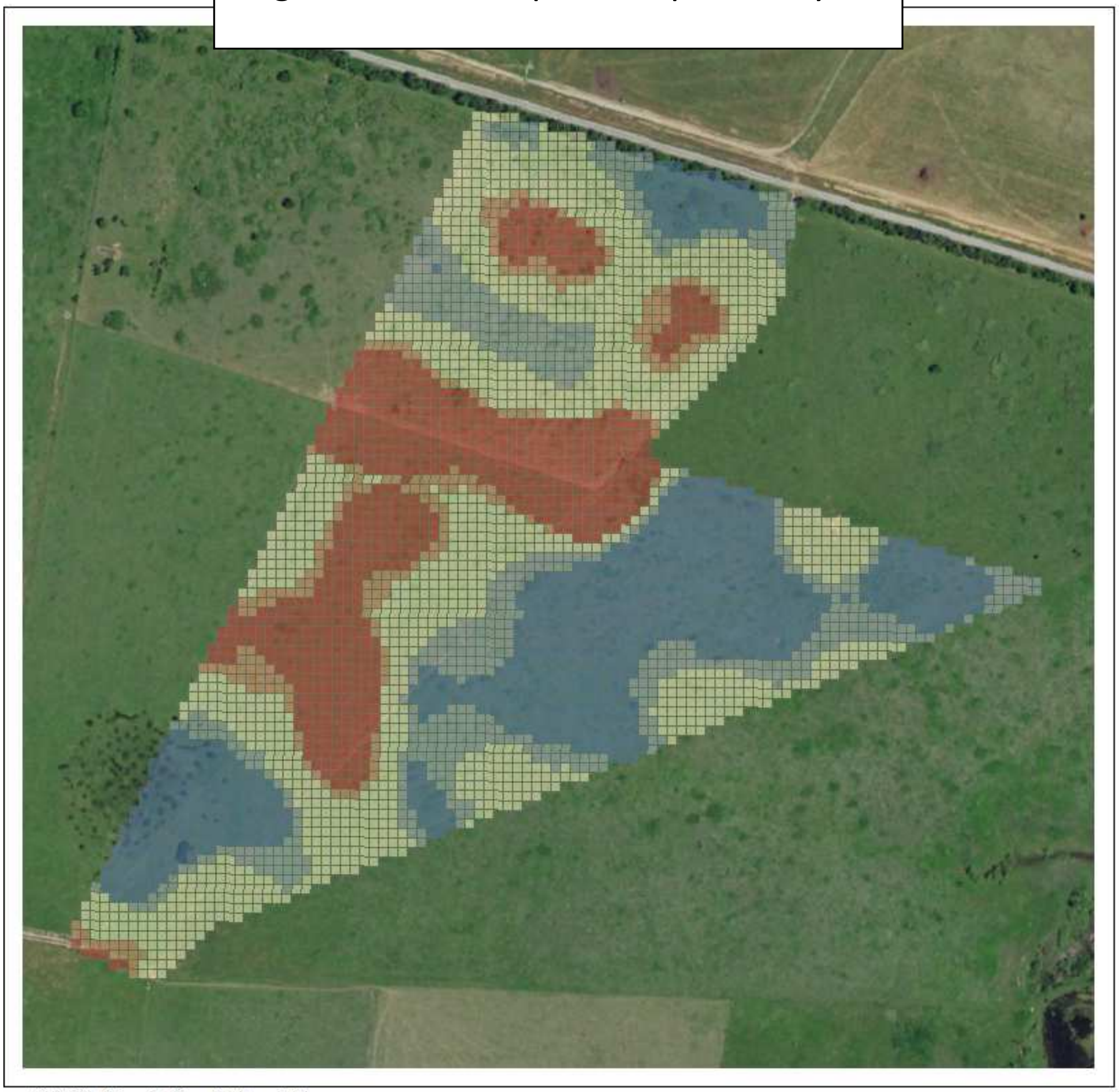


Figure 2.17 shows the output for the Optimized Hot Spot Analysis for one cow in the rotational grazing treatment, replicate R1, during the summer deployment

Figure 2.18. Daily Area Explored (ha)

The continuous grazing treatment had greater daily Area Explored in the summer (P = 0.04), the fall (P = 0.02), and overall (P = 0.02).

