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EFFECT OF GRAZING PRESSURE ON CATTLE GRAZING COOL SEASON
ANNUAL FORAGES

BY
BROOKE BRUNSVIG

A thesis submitted in partial fulfillment of the requirements for the

Master of Science

Major in Animal Science

South Dakota State University

2017

EFFECT OF GRAZING PRESSURE ON CATTLE GRAZING COOL SEASON
ANNUAL FORAGES

This thesis is approved as a creditable and independent investigation by a candidate for the Master of Science in animal Science degree and is acceptable for meeting the dissertation requirements for this degree. Acceptance of this does not imply that the conclusions reached by the candidates are necessarily the conclusions of the major department.

~~Derek Brake, Ph.D.~~
Thesis Advisor

Date

~~Joseph Cassady, Ph.D.~~
Head, Department of Animal Science

Date

~~Dean,~~ Graduate School

Date

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CONTENTS

ABBREVIATIONS.....	vi
LIST OF FIGURES.....	viii
LIST OF TABLES.....	ix
ABSTRACT.....	x
CHAPTER 1: LITERATURE REVIEW.....	1
INTRODUCTION.....	2
GRAZING BEHAVIOR.....	2
GRAZING MANAGEMENT.....	9
CHANGES IN AGRICULTURE.....	14
COVER CROPS.....	16
CONCLUSION.....	18
LITERATURE CITED.....	20
CHAPTER 2:.....	30
INTRODUCTION.....	33
MATERIALS AND METHODS.....	34
Animals.....	34
Grazing experiment.....	35
Sampling procedures and laboratory analyses.....	36
Calculations.....	37
Statistical analysis.....	39
RESULTS AND DISCUSSION.....	39

Climate.....	39
Forage intake.....	40
Ruminal parameters.....	42
Nutrient intake, total-tract digestion, and dry matter intake.....	43
Nitrogen retention and performance.....	45
CONCLUSION.....	47
LITERATURE CITED.....	49

ABBREVIATIONS

ADF	acid detergent fiber
BW	body weight
C	Celsius
d	day
DM	dry matter
DMI	dry matter intake
g	gram
H ₂ SO ₄	sulfuric acid
ha	hectare
kg	kilogram
km	kilometer
L	liter
M	molar
Mcal	mega calorie
ME	metabolizable energy
mg	milligram
mL	milliliter
mm	millimeter
mM	millimolar
mmol	millimole
N	nitrogen
NE	net energy

NaOH	sodium hydroxide
NDF	neutral detergent fiber
OM	organic matter
TiO ₂	titanium dioxide
VFA	volatile fatty acid
vol	volume
wt	weight

LIST OF FIGURES

Figure 1.1. Relationship of animal production and land use efficiencies.....	13
Figure 1.2. United States Department of Agriculture Agricultural Research Service cover crop chart.....	17
Figure 2.1. Effects of stocking density and time on proportional intake of brassica to grass among cannulated heifers grazing brassica and grass.....	69

LIST OF TABLES

Table 2.1. Available above ground forage biomass and chemical composition (DM basis) of grass and brassica.....	63
Table 2.2. Effect of stocking density and time on ruminal parameters of cannulated heifers grazing brassica and grass paddocks.....	64
Table 2.3. Effect of stocking density and time on nutrient selection of ruminally cannulated heifers grazing brassica and grass paddocks.....	65
Table 2.4. Effect of stocking density on DMI and nutrient digestion of heifers grazing brassica and grass paddocks.....	66
Table 2.5. Effect of stocking density on N balance of heifers grazing brassica and grass paddocks.....	67
Table 2.6. Effect of stocking density on N balance of heifers grazing brassica and grass paddocks.....	68

ABSTRACT

EFFECT OF GRAZING PRESSURE ON CATTLE GRAZING COOL SEASON

ANNUAL FORAGES

BROOKE BRUNSVIG

2017

Ruminants can use plant fiber to produce food products that provide nourishment to humans. However, a precise understanding of specific plants selected by grazing ruminants remains elusive. Many long- and short-term factors impact cattle grazing behavior. Ultimately, grazing behavior can affect forage available for grazing, nutrient density of forage, dry matter intake, and animal performance. A myriad of grazing management strategies have been developed utilizing animal behavior to allow more efficient use of forage resources. Many management strategies based on manipulation of grazing behavior are simple and cost effective.

Optimal performance of individual animals and amount of animal products produced per unit of land are often the primary goal of many management strategies that manipulate grazing behavior in response to changes in grazing pressure. Under- and over-grazing are inefficient and can be detrimental to individual animal performance and efficiency of production from land resources. Integration of cropping systems and cattle production systems by use of crop biomass as a forage resource to cattle can allow greater efficiency of use of land resources. Historically, integrated crop and livestock systems were prevalent in the United States, but recent agricultural economies have incentivized segregation of crop and livestock production systems and have decreased

forage resources available for cattle. Similarly, cover crop planting has been a common agronomic practice to improve soil for nearly all of recorded history, but use of cover crops diminished in the United States during the latter half of the twentieth century. Nonetheless, interest in cover crops has renewed in the early twenty-first century. Cover crops can allow agronomic improvements during times tillable lands would be otherwise fallow, and cover crops may provide a good forage resource to cattle. However, greater knowledge of effects of common grazing management strategies on performance of cattle grazing cover crops are needed before large improvement in production of cattle grazing tillable land planted to cover crops can be realized. Increased production of cattle grazing cover crops could allow large improvement in efficiency of agricultural production systems and concomitantly allow greater efficiency in use of land resources.

CHAPTER 1:
LITERATURE REVIEW

INTRODUCTION

Cellulose is a carbohydrate that is the main component of plant cell walls (Van Soest, 1994), and accounts for over 50% of all organic carbon on Earth (Voet et al., 2013). Plants produce cellulose from carbon dioxide and sunlight by photosynthesis. Unfortunately, digestion of cellulose is limited in mammals because mammalian enzymes cannot degrade glycosidic bonds in cellulose and other plant structural carbohydrates. However, a large number of anaerobic bacteria and fungi can degrade glycosidic bonds found in plant cell fibers. The ruminant (e.g., giraffe, cattle, sheep, goats, deer, and elk) digestive tract has evolved a pregastric environment (reticulorumen, and omasum) that allows for proliferation of anaerobic microbiota. Concurrently, anaerobic microbes provide organic acids (e.g., acetic acid, propionic acid, butyric acid) and alcohols to ruminant species that allows ruminants to use plant fiber to meet physiological needs. Indeed, ruminants can capture up to all their energy needs from organic acids from ruminal fermentation of feed. Ultimately, the symbiosis between ruminants and fermentative anaerobes allow ruminants to utilize energy from sunlight via plant cellulose and to produce high quality animal protein for human consumption. Additional benefit from human food production from ruminants is that ruminants are not dependent upon the same food sources as humans. Nearly two-thirds of the land area on Earth is unsuitable for crop production, but can contribute to human food production via grazing animals. Further, increases in efficiency of grazing could allow for greater production of human food for the growing world population. However, feed acquisition by grazing ruminants is multifaceted and complex.

GRAZING BEHAVIOR

Activities involved in the acquisition of forage (i.e., grazing behavior) of cattle are dynamic. Grazing behavior has large impacts on diet nutrient density, digestibility, and performance of cattle. Thus, it is not surprising that for more than 300 years a large amount of effort by many researchers has focused on achieving a greater understanding of grazing behavior in cattle (Lamarck, 1809). Nonetheless, a precise understanding of grazing behavior remains equivocal and a myriad of factors (topography, plant characteristics, learned behavior, and physiological status) apparently affect long-term grazing behavior in cattle. Additionally, daily changes in bouts and duration of movement, rumination and rest in cattle are largely influenced by thirst, ambient temperature, energy balance, and time of day (Stafford-Smith, 1988).

Rumination (i.e., regurgitation, remastication, resalivation and redeglutition of feed) and herd behavior are protective strategies of cattle. Evolution of the ruminant stomach allowed ruminants to ingest and digest large quantities of food with a small risk of predation (Van Soest, 1994). In addition to mitigating risk of predation, rumination also aids in digestion of plant cell wall constituents. Physical form, differences in plant cell wall constituents, and plant maturity effect energy expenditure (Jaster and Murphy, 1983) associated with and time spent ruminating (Welch and Hooper, 1988).

Temperature and photoperiod (i.e., daily amounts of sunlight) influence cattle movement and rest (Ruckebusch, 1988), and differences in movement and sleep patterns can have large influences in grazing behavior. Generally, cattle graze mostly at morning

and twilight and spend between 5 and 12 hours per day eating depending on daily amount of light, rate of intake, cell wall content of feed and animal variations (Welch and Hooper, 1988). During times of cold stress dry matter intake (DMI) is increased and cattle graze for greater amounts of time daily (Ruckebusch, 1988) to meet increased maintenance energy requirements. Thermal impact is based on environment (e.g., air temp humidity, wind, solar radiation, water availability) and metabolic heat production associated with digestion and body movement. Generally, during times of heat stress cattle avoid great amounts of movement and more grazing occurs at night. Various technologies (e.g., sprinklers, shade) can mitigate heat stress in cattle (Kendall et al., 2007); however, in many grazing scenarios these technologies are not easily implemented. Thus, water availability is of great importance to mitigating heat stress in grazing cattle, and water availability often modifies grazing behavior (Kendall et al., 2007).

