STRATEGIC MANAGEMENT OPTIONS TO OPTIMIZE BEEF CATTLE PRODUCTION

A Dissertation

by

COLTON RAY ONEY

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Chair of Committee,	Tryon A. Wickersham
Co-Chair of Committee,	Jason E. Sawyer
Committee Members,	Clay P. Mathis
	David P. Anderson
Head of Department,	G. Cliff Lamb

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ABSTRACT

A series of experiments were designed to test the feasibility of various strategic management options to optimize beef cattle production. In the first experiment, heifers were developed utilizing phase feeding nutritional program to assess the reliability of these programs on reproductive performance while also determining differences in apparent efficiency among strategies. Reproductive performance was not affected by feeding program, and based on degree of intake restriction maintenance energy requirements can be reduced 20-35%. Next, a three herd rotational semi-confinement cow-calf production experiment was designed to identify challenges and advantages to intensive cow-calf systems devised to increase cow-calf production efficiency without having to purchase more land. By limit-feeding cows in confinement for four months out of the year and allowing multiple chances to conceive within a production year, production per unit of land and per cow increased by 42 and 34%, respectively. Defining optimal bunk space allowance for limit-fed cows is important to ensure that each cow being fed has the opportunity to consume the targeted amount of feed to meet requirements, and simultaneously manage fixed and variable costs of intensive production. Therefore a third experiment was designed with the objective of defining the relationship between bunk space allowance on weight change and within-group variance in weight maintenance of cows being limit-fed in confinement. Results of this study suggest that 45.7 cm of bunk space per cow will allow each cow to consume

sufficient amounts to meet her requirements while also reducing the variable costs associated with feed and the fixed costs associated with pen and bunk space. Lastly, a study comparing cattle performance when grazing wheat, oats, or triticale was conducted to determine triticale's viability as an alternate winter forage. Results from this study suggest that animal performance among the three forage sources is similar during years of adequate precipitation or when stocking rate allows for an excess of forage available for grazing; however, when early growing season rainfall was below average, animal performance was greater in heifers grazing triticale. Overall, feasible strategic management options exist, and if implemented can increase the efficiency of beef cattle production.

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To my family and my fiancé:

I have received endless love and support from all of you and I feel extremely lucky and blessed to have all of you in my life.

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Contributors

This work was supervised by a dissertation committee consisting of Dr. Tryon Wickersham (committee chair) and Dr. Jason Sawyer (committee co-chair) from the Department of Animal Science, Dr. David Anderson from the Department of Agricultural Economics, and Dr. Clay Mathis of the King Ranch Institute for Ranch Management.

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INTRODUCTION AND REVIEW OF LITERATURE

Introduction

In June of 2013 the United Nations projected that world population will increase from 7.2 billion to 8.2 billion by 2025, and to 9.6 billion by 2050. Currently in North America, animal sourced proteins provide 68% of total protein consumption (Wu et al., 2014). Both the growing population and increases in per capita income are expected to increase demand for animal-sourced foods (Ozturk, 2016); according to Herrevo et al. (2013) average meat consumption per capita worldwide is expected to increase from 40.0 kg in 2013 to 51.5 kg in 2050.

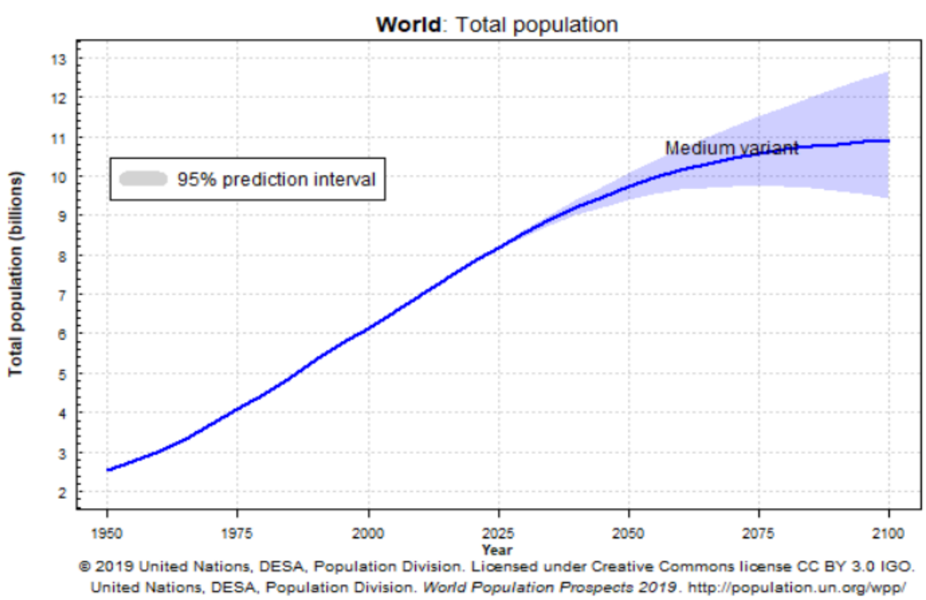

Figure 1. World population (United Nations, 2019)

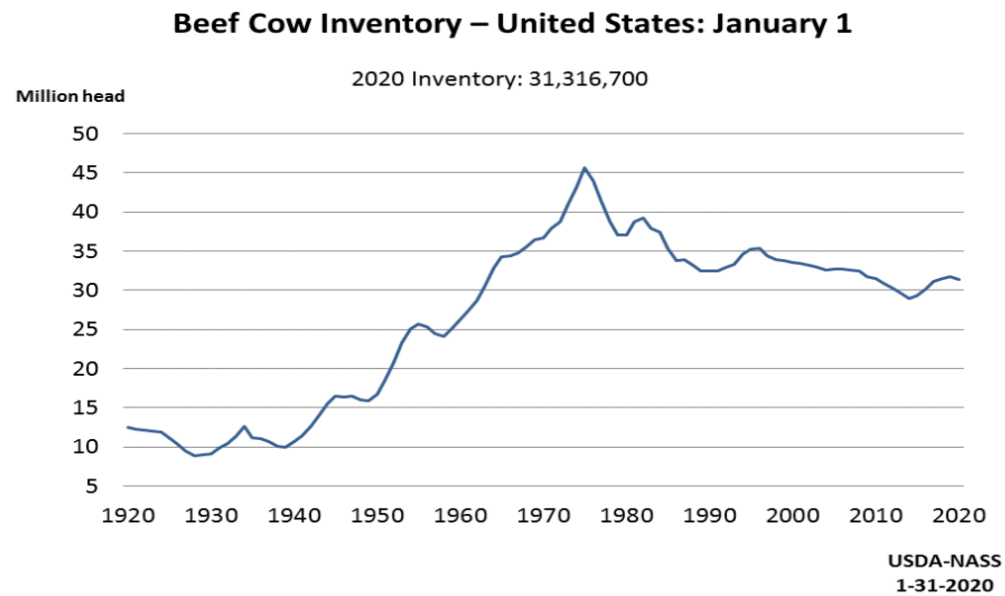

Figure 2. Beef cow inventory (USDA-NASS, 2020)

Beef cattle production historically has depended on having access to grazing lands; however, due to both the conversion of grass lands into crop lands and urban sprawl, gaining additional access to grazing land has been increasingly difficult. A combination of increased land costs and increased costs of production has encouraged more efficient production. Thus, even though the United States beef cow inventory has decreased from more than 45 million head in the mid 1970's to just over 31 million head in 2020 (USDA, 2020), total beef production has increased.

In order to meet the nearly 30% increase expected in animal sourced protein demand, with less land available for production, there is a need to further increase the efficiency in which beef cattle are produced. In the face of decreasing land availability, the FAO (2011) proposed sustainable intensification as a strategy to meet global protein demand. In cow-calf systems variable costs, specifically feed costs, drive sustainability of intensified systems.

Reports by Loerch (1996), Schoonmaker et al., (2003), and Sawyer and Wickersham (2013) have demonstrated potential advantages in limit-fed cow systems. Previous research from our lab (Trubenbach et al., 2019) has demonstrated that limit feeding cows a high-energy diet can reduce apparent maintenance requirements by 23.5%, increasing total efficiency of the production system and offering a mechanism to control feed costs while maintaining productivity. Intensified (partial or total confinement) cow-calf systems reliant upon managed feed consumption may require enhanced management of nutrition, health, and space relative to more typical confinement dairy or beef finishing systems designed for *ad libitum* feed consumption.

Therefore, in order to facilitate the increase in sustainable, intensive, beef cattle production, the following objectives were created: 1) evaluate managed feeding programs for developing heifers to assess the reliability of these programs on reproductive performance of heifers while also determining differences in apparent efficiency among strategies; 2) evaluate productivity from an intensified system based on managed feeding periods for cow-calf production; 3) define the relationship between bunk space allowance on weight change and within-group variance in weight maintenance of cows being limit-fed in confinement; and 4) compare cattle performance when grazing wheat, oats, or triticale and determine if triticale is an alternate winter forage with reduced performance risk when precipitation is limited.

Net Energy System

Energy, or the ability to do work, drives all living things. The energy released as heat when an organic substance is completely oxidized to carbon dioxide and water is gross energy (GE); however, gross energy is not a good indicator of energy available to the animal. Digestible energy (DE), or the gross energy of the diet minus the energy lost in the feces, has greater value as a predictor of energy available to the animal than GE because it reflects diet digestibility. Although a better predictor than GE, DE fails to capture losses of energy associated with digestion and metabolism. Total digestible nutrients (TDN) is similar to digestible energy and has no particular advantages or disadvantages, although TDN is more commonly used. Total digestible nutrients is converted to DE using the equation: 1 kg of TDN = 4.4 Mcal of DE. Metabolizable energy (ME) of the feed, or the energy available to the animal for maintenance and growth, is defined as GE minus fecal energy (FE), urinary energy (UE), and gaseous (GASE) energy losses. Metabolizable energy required by the animal equals heat energy (HE) plus retained energy (RE), and ME is used as a reference value for net energy (NE). Retained energy is energy used for depositing tissue, fetal growth, or milk production, while HE is an energetic loss to the system. Heat energy, or energy lost from the system, is observed in basal metabolism, activity, product formation, digestion and absorption, thermal regulation, heat of fermentation, and waste formation and excretion. Heat increment is the energy associated with consuming feed and is comprised of: product formation, digestion and absorption, heat of fermentation, and waste formation and excretion. Heat energy produced when the animal is in the fasting state is considered the maintenance requirement for the animal.

The ratio of ME to DE used by the used in standard models (NRC, 1984) was 0.82 and according to updated publications (NRC, 2000; NASEM, 2016) the ME:DE for most forages and mixtures of forages and cereal grains is approximately 0.80. However; Vermorel and Bickel (1980) presented data that suggested growing cattle can have an ME:DE ranging from 0.82 to 0.93. Data from Hales et al. (2012) also support ME:DE ratios greater than 0.8. Conversely, Hemphill et al. (2018) reported a range of ME:DE from 0.74 to 0.82 in bred heifers being limit-fed a cornstalk-based diet. The ratio of ME to DE varies with intake, age of animal, and feed source. Because there are not currently available recommendations to accurately predict this variability, NASEM (2016) recommend the ratio of 0.82 should continue to be used as a base.

The value of feed energy available for energy retention is measured by determining RE at two or more amounts of energy intake (IE). Therefore NE of a feed or diet can be calculated by the change in RE divided by the change in IE. Animal heat production at zero feed intake equals the animals NE requirement for maintenance, therefore the ability of a the diet to meet NE required for maintenance is expressed as NEm and can be calculated by heat production at zero intake divided by the amount of feed intake required for zero retained energy. Net energy retained (NEr) is calculated by dividing RE by the amount of feed consumed in excess of maintenance requirements. Garrett (1980) reported equations to convert ME values to NE for maintenance and NE for gain where: NE for maintenance = 1.37 ME – $0.138ME^2$ + 0.0105 ME^3 – 1.12 and NE for gain = 1.42 ME – 0.174 ME^2 + 0.0122 ME^3 – 1.65.

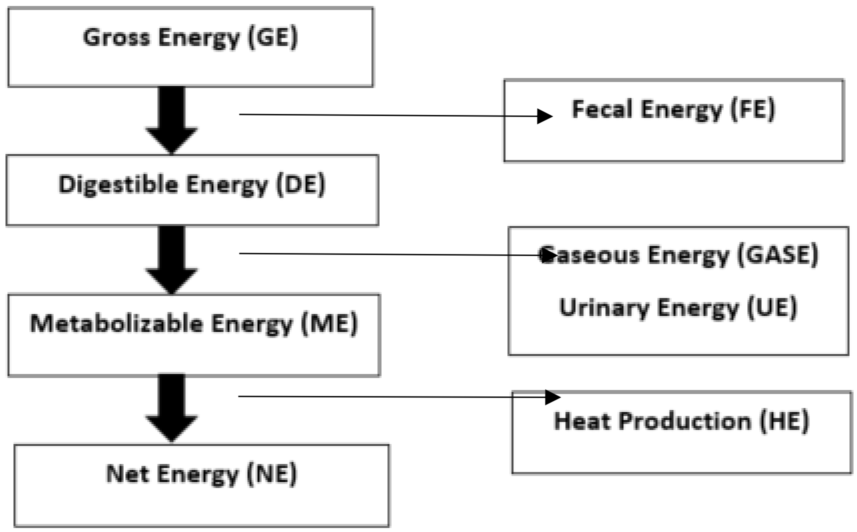

Figure 3. Outline of partitioning in beef cattle (NASEM, 2016).

The maintenance energy requirement for animals is defined as the amount of feed energy intake that will result in no net loss or gain of energy from tissues of the body. Ferrell and Jenkins (1987) reported that ME required for maintenance represents approximately 70 percent of the total ME required by mature beef cows, and in mature breeding bulls ME required for maintenance represents approximately 90 percent of the total ME required. The ME required for maintenance (Mcal/d) can be calculated by multiplying 0.077 (mcal) by empty body weight (kg) to the ¾ power. Maintenance energy requirements can vary with body weight, breed, sex, age, stage of production, previous nutrition and intake.

Overall the net energy system has proven to be a reasonably good model for cattle nutrition. Although typically accepted as fixed by practitioners, evidence suggest that maintenance requirements can be altered by a number of factors. Management of these factors provides an opportunity to increase efficiency.

Limit Feeding

Limit-feeding has been most commonly evaluated in backgrounding and finishing operations to increase feed efficiency (Plegge, 1987; Hicks et al., 1990; Murphy and Loerch 1994). Schmidt et al. (2005) fed a finishing diet to steers at three different levels: *ad libitum*, 90% of *ad libitum*, and 80% of *ad libitum* intake and observed greater ADG and G:F in steers limit fed at 80% *ad libitum* compared to steers fed *ad libitum*. Contrary to data presented by Schmidt et al. (2005), Murphy and Loerch (1994) fed an all concentrate diet at *ad libitum*, 90% *ad libitum*, and 80% *ad libitum* intake and observed decreased ADG in limit-fed steers compared to steers *ad libitum* fed steers, however, an increase in feed efficiency was observed. Hicks et al. (1990) restricted steers being fed a high concentrate finishing diet to 85% *ad libitum* and observed a G:F ratio of 0.124 compared to a G:F ratio of 0.113 in cattle being fed at *ad libitum*.

Age of the animal and severity of the nutritional challenge both effect the degree to which performance is altered during limit-feeding. In studies that utilized cattle that were 8 months or older (Sully and Morgan, 1982; Mader et al., 1989; Carstens et al., 1991; Harris, 1994) increased lean weight gain and decreased fat deposition during compensatory growth was reported. However, in studies that utilized cattle less than two months of age (Stuedemann et al., 1968; Tudor et al., 1980; Abdalla et al., 1988) increased fat deposition was reported for cattle experiencing compensatory growth. Length of the challenge period has also been shown to affect the performance of animals after realimentation to feed (Ledger 1977; Carstens 1995).

Limit-feeding has been shown to increase diet utilization (Galyean et al., 1979; Zinn and Owens, 1983; Murphy et al., 1994) and may result in altered maintenance requirements (Trubenbach et al., 2019). In animals receiving a normal diet, not restricted, the maintenance requirement for metabolizable energy is between 420 and 450 kJ/kgBW^0.75 (0.1 - 0.11 Mcal/kgBW^0.75; Ryan et al., 1993). However, in animals that have been maintained at a constant weight over a long period of time maintenance requirements have been reported to be much lower. Turner and Taylor (1983) conducted a study with cattle held at a constant feed intake and equilibrated to a constant body weight and they observed decreased maintenance requirements. At a fixed level of intake, reducing the maintenance requirement increases energy available for growth or other forms of RE. During the undernourishment or challenge period, it is likely that metabolically active tissues such as the digestive tract and the liver are reduced in size and activity (Ryan et al., 1993).