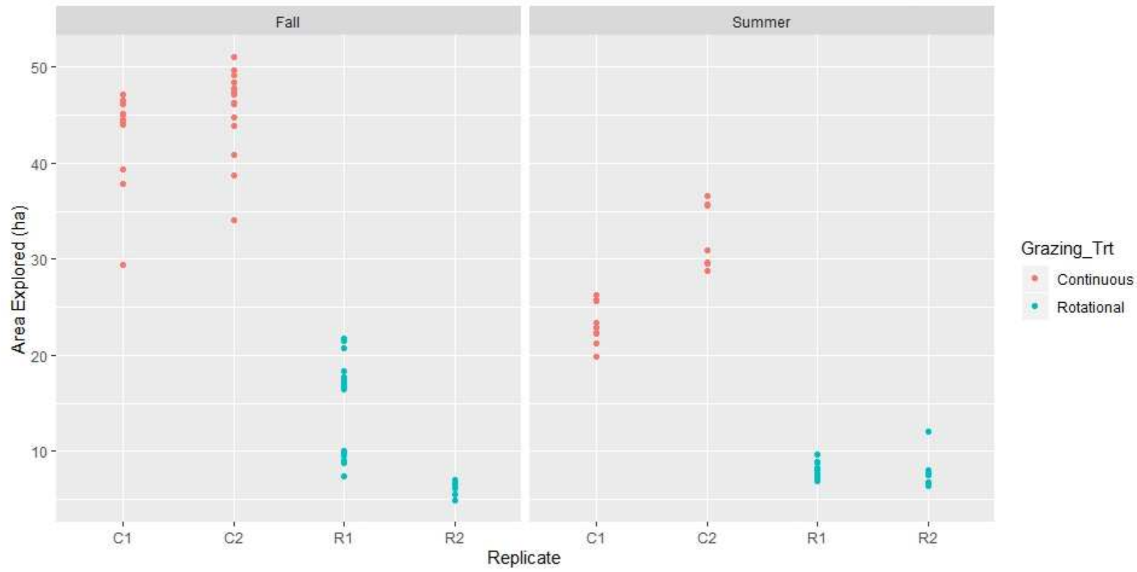


Figure 2.19. Daily Spatial Search Pattern (%)

The rotational grazing treatment had greater daily spatial search patterns overall (P = 0.01), and tended to have greater daily search patterns in the fall (P = 0.07), but not the summer (P = 0.12).

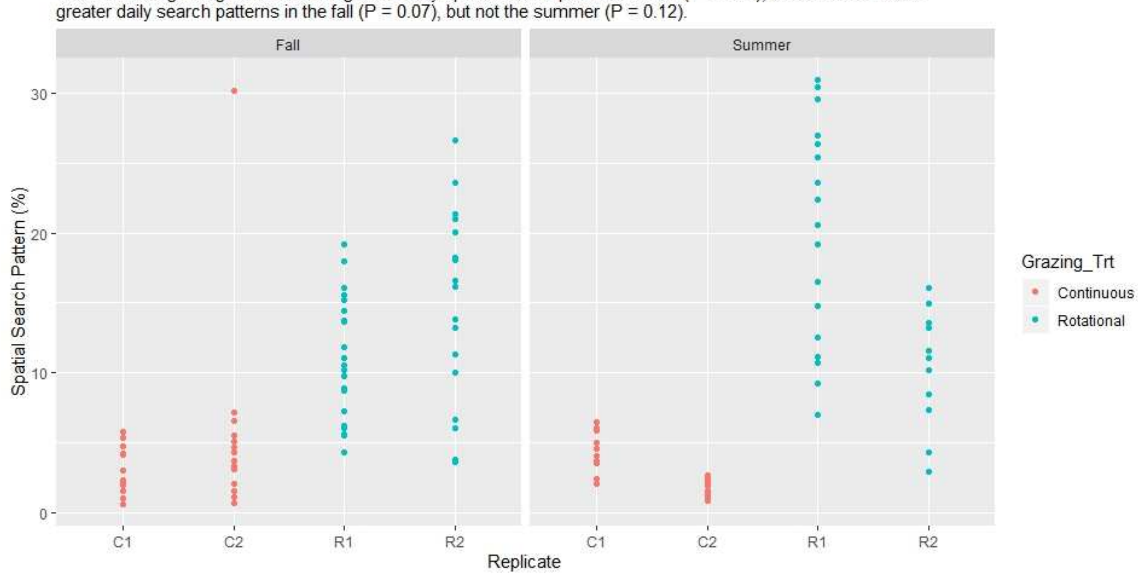


Figure 2.20. Percent of Pasture Visted Daily

The cattle in the rotational grazing treatment visited a larger percentage of their paddock daily in the summer (P = 0.04), fall (P = 0.02), and overall (P = 0.03).