The most abundant nutrient in the body of cattle is water and limiting water is deleterious to health and performance (NRC, 2016). Body water facilitates homeorhesis in thermoregulation, systemic distribution of nutrients in vivo, nutrient metabolism, waste excretion, and nerve signaling. Water consumption increases with dry or salty feeds and higher ambient temperatures (Allen and Collins, 2003). Additionally, water requirements vary based on DMI, physiological status, and ambient temperature (NRC, 2016). Cattle rest and ruminate close to water sources between meal bouts (Sproul et al., 2008; Mantey and Peper, 2010). Therefore, it is not surprising that cattle graze a greater

amount of forage OM that is near water compared to forage OM more distant from water sources (Howery et al., 1996).

Differences in topography can affect growth and utilization of different plant species (Senft, 1987; Launchbaugh et al., 1990). Cattle typically graze valley bottoms and level land near water (Mueggler, 1965; Cook, 1966). When cattle travel more than 0.8 km in steep or rugged pastures or more than 1.6 km in smooth flat pastures (Valentine, 1963) grazing capacity decreases and land is not uniformly utilized (Valentine, 1947).

Additionally, cattle will generally avoid grazing slopes greater than 10% (Mueggler, 1965; Cook, 1966), but sensitivity to topography seems to vary by breed. For example, Tarentaise cows often utilize steep slopes, and Tarentaise and *Bos indicus*-influenced breeds (i.e., Santa Gertrudis and Piedmontese) will travel further from water in comparison to *Bos taurus* (e.g., Hereford, Black Angus) cows (Herbel and Nelson, 1996; Bailey et al., 2001; Rook et al., 2001; Van Wagoner et al., 2006). Breed differences to topography are likely related to regional differences in which breeds originated. Nonetheless, cattle generally stay in an area longer and return more frequently to areas of great nutrient density with large availability of preferred forages (Senft et al., 1987; Bailey et al., 1989; Bailey, 1995) in comparison to areas of poor forage quality.

Fossil remains of dinosaurs suggest herbivore feeding strategies (Van Soest, 1994) and pregastric fermentation (Farlow, 1987). Thus, it is likely that forage plants and grazing animals have coevolved for millions of years. Grazing pressure and predation of plants likely contributed to development of the ability of rapid regrowth in plants after part of the plant is removed (e.g., evolution of the meristem). Indeed, many plants that

have adopted strategies of rapid regrowth often store energy reserves where material removal is rare (e.g., roots, rhizomes; Van Soest, 1994). Alternatively, other plants have evolved characteristics that make the plant undesirable to eat (Briske, 2007), and plants that have developed traits to discourage grazing contain a variety of physical (e.g., spines, thorns) and chemical (e.g., alkaloids, tannins, glucosinolates, and nitrates) factors. Nonetheless, both plants and animals have coevolved mechanisms of defense and utilization respectively.

Alkaloids are a common defense mechanism in tall fescue and perennial ryegrass (Briske, 2007), but alkaloids often diminish over time. This unique evolutionary trait of some plants is a deterrent to grazing when plants are immature and allows seed to be produced (Van Soest, 1994). However, plants often benefit from grazing as a method of seed distribution, and diminishing alkaloid content allows grazing of senescent plants and subsequent seed dispersal. Cattle can often rapidly detect toxic secondary plant defensive compounds by post-ingestive feedback mechanisms (Provenza, 1995). Generally, cattle ingest small amounts of plants containing toxic compounds with an array of other plant species to reduce effects of the toxic substances (Freeland and Janzen, 1974) and to adapt to optimal amounts of intake (Provenza, 1995) Typically, cattle display a greater aversion to toxic compounds in plants that induce a greater severity of illness. Yet, avoidance of plants containing toxic compounds decreases with increased amounts of time between illness and when available forage resources are limited.

Young herbivores experience and learn about their environment and foraging skills from their dams and herd mates (Launchbaugh and Provenza 1991; Launchbaugh

and Howery, 2005). Lambs fed a diet containing toxins early in life selected a less diverse diet later in life compared to lambs not previously fed toxins. Conversely, young lambs fed a diverse diet selected a more diverse diet in comparison to lambs fed toxins (Catanese et al., 2012). Additionally, lambs fed specific plants with their dams selected the same plants without their dams (Nolte et al., 1990) indicating that grazing behavior is at least in part impacted by social interactions of ruminants.

Energy often first limits production in cattle and cattle eat to a common caloric endpoint when intake is not limited by bulk fill (Allen et al., 2009; NRC, 2016; NRC, 2001). However, in grazing scenarios, DMI is a function of quantities of available feed and nutrient demand (Coleman and Moore, 2003) and when nutrient density is small intake is limited by bulk fill. Chemostatic regulation of DMI in cattle occurs when cellular metabolism and production of ATP triggers chemical signals that elicit satiety (Allen et al., 2009). Indeed, hepatic oxidation of metabolites and generation of ATP appears to precisely describe short-term DMI in cattle (Allen et al., 2009). Similarly, Provenza (1995) suggested DMI in grazing cattle was controlled by post-ingestive feedback and concluded that ruminal fermentation products trigger cessation of intake. Provenza (1995) further explained that more nutrient dense feed elicits satiety at greater rates than feed with less nutrient density.

When ruminal fermentation of fibrous feeds is limited because ruminally degradable intake protein or nitrogen is insufficient, DMI is often regulated first by bulk fill before energy needs of cattle are met. Indeed, smaller nutrient density in forage often

reduces DMI because of fill, but greater intake of more digestible forage can increase intake until caloric requirements are met (Provenza, 1995). Plegge et al. (1984) concluded that DMI was limited by ruminal capacity when metabolizable energy (ME) content of feed was below $3.1 \text{ Mcal ME} \times \text{kg}^{-1} \text{ DM}$ and at greater ME chemostatic mechanisms controlled satiety. Conrad (1966) concluded that when DM digestibility exceeded 67% DMI was regulated by chemostatic mechanisms (Forbes, 1980; Ellis et al., 1984; Van Soest, 1994) and when DM digestion was below 67% bulk fill regulated DMI. Generally, slower ruminal passage rate associated with roughage consumption is responsible for decreased DMI, but roughage also increases rumination and ruminal retention time that facilitates greater digestion of feed. Ultimately, increased rumination and decreased DMI reduce time spent foraging.

Ideally, forages provide nutrients to support maintenance, growth, reproduction, or lactation. However, it seems likely that energy requirements can be altered by grazing, and nutrient needs are affected by physiological status. Intake, ruminal capacity, and grazing efficiency are all affected by changing physiological needs (Hodgson, 1977). Bell (1973) concluded that yearling cattle and nonlactating cows utilize pasture more evenly and utilize greater slopes (Bailey et al., 2001) than cow-calf pairs and lactating cows. Pregnancy can also increase time spent eating, but also slows the rate of intake compared to non-pregnant cattle (Welch and Hooper, 1988). Yet, physiological need for greater nutrient intake apparently cannot overcome limits of ruminal capacity of forage fed cattle. Hayirli et al. (2002) reported that NE intake for maintenance ($r^2 = 0.33$) and lactation ($r^2 = 0.05$) were poorly correlated to parity. Thus, young cows may not be able

to consume adequate amounts of forage and subsequently energy when pregnant or lactating.

Effects of both long-term (topography, plant characteristics, learned behavior, and physiological status) and short-term (thirst, ambient temperature, energy balance or hunger, and time of day have large effects on movement and rumination and rest) factors that influence grazing behavior are apparently consistent; however, a complete understanding of these complex and often interrelated factors that affect grazing behavior remains elusive. Knowledge of long- and short-term grazing behavior can allow various management strategies to augment use of forage resources. It seems reasonable that management strategies that allow consistent improvements in utilization of forage resources and require only modest inputs (e.g., cost, labor) are likely to be more broadly implemented. Manipulation of grazing pressure (stocking density, stocking rate, and herbage allowance) are among the easiest and most cost-effective management strategies to implement in most grazing systems.

GRAZING MANAGEMENT

Livestock managers have a myriad of tools available to manage grazing behavior (i.e., manipulation of grazing to realize specific objectives) of cattle (Allen et al., 2011). Placement of water, salt and mineral, and fencing are all effective strategies to influence grazing behavior and subsequently pasture utilization. Additionally, grazing behavior of cattle can be modified by changing grazing pressure or number of animal units. However, responses of cattle to changes in grazing pressure can be complex and no one method

guarantees cattle will graze an area as expected. Nonetheless, modifications in grazing pressure (stocking density, stocking rate, and herbage allowance) are among the easiest management tools to implement and do not require large initial investment costs.

The importance of water to grazing cattle allows water location to be used as a management strategy, and development of water sources can improve pasture utilization and reduce impacts of grazing on riparian areas (Valentine, 1947; Rigge et al., 2013). However, pasture utilization based on distance from water is less effective in pastures smaller than 1.6 km². In addition to water, placement of salt and mineral supplements can be used to encourage more uniform use of forage resources in pastures. Sproul et al. (2008) reported that cattle spend 40% of their time within 594 meters of self-fed supplements and that molasses based mineral supplements were effective in distributing grazing utilization by cattle (Sproul et al., 2008). However, placement of mineral supplements was less effective when grasses more adequately met mineral requirements and when mineral supplements were placed in apparently undesirable locations (Sproul et al., 2008). Nonetheless, others (Cook et al., 1966) reported that salt placement influenced cattle to climb slopes but there were less frequent visits to salt blocks on slopes versus flatter ground.