Generally, as intake increases total diet digestibility decreases (Galyean, 1979; Murphey et al., 1994); limiting intake has been shown to increase digestibility and can be attributed to a slower passage rate and resulting greater extent of ruminal digestibility (Blaxter et al., 1964; Ellis 1978). Mould and Ørskov (1983) observed increased fiber digestion associated with a greater rumen pH when intake was restricted, and Colucci et al., (1982) observed a greater extent of starch digestion during restriction. Modeled by Mertens (1983), increased feed intake increases passage rate, and therefore decreases digestibility.

Murphy et al., (1994) observed an increase in OM digestibility in lambs being fed a concentrate diet from 77.69% in lambs being fed *ad libitum* to 80.64% and 81.49% in lambs being fed at 90 and 80% of *ad libitum* intake, respectively. Murphy et al. (1994) found that restricting intake of concentrate diets from *ad libitum* to 90 and 80% *ad libitum* intake linearly ($P < 0.01$) increased measured NE values of the diet for maintenance and gain, suggesting that diet utilization increased resulting in an effective increase in dietary ME concentration. While it is clear that dietary energy utilization is increased in limit-fed scenarios this increase alone cannot fully account for the increases in performance; therefore it is likely that maintenance and/or gain requirements are also reduced.

The amount and the type of energy deposited effect the rate at which animals increase in weight. Depositing lean weight (protein) requires less energy per unit of gain compared to fat. After a nutritional challenge, animal growth patterns can be shifted to deposit a greater proportion of lean weight gain and will have reduced NE requirements allowing for increased growth rates after the challenge period (Ryan et al. 1993). Carstens et al. (1991) found that steers that underwent compensatory growth contained 12% more empty-body protein and 25% less empty body fat when compared to continuous growth steers. Correspondently, both Smith et al. (1977) and Harris (1994) found that steers who had undergone compensatory growth deposited less fat compared to steers on continuous growth programs.

Previous publications (NRC, 1984; Carstens et al., 1991) suggest that the increase in growth efficiency observed in cattle during and following a period of limit-feeding is attributed to a decrease in NEg requirements rather than a decrease in maintenance. Specifically, NRC (1984) recommends decreasing NEg requirements by 11.4% and Carstens et al. (1991) suggest that NEg requirements of feedlot steers be decreased by 18% following a period of limit-feeding. However, the NASEM (2016) suggests that NEm requirements be decreased during limit-fed situations. The calculations in the NRC (1996, 2016) utilize rate of gain and EQSBW in the calculation to account for differences in composition of gain. While it is likely requirements for both maintenance and growth are altered, it is often convenient to attribute differences to one or the other, and because the EQSBW scalar accounts for shifts in composition, and growth rate is directly observable, differences can be assigned to alterations in maintenance requirements.

Sainz et al. (1995) observed 17% reduction in maintenance requirements in limit-fed steers compared to *ad libitum* fed steers. Koong et al., (1985), and Jenkins and Ferrell (1997) observed decreases in cow maintenance energy requirements following periods of feed restriction. Similarly, Trubenbach et al., (2019) found that feeding cows a high energy diet at 76% of the energy requirement predicted by NASEM (2016) was sufficient to achieve maintenance, and Freetly and Nienaber (1998) reported a 22%

reduction in maintenance energy requirements when intake of mature cows was restricted to 65%.

Several mechanisms for reduced requirements have been proposed, including decreased protein turnover, cellular ion transport, and mass and total metabolism of metabolically active organs (McBride 1990). In cattle, visceral organs account for 40-50% of total body energy consumption, yet the liver and gastrointestinal tissues represent only 8-15% of total body weight (Reynolds et al., 1991). Johnson et al. (1990) and Burrin et al. (1990) suggested that visceral organs of cattle and sheep decrease when fed at maintenance compared to *ad libitum.* The observed differences in proportions of visceral organ mass in relation to body weight during limit-feeding suggest that reduced visceral organ mass may constitute a mechanism for reduced maintenance requirements. Limit-feeding has also been shown to decrease splanchnic tissue mass and subsequent heat production (McLeod and Baldwin, 2000; Camacho et al., 2014) increasing the efficiency of energy use. Freetly and Nienaber (1998) described decreases in maintenance requirements in limit-fed scenarios and attributed them to shifts in equilibrium FHP. Similarly, Birkelo et al. (1991) observed decreases in FHP and subsequent reduction in maintenance requirement by limiting intake.

Overall, limit-feeding increases energy efficiency of diet utilization and also reduced maintenance requirements. Limit-feeding is a management strategy that provides an opportunity to increase efficiencies in intensively managed systems.

Developing heifers utilizing a phase feeding program

Development of replacement heifers is critical to the sustainability of beef production. Standard heifer development goals include producing replacements that reach puberty and conceive early, sustain pregnancy, calve unassisted, and rebreed quickly (Lynch et al., 1997; Funston and Deutscher, 2004; Lardner et al., 2014). Because investment in breeding females is a significant component of the total cost structure of cow-calf operations, cost of development (COD) and development efficiency (costs of achieving development goals) are also important.

Historically, the recommendation has been to grow heifers to 60 to 66% of mature BW prior to breeding (Patterson et al., 1992). In theory this would allow heifers one or more estrus cycles prior to breeding, and allow them to calve at 2 years of age and approximately 80% of mature BW. More recent studies have demonstrated that heifers grown to 50 to 57% of mature BW achieve conception rates equivalent to heifers developed to a greater percentage of mature BW (Funston and Deutscher, 2004; Martin et al., 2008; Lardner et al., 2014). Obtaining replacement breeding livestock, whether obtained through internal development or purchased from an outside source, is one of the largest capital requirements in cow-calf operations. Because of the large capital costs associated with replacement females, there have been attempts to reduce the cost of developing heifers. The largest production cost associated with heifer development is feed cost (Freetly et al., 2001); therefore, there has been a large focus on decreasing the feed cost associated with heifer development. One method that could potentially reduce development cost is the utilization of a phase feeding development program.

Managed growth for the majority of development followed by a period of 40 – 50 days of accelerated growth to achieve weight targets results in conception rates similar to those observed when using strategies reliant on constant growth rate, and decrease total feed inputs required for heifer development (Clanton et al., 1983; Lynch et al., 1997). However, several studies utilizing managed growth to develop heifers have reported growth rates that deviated from programmed growth paths (Clanton et al., 1983; Minton et al., 1994; Lynch et al., 1997), suggesting that accurately predicting performance has proven difficult in limit-fed scenarios.

Managed growth can be achieved through dietary energy dilution at *ad libitum* consumption, or through controlled intake of more energy dense diets. Clanton et al. (1983), Lynch et al. (1997) and Freetly et al. (2001) reported that less feed was required to develop heifers to common BW when they were developed using phase feeding (limited intake for a period followed by increased intake in subsequent period) compared to heifers on a constant gain regime. These authors' concluded that post weaning growth patterns can be altered to reduce feed costs without altering reproductive performance as long as heifers met a minimal % of mature BW prior to breeding. This provides an opportunity for producers to minimize feed inputs without sacrificing reproductive performance, increasing efficiency of heifer development.

While phase feeding development of heifers has been shown to increase development efficiency, accurately predicting performance in limit-fed scenarios has proven difficult. In heifers fed at or near maintenance, Clanton et al. (1983), Minton et al. (1994) and Lynch et al. (1997) all observed ADGs that exceeded ADGs predicted by

NRC equations. Lynch et al. (1997) limit-fed heifers and programmed them to gain 0.11 kg/d for a period of 112 d and observed an actual ADG of 0.25 kg/d. Similarly, Cardoso et al. (2014) programmed heifers to gain 0.35 kg/d when consuming a restricted diet after a period of *ad libitum* intake and observed an ADG of 0.43 kg/d. These data suggest that NRC values tend to underestimate performance of limit-fed animals, particularly as intake decreased further from *ad libitum*.

As discussed above, limit-feeding has been show to increase energy utilization of the diet and decrease maintenance requirements. However, in order to more accurately predict growth rates of growing animals in limit-fed situations the degree to which energy utilization is increased and maintenance requirements are altered is important to accurately predict performance.

Because the investment in replacement females is a large component to the total cost structure of cow-calf systems, it is important to consider COD and development efficiency. Utilizing phase feeding to develop heifers is a management strategy with the potential to decrease COD, and increase development efficiency.

Rotational semi-confinement cow-calf production

Increased feed and supplementation costs associated with drought conditions can lead to large economic losses to ranchers (Eakin and Conley, 2002). Feeding cows in confinement (intensification) during periods of limited forage availability (drought) allow producers an outlet to provide nutrients so that requirements are met without damaging future forage production while also preventing partial or complete herd liquidation. Furthermore, intensification of cow-calf systems could potentially help meet the increasing demand for animal protein without increasing land requirements (Sawyer and Wickersham 2013).

Average pasture value for the United States as of August 2, 2018 was $1,390/acre; however, all Corn Belt states exceed this average with both Iowa and Illinois having pasture valuations in excess of $3000/acre (USDA, 2018). Land is the largest capital requirement for new or expanding cow-calf operators, and at current values represents a significant barrier to both market entry and herd expansion. Intensification (partial or total confinement) of cow-calf systems is an alternative, potentially reducing capital costs associated with land acquisition for lower cost alternatives. The ready supply of nutrient dense co-products has prompted an increase in intensified (partial or total confinement) cow-calf production systems designed to increase the amount of beef produced per unit area of land.

In confinement settings feed costs represent 80% of the total cost of production (Eizmendi, 2015a); for an economically viable confinement system feed costs must be optimized against production outcomes. Trubenbach et al. (2019) demonstrated that limit feeding cows a high-energy diet can reduce apparent maintenance requirements by as much as 24%, potentially increasing energetic efficiency of cow-calf systems and offering a mechanism to control feed costs while maintaining productivity.

Sawyer and Wickersham (2013) suggested that a cow-calf production system can be viewed as a transaction in calories where the ranch produces calories (grazed or harvested forages) that are consumed by livestock and converted into salable product. A model was developed to describe the “value” of a calorie, by comparing the costs of calories from the ranch and from exogenous sources, to make decisions regarding expansion and/or intensification. A balanced system, or a properly stocked cow-calf operation, would produce 100% of the caloric requirement for production; while meeting protein and mineral requirements with supplementation. For a producer who is currently operating in a balanced system, land acquisition or the purchasing of exogenous calories (produced off-site and imported) are the main sources of expanding the caloric base. In the model presented by Sawyer and Wickersham (2013) the four-month confinement period represents a 42.6% increase in harvestable forage that can be added to the supply. Adding additional cows to the herd to harvest the extra forage results in an equivalent increase in demand, bringing the forage system back into balance and allowing an increase in herd size by 42.6%. Results of the model suggest that by placing cows into confinement for a portion of the year, the increase in cattle numbers and resulting increase in output is greater than the increase in added inputs, increasing overall production efficiency per unit of land by 42%.

Baber et al. (2019) compared five management scenarios including 1) cow-calf system continuously grazing pasture for the entire production year, 2) cows that continuously grazed pasture for the entire production year but in a drought year and had to be fed hay, 3) cows that were confined in drylots and limit-fed from time of weaning until 30 d prior to calving (approximately 120 d), 4) cows that were confined in drylots and limit-fed from day of weaning until breeding (approximately 240 d) and 5) cows that were confined in drylots and limit-fed for the entire production year. Results from this study suggest that net return per cow was greatest for cows that continuously grazed pasture for the entire production year in a non-drought year ($296.16) and net return per cow was least for cows continuously grazing in a drought year ($3.34). Of the three confinement strategies modeled, cows being limit-fed in confinement for 120 d had the greatest net return per cow ($249.34), cows confined for 240d was intermediate ($201.11), and cows confined for the entire production year had the lowest net return per cow ($102.16). While Baber et al. (2019) observed the greatest net return when cattle grazed for the entire production year, if the model presented by Sawyer and Wickersham (2013) is considered, there appears to be an opportunity to increase overall production per unit of land by feeding cows in confinement for a portion of the year.

Partial confinement also lends itself well to implementing multiple calving seasons. Selk (2002) suggested that utilizing a dual calving season will potentially allow cattle producers to take advantage of seasonal highs in the cattle market, minimize price risk by spreading their marketing opportunities out and reduce bull costs. More importantly, utilizing multiple calving seasons can provide open cows another opportunity to conceive within the same production year. Because investment in breeding livestock is a large component of the total cost structure of cow-calf operations, maximizing the productive life of a cow is important in order to get a return on investment from that cow. Using a system dynamic model Payne et al. (2009) found that utilizing a dual calving system required less investment in breeding livestock when compared to single season (spring and fall) calving systems because the dual calving system provided an opportunity for an open cow from either calving herd an additional opportunity to become pregnant reducing the number of cows culled annually and increasing the productive life of cows.

Overall, partial confinement of cows allows for an increase in carrying capacity of the operation, increasing production per unit of land. Also, by implementing multiple calving seasons within the production year, culling rates are reduced; therefore, reducing the amount required to invest in replacement females.

Bunk space requirement of cows being limit-fed in confinement

As mentioned above, systems reliant upon managed feed consumption require enhanced management of nutrition, health, and space relative to more typical confinement dairy or beef finishing systems designed for *ad libitum* feed consumption. In order to optimize variable costs of feed and fixed costs associated with pen and bunk space, defining proper bunk space requirements is important. Due to the restriction in feed offered, it may be necessary to provide more bunk space than typically recommended in *ad libitum* intake systems so that all animals may attend the bunk simultaneously. While there is thorough literature pertaining to the effects of limit-feeding on cow performance (Koong et al., 1985; Jenkins and Ferrell 1997; Trubenbach et al., 2019), literature pertaining to space requirements of limit-fed cows is minimal. Some space optimization studies have been performed in finishing (Taylor 1984; Zinn 1989; Gunter et al., 1996) and dairy systems (Olofsson 1999; DeVris et al., 2004; Huzzey et al. 2006); however, to my knowledge only anecdotal reports (Jenkins 2014; Eizmendi 2015) exist for limit-feeding cows in confinement.

Zinn (1989) conducted a two-year study comparing bunk space allowances of 14, 30, 45, and 60 cm/hd in limit-fed calves consuming a finishing diet consisting of 62.5% steam-flaked corn and concluded that feedlot performance was not influenced ($P > 0.20$) by space allotments and providing greater than 15 cm/hd will not improve performance. Gunter et al. (1996) fed steers a finishing diet consisting of 58% steam-flaked milo and provided 12.7, 20.3, 27.9, or 35.6 cm of bunk space per head and observed no effect of bunk space allowance on ADG ($P > 0.29$) or DMI ($P > 0.17$). When cattle consume a high concentrate finishing diet, it is recommended to provide 15 cm of bunk space per head (Elam and Grainger 1977; Taylor 1984), and results of the studies by Zinn (1989) and Gunter et al. (1996) suggest that bunk space allowance when limit-feeding high concentrate diets in a finishing system do not need to be increased.

Olofsson (1999) fed dairy cows a 50% grass silage 50% concentrate diet and provided feeding stations at either 1 or 4 cows per station and observed shorter eating time, more displacements at the feeding station, and more aggressors when feeding station was restricted from 1 cow per station to 4 cows per station. DeVries et al. (2004) fed dairy cows a TMR consisting of 30% corn silage, 8% grass silage, 4% alfalfa hay, 5% grass hay, 16% steam-rolled corn, and 37% concentrate mash and provided either 0.5 or 1.0 m of feed alley space per animal. DeVries et al. (2004) observed reduced frequency of aggressive interactions and increased feeding time as feed alley space was increased from 0.5 to 1.0 m per animal and recommended increasing feeding space to increase feeding activity and reduce aggressive interactions. Huzzey et al. (2006) fed dairy cows a TMR consisting of 21.5% grass silage, 14.6% corn silage, 5.6% alfalfa hay, 3.5% grass hay, 32.3% energy blend, and 22.5% concentrate mash and provided 0.81, 0.61, 0.41, or 0.21 m of linear bunk space per cow. Huzzey et al. (2006) concluded that increasing the stocking density at the bunk increased the frequency at which cows were displaced, and in order to reduce competition and increase feeding activity recommended avoiding overstocking at the bunk.