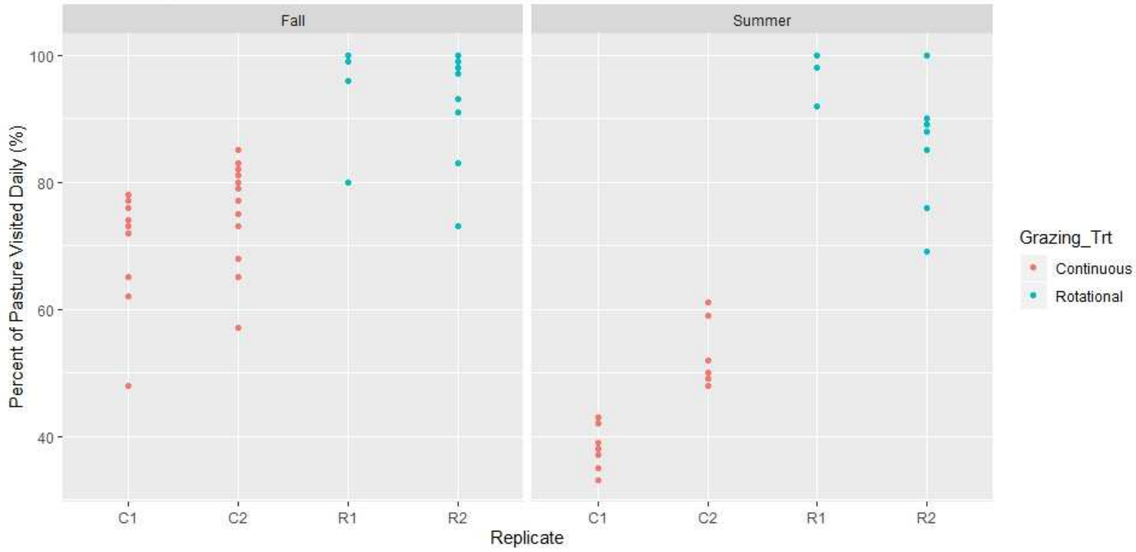


Figure 2.21. Area Explored and Spatial Search Pattern

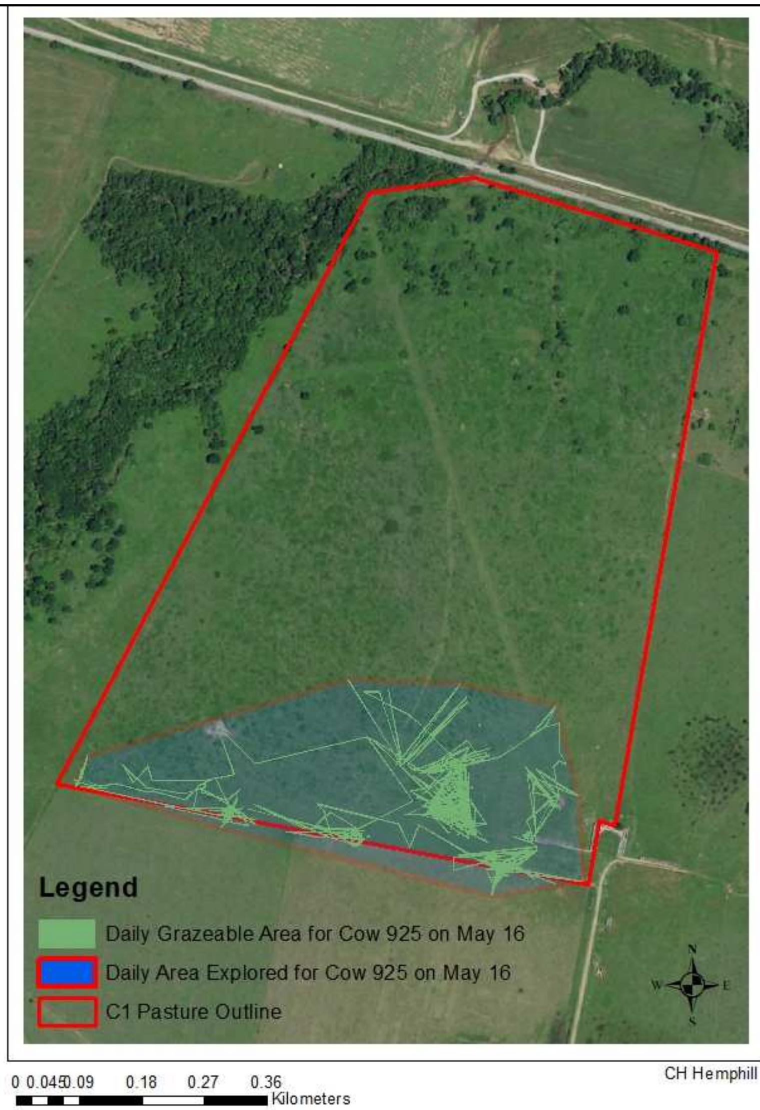
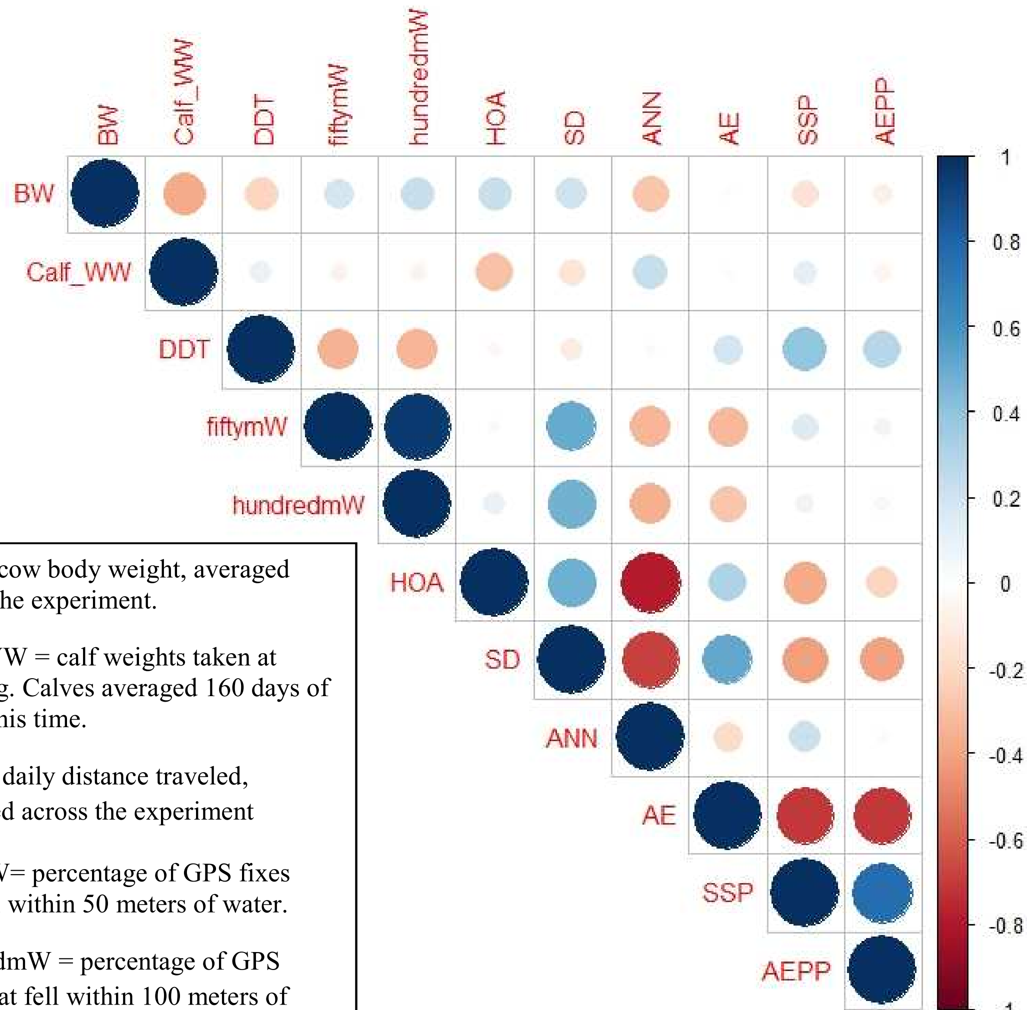