Stocking density is often defined as the number of animals or animal units per land area at a time. Alternatively, stocking rate is stocking density for a specific amount of time (e.g., one month) and can be changed by differences in animal units or time. Generally, the goal of stocking rate is to more appropriately match grazing pressure and

actual forage allowances. Altering stocking rate may greatly benefit forage availability and quality for cattle, but it is not possible or practical in all situations. Typically, stocking rate is often changed by altering amounts of time available for grazing rather than change number of animal units in a fixed amount of time (e.g., continuous, rotational, strip, deferred, intermittent). Dry matter intake and diet digestibility greatly affect production per animal (Blaser et al., 1959), but forage quantity and forage quality are not accounted for in stocking rate.

Herbage allowance or amount of forage biomass per animal BW is defined as an instantaneous measure (Allen, et al., 2011), but it is often expressed per unit of time (Sollenberger et al., 2005). In a grazing period, it can be difficult to measure biomass changes accurately in a vegetative state or account for trampling, plant decay, or animal intake. Indeed, when stocking rate is remains unchanged herbage allowance typically varies within a grazing period. Alternatively, the “put and take” management strategy is when herbage allowance is controlled by continually monitoring forage available for grazing and number of animals are changed. Blaser et al. (1981) reported that body weight (BW) gain in the grazing period did not differ when stocking rate was fixed but that when herbage allowance was controlled BW gain per ha was 61% greater because of apparent improvements in diet quality. Put and take management assures adequate forage quality and quantity is available through the entire grazing period, but can be a difficult strategy for producers to implement. Producers do not usually have reserve animals easily available to add animal density to a pasture, and continually buying and selling animals to change herbage allowance is impractical.

Overall, grazing pressure describes the relationship between need for forage resources by cattle and forage OM available for grazing within a pasture. Maximum animal production per acre of land is referred to as the carrying capacity of the area of land (Van Soest, 1994). It is important to note that maximum animal production and maximum forage production do not occur at the same grazing pressure. Mott (1960) described optimal grazing pressure as amounts of grazing pressure that could facilitate sustained forage production and efficient animal production. However, when grazing pressure does not ideally match forage resource then temporal incidences of either under- or over-grazing arise. Under-grazing occurs when grazing pressure has little effect on plant productivity and forage biomass largely exceeds forage needs of cattle. Under-grazing increases amounts of mature plants, and decreases forage digestibility contributing to reduced animal performance (Newman et al., 2002). Additionally, under-grazing allows for nearly unlimited species selection and can lead to less pasture species diversity (Pieper, 1994; Jones, 2000). Nutrient demand has large effects on DMI of cattle (Allen et al., 2009; Forbes and Gregorini, 2015) and chemical feedback mechanisms determine the amount of DMI of when intake is not limited by bulk fill. Indeed, cattle generally select the most nutrient dense forages available to meet metabolic nutrient demands (Belovsky, 1984; Pyke, 1984). However, when rates of digestion are small ruminal bulk fill can limit DMI and prevent adequate amounts of nutrient intake needed to optimize animal performance. Under-grazing can limit DMI by reducing rates of digestion and augmenting ruminal bulk fill. Over-grazing occurs when forage DM is reduced by the number of animals stocked faster than plant re-growth occurs. Typically,

when pastures are over-grazed plants are in a more immature stage of growth and concomitantly more digestible to cattle. However, over-grazing limits DMI and capriciousness in diet selection because competition between cattle for forage resources is large (Black and Kenney, 1984; Van Soest, 1994). Thus, over-grazing can limit intake and nutrient density of diets among grazing cattle because diet selection is reduced. Clearly, over-grazing and under-grazing pastures are detrimental to both land, future forage yields (West and Nelson, 2003), and animal production.

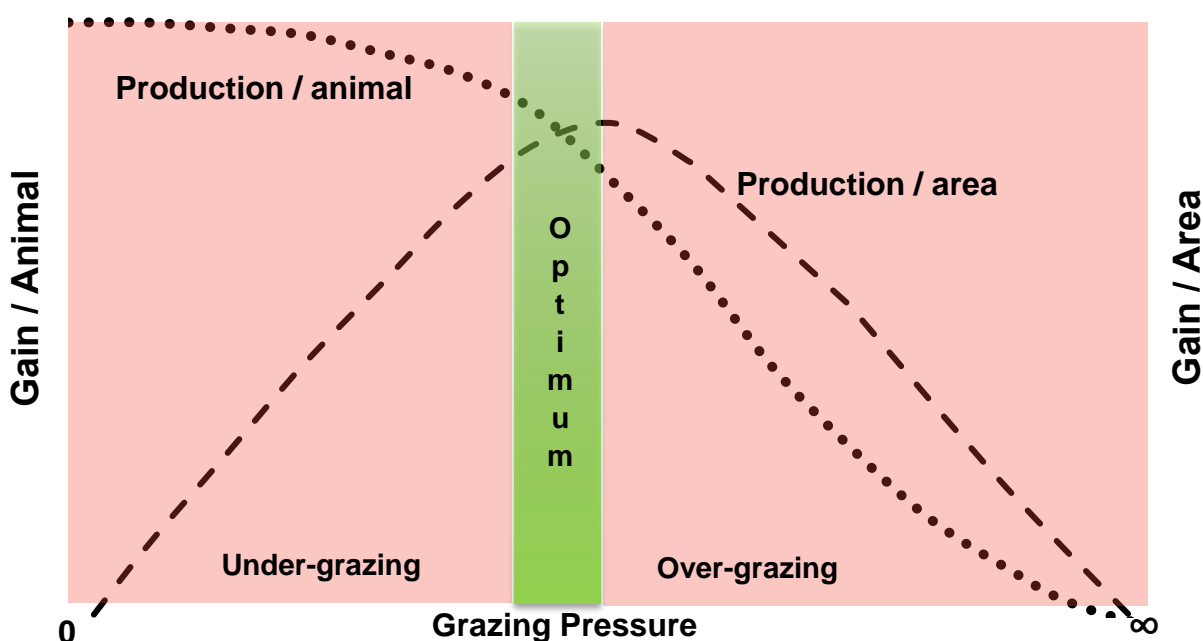


Figure 1.1. Relationship of animal production and land use efficiencies, adapted from Mott (1960).

efficiency of production per land area when pastures were optimally, under- or over-grazed (Figure 1.1; adapted from Mott, 1960). Mott reported that increased grazing pressure gradually reduces performance per animal presumably because diet quality decreases as cattle become less selective. Yet, increased animal pressure improves forage

utilization and therefore animal performance per area of land. The point at which DMI or forage availability becomes limiting results in drastic decreases in both performance per animal and performance per land area or land efficiency, and optimally grazing pressure was defined by Mott (1960) as the point at which performance per animal and production per land area intersect. Generally, modest amounts of under-grazing will result in improved individual animal performance, but production per land area is inefficient. Alternatively, over-grazing reduces available forage and DMI limits any individual animal production to an extent that also reduces efficiency in production per land area. Severe over-grazing may also limit future forage growth and biodiversity of plant species in pastures.

Clearly, many management strategies can be used to influence utilization of forage resources, and production goals may vary between different production systems. However, use of grazing management practices to allow cattle production in crop production systems could allow for even greater improvement in efficiency of use of land resources.

CHANGES IN AGRICULTURE

Farming of crops and livestock in the United States has been predominately integrated; however, production of crops and livestock has become increasingly segmented since World War II (Dimitri et al., 2005). More recent agricultural economies have incentivized even greater amounts of segregation in production of crops and livestock. Specifically, corn price increased by more than 359% from 2000 to 2012

(NASS, 2016), which contributed to a more than 80% increase in cropland value in the Northern plains (North Dakota, South Dakota, Nebraska and Kansas), concomitantly, pasture value increased more than 30% (USDA, 2012). Relative changes in land value incentivized farmers in the Western Corn Belt (North Dakota, South Dakota, Nebraska, Minnesota and Iowa) to convert more than 3.2 million ha of grassland into cropland for production of corn or soybeans between 2006 and 2011 (Wright and Wimberly, 2013). Further, little amounts of converted grasslands have returned to pasture despite reductions in grain prices and reduced values in cropland and grassland since 2011. These recent changes in land use have decreased available grasslands and have limited grazing opportunity.

Feed costs can account for up to half of all cow-calf production costs. Further, cow-calf production costs are greatest in the Northern plains (Short, 2001). Large cow-calf production costs in the Northern plains are likely related to relatively less available days for grazing in comparison to other regions in the United States. Pasture is often the least costly feed source to cattle, and allowing animals to graze forage can reduce production costs because harvested feeds and forages are costly. Because of labor, fuel, transportation, and storage facilities, the cost per Mcal of maintenance energy provided to the animal is larger than the cost to let the animal harvest forage. Thus, cost of cattle production is often increased when days available for grazing are limited. Biomass from cropland may be useful to increase available feed resources to cows (Anderson and Schatz, 2002). Annual forages planted after grain harvest may allow greater forage resources available in the Northern plains to extend the grazing season.

Planting annual forages, often referred to as cover crops, to fallow tillable land has received attention as a method to mitigate soil erosion and nitrogen loss, and increase nutrient cycling to soil (Lu, 2000). Tillable land area planted to cover crops has linearly increased in the United States in the past 10 years (SARE, 2016) to more than 4.1 million ha (USDA, 2014). A majority of the increase in planting cover crops has occurred in the upper Midwest where the most benefit could be realized because land can be left unproductive for up to 50% of the year and cow-calf production costs are greatest. Thus, grazing cover crops can allow for greater efficiency of land use by dual plant and animal production from the same land resources.

COVER CROPS

Cover crops were commonly used between crop rotations as a primary method of fertilizing and soil improvement since before the inception of the United States (Groff, 2015) and remained a common practice in agriculture until the mid-twentieth century (Ingles, 2017). Nonetheless, interest in cover crops was renewed in the late-twentieth century in response to a growing interest in sustainable agriculture practices.