Wagnon (1965) evaluated social dominance in range cows and its effect on supplemental feed intake, and suggested that optimum feeding conditions (cows spend equal amount of time at the bunk) occur when cows have to stand close together at the trough (or bunk), presumably only seeing the cows on each side. Wagnon (1965) observed less fighting and position changing when trough space was decreased from 182.9 cm to 91.4 cm of trough space per cow. Results from this study suggest that when cows have a lot of space they have room to fight and chase subdominant cows away, whereas less space makes cows feed closer together and less likely to back away from the bunk to chase other cows off.

Jenkins (2014) recommended that cows being limit-fed in a confinement setting be allowed a minimum of 60.96 cm of linear bunk space per head, regardless of production stage (i.e. dry, lactating), while Eizmendi (2015b) recommends 45.72 cm of bunk space for dry cows and 91.44 cm for lactating cows. However, neither report data indicating measurement of optimal space, rather, these authors' relayed anecdotal reports.

As with land, space in a confinement feeding system represents an allocation of capital, and a need to define optimal space allowances exists. Defining optimal space allowance in limit-fed cow settings can increase the overall efficiency of intensive cow-calf production systems.

Utilizing small-grains as forage

Stocker cattle production is prevalent in the Southern Great Plains due to the availability of weaned calves and environmental conditions favoring production of small-grains as a source of high-quality forage during the fall, winter, and spring. In these systems, sufficient forage biomass is produced to support grazing for greater than 90 days a year (Rouquette, 2017) and gains in excess of 0.91 kg/d with greater gains observed when implants and ionophores are provided (Horn et al., 2005; Beck 2013). Wheat is the most common small-grain species for winter forage production with 12.2 million acres planted in the Southern Great Plains in 2017 (USDA, 2017), followed by oats, rye, and triticale. While not as prevalent as wheat, oat pasture accounts for a substantial portion of the forage produced for stockers, and produces gains of 0.7 kg/d (Rosso 1992).

Stocking rate of small-grain pastures is a management variable that directly effects intake and animal performance (Bransby et al., 1988). Forage production of cool-season annuals (including small grains such as wheat, oats, and triticale) follows a biphasic growth curve in which forage production is greater in the spring compared to the fall and winter. A common management strategy is to overstock in the fall and winter and substitute supplement for forage intake so that in the spring, during the period of rapid forage growth, animals are stocked to match available forage. Forage allowance (expressed as kg DM·100 kg $BW^{-1}\cdot d^{-1}$) required for maximum gain has a reported critical level between 22 and 27 kg DM·100 kg BW^{-1}·d^{-1} (Redmon et al., 1995, Pinchak et al., 1996). Coblentz and Walgenbach (2010) observed linear (P < 0.01) increases in forage mass of small grain forages from early fall into late winter. Because intake is directly related to forage availability, during the period of overstocking sometimes observed in the fall and winter, cattle are essentially being limit-fed.

In forage based settings, intake is typically limited by gut fill or forage availability, rather than chemostatic or energy fill. When forage is not limiting, rumen capacity and rate of passage are the primary regulators of intake capacity in forage based diets (Conrad et al., 1964), suggesting that ruminants consuming forage based diets eat to a constant fill, providing that forage availability is sufficient. During overstocking periods (or limited forage availability), supplement is used as an additive to the diet whereas when forage availability is not limiting supplements are used as a substitute of forage intake. By overstocking small grain forages early in the growing season, cattle are limit-fed and during the rapid spring growth of the forage are likely to experience increased ADG due to reduced requirements caused by the overstocking (limit-feeding).

Utilizing small grains as a source of forage in the fall, winter, and spring months is common; however, heavier stocking rates early in the forage growing period could lead to limited forage availability. Therefore, it is likely that forage intake of cattle grazing heavily stocked pasture early in the growing period is limited.

To facilitate the increase in sustainable, intensive, beef cattle production, the following objectives were created: 1) evaluate growth programs with different degrees of restriction followed by common final phase growth rates and to assess the reliability of these programs on reproductive performance of heifers while also determining differences in apparent efficiency among strategies; 2) determine production differences amongst herds calving in different seasons and if allowing cows multiple chances to conceive within a given year decreases culling rates and reduces capital investment required for replacement females, while also quantifying any changes in production efficiency captured by providing cows multiple chances to breed within a year; 3) define the relationship between bunk space allowance on weight change and within-group variance in weight maintenance of cows being limit-fed in confinement; and 4) compare cattle performance when grazing wheat, oats, or triticale and determine if triticale is an alternate winter forage with reduced performance risk when precipitation is limited.

CHAPTER II

PHASE FEEDING DEVELOPMENT OF HEIFERS: THE EFFECT OF GROWTH PATH ON REPRODUCTIVE PERFORMANCE AND EFFICIENCY OF EACH LEVEL OF GROWTH

Introduction

Heifer development emphasizes producing replacements that reach puberty and conceive early, sustain pregnancy, calve unassisted, and rebreed quickly (Lynch et al., 1997; Funston and Deutscher, 2004; Lardner et al., 2014). Investment in breeding females is an important component of the total cost structure of cow-calf operations; therefore, cost of development (COD) and development efficiency (costs of meeting development goals) are also important.

Previous reports recommended growing heifers to 60 to 66% of mature BW prior to breeding (Patterson et al., 1992; Lynch et al., 1997); however, more recent studies have demonstrated that heifers grown to 50 to 57% of mature BW achieve conception rates equivalent to heifers developed closer to the previously recommend 60 to 66% of mature BW (Funston and Deutscher, 2004, Martin et al., 2008; Lardner et al., 2014). Managed growth for the majority of development followed by a period of 40 – 50 days of accelerated growth to achieve weight targets results in conception rates similar to those observed when using strategies reliant on constant growth rate, while decreasing total feed inputs (Clanton et al., 1983; Lynch et al., 1997). Several studies utilizing managed growth to develop heifers have reported growth rates greater than the programmed growth paths (Clanton et al., 1983; Minton et al., 1994; Lynch et al., 1997), demonstrating that accurate prediction of performance is difficult in limit-fed scenarios.

Managed growth can be achieved through dietary energy dilution at *ad libitum* consumption, or through controlled intake of more energy dense diets. Limit-feeding increased diet utilization (Galyean et al., 1979; Zinn and Owens, 1983; Murphy et al., 1994) and resulted in reduced maintenance requirements (Freetly and Nienaber 1998; Trubenbach et al., 2019). Therefore, to accurately predict growth rates in limit-fed scenarios it is important to understand the degree to which limit-feeding increases diet utilization and alters efficiency of energy use.

Utilizing phase feeding nutritional programs to develop heifers is a well-described management strategy for producers capable of feeding in a dry lot to minimize feed inputs (Clanton et al., 1983; Lynch et al., 1997; Cardoso et al., 2014); however, there is considerable risk associated with failing to accurately predict growth performance leading to reductions in reproductive success. Therefore, our objectives were to evaluate growth programs with different degrees of growth restriction followed by a final phase with a common targeted growth rate and to assess the effect of these programs on reproductive performance while determining the efficiency of each level of growth restriction.

Materials and Methods

Experimental protocols were approved by the Agricultural Animal Care and Use Committee of Texas A&M AgriLife Research.

Year 1

Eighty-five crossbred beef heifers were weaned (d -93), weighed, and maintained under common management for 93 ± 4 d at the McGregor Research Center, McGregor, TX. Heifers were stratified by herd of origin and d -7 BW. Within strata, heifers were randomly assigned to one of 30 pens equipped with individual Calan gate feeders (American Calan, Northwood NH). Within pens heifers were randomly assigned to 1 of 3 treatment groups: low (**L**, n = 28), medium (**M**, n = 28), or high (**H**, n = 29). All heifers consumed a common diet (Table 1) consisting of cracked corn (42%), dried distillers' grains (26%), alfalfa hay (26%), and molasses (6%); 76 g of a pre-mixed supplement was hand added and incorporated in individual bunks daily to supply 100 mg monensin/d.

Table 1. Ingredient and nutrient composition of diet

Item	
Ingredient[1]	*% of diet*
Corn – cracked	42
Dried distillers' grains	26
Alfalfa hay	26
Molasses	6
Component	
DM basis, %	
OM	93.5
ADF	20.6
CP	14.0
TDN	78.7
Energy, Mcal/kg	
GE	3.95
NE_m[2]	1.87
NE_g[2]	1.14

[1]Rumensin pre-mix top dressed daily; approximately 100 mg monensin·heifer^{1}·d^{-1}

[2]Calculated by converting ME values as reported by Garrett (1980)

The diet was fed to achieve different programmed rates of growth for each treatment. Target growth rates during phase 1 (P1; d 0 – 49) were 0 kg/d (L), 0.45 kg/d (M), or 0.80 kg/d (H). Growth rate in phase 2 (P2; d 50 - 90) was programmed to be 1.36 kg/d for all treatments (Figure 4), such that heifers receiving the H treatment would achieve a traditional target BW (60% mature BW; mature BW estimated as 522 kg). Heifers receiving M and L treatments were programmed to gain at the same rate as H in P2, but due to lower P1 growth rates were programmed to achieve 55 and 50% of mature weight resulting in a range of targets relative to mature BW among treatments.

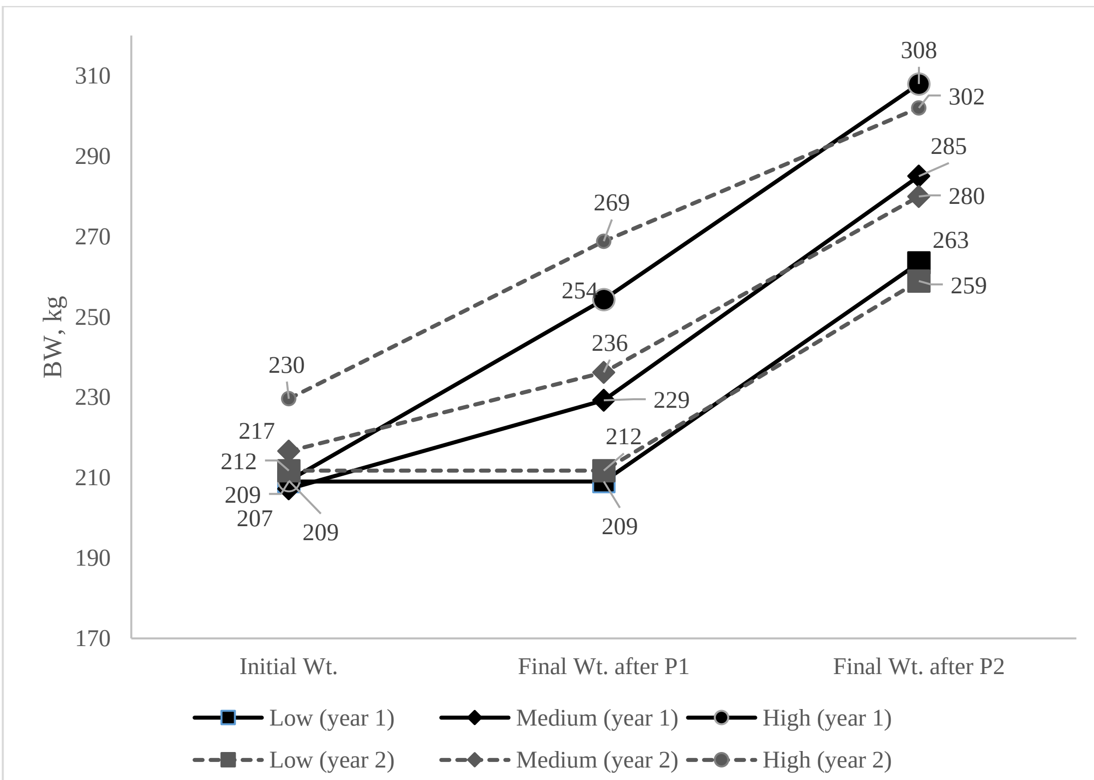

Figure 4. Year 1 and 2 projected body weights (kg) of heifers based off programed ADG when developed on three levels of phase feeding.

Daily feed amounts required to achieve growth targets were predicted for each animal by determining the average, maximum, and minimum starting BW of each treatment group and calculating the projected mid-weight of each, based on programmed rates of gain during P1. Using predicted BW at d 49 as the end BW goal for P1, daily feed intake required to reach that goal was determined for heifers at the average, maximum, and minimum starting BW within each treatment using standard prediction equations (NASEM, 2016). These three values were expressed as a percentage of the respective BW and averaged to establish daily feeding rate as a percentage of individual BW for each treatment. Individual starting BW were then multiplied by the treatment intake rate to determine individual daily intakes. A similar procedure was used to determine intake targets in P2, where the programmed ending BW for P1 was used as the initial BW for P2, and ending BW for P2 was predicted as the P2 initial BW plus the total programmed gain for P2. Heifer NEm and NEg requirements along with predicted DMI required to meet targeted programs of growth are presented in Table 2. It is important to note that for all treatments, feeding programs were developed prior to treatment application, and were not amended during the experimental period to correct for deviations from predicted values.

Heifers were initially adapted to housing and feeding protocols for 17 d on the experimental diet at 3.6 kg/d with continuous access to water. Heifers were housed in pens with a maximum of 3 animals/pen in an open sided barn. At 329 ± 43 d of age heifers (203 ± 43 kg) began their pre-programmed treatments with daily feeding at

Table 2. Requirements and total DMI required for heifers developed on three levels of phase feeding

	Heifer Requirements		
Treatment	NEm, Mcal/d[1]	NEg, Mcal/d[2]	Total DMI, kg[3]
Phase 1			
Year 1			
Low	4.23	0.00	110
Medium	4.37	1.31	165
High	4.57	2.58	220
Year 2			
Low	4.27	0.00	111
Medium	4.49	1.18	163
High	4.83	2.72	233
Phase 2			
Year 1			
Low	4.64	4.68	255
Medium	4.94	4.99	272
High	5.29	5.33	291
Year 2			
Low	4.63	2.61	187
Medium	4.96	2.79	200
High	5.35	3.01	216

[1]NEm = 0.077*MidpointBW^0.75
[2]NEg = 0.0635*EBW^0.75*EBG^1.097
[3]DMI for the entire phase (P1 46 d; P2 41 d) calculated using ME of diet based off tabular NRC values

0800h. On d 49 heifers were adapted to P2 intake levels by increasing daily ration allotment in equal amounts over a 7-d period.

Weekly blood samples and BW were obtained throughout the e project for determination of pubertal status and growth performance, respectively. Blood was collected from the jugular vein by venipuncture into evacuated serum separator tubes and placed on ice until collections were complete. Samples were centrifuged at 1500 × *g* for 15 min, serum was decanted into 1.5 ml micro centrifuge tubes and frozen at -20°C until analyzed.

Measurements of intake and digestion were collected on d 41 through d 43 (P1) and d 83 through d 85 (P2) from 10 randomly selected animals within each treatment group; different animals were randomly selected for each phase. Fecal production was estimated using acid detergent insoluble ash (ADIA) as an internal marker. Fecal grab samples were collected every 12 h with sample time advancing 2 h each day so that 6 samples were obtained over each 3 d collection period. Fecal samples were individually frozen and stored at -20°C. Prior to analysis, each sample was thawed and thoroughly mixed before being composited by weight within animal and period.

On d 90, all heifers were synchronized using the PG 5-day CO-SYNCH + CIDR protocol, “Bee Synch”, for fixed-time AI for *Bos indicus* cattle (Johnson et al., 2016). Heifers received a 5 ml injection of $PGF_{2\alpha}$ (Lutalyse®; Zoetis, New Jersey, USA) and 2 ml GnRH (Factrel®; Zoetis Inc., Madison, NJ) on d 0 of synchronization (d 90 of study) and a controlled internal drug release (CIDR®) insert (Zoetis, New Jersey, USA). Removal of CIDR occurred on d 5 of synchronization, and 4 ml of Lutalyse was administered. On d 8 of synchronization 10 ml of Factrel was administered at the time of AI. On the day following AI heifers were turned out with bulls on a common pasture for 56 d. Blood samples were collected on d 126 and d 154 of the study by jugular venipuncture into evacuated serum separator tubes, placed on ice, and transported to the Texas Veterinary Medical Diagnostic Laboratory (TVMDL, College Station, Texas, USA) for determination of pregnancy status using Pregnancy Specific Binding Protein (Merrill et al., 1979).