Figure 2.21 illustrates the Area Explored, Daily Grazeable Area, and the pasture outline for one cow (925) on one day (May 16). The area shaded in blue illustrates the Area Explored, created by making a polygon around all the GPS coordinates for this cow on May 16. In this example the Area Explored was 147,661 meters $^{2.}$ The green line shows the area this cow could have grazed on this day, created by multiplying the daily distance traveled (21176.5 meters) by 1 meter (21176.5 meters^2). The Spatial Search Pattern in this example is 14.34% (21176.5 m^2 ÷ 147661 m^2 = .1434 x 100 = 14.34%). The Area Explored (147,661 m^2) for May 16 was 24.32% of the overall pasture (607,074 m^2).

Figure 2.22 Correlations



BW = cow body weight, averaged across the experiment.

Calf_WW = calf weights taken at weaning. Calves averaged 160 days of age at this time.

DDT = daily distance traveled, averaged across the experiment

fiftymW= percentage of GPS fixes that fell within 50 meters of water.

hundredmW = percentage of GPS fixes that fell within 100 meters of water.

HOA = the results from the Hot Spot Analysis.

SD = the results from the Standard Distance Analysis.

ANN = the results from the Average Nearest Neighbor Analysis.

AE = the results from the Area Explored Analysis.

SSP = the results from the Spatial Search Pattern Analysis.

AEPP = Area Explored as a percentage of the paddock available to the cow.

Figure 2.23. Dietary Crude Protein

The continuous grazing treatment had consistently higher CP (P = 0.01).

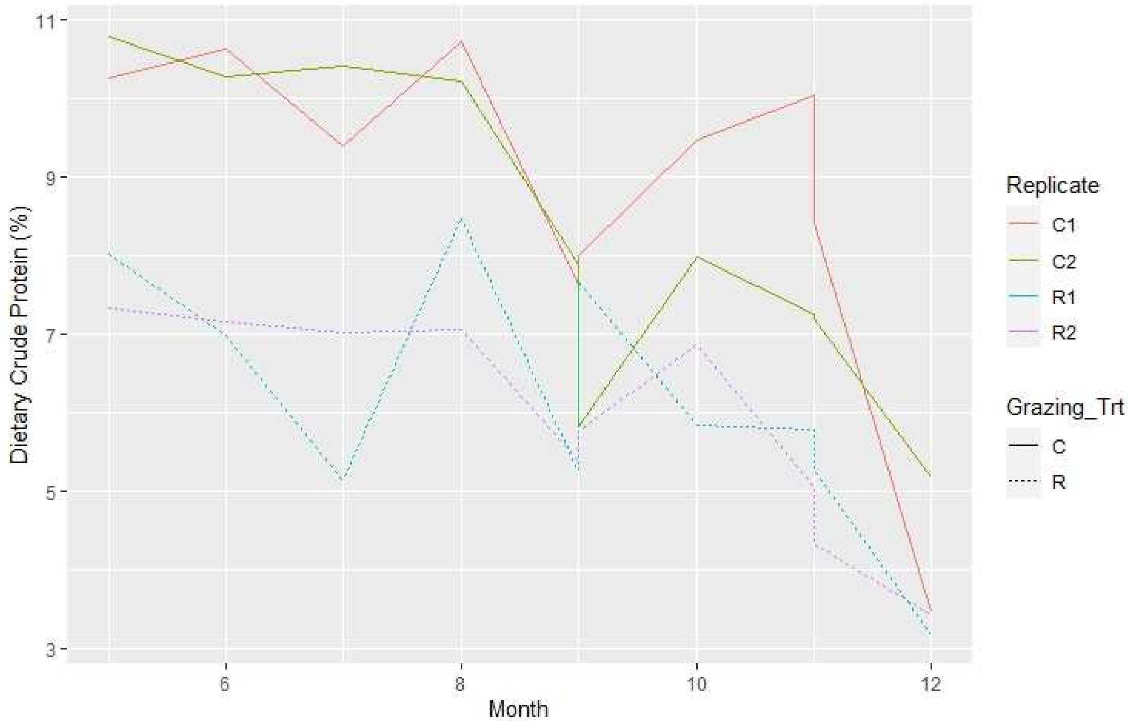


Figure 2.24. Digestible Organic Matter

The continuous grazing treatment had consistently higher DOG (P = 0.02).