Increases in cover crop use have also resulted from establishment of federal programs (e.g., Natural Resource Conservation Services environmental quality incentives program; NRCS, 2017) designed to incentivize environmental stewardship. Many plants have been categorized as cover crops (Figure 1.2; USDA-ARS, 2017)(Figure 1.2). Generally, cover crops can be separate to 6 categories: cool season grasses, warm season grasses, cool season broadleaves (non-legume), warm season broadleaves (non-legume),

cool season broadleaves (legume), and warm season broadleaves (legume). Most cover crops are annual species; however, cover crops also include biennial, and perennial plants. The wide variety of cover crops subsidized by federal programs allow for

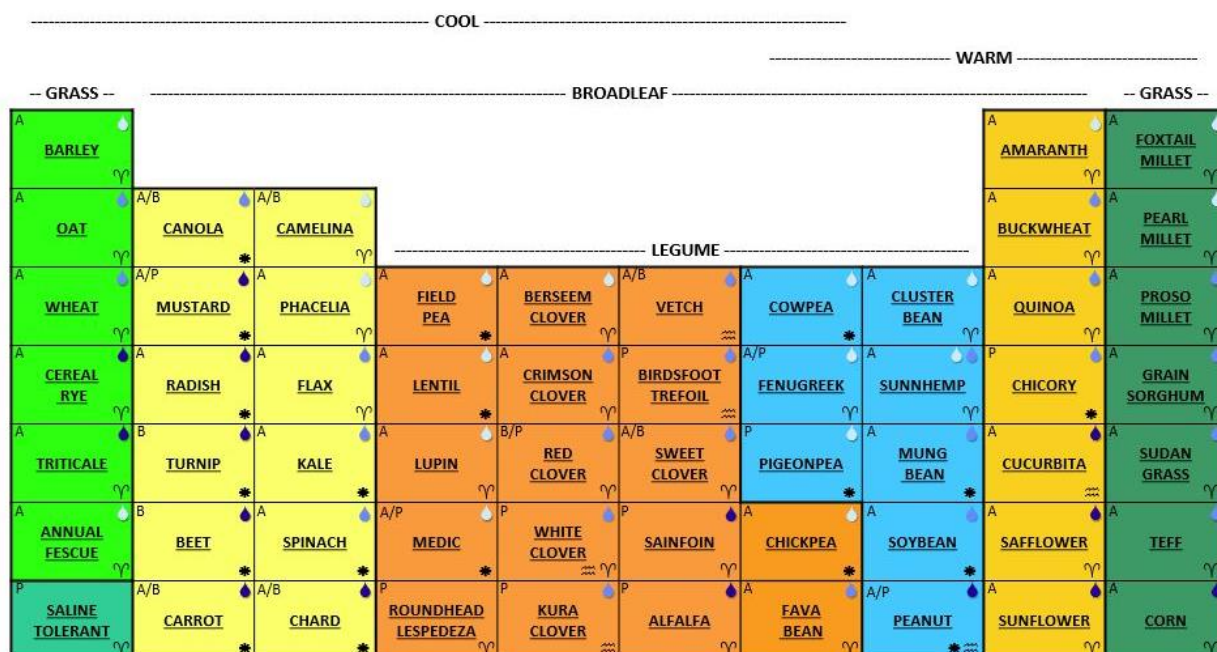


Figure 1.2. United States Department of Agriculture Agricultural Research Service cover crop chart. (USDA, 2017)

appropriate selection of plants able to grow in varying conditions. The amount of days available for plant growth varies among different regions of the United States. A recent annual report (SARE, 2016) on cover crop use in the United States indicated that cover crops were mostly planted for improvement of soil health and erosion and that cereal rye was the most frequently planted cover crop. Northern temperate climates utilize annual cool season cover crops with more rapid growth in comparison to cover crops typically planted in more southern climates. Apparently, turnips can be grazed 60-90 days after planting and in vitro DM digestibility of grazed cover crop mixtures can remain above

70% even as forages mature (Titlow et al., 2012). Additionally, brassica forages appear to be very nutritious to cattle (Underwood, 1992; Smart et al., 2004), and Underwood (1992) concluded that forage brassicas were a nutrient dense, fast growing crop with large amounts of CP and NE concentrations and small amounts of structural fiber.

Generally, cover crops produce appreciable amounts of forage OM and may allow large opportunity to increase forage resources available to cattle. However, a number of cover crop species contain or accumulate secondary compounds detrimental to cattle performance and health. Hairy vetch, flax, sorghum, millet and some sweet clovers can contain compounds poisonous to cattle. Many small grain grasses can also accumulate nitrates and legumes are commonly associated with bloat issues (Farney, 2016). Similarly, plants in the brassicaceae family can cause polioencephalomalacia, nitrate poisoning, and bloat.

Many brassica and grass cover crops can store nitrogen during times of physiological stress as nitrate (e.g., diminishing temperatures, drought; Belesky et al., 2007; Sun et al., 2012). Forages containing nitrates are potentially toxic to cattle and other ruminants not adapted to them (Emerick, 1988). Reduction of nitrate to nitrite can be toxic if large amounts of nitrite are ruminally absorbed. Nitrite is absorbed into the bloodstream and binds hemoglobin with greater affinity than oxygen to form methemoglobin when nitrite is not reduced to ammonia. Methemoglobin cannot carry oxygen and large amounts of methemoglobin contribute to hypoxia. Amounts of nitrate intake, liquid and particulate passage rate, and rates of ruminal nitrate reduction to

ammonia are factors in nitrate poisoning in cattle. However, ruminal capacity for nitrate reduction to ammonia (Farra and Satter, 1971; Allison and Reddy, 1984; Emerick, 1988; Van Soest, 1994; Leng, 2008) can be largely increased when nitrate is slowly introduced (Lee et al., 2015a; Lee et al., 2015b). Generally, reductions in diversity of plant species and increases in grazing pressure reduce selection of plant species among ruminants (Black and Kenney, 1984; Van Soest, 1994). Increased grazing pressure may encourage intake and therefore adaption to plant types with measurable nitrate levels when plants without toxic compounds are available to graze.

CONCLUSION

Grazing management strategies have been developed to increase pasture utilization by influencing short- (thirst, ambient temperature, energy balance or hunger, and time of day) and long-term (topography, plant characteristics, learned behavior, and physiological status) grazing behavior of cattle. Many management strategies are simple and cost effective to implement, whereas some are costly and labor intensive. Grazing pressure is a commonly used management tool, but under- and over-grazing are detrimental to both animals and land or forage resources. However, effects of grazing pressure on behavior are complex and not well defined.

Recent increases in amounts of tillable land planted to cover crops offer opportunity to increase forage resources to cattle. Yet, information on cattle grazing mixtures of cover crops is limited. Increased knowledge of management strategies among

cattle grazing cover crops can allow for greater integration of livestock and crop production systems that allow for improved use of land resources.

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CHAPTER 2:**Effect of stocking density on performance, diet selection, total-tract digestion and nitrogen balance among heifers grazing cool season annual forages¹**

B. R. Brunsvig*, A. J. Smart[†], E. A. Bailey[‡], C. L. Wright*, E. E. Grings*, and D. W. Brake*²

*Department of Animal Science, South Dakota State University

[†]Department of Natural Resource Management, South Dakota State University, Brookings 57007

[‡]Department of Agricultural Sciences, West Texas A&M University, Canyon 79015

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ABSTRACT

Grazing annual cool season forages after grain harvest may allow opportunity to increase efficient use of tillable land. However, data are limited regarding effects of stocking density on diet selection, nutrient digestion, performance and N retention among cattle grazing annual cool season forage. We allowed heifers blocked by initial BW (261 ± 11.7 kg) and randomly assigned to 1 of 12 paddocks (1.1-ha) to graze a mixture of grass and brassica for 48 d. Each paddock contained 3, 4, or 5 heifers to achieve 4 replicates of each stocking density treatment. Ruminally cannulated heifers allowed measures of diet and nutrient intake. Effects of stocking density on diet and nutrient selection were measured after 2, 24 and 46 days of grazing, and BW was measured at the beginning, middle and end of the experiment as the average of d 1 and 2, d 22 and 23, and d 47 and 48, respectively. Measures of DMI and DM, OM, NDF and ADF digestion were collected from d 18 to 23. Increased stocking density increased intake of brassica relative to grass after 24 d, but intake of brassica compared to grass was not different after 48 d (stocking density \times time, $P < 0.01$). Increased stocking density increased DM (quadratic, $P < 0.01$), OM (quadratic, $P = 0.01$) and NDF (quadratic, $P = 0.05$) digestion, and stocking density tended to increase DMI (quadratic, $P = 0.07$). Additionally, increased stocking density quadratically increased ($P = 0.05$) N retention, but did not affect overall BW gains. Increased stocking density did, however, contribute to small linear decreases ($P = 0.05$) in BW gain after 22 d of grazing, but BW gains during the latter half of this study (i.e., d 22 to 48) were nearly 6.7-times greater compared to BW gains after 22 d. Ruminal concentration of acetate:propionate was least after 24 d of grazing and ruminal nitrate concentration tended to decrease linearly ($P = 0.06$) with

greater amounts of time. Ruminal liquid and particulate fill and amounts of VFA were less with greater amounts of time. Apparently, binary mixtures of brassica and grass planted after grain harvest can provide opportunity to increase efficient use of land and forage resources. Increased stocking density may facilitate a more rapid adaptation to and intake of brassica among cattle grazing brassica-grass based pastures.