Year 2

Ninety crossbred beef heifers were weaned (d -108) weighed, and held under common management for 108 days at the McGregor Research Center, McGregor, TX. Heifers were stratified, assigned to pens and randomly assigned to treatments in the same manner as year 1. Treatments groups in year 2 consisted of: low (**L**, *n* = 30), medium (**M**, *n* = 30), or high (**H**, *n* = 30). All heifers consumed the same diet and pre-mix as year 1. Heifers programmed to achieve a targeted growth rate for each treatment consisting of 0 kg/d (L), 0.4 kg/d (M), or 0.8 kg/d (H) from d 0 to d 49 (P1). All heifers were then programmed to achieve a growth rate of 0.8 kg/d from d 50 to d 90 (P2; Figure 4) in order for the H treatment group to meet a target of 60% of mature BW. Mature BW (496 kg) was estimated as the average weight of the heifers' dams at weaning. Based on projected BW at d 49 it would take 0.8 kg/d of gain for the H treatment to meet target BW of 60% mature weight.

Programmed gains in year 2 were lower than the programmed gains in year 1 for two reasons: initial weights of heifers were greater in year 2 compared to year 1, and mature weight estimate was lower (522 kg in yr 1, 496 kg in yr 2). Therefore, the ADG required for heifers assigned to H was lower in yr 2, and other treatments were adjusted accordingly. Heifer NEm and NEg requirements along with predicted DMI required to meet targeted programs of growth are depicted in table 2.

Daily feed amounts for each animal were determined as in year 1. At 330 ± 30 d of age heifers (275 ± 52 kg) began programmed treatments with daily feeding at 0800h. Beginning on d 49 heifers were adapted to their increased P2 daily intake over a 7-d period. Weekly blood samples were obtained from d 0 to 90 as described for year 1.

Feed samples were collected weekly and stored at -20°C then thawed and composited for each phase. Fecal samples were frozen and stored at -20°C. Fecal output was estimated using ADIA as an internal marker. A fecal grab sample was collected from each heifer on d 46 and 48 (during final week of P1) and d 87 and 89 (during final week of P2, prior to initiation of estrus synchronization); dietary ADIA was determined from feed samples collected during same weeks.

On d 90, heifers were synchronized and artificially inseminated using the same protocol as year 1. Following AI, heifers were held for six days prior to being exposed to bulls on a common pasture for 60 d. Pregnancy status was determined by blood test on d 130 and d 218 of the study via Pregnancy Specific Binding Protein assay (Texas Veterinary Medical Diagnostic Laboratory, College Station, Texas, USA).

Laboratory analysis

Feed and fecal samples were dried in a forced-air oven for 96 h at 55°C and allowed to air-equilibrate then weighed for determination of partial DM. Feed samples were composited within phase while fecal samples were composited within heifer for each phase. Feed and fecal samples were then ground through a 1-mm screen using a Wiley Mill (Thomas Scientific, Swedesboro, NJ) and dried at 105°C for 24 h for determination of DM. Organic matter was determined as the loss in dry weight upon combustion in a muffle furnace for 8 h at 450°C. Analysis for ADF was performed using an Ankom Fiber Analyzer with sodium sulfite omitted and without correction for residual ash (Ankom Technology Corp., Macedon, NY) and determination of ADIA was accomplished by combusting ADF residue in a muffle furnace for a minimum of 8 h at 450°C. Energy values were determined by direct calorimetry using a Parr 6300 Calorimeter (Parr Instrument C., Moline, IL). Individual diet ingredients were sent to a commercial laboratory (SDK labs, Hutchinson, KS) for analysis of crude protein and total digestible nutrients (TDN).

In year 1, circulating progesterone levels were determined using a commercial RIA kit (Coat-A-Count, Siemens Healthcare, Malvern, PA). Samples were thawed in a refrigerator for 12 h and 100 µl of serum was pipetted into coated tubes. Progesterone-^{I25} (1 ml) was added and tubes were centrifuged and incubated for 2 h at 37°C before being decanted and counted on a gamma counter. Blood analysis for pregnancy determination was performed by Texas A&M Veterinary Medical and Diagnostic Lab (College Station, TX) via BioPRYN bovine pregnancy test (BioTracking, Inc., Moscow, ID).

Year 2 circulating progesterone levels were determined using a TOSOH AIA-360 Automated Immunoassay Analyzer (Goregaon, Mumbai, India). Blood analysis for pregnancy determination was performed by Texas A&M Veterinary Medical and Diagnostic Lab (College Station, TX) via BioPRYN bovine pregnancy test (BioTracking, Inc,. Moscow, ID).

Calculations

Fecal production was calculated as:

$$\text{Fecal production, kg DM/d} = \frac{\text{Diet ADIA (g/d)}}{\text{Fecal ADIA concentration (g/kg DM)}}$$

Where:

Diet ADIA = ADIA in Diet (g/kg DM) × DMI (kg/d)

Digestibility of DM, OM, ADF were calculated using:

$$\text{Digestibility, \%} = \left(\frac{\text{Intake} - \text{Fecal}}{\text{Intake}}\right) \times 100$$

Where:

Intake = DMI (kg/d) × dietary nutrient concentration (% DM)

Fecal = Fecal production (kg DM/d) × fecal nutrient concentration (% DM)

Digestible energy intake (DEI) was calculated using:

DEI, Mcal = GEI – FE

Where:

GEI = DMI (kg) × Dietary energy concentration (Mcal/kg DM)

FE = Fecal production (kg DM/d) × Fecal energy concentration (Mcal/kg DM)

Heat energy (HE) was calculated using:

HE= MEI-MEg

Where:

Metabolizable energy intake (MEI) = ME of diet × kg of DM intake

ME of diet = 2.84 Mcal/kg

Metabolizable energy for gain (MEg) = (RE / NEg of the diet) × ME of diet

$RE = 0.0635 \times EBW^{0.75} \times EBG^{1.097}$

$NEg \text{ of diet} = 1.42ME - 0.174ME^2 + 0.0122ME^3 - 1.65$

Cost of development (COD) was calculated using:

COD ($/hd) = Calf cost + Feed cost + Grazing Fee + Yardage Fee

Where:

Calf cost = $668/heifer

Feed Cost ($/hd) = (TMR cost ($/kg) × DMI in P1 (kg/d)) + ((TMR cost ($/kg) × DMI in P2 (kg/d))

Grazing fee = $0.67/heifer/d

Days charged to grazing in year 1 = 93 ± 4

Days charged to grazing in year 2 = 108

Yardage fee = $0.40/heifer/day

Days in confinement = 90 (both years)

Net cost per pregnancy (NCPP) was calculated for each treatment using:

CPP ($/pregnancy) = COD ($/hd) / Pregnancy rate (%)

Realized Cost per pregnancy (RCPP) was calculated for each treatment using:

RCPP ($/pregnancy) = CPP - (Value of open heifer × (1 – Pregnancy rate)

Where:

Value of an open heifer = $945

Cattle prices reflect average prices of the sale barns in the region during the two years of the study. Grazing rate was assigned to cover costs of pasture fertilizer and labor, and yardage fee represents non-research daily operating overheifer costs at the McGregor Research Center, McGregor, TX.

Statistical analysis

Animals were individually fed for the entirety of treatment application periods, and thus served as the experimental unit in all analyses. Average daily gain was determined for each animal by regressing BW on study day within each growth period using regression procedures of SAS (SAS Inst., Inc., Cary, NC). Slope coefficients (ADG values) and other continuous response variables were analyzed using mixed model procedures of SAS, where the effects model included fixed effect of treatment and year, and heifer sire type was included as a random effect. Pregnancy and pubertal data were analyzed using binomial distribution in the GLIMMIX procedure of SAS (SAS Inst., Inc., Cary, NC). The effects model included treatment and year, while sire type was included as a random effect. Significance was determined at $P \leq 0.05$.

Results and Discussion

At weaning heifers in year 2 weighed more than heifers in year 1 and heifer dams weighted less in year 2 than year 1, these differences reduced the amount of gain required to achieve the targeted weight. Ultimately, these differences led to a treatment × year interaction ($P < 0.01$) effect on DMI in P1. Accordingly, there was a treatment × year interaction ($P \leq 0.05$) for all response variables in P1 that were driven by DMI (GEI, DEI, ADG, programmed and observed MEI, programmed HE and RE). There was no treatment × year interaction ($P \geq 0.09$) of P2 DMI; however, there was a treatment × year interaction ($P \leq 0.05$) for programmed and observed MEI, HE and programmed RE. All treatment × year interactions were driven by treatment structure and ordering of response was not changed only magnitude of response; therefore, data from both years were pooled and re-analyzed without the interaction term.

By design, ADG in P1 was greatest for heifers receiving the H treatment, intermediate for heifers on the M treatment, and lowest for the heifers on the L treatment ($P < 0.01$; Table 3). Heifers receiving the L and M treatments exceeded target ADG by 0.35 and 0.25 kg/d, respectively and heifers receiving the H treatment exceeded their targeted ADG by 0.05 kg/d. By design, DM, GE, and DE intake differed among treatments during P1 ($P < 0.01$; Table 4); each was greatest for heifers receiving the H treatment, intermediate for heifers receiving the M treatment, and least for those heifers receiving the L treatment. Organic matter digestion in P1 was greater for heifers receiving the L (84%) treatment compared to heifers on the H treatment (80%; $P < 0.01$); heifers receiving the M treatment were intermediate to and not different ($P \geq 0.09$) from heifers receiving either the L or H treatments. There were no significant differences among treatments ($P = 0.42$) in ADF digestion during P1.

Table 3. Average daily gain and total weight gain of heifers developed on three levels of phase feeding

Item	Treatment[1]			SEM	*P-Value*
	Low	Medium	High		
Phase 1					
ADG, kg/d[2,3,4]	0.35[c]	0.68[b]	0.85[a]	0.07	< 0.01
G:F[4]	0.14[b]	0.19[a]	0.19[a]	0.03	< 0.01
Phase 2					
ADG, kg/d[2,4]	1.23	1.24	1.16	0.10	0.80
G:F[4]	0.22[a]	0.22[a]	0.20[b]	0.01	< 0.01
Total					
Total ADG, kg/d[4]	0.81[b]	0.95[a]	0.97[a]	0.03	< 0.01
Total Wt. Gained, kg[4]	61.2[c]	72.1[b]	82.2[a]	2.73	< 0.01

[a,b,c]Within a row, means without a common superscript differ (P < 0.05)
[1]Treatments represent programmed rates of gain. Year 1 Phase 1: Low, 0.00 kg/d; Medium, 0.45 kg/d; High, 0.80 kg/d; all heifers were programmed to gain 1.36 kg/d in phase 2. Year 2 Phase 1: L = Low, 0.00 kg/d; M = medium, 0.40 kg/d; H = high, 0.80 kg/d; all heifers were programmed to gain 0.80 kg/d in Phase 2
[2]Average daily gain was calculated by regressing individual BW
[3]Treatment × Year ($P = 0.05$)
[4]Year ($P \leq 0.03$)

Table 4. Intake and diet digestion by heifers developed on three levels of phase feeding

	Treatment[1]				
Item	Low	Medium	High	SEM	*P-Value*
Phase 1					
DM Intake, kg/d[2,3]	2.54[c]	3.54[b]	4.59[c]	0.17	< 0.01
Energy Intake, Mcal/d					
GE[2,3]	10.8[c]	14.9[b]	20.3[a]	0.40	< 0.01
DE[2]	8.81[c]	12.5[b]	16.3[a]	0.33	< 0.01
Digestion, %					
OM	84.0[a]	82.0[ab]	80.0[b]	2.00	< 0.01
ADF	63.0	61.0	62.0	3.00	0.42
Phase 2					
DM Intake, kg/d[3]	5.56[c]	5.90[b]	6.06[a]	0.48	< 0.01
Energy Intake, Mcal/d					
GE[3]	24.3[b]	25.6[a]	25.9[a]	0.45	< 0.01
DE[3]	19.0[b]	20.4[a]	20.9[a]	0.51	< 0.01
Digestion, %					
OM	77.0	79.0	80.0	2.00	0.06
ADF	63.0	64.0	65.0	3.00	0.44

[a,b,c]Within a row, means without a common superscript differ (P < 0.05)
[1]Treatments represent programmed rates of gain. Year 1 Phase 1: Low, 0.00 kg/d; Medium, 0.45 kg/d; High, 0.80 kg/d; all heifers were programmed to gain 1.36 kg/d in phase 2. Year 2 Phase 1: L = Low, 0.00 kg/d; M = medium, 0.40 kg/d; H = high, 0.80 kg/d; all heifers were programmed to gain 0.80 kg/d in Phase 2
[2]Treatment × Year ($P \leq 0.02$)
[3]Year ($P \leq 0.01$)

Greater digestion by heifers receiving the L treatment during P1 can be attributed to lower intake which allowed for a slower passage rate and greater extent of ruminal digestion (Blaxter et al., 1964; Ellis 1978). Modeled by Mertens (1983), increased feed intake increases passage rate, and therefore decreases digestion. Murphy et al., (1994) observed an increase in OM digestion by lambs fed a concentrate diet from 77.7% in lambs fed *ad libitum* to 80.6% and 81.5% in lambs fed at 90 and 80% of *ad libitum* intake, respectively. Murphy et al. (1994) found that restricting intake of concentrate diets from *ad libitum* to 90 and 80% *ad libitum* intake linearly ($P < 0.01$) increased measured NE values of the diet for maintenance and gain, suggesting that diet utilization increased resulting in an effective increase in dietary ME concentration.

The ratio of ME to DE used by the NRC (1984) was 0.82 and according to updated NRC publications (2000, 2016) the ME:DE for most forages and mixtures of forages and cereal grains is approximately 0.80, however; Vermorel and Bickel (1980) presented data that suggested growing cattle can have an ME:DE ranging from 0.82 to 0.93. Data from Hales et al. (2012) also support ME:DE ratios greater than 0.8. Conversely, Hemphill et al. (2018) reported a range of ME:DE from 0.74 to 0.82 in bred heifers being limit-fed a cornstalk based diet. The current study did not measure urinary and gas energy losses; therefore, the 0.82 ME:DE ratio suggested by the NRC was used when predicting performance and calculating ME values of diets.

Using observed DE and a ME:DE ratio of 0.82 to calculate ME concentration, ME concentration of the H treatment was 2.82 Mcal/kg, 2.84 Mcal/kg for the M treatment and 2.91 Mcal/kg for the L treatment. This suggest that as degree of intake restriction increases further from *ad libitum* intake, ME values increase. Similar to this observation, Murphey et al. (1994) found that as intake decreased further from *ad libitum* the ME content of the ration becomes slightly higher than predicted by tabular values from NASEM (2016).

Increased digestion and the corresponding increase in ME concentration of the diet for heifers receiving the L treatment resulted in greater than expected ME intake. Observed ME intake (7.36 Mcal/d) for heifers receiving the L treatment was 0.18 Mcal/d greater than the programmed ME intake (7.18 Mcal/d). Observed ME intake (10.08 Mcal/d) for heifers receiving the M treatment was not different from programmed ME intake (10.08 Mcal/d), and observed ME intake of heifers receiving the H treatment (13.68 Mcal/d) was 0.10 Mcal/d less than programmed ME intake (13.78 Mcal/d; Table 5). This agrees with data presented by Galyean et al., 1979; Zinn and Owens, 1983; and Murphy et al., 1994, who found that limit-feeding can increase diet energy utilization. For the H treatment, a ME:DE ratio of 0.85 (rather than 0.82) would be required to account for the difference between programmed and observed gains. However, to account for differences in programmed and observed gains in heifers receiving the L and M treatments, ME:DE ratio would have to be 1.02 and 0.97, respectively. However, because the diet used in the current study was a growing diet with a mixture of forage and concentrate, it is reasonable to believe that the ME:DE ratio of these heifers is similar to that reported by Hemphill et al. (2018). Therefore, while some increase in ME conversion from DE above 0.82 may have occurred, it is unlikely that such increases alone explain the deviation in observed versus programmed outcomes. Therefore,

Table 5. Programed and observed maintenance and retained energy of heifers developed on three levels of phase feeding.