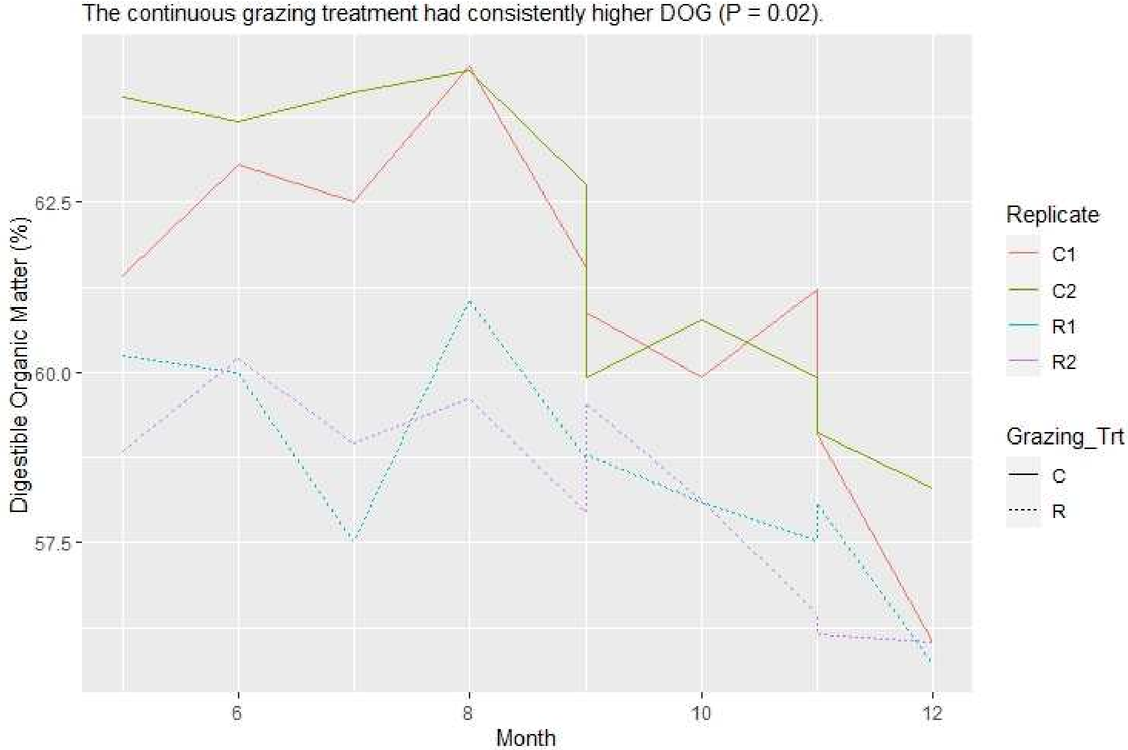


Figure 2.25. Fecal Nitrogen

The continuous grazing treatment tended to have greater fecal N (P = 0.07).