Key Words: Brassica, Cattle, Digestion, Nitrogen retention, Performance

INTRODUCTION

Planting annual cool season forages after grain harvest provides opportunity to enhance nutrient cycling to soil and mitigate erosion and loss of soil nutrients in tillable land (Sulc et al., 2007). Thus, it is not surprising that land planted to annual cool season forages after grain harvest has linearly increased (SARE, 2016) to more than 4,100,000 hectares in the United States (USDA, 2014). Grazing annual cool season forages (e.g., brassicas, grass) planted after grain harvest may allow concurrent increases in efficiency of land use and forages available to grazing cattle. Many brassicas planted to tillable land allow for appreciable amounts of forage OM that contain large concentrations of ME and non-structural carbohydrates in comparison to grasses (Barry, 2013). However, brassicas can accumulate secondary plant defensive compounds (e.g., nitrates) that can be deleterious to grazing cattle (Belesky et al., 2007; Sun et al., 2012). Currently, only limited data are available regarding cattle grazing annual cool season forages planted after grain harvest. Grazing pressure (e.g., stocking rate, stocking density, forage allowance) has large effects on diet digestion, forage selection, and cattle performance (Van Soest, 1994). Indeed, a myriad of factors (Launchbaugh and Provenza, 1991; Provenza, 1995; Provenza, 1996; Catanese et al., 2012) can affect forage selection among grazing cattle, and cattle often avoid intake of plants that contain secondary compounds that diminish performance or health (Freeland and Janzen, 1974). Mott (1960) proposed that an ideal amount of grazing pressure would allow optimal animal performance and forage utilization. Amounts of grazing pressure that optimize animal performance and forage utilization often affect diet selection and grazing behavior among cattle. Therefore, our objective was to evaluate effects of stocking density on diet, nutrient

selection, nutrient digestion, N balance and performance among cattle grazing a mixture of brassica and grass.

MATERIALS AND METHODS

All protocols involving the use of animals were approved by the South Dakota State University Institutional Animal Care and Use Committee.

Animals

Fourteen Angus (initial BW = 267 ± 21.4 kg) and 25 Angus \times Simmental heifers (initial BW = 281 ± 21.0 kg) were blocked by initial BW and randomly allocated to 1 of 3 stocking density treatments. An additional 5 Angus (initial BW = 223 ± 51.4 kg) and 5 Angus \times Simmental (initial BW = 234 ± 37.7 kg) heifers were surgically fitted with ruminal cannulas to allow measures of diet selection and ruminal parameters. Heifers were vaccinated against clostridial bacterin-toxoids (Calvary 9; Merck Animal Health, Madison, NJ) 19 d prior to and at cannulation. Heifers were also vaccinated against infectious bovine rhinotracheitis, bovine viral diarrhea and bovine respiratory syncytial virus (Bovi-Shield; Zoetis Animal Health, Parsippany, NJ) and papilloma (Wart Shield; Novartis Animal Vaccines, Inc., Larchwood, IA) at 19 d prior to cannulation. Ruminal fistulation surgeries were performed 33 d prior to grazing via a modified one-stage procedure (Kristensen et al., 2010) with cattle standing. Cattle were locally anesthetized (lidocaine-HCl) at the left-flank and provided intravenous analgesia (2.2 mg/kg BW of flunixin meglumine; Banamine; Merck Animal Health) and prophylactic antibiotics by subcutaneous injection at the base of the ear (6.6 mg/kg ceftiofur; Exceed; Zoetis Animal

Health) and intramuscularly (20,000 units/kg penicillin; Bactracillin G; Aspen Veterinary Resources, LTD, Greeley, CO) immediately prior to surgery. Subsequently, heifers were provided intravenous analgesia and intramuscular antibiotic daily after cannulation for 3 and 6 d, respectively. If local inflammation was observed at the surgical site or if rectal temperature was greater than 40 °C for more than 3 d following cannulation then analgesia was provided for 5 d. Immediately after surgery, calves were returned to pasture and recovered with their dams for 11 d followed by weaning via fence line separation. Once daily for 14 d following cannulation the surgical site was cleaned with an iodine scrub (7.5% Providine; Purdue Products, Stamford, CT) and monitored for inflammation; rectal temperature was measured as an indicator of infection. Heifers were treated with an anthelmintic (LongRange; Merial Limited, Duluth, GA) 4 d post-surgery. After 14 d, no local inflammation was observed at the surgical site and rectal temperatures were 38 ± 0.26 °C. After recovery, cannulated heifers were randomly assigned to stocking density treatments.

Grazing Experiment

The study was conducted 1.5 km north of Brookings, SD (44°20'22.21"N, 96°48'7.84"W). After oat harvest and removal of oat residue by baling, a binary mixture of grass and Brassicaceae (mustard family; here after referred to as brassica) was planted 6 days after an application of glyphosate. The seed mixture consisted of 66.5% *Lolium perenne* L., 20% *Raphanus sativus* L. and 13.5% *Brassica rapa* L. and was seeded at a rate of $16.6 \text{ kg} \times \text{ha}^{-1}$ on July 28, 2015. Subsequently, the field was fenced into 12 paddocks for grazing.

Different stocking densities were achieved by assigning 3, 4 or 5 heifers to 1 of 12 paddocks (1.1-ha) and allowing cattle to graze for 48-d to obtain a stocking rate of 1.7-, 2.3- and 2.9-AUM \times ha⁻¹, respectively. Heifers were allowed to graze their paddocks beginning October 14, 2015 and remained until November 30, 2015. In 9 of the 12 paddocks 1 ruminally cannulated heifer was included to allow measures of diet selection and nutrient intake. Before the trial initiated, heifers grazed a pasture that consisted of smooth brome (*Bromus inermis* Leyss. *subsp. inermis*), creeping foxtail (*Alopecurus arundinaceus* Poir.), and big bluestem (*Andropogon gerardi* Vitman).

Forage biomass was sampled 11 d prior to grazing by clipping 30 quadrats (0.25 m²) stratified across the field prior to assignment of the 3 stocking density treatments and 4 replicate paddocks. Clippings were dried for 14 days in a forced air oven (60 °C). After drying, samples were separated into either forage from brassica or grass and composited by paddock. Subsequently, forage composition was determined gravimetrically, and chemical composition (OM, N, NDF, ADF, acid detergent insoluble ash, nitrate-N and nitrite-N) was analyzed.

Sampling Procedures and Laboratory Analyses

Heifer BW was recorded for 2 consecutive days beginning on d 1, 21, and 47. Diet samples were collected by total ruminal evacuation (Reid, 1965) on d 2, 24 and 46. Ruminal contents of cannulated heifers were totally evacuated, weighed and subsampled for determination of ruminal liquid and DM fill (Froetschel and Amos, 1991) and analyses of DM, VFA, ammonia, nitrate-N and nitrite-N concentration. Subsequently, heifers were returned to the appropriate paddock and allowed to graze for 45 min. After

45 min., ruminal contents were removed, weighed, and sampled for analysis of DM, OM, NDF, ADF, N, acid detergent insoluble ash (ADIA) and starch. Ruminal contents removed prior to diet sampling were replaced before heifers were allowed to return to paddocks.

Nitrogen balance was measured from d 18 to 23. Spot fecal samples were collected from d 9 to 14 for determination of background TiO_2 . At 0800 from d 18 to 23, a bolus of TiO_2 was administered for estimation of fecal output (Titgemeyer et al., 2001). Urine (70 g) and feces (50 g) were collected and each was composited daily from d 18 to 23 by spot sampling. Urine was acidified with 5.5 mL H_2SO_4 (10% wt/wt) before it was composited. All samples were frozen at -20°C . Time of spot sampling was delayed by 2 h daily so that composites reflected every other hour in a 12 h period. Feces was analyzed for DM, OM, NDF, ADF, ADIA, N and TiO_2 concentration. Urine was analyzed for creatinine, and N. Dry matter intake and DM digestion were estimated from measures of fecal output, and concentration of dietary and fecal ADIA.

Partial DM of diet samples, ruminal digesta and feces was determined by drying in a forced air oven (55°C) for 24 h, and samples were allowed to air equilibrate prior to weighing. After measures of partial DM samples were ground to pass a 1 mm screen (Thomas Wiley Laboratory Mill Model 4; Thomas Scientific USA, Swedesboro, NJ). Measures of DM were determined by drying for 16 h at 105°C . Organic matter was determined by combustion (500°C). Neutral detergent fiber was measured with addition of α -amylase and sodium sulfite; ADF was measured non-sequential to NDF (Van Soest et al., 1991). Acid detergent insoluble ash was determined by combustion subsequent to determination of ADF. Diet, fecal and urinary N was determined by the Dumas procedure

(method no. 968.06; AOAC, 2012; Rapid N III; Elementar, Mt. Laurel, NJ). Urinary creatinine was measured colorimetrically (DetectX; Arbor Assays, Ann Arbor, MI) by the modified Jaffe reaction described by Slot (1965) and Heinegard and Tederstrom (1973). Ruminal ammonia was analyzed with a colorimetric reaction catalyzed by phenol-hypochlorite (Broderick and Kang, 1980). Titanium dioxide in feces was measured as described by Short et al. (1996). Starch in diet and forage samples was determined using the glucogenic assay described by Herrera-Saldana and Huber (1989); glucose was quantified by glucose oxidase (Gochman and Schmitz, 1972), and unpolymerized glucose was determined when no α -amylase was added. Ruminal VFAs were determined by gas chromatography as described by Vanzant and Cochran (1994).