Item	Treatment[1] Low	Medium	High	SEM	*P-Value*
Phase 1					
MEI, mcal[2]					
Programmed[3,4]	7.18^{c}	10.08^{b}	13.78^{a}	0.18	< 0.01
Observed[4]	7.36^{c}	10.08^{b}	13.68^{a}	0.18	< 0.01
Maintenance energy, Mcal ME $\cdot d^{-1}$					
Programmed[3,4]	7.18^{b}	7.22^{b}	7.75^{a}	0.17	< 0.01
Observed[4]	4.81^{b}	5.11^{b}	7.22^{a}	0.26	< 0.01
Difference in Programmed and Observed ME	2.37^{a}	2.11^{a}	0.50^{b}	0.27	< 0.01
Retained energy, Mcal ME $\cdot d^{-1}$					
Programmed[3]	0.00^{c}	1.27^{b}	2.66^{a}	0.04	< 0.01
Observed[4]	1.16^{c}	2.18^{b}	2.85^{a}	0.13	< 0.01
Phase 2					
MEI, mcal[2]					
Programmed[3,4]	15.71^{c}	16.60^{b}	17.30^{a}	0.35	< 0.01
Observed[4]	15.49^{b}	16.67^{a}	17.24^{a}	0.35	< 0.01
Maintenance energy, Mcal ME $\cdot d^{-1}$					
Programmed[3,4]	7.13	7.53	7.59	0.25	0.07
Observed[4]	5.17^{c}	5.91^{b}	6.72^{a}	0.36	< 0.01
Difference in Programmed and Observed ME	1.93^{a}	1.63^{ab}	0.88^{b}	0.47	0.03
Retained energy, Mcal ME $\cdot d^{-1}$					
Programmed[3,4]	3.72^{b}	3.93^{ab}	4.21^{a}	0.21	0.02
Observed[4]	4.51	4.64	4.56	0.19	0.52

[a,b,c]Within a row, means without a common superscript differ ($P < 0.05$)

[1]Treatments represent programmed rates of gain. Year 1 Phase 1: Low, 0.00 kg/d; Medium, 0.45 kg/d; High, 0.80 kg/d; all heifers were programmed to gain 1.36 kg/d in phase 2. Year 2 Phase 1: L = Low, 0.00 kg/d; M = medium, 0.40 kg/d; H = high, 0.80 kg/d; all heifers were programmed to gain 0.80 kg/d in Phase 2

[2]Metabolizable energy intake (MEI) = DMI * ME of diet

[3]Treatment × Year ($P \leq 0.02$)

[4]Year ($P \leq 0.05$)

increased efficiency, measured as greater than predicted gain, is at least partially attributed to decreased requirements for maintenance. Trubenbach et al. (2019) reported that limit-feeding reduced apparent maintenance requirements in cows.

Programmed ME (Mcal of ME·d^{-1}; Table 5) is the difference in programmed ME intake (MEI; Mcal of ME·d^{-1}) and programmed ME for gain, observed ME is the difference between observed MEI and observed ME for gain. Programmed ME used for maintenance in P1 was least for the heifers on the L treatment (7.18 Mcal/d), heifers on the M treatment (7.22 Mcal/d) were not different from heifers on the L treatment; however, heifers on the H treatment had a programmed ME requirement for maintenance greater than both the L and M treatments (7.75 Mcal/d; $P < 0.01$). Greater programmed ME required for maintenance observed in heifers receiving the H treatment is attributed to a heavier programmed midpoint BW, thus increasing maintenance requirement. Programmed ME required for maintenance averaged across all three treatments was 7.38 Mcal/d.

Observed ME used for maintenance (calculated by the difference in observed MEI and observed ME used for gain) in P1 was greater ($P < 0.01$) for heifers on the H treatment (7.22 Mcal/d) compared to heifers fed the M (5.11 Mcal/d) and L (4.81 Mcal/d) treatments, which were not different ($P = 0.44$). Observed ME required for maintenance was 33% less than programmed ME required for maintenance for heifers receiving the L treatment, 29% less for heifers receiving the M treatment and 7% less for heifers receiving the H treatment (Table 5).

The calculations in the NRC (1996, 2016) utilize rate of gain and EQSBW in the calculation to account for differences in composition of gain. In our calculations it was assumed that compositional changes in energy required for growth due to a change in rate of gain are accounted for by the EQSBW scalar; therefore, all of the differences are attributed to reductions in maintenance requirements. Previous publications (NRC, 1984; Carstens et al., 1991) suggest that the increase in growth efficiency observed in cattle during and following a period of limit-feeding is attributed to a decrease in NEg requirements rather than a decrease in maintenance. Specifically, NRC (1984) recommends decreasing NEg requirements by 11.4% and Carstens et al. (1991) suggest that NEg requirements of feedlot steers be decreased by 18% following a period of limit-feeding. However, the NASEM (2016) recommends NEm requirements be decreased during limit-fed situations. While we recognize that almost certainly requirements for both maintenance and growth are altered, it is often convenient to attribute differences to one or the other, and because the EQSBW scalar accounts for shifts in composition, and growth rate is directly observable, we have assigned differences to alterations in maintenance requirements.

Phase 2 ADG was similar ($P = 0.80$) among treatments. Heifers that were programmed on the L and M treatments had observed ADG that were 0.15 and 0.16 kg, respectively, greater than programmed. Heifers programmed on the H treatment had an observed ADG 0.08 kg greater than the programmed ADG (Table 3).

By design, DMI in P2 was different among the three treatments ($P < 0.01$). Although heifers were programmed to have the same rate of gain during P2, DMI differed because of differences in BW at the end of P1 resulting in different predicted energy requirements to achieve P2 targeted rates of gain (Table 2). Accordingly, intake of heifers receiving the M treatment in P2 was 97% of the intake received by heifers on the H treatment in P2, and intake of heifers receiving the L treatment in P2 was 92% of the intake received by heifers on the H treatment in P2. Phase 2 GE and DE intake were similar ($P \geq 0.24$) for heifers on the H and M treatments (Table 4), averaging 25.8 Mcal/d GE and 20.6 Mcal/d for DE, while heifers on the L treatment consumed 24.3 Mcal/d GE and 19 Mcal/d DE ($P < 0.01$). Because DMI intake was different amongst all three treatments ($P < 0.01$) it would be expected that energy intake would differ amongst treatments as well. However, the 3% difference in DMI between the M and H treatments was not great enough to cause a significant difference in energy intake.

There was a tendency ($P = 0.06$) for OM digestion greater for the H and M treatments compared to the L treatment ($P > 0.06$; Table 4). Heifers receiving the L and M treatments had a 7 and 3% reduction in OM digestion in P2 compared to P1 and heifers on the H treatment had no change in digestion between periods. Feed offered and consumed by heifers on the L treatment was nearly 55% greater in P2 compared to P1, while consumption by heifers on the M treatment was 40% greater, and consumption of heifers receiving the H treatment was 24% greater. While programmed ADG of heifers receiving the H treatment was not different between P1 and P2, programmed midpoint BW in P2 was greater than P1 therefore feed offered was increased to address greater requirements. Decreased digestion observed in heifers receiving the L and M treatments during P2 compared to P1 is accounted for by the greater DMI. Observed and programmed ME intakes were similar within the M and H treatments; however, because of the reduced digestion by heifers receiving the L treatment, had slightly lower observed ME intake (15.49 Mcal/d) compared to programmed ME intake (15.71 Mcal/d; Table 5).

By design, programed and observed phase 2 MEI was greater in all treatments than P1 MEI ($P \leq 0.05$) and treatment rankings were similar with heifers fed the H treatment having the greatest MEI, those fed the M treatment being intermediate, and heifers fed the L treatment having the lowest MEI ($P < 0.01$). However, observed MEI in P2 was not different between heifers receiving the H and M treatments ($P = 0.14$) and were both greater ($P < 0.01$) than the MEI of heifers receiving the L treatment. Even though all treatments in P2 were programmed to have the same rates of gain, MEI targets differed as a result of BW differing between the three treatments at the end of P1.

In P2, there was a tendency ($P = 0.07$) for heifers receiving the H and M treatments to have a greater programmed ME requirement for maintenance compared to the heifers receiving the L treatment. Heifers receiving the H and M treatments had a programmed maintenance requirements of 7.59 and 7.53 Mcal/d, respectively, while heifers on the L treatment had a programmed ME requirement for maintenance of 7.13Mcal/d. While not statistically different, the 0.46 Mcal/d difference in programmed ME required for maintenance between the H and L treatment can be attributed to differences in BW at the start of P2.

Observed ME required for maintenance for heifers in P2 receiving the L treatment was 27% less than programmed ME required for maintenance, 21% less for heifers on the M treatment, and 11% less for heifers receiving the H treatment (Table 5). While all heifers had lower observed ME for maintenance values than programmed, the deviation increased as P1 target rates of gain decreased.

Limiting feed intake below *ad libitum* levels has been shown to improve feed efficiency Plegge 1987; Hicks et al. 1990; Loerch and Fluharty 1998). In P1, programmed maintenance energy requirements of heifers receiving the L treatment was 33% greater than observed maintenance energy, 29% greater than observed maintenance energy in heifers receiving the M treatment and 7% greater for heifers receiving the H treatment, suggesting that the degree of limit-feeding directly affects energy utilization. Loerch and Fluharty (1998) limit-fed cattle diets containing 3 Mcal ME/kg, and concluded that NRC (1984) equations became less accurate in predicting gain as intakes were reduced further from *ad libitum*. Similarly, Sainz et al. (1995) observed that maintenance energy requirements in steers being limit-fed 70% of *ad libitum* decreased by 17% compared to *ad libitum* fed steers. Our results suggest that maintenance energy requirements of heifers being limit-fed during the growing phase should be reduced between 20-35% dependent on degree of intake restriction; a magnitude of reduction similar to that observed in cows by Freetly et al. (2008) and Trubenbach et al., (2019).

Total weight gain was greatest ($P < 0.01$) for heifers on the H treatment at 82.2 kg and was not different from the programmed target weight of 83.5 kg. Heifers on the M treatment gained a total of 72.1 kg, exceeding targeted total weight gain of 65.1 kg by 10.7%. Heifers receiving the L treatment gained 61.2 kg (Table 3), exceeding targeted amount of growth (44.3 kg) by 38.1%. Day 49 BW was different between all three treatments by design; however, by day 90, BW of heifers receiving the H and M treatments were not separable (*P* = 0.16) and were greater than heifers receiving the L treatment (*P* < 0.01; Table 6).

Table 6. Body weight measurements and percent of mature body weight at breeding of heifers developed on three levels of phase feeding

	Treatment[1]				
Item	L	M	H	SEM	*P-Value*
BW, kg					
d 0[4]	211	214	218	7.96	0.08
d 21[4]	219[c]	230[b]	239[a]	7.33	< 0.01
d 49[4]	228[c]	246[b]	259[a]	7.71	< 0.01
d 77	269[b]	286[a]	295[a]	5.89	< 0.01
d 90	282[b]	300[a]	308[a]	6.43	< 0.01
Mature BW at Breeding, %[2]	56.4[b]	59.8[a]	61.4[a]	2.72	< 0.01

[a,b,c]Within a row, means without a common superscript differ (P < 0.05)
[1]Treatments represent programmed rates of gain. Year 1 Phase 1: Low, 0.00 kg/d; Medium, 0.45 kg/d; High, 0.80 kg/d; all heifers were programmed to gain 1.36 kg/d in phase 2. Year 2 Phase 1: L = Low, 0.00 kg/d; M = medium, 0.40 kg/d; H = high, 0.80 kg/d; all heifers were programmed to gain 0.80 kg/d in Phase 2
[2]Percent of mature Wt. at breeding: individual dam Wt. was used to calculate the percent of mature Wt. for each individual heifer at breeding.
[3]Treatment × Year ($P \geq 0.08$)
[4]Year ($P \leq 0.05$)

At the time of breeding, heifers on the H treatment had reached 61.4% of their mature weight, heifers on the M treatment had reached 59.8% of their mature weight and heifers receiving the L treatment had reached 56.4% of their mature weight (Table 6). Heifers receiving the H treatment were programmed to achieve 60% of their mature weight, suggesting that the model worked extremely well when programming the H treatment. However, heifers receiving both the M and L treatments exceeded their targeted % of mature BW. Heifers receiving the M treatment exceeded targeted % of mature BW by nearly 5% and heifers receiving the L treatment exceeded targeted % of mature BW by 6.4%, suggesting that as intake decreases further from *ad libitum* available prediction models become less accurate.

There were no differences ($P = 0.85$) in the percent of heifers who had achieved circulating levels of progesterone of ≥ 1.0 ng/ml prior to estrus synchronization (Table 7), averaging 30.7% across all three treatments. Pregnancy rates were similar across all treatments ($P = 0.19$) averaging 88.5%. Julian calving date was greater ($P = 0.05$) for heifers receiving the H treatment at 68.3 compared to heifers receiving the M and L treatments which were not different from each other at 61.7 and 63.1, respectively, suggesting that heifers on the L and M treatment had a greater proportion of heifers pregnant earlier in the breeding season, either through AI or natural service, compared to heifers on the H treatment (Table 7).

Patterson et al. (1992) recommended targeting a BW of 60 to 66% of mature weight prior to breeding heifers. Contrary to the Patterson et al. (1992) study, heifers receiving the L treatment only reached 56.4% of their mature weight at breeding; however, conception rate was not different from heifers on the M and H treatments which were both closer to the target recommended by Patterson et al, (1992). This agrees with data presented by Funston and Deutscher (2008) who conducted a heifer development study comparing conception rates of heifers developed to 55 and 60% of mature BW and found no differences in conception rates.

Table 7. Pregnancy rates, Julian calving date, mean calving days from AI and feed cost per pregnancy of heifers developed on three levels of phase feeding.

Item	Treatment[1,3,4] Low	Medium	High	SEM	*P-Value*
Pregnant, %	85.9	95.0	84.7	4.74	0.19
Cycled by d 84, %[2]	28.4	30.2	33.4	6.39	0.85
Julian calving date	63.1[ab]	61.7[b]	68.3[a]	3.29	0.05
Mean calving days from AI	294.1	292.7	299.2	3.05	0.06
Feed cost per pregnancy, $/heifer	68.31[c]	80.64[b]	92.04[a]	1.23	< 0.01
Cost of development, $/heifer	827.15[c]	838.10[b]	848.21[a]	1.68	< 0.01
Net CPP, $/heifer	966.59[b]	883.55[c]	1004.43[a]	1.92	< 0.01
Realized CPP, $/heifer	862.64[a]	831.57[c]	857.96[b]	1.91	< 0.01

[a,b,c]Within a row, means without a common superscript differ (P < 0.05)
[1]Treatments represent programmed rates of gain. Year 1 Phase 1: Low, 0.00 kg/d; Medium, 0.45 kg/d; High, 0.80 kg/d; all heifers were programmed to gain 1.36 kg/d in phase 2. Year 2 Phase 1: L = Low, 0.00 kg/d; M = medium, 0.40 kg/d; H = high, 0.80 kg/d; all heifers were programmed to gain 0.80 kg/d in Phase 2
[2]Represent those heifers who have had circulating levels of progesterone of ≥ 1.0 ng/ml at least once.
[3]Treatment × Year ($P \geq 0.34$)
[4]Year ($P \geq 0.08$)

Lynch et al. (1997) conducted a two year study developing heifers either on a phase feeding regime, similar to the current study, or an even gain strategy and found that in year one there was no differences in the timing of puberty among strategies. However, in year two Lynch et al. (1997) found that heifers being developed on a phase feeding regime were pubertal (circulating progesterone levels ≥ 1 ng/ml) later compared to heifers developed on an even gain regime. Additionally, they observed only 51% of heifers had reached puberty at the initiation of the breeding season, but by day 60 of the breeding period all heifers had reached puberty. Although only 30.7% of heifers in the current study had attained puberty at the onset of breeding, conception rates were in accordance with expected rates (Funston and Deutscher, 2004, Martin et al., 2008). Estrus synchronization has been shown to induce puberty in heifers (Short et al., 1976; Patterson et al., 1990) and could explain why pregnancy rates were acceptable, despite the relatively low percentage of heifers with circulating progesterone levels of ≥ 1.0 ng/ml prior to AI.