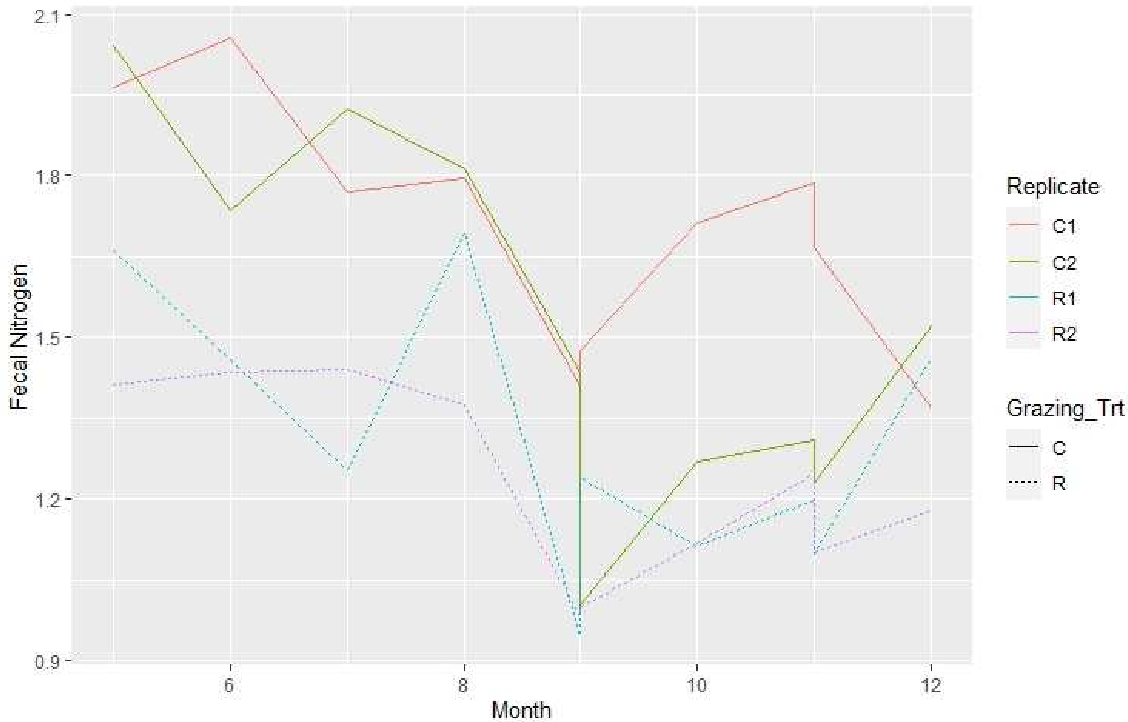
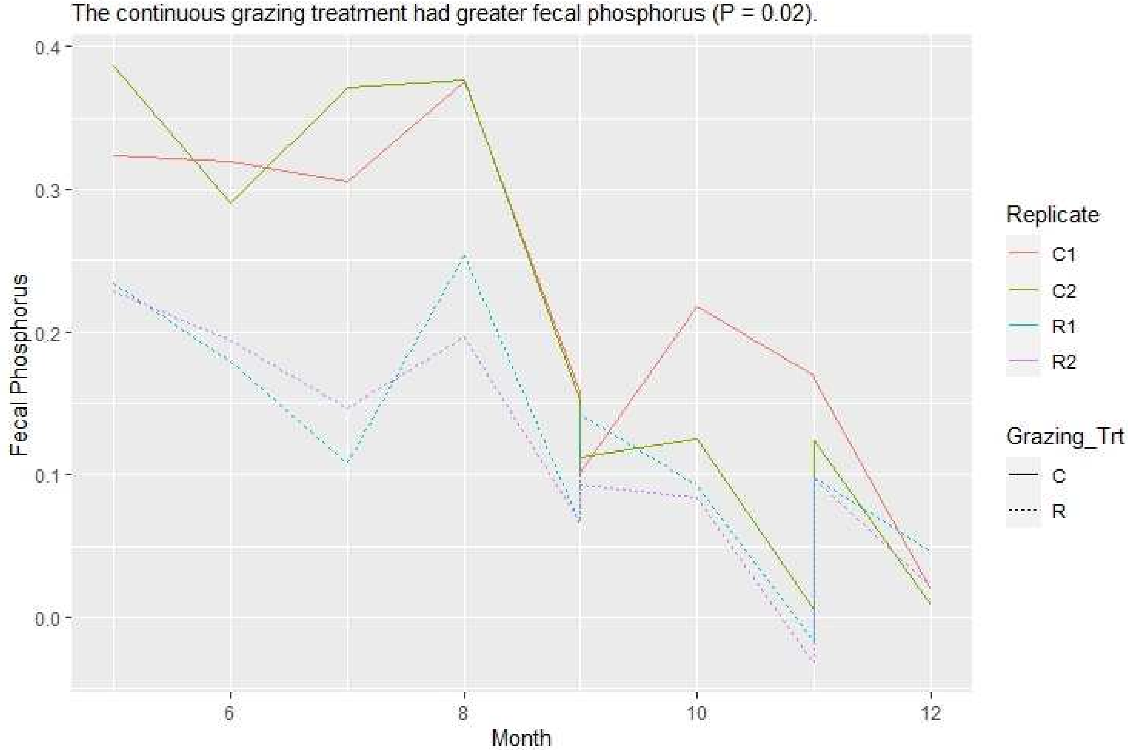
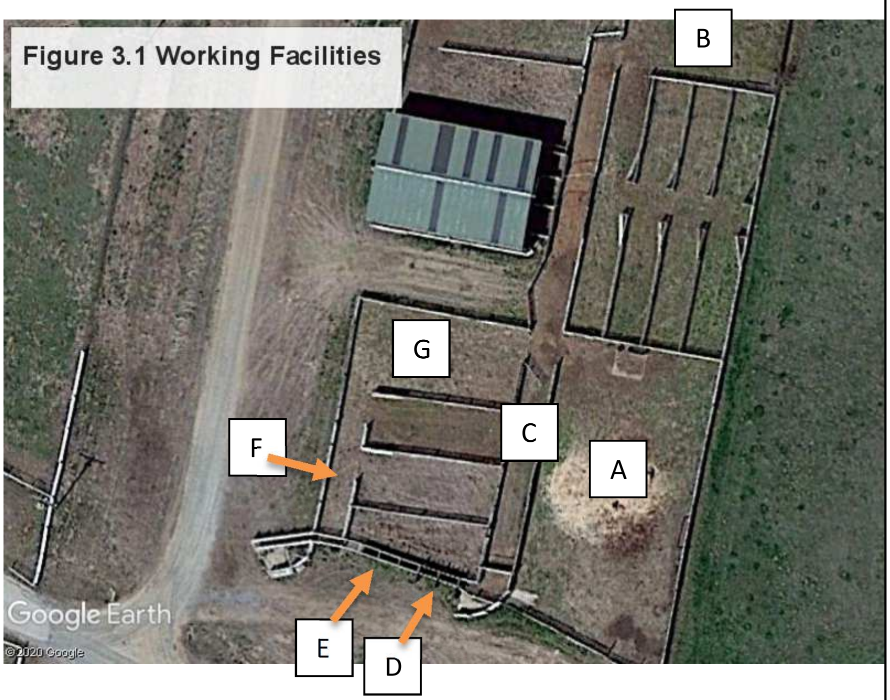


Figure 2.26. Fecal Phosphorus Content

The continuous grazing treatment had greater fecal phosphorus (P = 0.02).