Calculations

Dry matter was calculated as partial DM (55 °C) multiplied by DM measured after drying at 105 °C. Fecal output was calculated as the quotient of amount of TiO₂ bolused daily by TiO₂ concentration in feces corrected for amount of TiO₂ in feces prior to administering TiO₂ (Titgemeyer et al., 2001). Daily creatinine output was assumed to be 28 mg/kg of BW (Chizzotti et al., 2008). Urine output was estimated to be the quotient of creatinine output and urinary creatinine concentration. Urinary N output was calculated as the product of urine output and urine N concentration. Fecal excretion of N, OM, NDF, ADF and ADIA were calculated by multiplying daily fecal output by fecal concentration of N, OM, NDF, ADF, and ADIA, respectively. Dry matter intake was calculated as described by Merchen (1988):

$$\text{DM intake} = \text{fecal output} \times \frac{100}{\% \text{ indigestibility of DM}}$$

Intake of OM, NDF, and ADF was calculated as the product of DMI and OM, NDF, ADF in the diet sample collected at d 24, and N intake was calculated as the product of DMI and N intake from forage. Proportional intake of brassica and grass were calculated from NDF content in diet samples and NDF content in each forage. Subsequently, intake of each forage was determined as the product of proportional intake of brassica and grass and DMI. Forage N intake was the summed product of predicted brassica and grass intake and brassica and grass N content, respectively. Nutrient digestion was calculated as the difference of intake and fecal output. Nitrogen balance was calculated as the difference of N intake and N output from urine and feces. Ruminant DM fill was calculated as the product of the weight of wet ruminal contents and DM content. Ruminant liquid fill was calculated by difference between the weight of wet ruminal contents and DM fill.

Statistical Analysis

On d 24 one of the cannulated heifers was injured and replaced with another cannulated heifer which was used for the final ruminal evacuation on d 46. Additionally, data from a cannulated heifer grazing in an intermediate stocking density paddock and a non-cannulated heifer grazing in paddock with the least stocking density were removed from calculations of pen means for digestibility analyses because of an apparent marker failure. Data were analyzed with the MIXED procedures of SAS 9.3 (SAS Inst. Inc., Cary, NC). Measures of nutrient digestion and performance were analyzed as a completely randomized block design and paddock was the experimental unit. Stocking density was a fixed effect and block was a random variable. Differences between

stocking density were determined by linear and quadratic contrasts. Measures of diet selection and ruminal parameters were analyzed as repeated measures. Paddock was the experimental unit, and the model contained stocking density with block as the random term. The repeated term was day, with paddock serving as the subject. Compound symmetry was used for the covariance structure. Effects of stocking density and day were determined with linear and quadratic contrasts. When effects of stocking density \times day was significant ($P \leq 0.05$) differences of stocking density within day were separated by linear and quadratic contrasts.

RESULTS AND DISCUSSION

Climate

Temperature and precipitation data were obtained from a weather station located 3 km southeast of the grazing site. Average temperature during the grazing period was 5.1 ± 0.86 °C, and wind speeds averaged 11.8 ± 1.1 km \times h⁻¹. Additionally, rain events occurred on 6 days (11 ± 3.4 mm/d) and total precipitation was 66 mm. It is likely that little OM growth of brassica and grass occurred after heifers grazed paddocks due to cold temperatures and diminishing photoperiod.

Forage Intake

Paddocks consisted of a binary mixture of brassica and grass that contained $26.5 \pm 1.9\%$ and $60.8 \pm 1.2\%$ NDF, respectively. We estimated relative intake of brassica to grass from NDF content of masticate that was ruminally collected during measures of diet sampling and observed an interaction ($P < 0.01$) among stocking density and amount

of time heifers grazed on estimates of diet selection. As expected, we observed no difference ($P \geq 0.68$) in estimates of relative intake of brassica to grass after 2 d of grazing, but increased stocking density increased (quadratic, $P = 0.02$) brassica intake after 24 d of grazing. Interestingly, increased stocking density decreased (linear, $P < 0.01$) relative intake of brassica to grass after 46 d of grazing (Figure 1).

A precise understanding of how plant material is selected by grazing cattle remains equivocal; however, grazing pressure (Van Soest, 1994), previous grazing experience (Launchbaugh and Provenza, 1991), bulk-fill and chemostatic feedback mechanisms (Allen et al., 2009), and plant flavonoids (Provenza, 1995, 1996) can affect forage selection. Importantly, however, ruminants often avoid selection of plants with toxins that can reduce performance or digestion (Provenza, 1996; Catanese et al. 2012). In our experiment, cattle grazed greater amounts of grass at d 2 compared to d 24. Grass contained no nitrate, but brassica contained $0.16 \pm 0.03\%$ nitrate-N (Table 1). Forages containing nitrates are potentially toxic to cattle that are not adapted to nitrates (Emerick, 1988). Amount of nitrate intake, liquid and particulate passage rate, and rates of ruminal nitrate reduction to ammonia can effect nitrate poisoning in cattle. Ostensibly, ruminal capacity for nitrate reduction to ammonia can quickly adapt to large amounts of nitrate intake (Farra and Satter, 1971; Allison and Reddy, 1984; Emerick, 1988; Van Soest, 1994; Leng, 2008). Small daily amounts of nitrate intake can augment ruminal capacity for nitrate reduction to ammonia (Lee et al., 2015a; Lee et al., 2015b). Perhaps after only 2 d of grazing, heifers foraged mostly grass because of previous grazing experience, and larger amounts of nitrate in brassica. Generally, reductions in diversity of plant species and increases in grazing pressure reduce selection of plant species among ruminants

(Black and Kenney, 1984; Van Soest, 1994). Indeed, brassica intake was greater among heifers grazing pastures at greater stocking density after 24 d. It is possible that increased grazing pressure allowed for incremental increases in intake of brassica and concomitantly increased nitrate intake. If stocking densities in our study allowed for small daily increases in brassica and nitrate intake it is likely that ruminal nitrate reductive capacity of heifers was increased. Ruminal nitrate concentration tended to decrease (linear, $P = 0.06$; Table 2) even though estimates of brassica intake increased. Greater ruminal reductive capacity of nitrate could allow greater intake of brassica. Typically, cattle select plants with greater nutrient density, but increased grazing pressure decreases diet quality because selection is reduced (Cook et al., 1953; Pieper et al., 1959; Bryant et al., 1970; Ellis et al., 1984). Data are limited on digestibility of brassicas among cattle; however, several authors (Nicol and Barry, 1980; Sun et al., 2012) have reported that, in sheep, forage from brassica had greater total-tract digestion in comparison to grass. Thus, increased grazing pressure may have facilitated increased intake of the more nutrient dense brassica after less amount of time spent grazing. Heifers in paddocks with the least amount of stocking density had the greatest intake of brassica relative to grass after 46 d of grazing. It is possible that heifers housed in paddocks with greater intake of brassica nearer to the beginning our study had less amounts of forage OM available from brassica at the end of the study because of greater brassica intake earlier in the experiment and greater amounts of trampling.

Ruminal Parameters

Increased ruminal reduction of nitrate has been associated with increased acetic acid concentration and decreased concentration of propionic acid (Farra and Satter, 1971; Klop et al., 2015; Olijhoek et al., 2016) and methane (Johnson and Johnson, 1995). Ruminal nitrate concentration ($\mu\text{mol/L}$) and amount (μmol) tended to decrease (linear, $P = 0.06$; Table 2.) as heifers grazed brassica and grass for greater amounts of time. Total ruminal liquid ($P < 0.01$) and DM ($P < 0.01$) fill, and VFA concentration ($P < 0.01$) and amount ($P < 0.01$) decreased with greater amounts of time. Interestingly, acetic acid concentration was least and propionic acid concentration was greatest after 24 d, but concentration of acetic and propionic acid was similar to amounts observed at the beginning of the study after 46 d. Similarly, Sun et al. (2012) reported reduced concentrations of acetic acid relative to propionic acid among sheep fed brassica than when sheep were fed perennial ryegrass. Phillips and Horn (2008) reported that ruminal liquid and particulate fill decrease when cattle transition to diets with greater nutrient density. It is likely that ruminal concentration and amounts of fermentative end products and ammonia measured at the beginning of our study (d 2) were reflective of the common mixed grass pasture that heifers grazed before grazing brassica and grass. However, differences in concentration and amount of ruminal end products was also likely reflective of greater selection of grass relative to brassica at the beginning our study. Increased intake of brassica could have depressed activity of ruminal fibrolytic bacteria (Marais et al., 1988). Additionally, brassica contained less NDF than grass (Table 1), and generally brassica contains larger amounts of more rapidly fermentable carbohydrate (e.g., soluble sugars, pectins) relative to amounts of structural carbohydrate (i.e., cellulose and hemicellulose; Barry, 2013). Ruminal starch content was also greatest at d 24

(quadratic, $P < 0.01$). Greater fermentation of more rapidly fermentable carbohydrate is often associated with increased ruminal concentration of propionic acid and decreased ruminal concentration of acetic acid (Owens and Goetsch, 1988; van Gastelen et al., 2015; NRC, 2016).