Feed cost, and therefore total cost of development, was greatest ($P < 0.01$) for heifers receiving the H treatment, intermediate for heifers on the M treatment, and least for heifers on the L treatment (Table 7). Net cost per pregnancy (NCPP) was greatest ($P < 0.01$) for heifers receiving the H treatment, intermediate for heifers receiving the L treatment and least for heifers receiving the M treatment. Realized cost per pregnancy (RCPP) was greatest ($P < 0.01$) for heifers receiving the L treatment, intermediate for heifers receiving the H treatment and least for heifers receiving the M treatment (Table 7). Decreased NCPP observed in heifers receiving the M treatment can be attributed to the numerically greater percentage of heifers who became pregnant on the M treatment compared to the L and H treatments. While not statistically different ($P = 0.19$) heifers receiving the M treatment had only 3 open heifers across both years compared to 8 and 9 open heifers for the L and H treatments, respectively. Therefore, even though cost of development (COD) was less for the heifers receiving the L treatment, because of the greater number of open heifers in the L treatment compared to the M, the net cost per pregnancy was least for the heifers on the M treatment. A similar trend was observed in RCPP, but because the potential income value of open heifers (marketed as 750lb feeder heifers) is accounted for, the realized cost per pregnancy is reduced. It is important to note that RCPP varies based on market value of feeder heifers. In the current scenario open heifers had a market value of $945/heifer (market value greater than the COD) resulting in RCPP that was $104, $52, and $147 less than the NCPP for the L, M, and H treatments, respectively, due to the recovered cost from selling open heifers at a market value greater than the COD. However, if market value of feeder heifers is less than the COD, then the resulting RCPP is not reduced because COD is not fully recovered from the selling of open heifers. For example, if market value of heifers was $800/heifer, then the resulting RCPP would be greatest ($P < 0.01$) for heifers receiving the H treatment ($944.80/heifer), intermediate for the M treatment ($932.10/heifer), and least for the L treatment ($918.55/heifer).

Conclusion

Utilizing a programmed feeding strategy is an effective method to minimize cost of development when developing heifers without sacrificing reproductive performance.

However, it is important to consider the accuracy of predictive models when programming gains in limit-fed situations. Models used to develop feeding programs may not account for increases in diet utilization or apparent decreases in energy requirements that result from limit-feeding, and the magnitude of difference depends upon the degree of intake restriction. Relying strictly on standard models to program performance and intake likely result in achievement of growth targets but at potentially higher or above-optimal cost. Based on degree of intake restriction, maintenance energy requirements of heifers can be reduced 20-35% and will continue to be lower than predicted during 45 d of realimentation, although to a lesser extent (20%). Efficient and effective development of replacement heifers is critical to sustainable beef production and utilizing a programmed feeding strategy has proven to be an effective method of decreasing cost of development and increasing development efficiency (costs of achieving development goals).

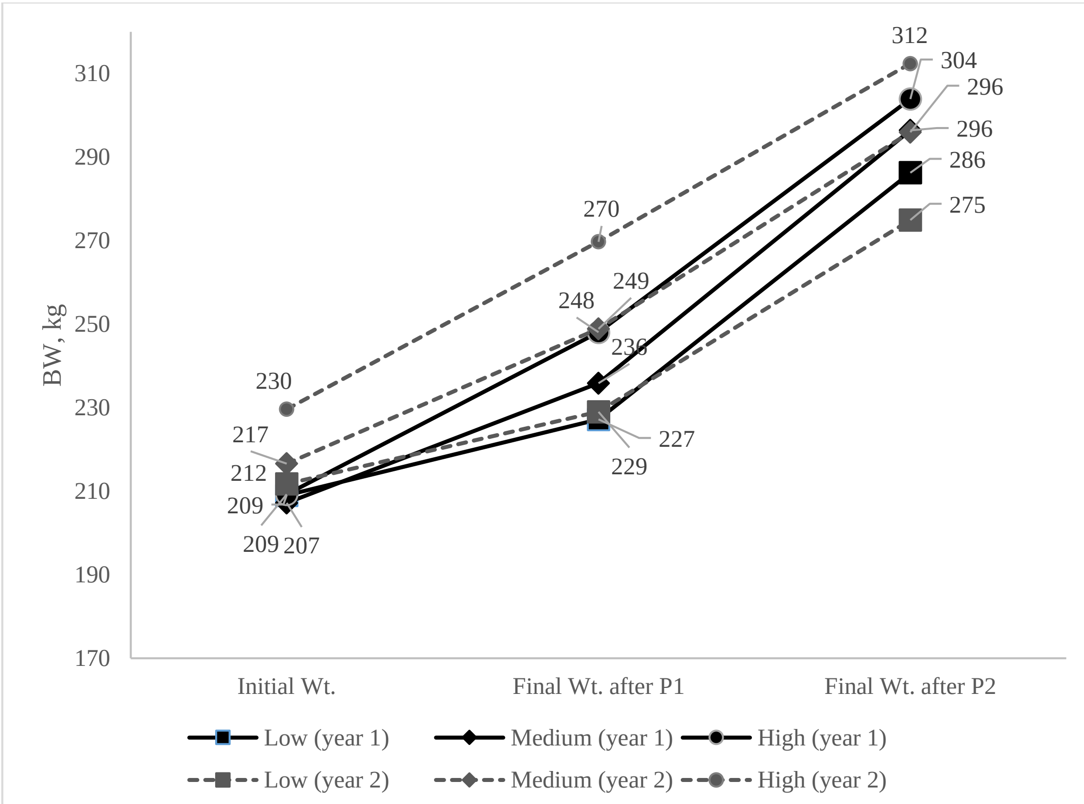

Figure 5. Year 1 and 2 body weights (kg) of heifers based off observed ADG developed on three levels of phase feeding.

CHAPTER III

ROTATIONAL SEMI-CONFINEMENT COW-CALF PRODUCTION

Introduction

In June of 2013 the United Nations projected that the world population will increase from 7.2 billion to 8.2 billion by the year 2025 and to 9.6 billion by the year 2050. Currently in North America, animal sourced proteins provide 68% of total protein consumption (Wu et al., 2014). Both the growing population and increases in per capita income are expected to increase demand for animal-sourced foods; average meat consumption per capita worldwide is expected to increase from 40.0 kg in 2013 to 51.5 kg in 2050 (Herrevo et al., 2013).

Beef cattle production has historically depended on access to grazing lands; however, due to conversion of grass lands into crop lands, recreational lands, and urban sprawl, beef cattle expansion, particularly the cow-calf sector, has been hindered. To meet the nearly 30% increase expected in animal sourced protein demand, with diminishing land available for production, there is a need to increase both production efficiency and land-use efficiency of cow-calf operations. The FAO (2011) proposed intensification of livestock production systems as a solution for meeting global protein demand in the face of decreasing land availability.

In intensified production settings (partial or total confinement) feed costs represent up to 80% of the total production cost (Eizmendi, 2015). In order for intensified cow-calf production to be economically viable, feed costs need to be optimized against production outcomes. Trubenbach et al. (2019) demonstrated that limit feeding cows a high-energy diet can reduce apparent maintenance requirements by 23.5%, potentially increasing energetic efficiency of cow-calf systems and offering a mechanism to control feed costs while maintaining productivity.

Selk (2002) suggested that utilizing a dual calving season potentially allows cattle producers to take advantage of seasonal highs in the cattle market and minimize price risk by spreading their marketing opportunities out. More importantly, utilizing multiple calving seasons can provide open cows another opportunity to conceive within the same production year. Because investment in breeding livestock is a large component of the total cost structure of cow-calf operations, it is important to maximize the productive life of a cow to realize the largest return on investment possible from that cow. Using a systems dynamics model Payne et al. (2009) found that utilizing a dual calving system required less investment in breeding livestock when compared to single season (spring or fall) calving systems, because the dual calving system provided an opportunity for an open cow from either calving herd an additional opportunity to become pregnant reducing the number of cows culled annually.

Sawyer and Wickersham (2013) modeled a semi-confinement cow-calf system and found that by placing cows in confinement for a four month period (1/3 of the year), producers would be able to increase their herd size by 42% without the addition of more land, increasing production efficiency per unit of land.

Based on these studies, we hypothesize that a system employing multiple calving seasons, where cows are managed intensively for a portion of the production year, will increase total production of beef per unit of land area, partially relieving the demand for additional land. To evaluate the feasibility of operating such a system, a three-herd, semi-confinement cow-calf production system was designed to identify challenges and advantages to intensive cow-calf systems devised to increase cow-calf production efficiency without having to purchase more land.

Our experimental objectives were to 1) determine production differences amongst herds calving in different seasons; 2) determine if allowing cows multiple chances to conceive within a production year decreases culling rates and reduces capital investment required for replacement females; and 3) quantify any changes in production efficiency captured by providing cows multiple chances to breed within a year.

Materials and Methods

A five year rotational semi-confinement cow-calf production system (RWB) was implemented using an initial one hundred and thirty-four spring born heifers (¾ Angus × ¼ Nellore). Heifers were separated into three weight groups: heavy, medium, and light. The heavy group was designated as the "red" herd, the medium weight heifers were designated as the "white" herd, and the light weight heifers were designated as the "blue" herd. Heifers were divided to make three unique herds with separate breeding seasons. The red herd calved in the spring (January to February), the white herd calved in the summer (May-June), and the blue herd calved in the fall (September to October).

For each herd, breeding females were housed in a drylot setting for four months per year beginning at calf weaning, and were limit fed a diet consisting of 35% chopped milo stalks, 29.5 % dry rolled corn, 27.5% dried distillers' grains, 6% cane molasses, and 2% mineral/vitamin supplement (Table 8).

Table 8. Ingredient and nutrient composition of diet.

Item	
Ingredient[1]	*% of diet*
Corn – rolled	29.5
Dried distillers' grains	27.5
Milo stalks	35
Molasses	6
Mineral/Vitamin Supplement	2
Component, DM basis, %	
ADF	20.3
CP	15.3
TDN	71.1
ME, Mcal/kg	2.56
NE_m, Mcal/kg	1.78
NE_g, Mcal/kg	1.06

[1]Limit-fed diet fed to all treatments
[2]Calculated as reported by Garrett (1980)

Energy requirements were estimated according to standard equations (NASEM, 2016) to determine the amount of total mixed ration (TMR) to be provided daily during the confinement period. Total requirements were calculated as the sum of maintenance and gestation requirements. Maintenance requirements (NE_m, Mcal/d) were calculated using the equation:

$$NE_m = 0.077 \times EBW^{0.75}$$

$$EBW = SBW \times 0.891$$

$$SBW = BW \times 0.96$$

where EBW = empty body weight, kg; SBW = shrunk body weight, kg; and BW = body weight, kg.

Requirements for gestation (NE_y, Mcal/d) were calculated using the equation:

$$NE_y = [CBW \times (0.4504\text{-}0.000766t) \times e^{(0.03233 - 0.0000275t)t}] / 1{,}000 * k_m$$

$$k_m = NE_m/ME$$

where CBW = calf birth weight, 30 kg; t = days in gestation, d; NE_m = diet NE_m concentration, Mcal/kg; ME = diet metabolizable energy concentration, Mcal/kg

Cows were then fed at 82% of total (maintenance + gestation) energy requirements (Trubenbach et al., 2019).

One month prior to anticipated initiation of calving season, cows were returned to pasture. Following calving season, cows were exposed to bulls for a 42-d natural service breeding season. The same bulls were used for all herds within a given year. Calf processing (branding) took place approximately 70 days after the start of calving, and weaning occurred when calves were approximately 7 months old (Figure 6). Blood samples were collected 30 days after the end of the breeding season by jugular venipuncture into evacuated serum separator tubes, placed on ice, and transported to the Texas Veterinary Medical Diagnostic Laboratory (TVMDL, College Station, Texas, USA) for determination of pregnancy status using Pregnancy Specific Binding Protein assay.

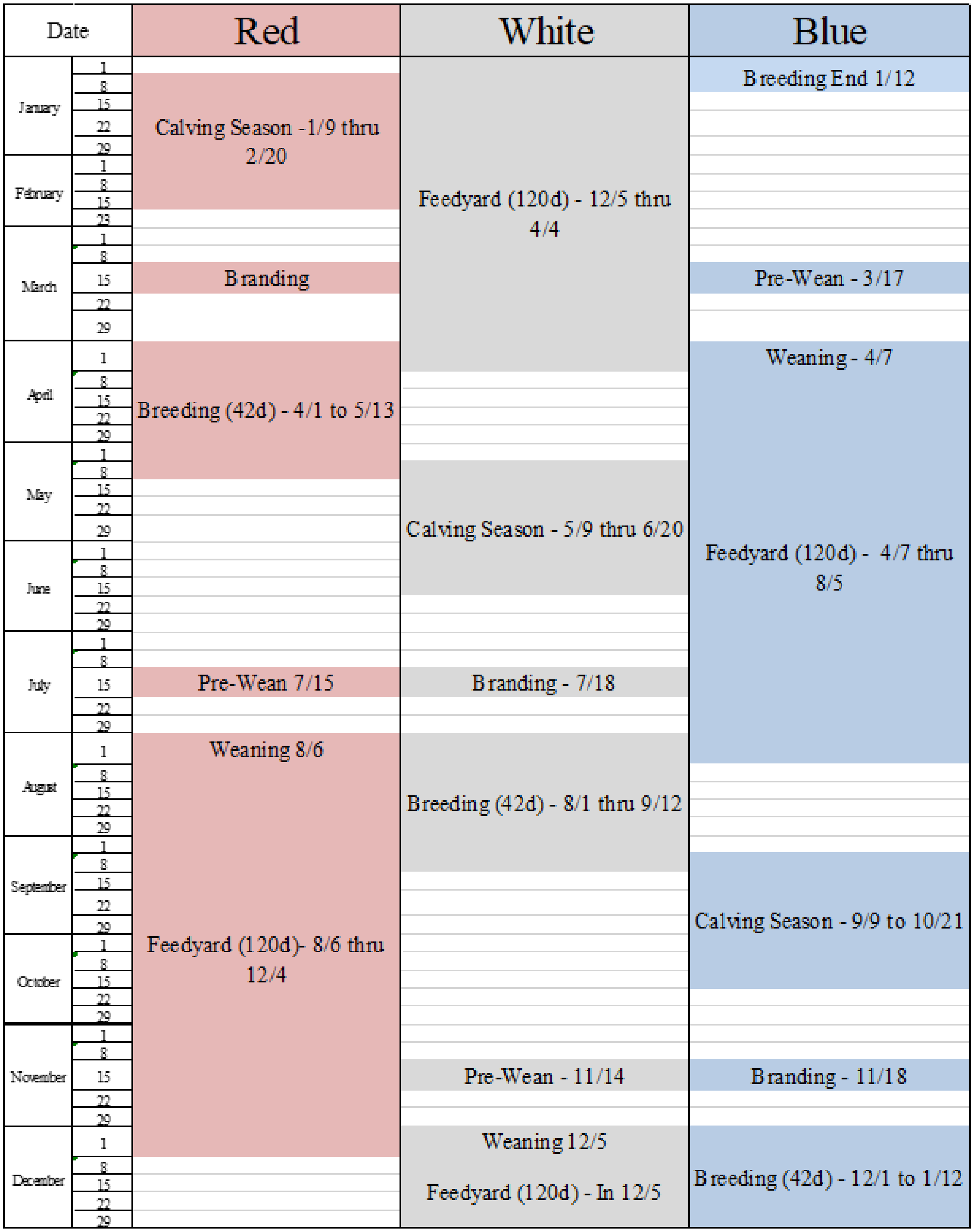

Figure 6. Schedule of RWB production system.

Time of weaning in a given herd corresponded to the initiation of the breeding season in the subsequent herd group; therefore, cows determined open were moved into the subsequent herd group and were exposed for another breeding season, rather than being placed into the feedlot with pregnant cows. Cows were allowed a maximum of two herd movements (2 failures to conceive), allowing for, at most, three chances to conceive within a production year. For example, if a cow in the red herd is open after her designated breeding season she was rolled to the white herd and had another chance to conceive. If she conceives in the white herd she remained in that herd. Cows were assigned a "strike" for every missed breeding opportunity and upon receiving a third strike cows were culled from the program. Every heifer calf born in the red herd was retained and developed under common management as a replacement female, and based on weight (similar to the initial sorting into herds) was assigned to either the red, white, or blue herds during their respective breeding season.

Because some cows appeared in more than one herd within the same year, production year and current herd were added to the ID. That way when a cow rolled to another herd it would be assigned a new ID so that the same ID didn't appear multiple times within a year. For example if cow "22C" started production year 3 in the red herd and was rolled to the white herd, her ID would be "22CRed3" initially but would change to "22CWhite3" when she was rolled to the white herd.

When comparing pregnancy rates between herds there was no difference in pregnancy rates per exposure and pregnancy rates per head. However, it is important to note that due to allowing cows multiple chances to conceive within a year, total pregnancy rates per exposure and per cow are not the same.

To compare our system (RWB), allowing cows multiple chances to breed within a year, to a strict culling system (Strict) a separate data set was created. We used the same cows and the same production data as in the RWB system. However, rather than being rolled to another herd and allowed another chance to breed, open cows were culled and removed from the system. This data set allowed us to compare the RWB system that allowed open cows another chance to breed within the same year to a more typical system that culls open cows immediately.