Cattle were gathered into A from the pasture, then pushed to the holding pens at B. They were then brought down the alley (C) and loaded into the chute (D). Chute scores were taken at D. Immediately after being released from the chute, Chute Exit Velocity was taken at E. They then made their way back up the alley at F. Alley scores were taken based on their behavior in this alley (F). They were then held in the pen identified as G.

Figure 3.2. Chute Scores

Chute scores increased through time ($P < 0.001$), but were unaffected by treatment ($P = 0.13$).

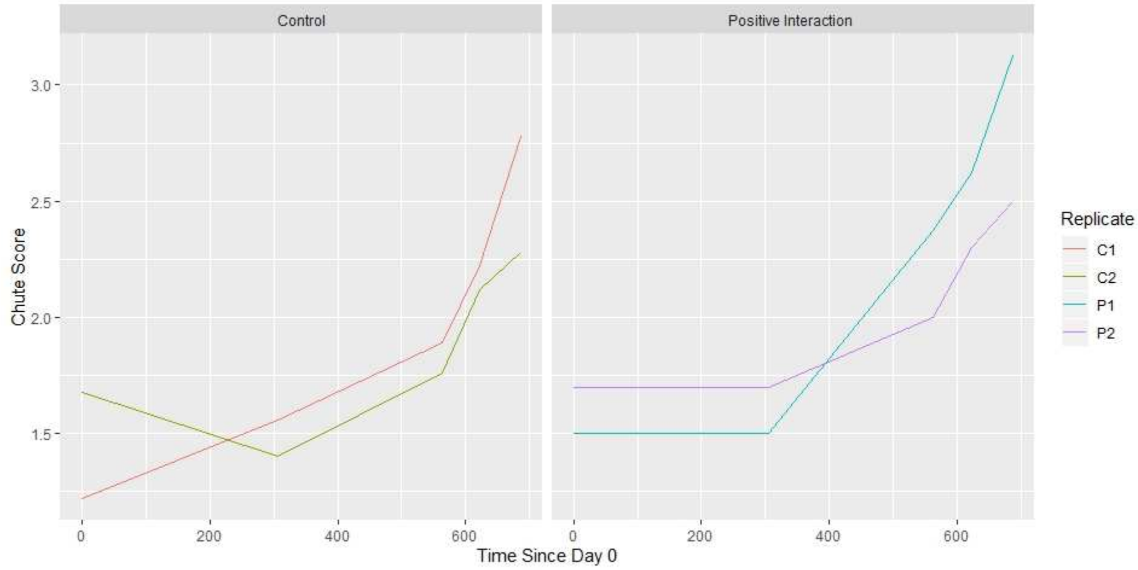


Figure 3.3. Chute Exit Velocity

Neither treatment nor time had an effect on chute exit velocity ($P > 0.63$).

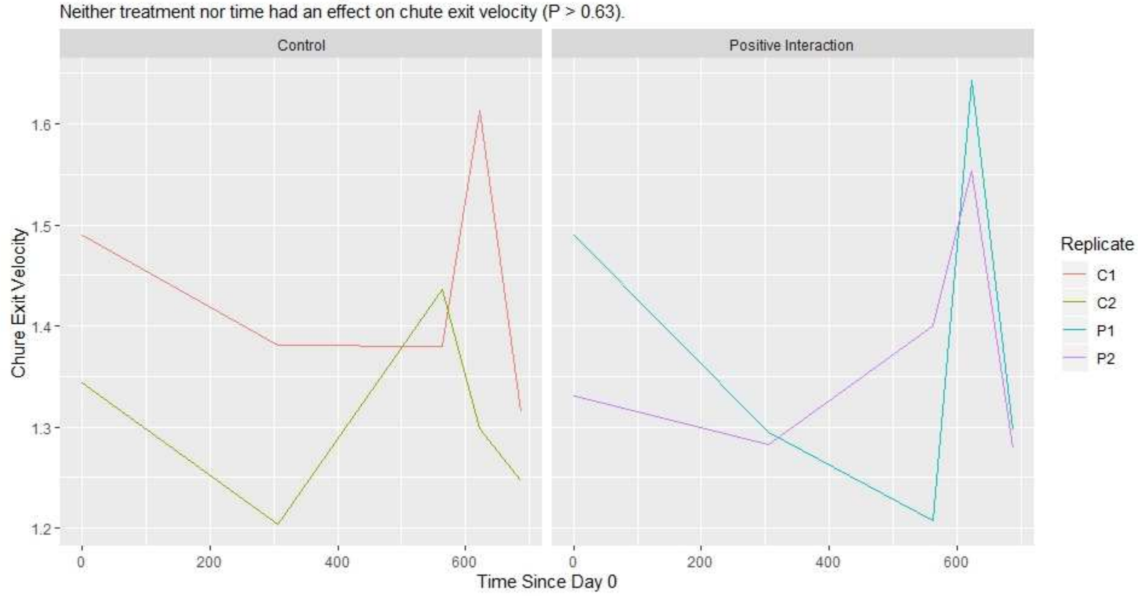


Figure 3.4. Alley Scores

Cattle in the positive interaction group had lower alley scores at P = 0.05.