Nutrient intake, total-tract digestion and DMI

Overall, diet OM ($82.6 \pm 1.5\%$), NDF ($42.2 \pm 1.7\%$), ADF ($33.5 \pm 0.51\%$) and ADIA ($4.9 \pm 0.51\%$) content was not affected by stocking density ($P \geq 0.25$; Table 3). However, diet OM was greatest and NDF and ADIA content were least after 24 d of grazing (quadratic, $P \leq 0.01$). Diet ADF content ($33.5 \pm 0.6\%$) was not affected by amounts of time that heifers grazed. Even though we did not observe any differences among stocking density at different amounts of time, diet selection for OM was numerically greatest among heifers grazing paddocks with greater amounts of stocking density (84.5% OM) and numerically least (82.9% OM) among heifers grazing paddocks with lesser stocking density after 24 d. Diet NDF and ADIA were numerically least among heifers in paddocks with greater amounts of stocking density (34.5% NDF; 2.8% ADIA) compared to heifers in paddocks with lesser stocking density (37.5% NDF; 4.2% ADIA) after 24 d. These data correspond with differences in estimates of relative intake of brassica and grass and to effects of stocking rate and time among ruminal measures. Further, measures of DM digestibility obtained from 18 to 23 d of grazing were greatest (quadratic, $P < 0.01$) and digestion of OM, NDF and ADF tended (quadratic, $P \leq 0.09$) to be greatest among heifers in paddocks with increased stocking density (Table 4).

Several authors have reported that brassica DM digestibility in sheep (Nicol and Barry, 1980; Sun et al., 2012) and OM digestibility in cattle (Clark et al., 1997) is greater in comparison to DM and OM digestion of grass. Nicol and Barry (1980) and Sun et al. (2012) reported DM digestibility of forage turnips among sheep was 89.3% and 80.8%, respectively. Typically, ryegrass DM digestibility ranges between 65% and 80% (Ellis et al., 1984; Sun et al., 2012), and increases in grazing pressure often decrease diet nutrient density and *in vitro* OM digestibility (Cook et al., 1953; Blaser et al., 1959, 1960).

Relatively few authors have reported measures of total-tract diet digestibility among grazing cattle in response to increased grazing pressure. Ellis et al. (1984) reported that increased grazing pressure among cattle grazing ryegrass reduced total-tract DM digestion. Similarly, Olson et al. (2002) reported that increased stocking density reduced total-tract OM digestibility among steers grazing short-grass prairie. We are unaware of any reports of effects of increased grazing pressure on total-tract digestion among cattle grazing brassicas and annual ryegrass. We observed increased digestibility in response to greater stocking density that was also concurrent with a greater proportional intake of brassica. Cattle often select familiar plants and avoid plants containing toxic secondary compounds (Launchbaugh and Provenza, 1991; Provenza, 1995; Provenza, 1996; Catanese et al., 2012). Increased stocking density in our study may have facilitated more rapid adaptation to and greater intake of brassica despite a lack of previous grazing experience among cattle and measurable amounts of nitrate in brassica.

Greater amounts of readily fermentable carbohydrate allow for increased rates of ruminal degradation, passage rate and subsequently DMI. Additionally, increases in diet digestibility allow greater DMI when DMI is limited by ruminal fill (Ellis et al., 1984;

Redmon et al., 1995). Brassica has less structural carbohydrate and greater apparent digestibility (Sun et al., 2012) than grass. Increased stocking density tended to increase (quadratic, $P = 0.07$; Table 4) DMI in our study. It is likely that greater proportional intake of brassica allowed for increased DMI compared to heifers that had a greater proportion of intake that was grass. When ruminal fill is not limiting chemostatic mechanisms control DMI (Allen et al., 2009) and cattle consume food to a constant energy end-point (Lofgren and Garrett, 1968; NRC, 2016). Brassica has nearly 41% more ME (3.1 Mcal ME/kg DM) compared to ryegrass (2.2 Mcal ME/kg DM; Sun et al., 2012; Lindsay et al., 2007). Plegge et al. (1984) concluded that DMI was maximized and likely regulated by chemostatic mechanisms when diet ME was near to $3.1 \text{ Mcal ME} \times \text{kg}^{-1} \text{ DM}$. If increased grazing pressure increased brassica intake it seems likely that heifers were able to more nearly meet predicted amounts of ME intake. Our estimates of proportional brassica and grass intake together with measures of DMI and apparent ME of brassica and grass indicate that ME intake among heifers in paddocks with the least stocking density was limited to 83% of predicted ME intake (NRC, 2016); however, increased grazing pressure resulted in estimates of ME intake nearly 24% greater than predicted ME intake (NRC, 2016).

Nitrogen Retention and Performance

There is a paucity of data related to effects of increased stocking density on measures of N retention, and we are not aware of any reports related to effects of increased stocking density on N retention among cattle grazing brassica and grass-based pastures. Increased stocking density did not affect N intake, or N excreted in urine or

feces ($P \geq 0.13$; Table 5). However, numerical differences in amounts of N intake and N excreted contributed to increased estimates of N retention in response to increased stocking density (quadratic, $P = 0.05$). Generally, measures of N retention are sensitive to greater lean tissue accretion; however, we did not observe an effect of increased stocking density on changes in BW (Table 6). Typically, increased stocking density decreases performance (Petersen et al., 1965; Bryant et al., 1970; Smart et al., 2010). We observed small, but statistically significant decreases (linear, $P = 0.05$) in performance in response to increased stocking density after 22 d, and BW gains were not different from 22 to 48 d of grazing. It is interesting, however, that even though we observed no difference in BW gains during the latter half of our experiment amounts of BW gain were nearly 6.7-times greater than amounts of BW gain from d 1 to 22. Typically, energy first-limits BW gains in cattle of similar size to the heifers in our study (Lofgren and Garrett, 1968; NRC, 2016), and several authors have reported that energy content of brassica exceeds energy content of ryegrass (Barry et al., 1994; Lindsay et al., 2007; Sun et al., 2012). Therefore, increased intake of brassica could allow for greater rates of BW gain. However, reports of BW gains among ruminants grazing brassica relative to grass-based pastures have differed. Campbell et al. (2011) reported that BW gains among sheep grazing brassica were nearly 14% less in comparison to sheep that grazed a grass and clover based pasture. Alternatively, Lindsay et al. (2007) observed a more than 38% increase in BW gains when sheep grazed brassica compared to grass. Phillips and Horn (2008) reported that calves required 7 to 14 d to adapt to wheat pastures before performance was increased. Data are limited on performance of cattle grazing brassica based pastures; however, Barry et al. (1981) reported that, even when mineral deficiencies do not limit

gain, BW gains were 27% less among cattle grazing brassica monocultures compared to cattle grazing grass during the first 42 d of grazing. Nonetheless, these authors (Barry et al., 1981) observed a 17% greater ADG compared to grass after cattle were allowed to graze brassica for greater amounts of time (i.e., 42 to 168 days of grazing). We observed increases in BW that were nearly twice the rates of gain reported by Barry et al. (1981) among cattle adapted to brassica monocultures. Many factors (e.g., BW, breed, sex, age, and grazing pressure) could have led to differences between our measures of BW gains and those reported by Barry et al. (1981); however, increases in stocking density in our study may have allowed for a more rapid adaptation to brassica and subsequently larger BW gains compared to those observed by Barry et al. (1981).

Growing cattle often experience compensatory gains in BW when realimented from diets that limit growth to diets that allows optimal rates of BW gain (Fox and Black, 1984; Choat et al., 2003; NRC, 2016). Santra and Pathak (1999) reported greater N retention in cattle during periods of compensatory growth. Perhaps increased grazing pressure allowed for more rapid increases in diet nutrient density by greater proportional intake of brassica, and subsequently, cattle grazing paddocks with increased stocking density realized increases in N retention nearer to the beginning of our experiment compared to cattle housed in paddocks with lesser stocking density. Yet, apparent linear increases in proportional brassica intake among heifers grazing paddocks with the least amount of stocking density could have facilitated similar compensatory gains after our measures of N balance and obviated differences in BW gain.

CONCLUSION

Brassica-grass mixtures planted after grain harvest appears to provide opportunity to increase forage resources available to cattle and to increase efficient use of land resources. Increased intake of brassica may allow greater DMI, and N retention; however, it is likely that cattle require adaptation before benefits from greater brassica intake can be realized. Increased stocking density may be a useful tool to producers to facilitate a more rapid adaptation to and intake of brassica among cattle grazing brassica-grass based pastures.

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Table 2.1. Available aboveground forage biomass and chemical composition (DM basis) of grass and brassica (mean \pm SEM)

Item	Grass	Brassica
Seeding Rate, $\text{kg} \times \text{ha}^{-1}$	11.0	5.6
Biomass ¹ , $\text{kg} \times \text{ha}^{-1}$	1223.5 \pm 393.4	4158.5 \pm 600.8
Chemical composition, %		
DM		
OM	83.4 \pm 1.7	81.3 \pm 2.0
N	1.7 \pm 0.11	2.7 \pm 0.21
NDF	60.8 \pm 1.2	26.5 \pm 1.9
ADF	61.4 \pm 1.3	27.8 \pm 1.1
ADIA ²	9.3 \pm 2.0	2.4 \pm 1.3
NO ₃ -N	ND ³	0.16 \pm 0.03
NO ₂ -N	ND ³	0.03 \pm 0.02

¹Measured 11 d prior to grazing.

²Acid detergent insoluble ash.

³Not detected.