At calving, calving date, calf sex, and calf weight were recorded. At branding calf weights were recorded, and calves were vaccinated for clostridial diseases (Covexin 8, MERCK Animal Health, Madison, NJ) and respiratory viral diseases using a killed virus vaccine (Triangle 5, Boehringer Ingelheim Animal Health USA, Duluth, GA), and steer calves received a Ralgro implant (MERCK Animal Health. Madison, NJ). Cows were weighed and vaccinated with Covexin 8 (MERCK Animal Health. Madison, NJ) and Triangle 5 (Boehringer Ingelheim Animal Health USA. Duluth, GA) at branding.

Statistical Analysis

To compare productivity among seasonal groups within the 3-group system cow BW, calf birth weight, and 205 d adjusted weaning weight were analyzed using the MIXED procedure of SAS (SAS Institute, Inc., Cary, N.C.) with cow serving as experimental unit. Model effects included herd and year. Pregnancy data were analyzed using binomial distribution in the GLIMMIX procedure of SAS (SAS Institute, Inc., Cary, N.C.). The effects model included herd and year. Significance was determined at $P \leq 0.05$.

To compare the RWB and Strict systems (3-group system allowing 2 strikes to a similar system with strict culling) yearly production data were summarized in excel. Because year is the replicate in this comparison, no treatment × year was testable; therefore, comparisons amongst herds were made using the data summary in excel.

Results and Discussion

Effect of calving season

There was a herd × year interaction ($P < 0.01$) effect on cow BW at feedlot exit, pre-weaning, and weaning (Table 9). Year one feedlot data is not available. In year 2, cows in the red herd had a greater BW ($P = 0.05$) exiting the feedlot compared to the blue herd and the white herd was not different ($P \geq 0.08$) from either the red or blue herds. In year 3, cow BW exiting the feedlot was similar across all herds ($P \geq 0.09$). In year 4, BW of cows exiting the feedlot in the blue herd was greater ($P = 0.01$) than both the red and white herds, which were not different ($P = 0.34$) from each other. Pre-weaning BW in years 1 and 4 was greater ($P \leq 0.01$) for cows in the red herd than cows in both the white and blue herds which were not different ($P \geq 0.53$) from each other. In years 2 and 3, pre-weaning BW of the red and white herds were similar ($P = 0.08$) and were both greater ($P < 0.01$) than the pre-weaning BW of the blue herd. Red herd cow BW at weaning in year 1 was greater ($P < 0.01$) than the white herd and the blue herd was not different ($P \geq 0.07$) from either the red or white herds. Cow BW at weaning were similar ($P \geq 0.07$) between the red and white herds in years 2 and 3, and in both

Table 9. Cow weights coming out of the feedlot, at pre weaning, and at weaning in each of the 4 production years.

Cow Wt., kg	Herds[1] Red	White	Blue	SEM	P-Value
Year 1					
Feedlot exit	n/a	n/a	n/a	n/a	n/a
Pre-weaning	391[a]	358[b]	353[b]	12.1	< 0.01
Weaning	403[a]	356[b]	364[ab]	22.3	< 0.01
Year 2					
Feedlot exit	449[a]	430[ab]	428[b]	11.1	0.05
Pre-weaning	431[a]	445[a]	353[b]	7.81	< 0.01
Weaning	423[a]	437[a]	360[b]	9.10	< 0.01
Year 3					
Feedlot exit	455	463	444	10.7	0.09
Pre-weaning	463[a]	462[a]	364[b]	8.16	< 0.01
Weaning	475[a]	464[a]	372[b]	7.84	< 0.01
Year 4					
Feedlot exit	501[b]	492[b]	521[a]	9.90	0.01
Pre-weaning	484[a]	447[b]	442[b]	8.34	< 0.01
Weaning	488[a]	443[b]	453[b]	8.57	< 0.01

[a,b,c]Within a row, means without a common superscript differ (P < 0.05)
[1]Herd represents spring (Red), summer (White), and fall (Blue) calving herds
[2]Treatment × Year ($P \leq 0.01$)

Table 10. Effect of calving season on cow-calf production.

	Herds[1]				
Item	Red	White	Blue	SEM	P Value
Year 1					
Pregnant, %[2,3]	88.0	83.3	82.9	0.06	0.54
Birth Wt., kg	29.7	30.4	29.9	1.48	0.72
205 d WW, kg[3]	190.5[a]	125.1[c]	146.6[b]	4.41	< 0.01
Year 2					
Pregnant, %[2,3]	68.4[b]	80.5[a]	40.3[c]	0.05	< 0.01
Birth Wt., kg	30.2[b]	33.5[a]	32.7[ab]	1.64	0.03
205 d WW, kg[3]	179.5[a]	152.5[b]	142.8[b]	4.65	< 0.01
Year 3					
Pregnant, %[2,3]	91.7	86.9	89.8	0.06	0.42
Birth Wt., kg	33.6[ab]	34.9[a]	31.6[b]	1.28	0.04
205 d WW, kg[3]	203.0[a]	181.1[b]	185.0[b]	3.62	< 0.01
Year 4					
Pregnant, %[2,3]	79.0	71.4	75.4	0.05	0.17
Birth Wt., kg	31.2[b]	34.0[a]	32.2[ab]	1.16	0.05
205 d WW, kg[3]	194.3[a]	162.7[c]	180.5[b]	3.32	< 0.01
Total					
Pregnant, %[2]	81.8[a]	80.5[a]	72.1[b]	0.03	0.01
Birth Wt., kg	31.2[b]	33.2[a]	31.6[ab]	0.70	0.01
205 d WW, kg	191.9[a]	148.6[c]	163.7[b]	1.99	< 0.01

[a,b,c]Within a row, means without a common superscript differ ($P < 0.05$)
[1]Herd represents spring (Red), summer (White), and fall (Blue) calving herds
[2]Pregnancies per exposure
[3]Treatment × Year ($P \leq 0.01$)

years were greater ($P < 0.01$) than the BW of the blue herd. Year 4 BW at weaning was greater ($P < 0.01$) for the red herd than both the white and blue herds, which were similar ($P = 0.24$).

Pregnancy rate per exposure and pregnancy rate per cow are not the same across all three groups because some cows were exposed more than once within a year; however, when analyzing the effect of season on pregnancy rate, pregnancy rate per exposure and per cow are not different because each cow was only exposed once per season. There was a herd × year interaction ($P < 0.01$) effect on pregnancy rate. In years 1, 3, and 4 there were no differences ($P \geq 0.17$) in pregnancy rates among treatments. However in year 2, the white herd had the greatest ($P < 0.01$) pregnancy rate, the red herd was intermediate, and the blue herd had the lowest pregnancy rate. Overall, average pregnancy rates during the experiment were not different ($P = 0.70$) between the red and white herds which were both greater ($P \leq 0.02$) than the blue herd (Table 10). Year 2 was populated with cows with either their first or second calves at their side, and this likely contributes to the low pregnancy rates observed. It is also important to note that year 2 occurred during a period of below average rainfall and the variation in pregnancy rates observed in year 2 could have been exacerbated by the dry weather. Deutscher et al. (1991) reported that cows calving in the spring had greater fertility than cows calving in the fall. Contrary to the findings of Deutscher et al. (1991), and similar to the results of the current study, Bagley et al (1987), Grings et al (2005) and Reisenauer et al. (2007) all reported no effects of calving season on conception rates.

There was also a herd × year interaction ($P < 0.01$) effect on 205 d adjusted weaning weight. Each year the red herd had a greater ($P < 0.01$) 205 d adjusted weaning weight compared to the white and blue herds. In year 1, the blue herd had a greater ($P < 0.01$) 205 d adjusted weaning weight than the white herd. In years 2 and 3, there was no difference ($P \geq 0.08$) in 205-d adjusted weaning weight between the white and blue herds averaging 166.8 and 163.9 kg, respectively. In year 4, the blue herd had a greater ($P < 0.01$) 205 d adjusted weaning weight at 180.5 kg compared to the white herd at 162.7 kg (Table 10). Grings et al. (2005) found that calves born in early or late spring (February or April) showed a tendency ($P = 0.06$) to wean at heavier weights when compared to June born calves.

The observed herd × year interaction effect on weaning weight can be attributed to variations in both cow milk production and the quality of forage intake which is driven by the precipitation pattern. Calves born from the RWB system all grazed similar forage sources until they were weaned; therefore, the differences in 205 d adjusted weaning weight can be attributed to the quality of available forage during their growth period between birth and weaning. Lyons et al. (2002) described the differences in forage quality and quantity in the different regions of Texas, and demonstrated the variability in CP and digestibility during different months of the year. In the Blackland Prairie region, forage CP and digestibility is greatest during spring, drops off in the summer, and begins to climb again during late winter and early spring.

Spring born (red) calves grazed from the time of birth up to mid-summer which allowed them access to less mature higher-quality forage resulting in greater 205 d weaning weights compared to the white and blue herds. Summer born (white) calves, had access to the same forage types as the red cows but later in the year. By this time the forage was more mature making it less digestible, overall causing a decrease in digestible energy available to the white calves. Fall born (blue) calves would initially be grazing the more mature summer grasses but from November to January would have had access to fresh Texas winter grass along with two months of spring grass prior to weaning, allowing for greater rates of gain compared to the white calves. Overall the variation in 205 d adjusted weaning weights can be attributed to the effect of season on forage quality. Similar to results from our study, Adams et al. (2001) and Grings et al. (2005) found that summer born calves had a lighter weaning weight than calves born in the spring and attributed this to declines in forage quality due to environmental conditions.

There was no herd × year interaction ($P = 0.65$) of birth weights. The white herd average birth weight was greater than ($P = 0.01$) the red herd average birth weight while the blue herd average birth weight was not different ($P \geq 0.07$) from either the red or white herds (Table 10). Although statistically different ($P = 0.01$) there was only a 2 kg difference between red and white herd birth weights. Contrary to the current study, Donald et al. (1962) found that spring born calves had greater birth weights than both summer and fall born calves. Grings et al. (2005) observed no difference in birth weight when comparing spring and summer born calves.

Effect of system on culling rates

During the 5 year study, 241 breeding females were inducted into the system. When comparing the RWB system to the strict culling system, 125 cows in the strict system were culled while only 20 cows in the RWB system were culled. It is important to note that cows in the strict system were culled (removed from the record) immediately after determination of an open pregnancy status while cows in the RWB system were moved into a subsequent herd and allowed another chance to conceive within the same production year. By allowing cows in the RWB system multiple opportunities to conceive within a year, culling rate over the 5 year study was decreased by 40% when compared to the strict culling system (Table 11).

Excluding the original population (as it was the same for each system), and assuming that replacement females will be added at 100% of the culling rate (maintain herd size) and that replacement heifers are valued at $1000 per heifer the investment in replacement breeding livestock over the 5 years would be $125,000 for the strict culling system and only $20,000 for the RWB system. Similarly, Payne et al. (2009) found that investment in breeding livestock was greater for single calving systems compared to a dual calving system that allowed open cows an additional opportunity to conceive in the same production year.

Table 11. Comparison of cow production based on management system.

Item	System[1]	
	RWB	Strict Cull
Year 1		
Breeding Females	126	126
Exposures	140	126
Total Pregnancies	119	110
Pregnancies, %[2]	94.4	87.3
Calves Born	116	108
Calves Weaned	103	95
Cows Culled	3	16
Calves Born / Cow	0.92	0.87
Year 2		
Breeding Females	189	174
Exposures	230	174
Total Pregnancies	149	111
Pregnancies, %[2]	78.8	63.8
Calves Born	149	110
Calves Weaned	140	104
Cows Culled	2	63
Calves Born / Cow	0.79	0.63
Year 3		
Breeding Females	211	135
Exposures	230	135
Total Pregnancies	206	121
Pregnancies, %[2]	97.6	89.6
Calves Born	202	117
Calves Weaned	195	113
Cows Culled	7	14
Calves Born / Cow	0.96	0.87
Year 4		
Breeding Females	229	143
Exposures	274	143
Total Pregnancies	206	111
Pregnancies, %[2]	90.0	77.6
Calves Born	205	111
Calves Weaned	192	107
Cows Culled	8	32
Calves Born / Cow	0.90	0.78
Total		
Breeding Females	241	241
Exposures	874	578
Total Pregnancies	680	453
Pregnancies, %[2]	282	188
Calves Born	672	446
Calves Weaned	630	419
Cows Culled	20	125
Calves Born / Cow	2.79	1.85

[1]RWB represents a semi-confinement cow-calf production system that allowed cows multiple chances to conceive within a year; Strict represents a semi-confinement cow-calf production system that culled all open cows immediately

[2]Percent pregnant represents the number of cows pregnant within a year, not based on exposures

Effect of system on production efficiency

In cow-calf systems, the largest investments are the land and the cows utilizing that land. Therefore, long term maximization of production per unit of land and lifetime production of the cow is important to ensure positive return on investments. In the model presented by Sawyer and Wickersham (2013) revenues per cow did not change, as they assumed no increase in cow productivity; therefore, increases in revenue were attributed solely to the increased capacity of the system. Results of the model suggest that by confining cows for four months out of the year production efficiency per unit of land is increased by more than 42%, as total output increased and land usage for grazing remained constant. While this model demonstrates a management strategy to optimize production per unit of land, it does not consider possible alterations in cow production when cows are allowed multiple chances to conceive within a production year.

In the current study, allowing cows that were open in the RWB system to roll into a subsequent breeding season resulted in 52% more exposures (opportunities to breed) when compared to the strict culling system. It also resulted in 33% more pregnancies over the 5 year study. In the RWB system 672 calves were born compared to 446 calves born in the strict culling system, increasing the number of calves available to market by 34% over the 5 years (Table 11).

Over the 5 year study, cows in the RWB system had 2.79 calves/cow compared to 1.85 calves/cow in the strict system, increasing calves produced per cow by 34%. By confining cows for four months out of the year Sawyer and Wickersham (2013) demonstrated that carrying capacity of the system could be increased without the addition of more land, increasing overall production per unit of land by 42%. Our findings suggest that over a 5 year period, production per cow increases 34% by allowing multiple chances to conceive within a year. Overall, by confining cows for four months out of the year and allowing cows multiple opportunities to conceive production efficiency per unit of land and per cow was increased.

Conclusion

Overall, pregnancy rates in the red and white herds were greater than (P = 0.01) pregnancy rates in the blue herd. Adjusted 205 d weaning weight was different amongst all herds but can be accounted for by the variability in forage quality in each calving season. It appears that when considering a single calving season in Central Texas spring calving is the best option in order to maximize both production of the cow and the calf.

When comparing the RWB system to a strict culling system over the 5 year study, culling rate was decreased from nearly 50% to less than 10%. In doing so, cows had the opportunity to remain in production longer which decreases the capital costs associated with the addition of replacement females into the herd. Allowing cows in the RWB system multiple chances to conceive within a production year resulted in 2.79 calves/cow over the 5 years compared to 1.85 calves/cow in the strict culling system (Table 11). When comparing the RWB system to the strict culling system, production efficiency per cow increased by 34%.

To meet protein demands of the growing population in the face of limited land availability, there is a need to increase the efficiency in which beef cattle are produced. By limit-feeding cows in confinement for four months out of the year and allowing multiple chances to conceive within a production year, production per unit of land and per cow increase by 42 and 34%, respectively.

CHAPTER IV

DEFINING BUNK SPACE REQUIREMENTS OF COWS BEING LIMIT-FED IN CONFINEMENT

Introduction

Average pasture value for the United States as of August 2, 2018 was $1,390/acre; however, all Corn Belt states exceed this average with both Iowa and Illinois having pasture valuations in excess of $3000/acre (USDA, 2018). Land is the largest capital requirement for new or expanding cow-calf operators, and at current values represents a significant barrier to both market entry and herd expansion. Intensification (partial or total confinement) of cow-calf systems is an alternative, potentially reducing capital costs associated with land acquisition creating lower cost alternatives. Ready supply of nutrient dense co-products has prompted an increase in intensified (partial or total confinement) cow-calf production systems designed to increase the amount of beef produced per hectare.

In confinement settings feed costs represent 80% of the total cost of production (Eizmendi, 2015a); for an economically viable confinement system feed costs must be optimized against production outcomes. Trubenbach et al. (2019) demonstrated that limit feeding cows a high-energy diet can reduce apparent maintenance requirements by as much as 24%, potentially increasing energetic efficiency of cow-calf systems and offering a mechanism to control feed costs while maintaining productivity.