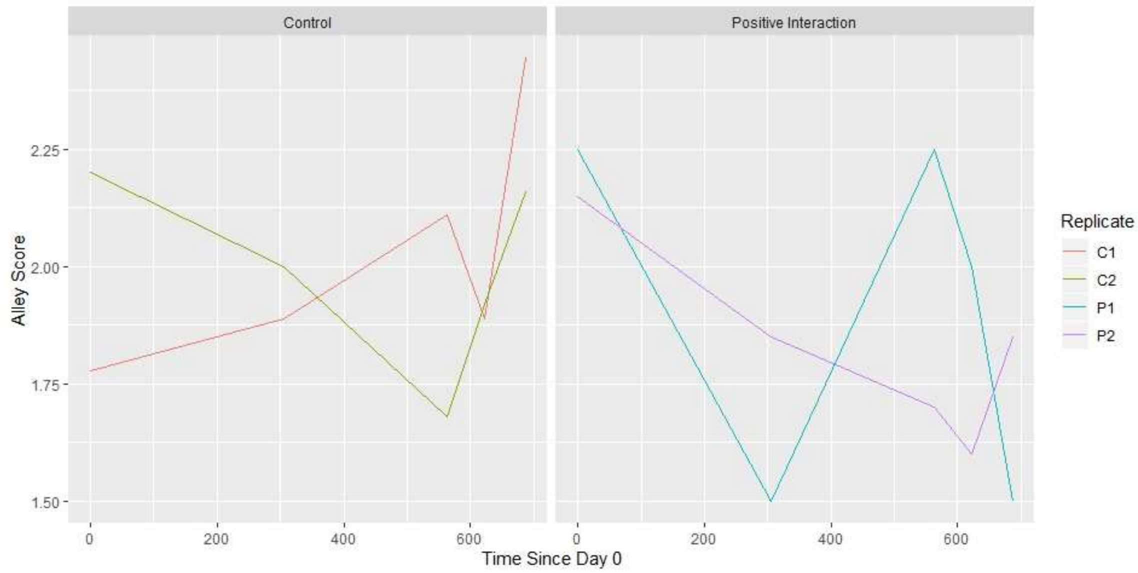
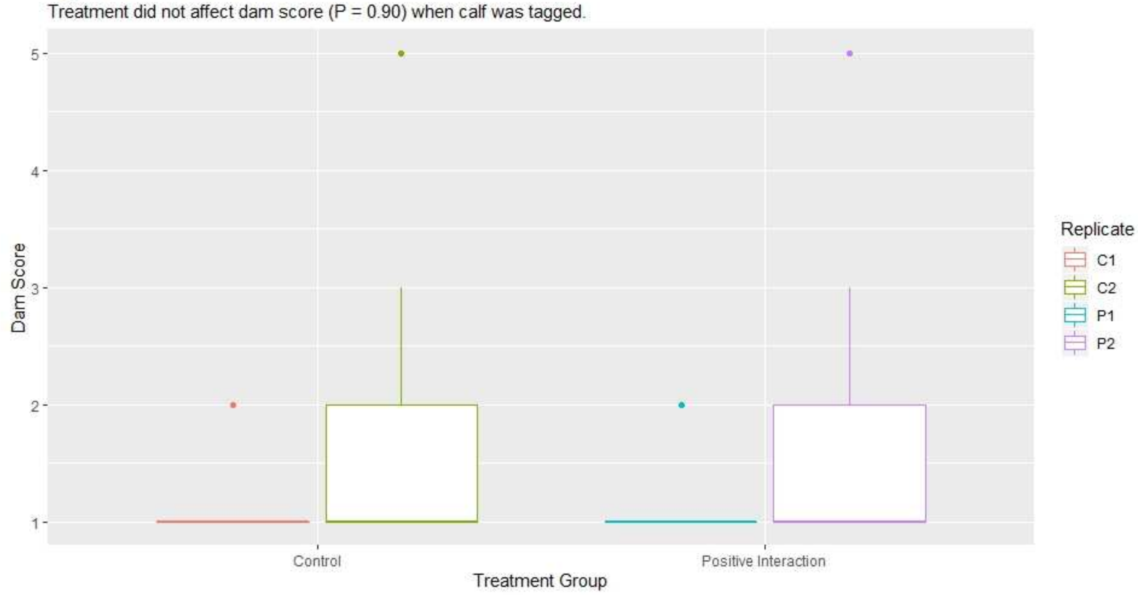


Figure 3.5. Dam Scores

Treatment did not affect dam score (P = 0.90) when calf was tagged.



VITA

Corban Haddon Hemphill

Candidate for the Degree of

Master of Science

Thesis: THE EFFECT OF ROTATIONAL GRAZING ON THE PERFORMANCE AND GRAZING BEHAVIOR OF COW-CALF PAIRS, AND THE EFFECTIVENESS OF FREQUENT HUMAN INTERACTION IN ALTERING THE TEMPERAMENT OF MATURE BEEF COWS

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- Southern Section American Society of Animal Science 2018-2020
- Society for Range Management 2014-2020