Table 2.2. Effect of stocking density and time on ruminal parameters of cannulated heifers grazing brassica and grass paddocks

Item	Stocking density ¹			Day			Stocking density		Day		Stocking density × Day
	3	4	5	2	24	46	Linear	Quadratic	Linear	Quadratic	
pH	6.4	6.3	6.3	6.2	6.1	6.7	0.94	0.99	0.06	0.16	0.60
Liquid fill	24.6	25.3	27.9	30.5	22.0	25.3	0.34	0.73	<0.01	<0.01	0.24
Particulate fill	2.9	2.7	3.4	4.2	2.2	2.6	0.29	0.29	<0.01	<0.01	0.47
Starch, % DM	3.9	3.9	4.0	3.2	6.0	2.7	0.99	0.97	0.53	<0.01	0.51
Total VFA, mM	94.7	86.7	95.4	123.4	77.2	76.2	0.95	0.44	<0.01	<0.01	0.44
Acetate:propionate	4.6	4.3	4.4	4.5	3.6	5.1	0.24	0.39	0.07	<0.01	0.36
	mol/100 mol										
Acetate	67.8	66.9	67.3	69.1	62.8	70.1	0.54	0.39	0.39	<0.01	0.63
Propionate	15.1	16.0	15.7	15.4	17.7	13.8	0.27	0.30	0.09	<0.01	0.30
Butyrate	13.3	13.5	13.2	12.0	15.9	12.1	0.80	0.72	0.82	<0.01	0.41
Isobutyrate	0.37	0.36	0.35	0.34	0.34	0.40	0.52	0.93	0.04	0.34	0.61
Valerate	1.8	1.8	1.9	1.6	2.0	1.9	0.29	0.71	0.03	0.02	0.53
Isovalerate	1.6	1.6	1.5	1.6	1.3	1.7	0.77	0.95	0.56	0.09	0.53
	mmol										
Total VFA, mol	2.4	2.2	2.8	3.8	1.7	1.9	0.39	0.36	<0.01	<0.01	0.30
Acetate	1632	1480	1934	2634	1054	1358	0.38	0.34	<0.01	<0.01	0.28
Propionate	369	342	440	592	298	261	0.37	0.39	<0.01	0.03	0.53
Butyrate	313	287	365	463	267	235	0.49	0.45	<0.01	0.06	0.20
Isobutyrate	8.7	7.8	9.6	12.7	5.9	7.5	0.53	0.34	<0.01	<0.01	0.10
Valerate	42.6	38.8	51.2	62.5	34.3	35.7	0.36	0.35	<0.01	0.02	0.64
Isovalerate	37.8	35.2	43.9	61.9	22.4	32.6	0.48	0.47	<0.01	<0.01	0.19
NH ₃	370	198	354	378	284	260	0.79	0.01	0.03	0.43	0.92
NO ₃ -N, µmol	3.1	3.9	1.6	7.4	0.75	0.42	0.54	0.51	0.06	0.32	0.88
NO ₂ -N, µmol	ND ²	ND ²	ND ²	ND ²	ND ²	ND ²	-	-	-	-	-

¹Number of heifers in each 1.1-ha paddock.

²Not detected.

Table 2.3. Effect of stocking density and time on nutrient selection of ruminally cannulated heifers grazing brassica and grass paddocks

Item, % DM	Stocking density ¹			Day			Stocking density		Day		Stocking density × Day
	3	4	5	2	24	46	Linear	Quadratic	Linear	Quadratic	
OM	82.7	82.1	83.0	82.0	84.6	81.2	0.90	0.71	0.45	<0.01	0.10
NDF	41.2	41.2	44.1	48.2	35.5	42.8	0.25	0.52	0.11	<0.01	0.54
ADF	33.4	33.2	34.0	33.6	32.8	34.1	0.48	0.49	0.82	0.61	0.78
ADIA ²	5.5	4.5	4.8	6.5	3.2	5.0	0.34	0.34	0.12	<0.01	0.90

¹Number of heifers in each 1.1-ha paddock.

²Acid detergent insoluble ash.

Table 2.4. Effect of stocking density on DMI and nutrient digestion of heifers grazing brassica and grass paddocks

Item	Stocking density ¹			SEM	Contrasts	
	3	4	5		Linear	Quadratic
DMI, kg	6.2	9.4	8.5	0.92	0.08	0.07
Digestibility, %						
DM	67.8	83.3	80.2	2.7	<0.01	<0.01
OM	76.7	87.5	84.6	1.7	0.01	0.01
NDF	69.0	79.8	78.6	2.6	0.02	0.05
ADF	74.1	83.5	80.1	2.7	0.15	0.09

¹Number of heifers in each 1.1-ha paddock.

Table 2.5. Effect of stocking density on N balance of heifers grazing brassica and grass paddocks

Nitrogen, g/d	Stocking density ¹			SEM	Contrasts	
	3	4	5		Linear	Quadratic
Intake ²	149.4	217.4	191.7	32.6	0.24	0.14
Urine	91.4	90.5	89.1	7.1	0.81	0.98
Fecal	52.7	48.0	52.5	3.5	0.95	0.13
Retained	5.3	79.5	50.1	28.9	0.12	0.05

¹Number of heifers in each 1.1-ha paddock.

²Nitrogen intake calculated as the product of DMI and N content of apparent forage intake.

Table 2.6. Effect of stocking density on initial¹ BW and gains of heifers grazing brassica and grass paddocks

Item	Stocking density ²			SEM	Contrasts	
	3	4	5		Linear	Quadratic
Initial BW, kg	257.8	258.9	266.3	11.7	0.28	0.63
Δ BW, kg						
Initial to intermediate ²	7.3	2.4	2.2	1.5	0.05	0.26
Intermediate to final ³	25.5	28.7	25.6	2.3	0.96	0.25
Initial to final	32.7	31.1	27.8	2.6	0.16	0.76

¹Average of d 1 and d 2 BW.

²Number of heifers in each 1.1-ha paddock.

³Average of d 21 and d 22 BW.

⁴Average of d 47 and d 48 BW.

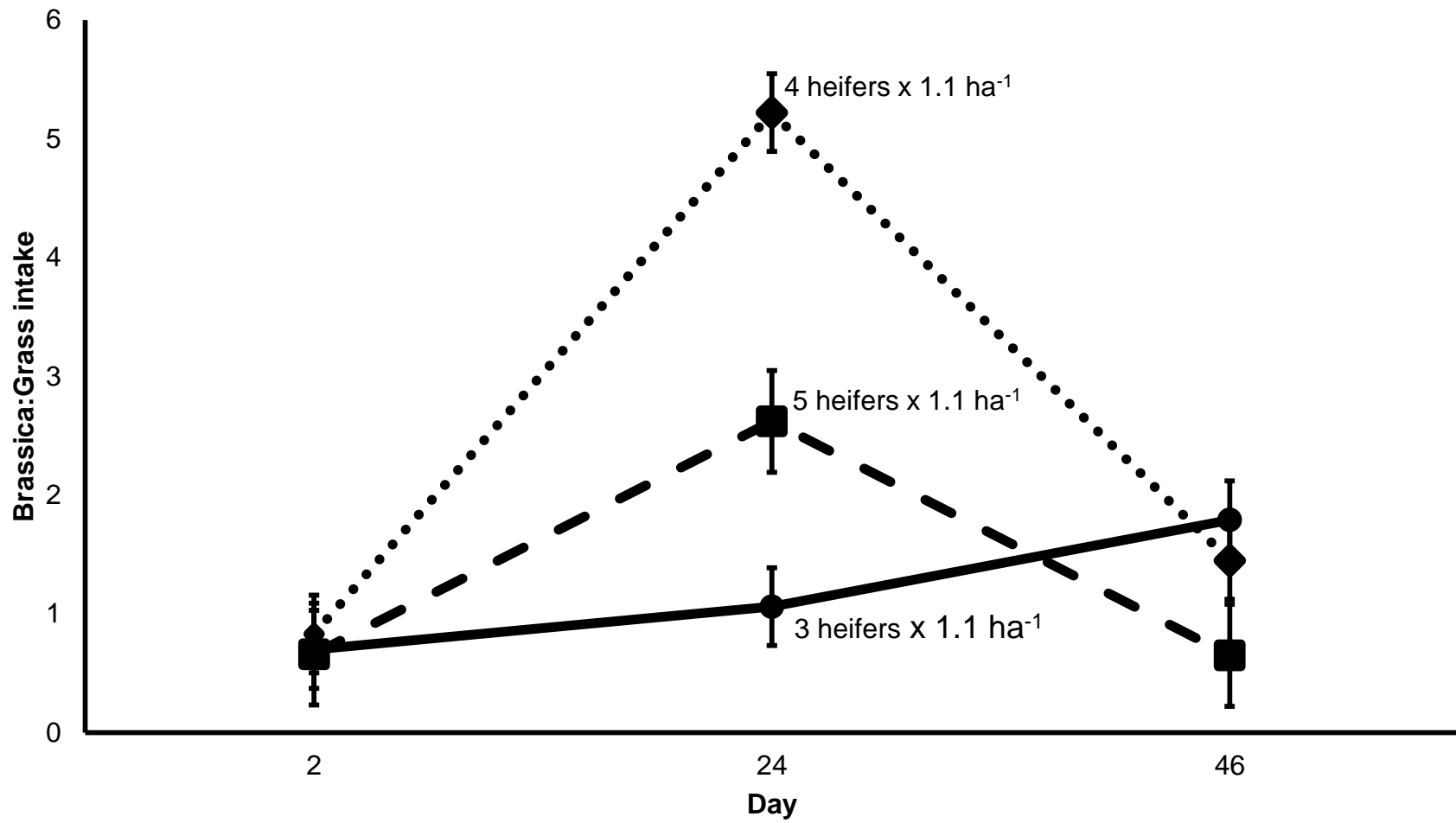


Figure 2.1. Effects of stocking density and time on proportional intake of brassica to grass among cannulated heifers grazing brassica and grass. Stocking density \times day $P < 0.01$.