Systems reliant upon managed feed consumption require enhanced management of nutrition, health, and space relative to more typical confinement dairy or beef finishing systems designed for *ad libitum* feed consumption. Restricting the feed offered may make it necessary to provide more bunk space than typically recommended in *ad libitum* intake systems so all animals may attend the bunk simultaneously. Inadequate bunk space allowance in dairy systems results in increased aggressive behavior leading to more competition and reordering at the bunk, decreased feeding activity, and greater variation of intake (Kondo et al., 1989; DeVris et al., 2004; Huzzey et al., 2006). Restricting intake is expected to increase occurrence of these negative outcomes observed in dairy cattle.

While space optimization studies have been performed in finishing (Zinn 1989; Gunter et al., 2000) and dairy systems (Olofsson 1999; DeVris et al., 2004; Huzzey et al. 2006), less information is available for limit-fed cow systems. Jenkins (2014) recommended that beef cows being limit-fed in a confinement setting be allowed a minimum of 61.0 cm of linear bunk space per cow, regardless of production stage (i.e. dry, lactating), while Eizmendi (2015b) recommended 45.7 cm of bunk space for dry beef cows and 91.4 cm for lactating beef cows. However, neither report presented data indicating measurement of optimal space, rather, these authors relayed anecdotal reports. As with land in extensive systems, bunk space in a confinement feeding system represents an allocation of capital, and a need to define optimal space allowance exists.

Defining optimal bunk space allowance for limit-fed cows will allow producers to ensure that each cow being fed has the opportunity to consume the targeted amount of feed to meet requirements, and simultaneously manage both fixed and variable costs of intensive production. Therefore, the objective of this experiment was to define the relationship between bunk space allowance on weight change and within-group variance in weight maintenance of cows being limit-fed in confinement.

Materials and Methods

Seventy-one pregnant, crossbred cows (¾ Angus × ¼ Nellore) either 7 (n = 19), 6 (n = 19), 5 (n = 14), 4 (n = 10), or 3 (n = 9) years of age in midgestation (approximately day 147) were utilized in a 4 × 4 Latin square design (4 treatments, four 21-d measurement periods) to determine the effects of bunk space allowance on intake, diet utilization, and body weight change. Cattle were weighed on d -7, stratified by BW and age and randomly assigned to 1 of 4 pens. Pens were soil surfaced, 112 × 28 meters, and were equipped with fountain waterers and concrete J-bunks (0.11 cubic meters of capacity per linear meter of bunk) Each pen contained 17 (n=1) or 18 (n = 3) animals.

Treatments consisted of bunk space allowance of 45.7, 61.0, 76.2, and 91.4 cm/cow. Diet consisted of 35% chopped milo stalks, 29.5 % dry rolled corn, 27.5% dried distillers' grains, 6% cane molasses, and 2% mineral/vitamin supplement (Table 12). Cattle were fed once daily at 0830. Prior to trial initiation cows were managed in confinement and limit fed the same diet for 28 d. After assignment to pen, mean BW of each pen was used to calculate energy requirements. Energy requirements were estimated per NASEM (2016) to determine the amount of total mixed ration (TMR) to be provided daily. Total requirements were calculated as the sum of maintenance and

Table 12. Ingredient and nutrient composition of diet.

Item	
Ingredient[1]	*% of diet*
Corn – rolled	29.5
Dried distillers' grains	27.5
Milo stalks	35.0
Molasses	6.0
Mineral/Vitamin Supplement	2.0
Component	
DM basis, %	
ADF	20.3
CP	15.3
TDN	71.1
ME, Mcal/kg	2.56
NE_m, Mcal/kg[2]	1.78
NE_g, Mcal/kg[2]	1.06

[1]Limit-fed diet fed to all treatments

[2]Calculated as reported by Garrett (1980)

gestation requirements. Maintenance requirements (NE_m, Mcal/d) were calculated using the equation:

$$NE_m = 0.077 \times EBW^{0.75}$$

$$EBW = SBW \times 0.891$$

$$SBW = BW \times 0.96$$

where EBW = empty body weight, kg; SBW = shrunk body weight, kg; and BW = body weight, kg.

Net energy requirements for gestation (NE_y, Mcal/d) were calculated using the equation:

$$NE_y = CBW \times (0.05855 - 0.0000996 \times DP) \times e^{0.0323 \times DP - 0.0000275 \times DP^2} / 1000$$

where CBW = calf birth weight, 30 kg; DP = days in gestation, 168 d during first two periods (average days in gestation during first two periods) and 210 d during final two periods (average days in gestation during final two periods)

Weight of gravid uterus was calculated using the equation:

$$CW = CBW \times 0.01828 \times e^{0.02 \times DP - 0.0000143 \times DP^2}$$

where CW = gravid uterus weight, kg; CBW = calf birth weight, 30 kg; DP = days pregnant; e = the base of the natural (Naperian) logarithm

Because calf birth weight and exact calving dates were not known at the initiation of the trial, during the first two measurement periods, gestation requirements were estimated at 0.13 Mcal/d, and during the remaining two periods gestation requirements were increased to 0.30 Mcal/d to reflect entry into the last trimester of pregnancy, feed delivery was adjusted accordingly. After determining energy requirements cows were allotted the amount of feed that corresponded to 82% of total energy requirements (Maintenance + Gestation) as described by Trubenbach et al. 2019.

Measurement periods were 21 d. Accordingly, cows were weighed on d 0, 21, 42, 63, and 84. Gross intra-period weight change per cow was calculated by difference between period initial and final weights, and weight of gravid uterus growth was then subtracted to yield net cow BW change independent of effects of pregnancy. Standard deviation (the square root of the sum of individual deviations from pen mean / number of observations) of weight change within pen was calculated to determine within group variance in BW. Diet samples were collected weekly and composited by period. Upon completion of the fourth period samples were sent to SDK Laboratories (Hutchinson, KS) for analysis of (DM, CP, ADF).

Statistical Analysis

Data were analyzed using the MIXED procedure of SAS (SAS Institute, Inc., Cary, N.C.) with pen serving as experimental unit. Model effects included the fixed effect of treatment and the random effect of measurement period. Standard deviation for each pen was calculated to create a new data set to compare deviations in weight change. Orthogonal polynomial contrasts were applied to determine the effect of increasing bunk space on response variables. Significance was declared at $P \leq 0.05$.

Results and Discussion

A quadratic effect ($P = 0.05$) of bunk space allowance on gross pen weight change was observed (Table 13). Gross BW change was greatest when bunk space was 45.7 cm/cow; increasing bunk space allowance to 61.0 cm/cow decreased gross BW

Table 13. Weight change and standard deviation in weight change of cows being limit-fed in confinement with increasing bunk space allowance.

	Treatment (cm/animal)[1]					P-value	
Item	45.7	61.0	76.2	91.4	SEM	Linear	Quadratic
Gross Wt. Change, kg	10.1[a]	5.76[b]	7.98[ab]	8.73[ab]	1.79	0.76	0.05
Deviation in Gross Wt. Change, kg	10.8	8.78	8.78	8.19	1.26	0.08	0.44
Gravid Uterus Wt. kg	4.56	4.61	4.58	4.58	0.18	0.97	0.86
Deviation in Gravid Uterus Wt. kg	0.94	0.96	0.96	0.93	0.08	0.95	0.65
Net Wt. Change, kg	5.60[a]	1.16[b]	3.32[ab]	4.38[ab]	1.83	0.80	0.04
Deviation in Net Wt. Change, kg	10.7	8.65	8.92	8.37	1.24	0.13	0.43

[a,b,c]Within a row, means without a common superscript differ ($P < 0.05$)

[1]Treatments represent centimeters of bunk space allowed per cow

Cubic ≥ 0.19

change, but additional increases in bunk space allowance resulted in continuing increases in gross BW change. There was a tendency for a linear effect (*P* = 0.08) of bunk space allowance on standard deviation in gross weight change. Pens with 45.7 cm of bunk space per cow had the greatest standard deviation of gross BW change; increasing bunk space resulted in decreases in standard deviation.

Because gross BW change may be reflective of changes in both the cow and the gravid uterus due to fetal growth, the weight change of the gravid uterus was retrospectively estimated for each cow within each experimental period. These adjustments allow for some removal of effects that may have resulted from different days of gestation during the trial. There were no linear (*P* = 0.97) or quadratic (*P* = 0.86) effects of bunk space allowance on gravid uterus growth. There were also no linear (*P* = 0.95) or quadratic (*P* = 0.65) effects of bunk space allowance on standard deviation of gravid uterus growth.

There was a quadratic effect (*P* = 0.04) of bunk space allowance on net pen weight change (Figure 7). As bunk space allowance increased from 45.7 to 61.0 cm/cow mean net BW change decreased by 4.44 kg. As bunk space allowance increased from 61.0 to 76.2 cm/cow mean pen weight change increased by 2.16 kg. Increasing bunk space allowance from 76.2 to 91.4 cm/cow caused mean pen weight change to increase by 1.06 kg. There were no linear (*P* = 0.13) or quadratic (*P* =0.43) effects of bunk space allowance on standard deviation in net weight change (Figure 8).

After accounting for weight of the gravid uterus, overall net BW of cows increased by 3.62 kg suggesting that even though cattle were fed at 82% of total

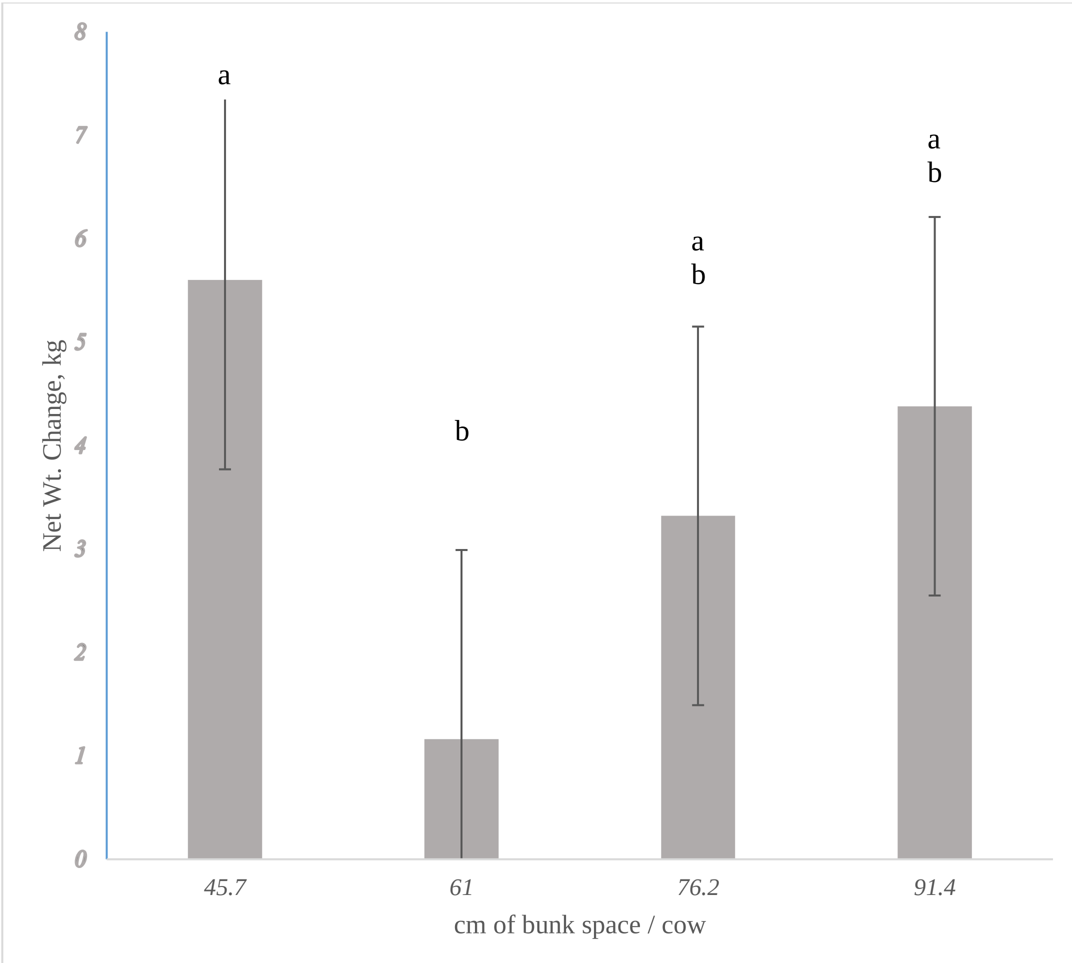

Figure 7. Net weight change of cows being limit-fed in confinement with increasing bunk space allowance. Linear (P = 0.80); Quadratic (P = 0.04); Cubic (P = 0.19)

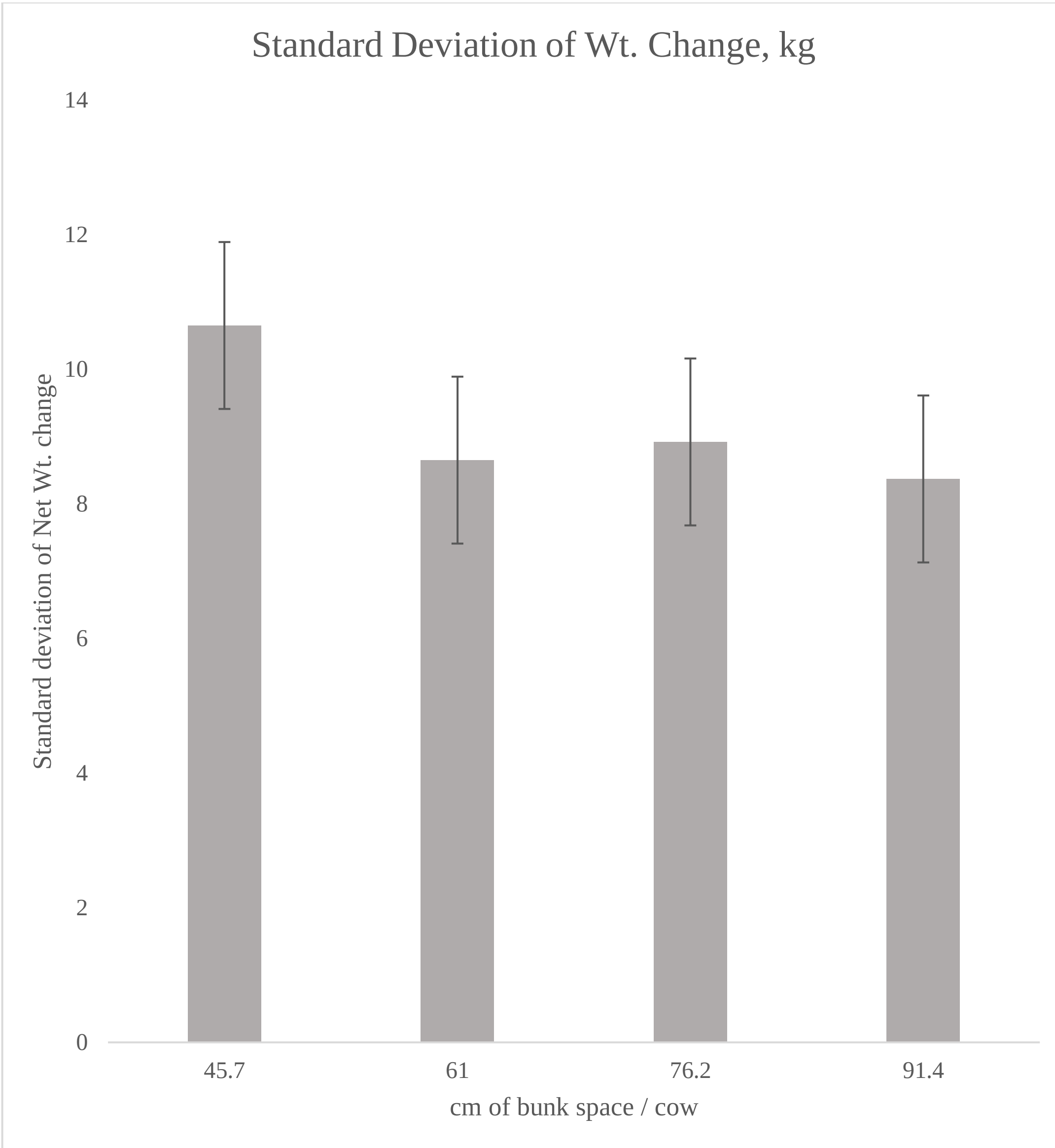

Figure 8. Standard deviation of net weight change of cows being limit-fed in confinement with increasing bunk space allowance. Linear (P = 0.13); Quadratic (P = 0.43); Cubic (P = 0.45)

recommended energy intake, sufficient energy was supplied for cows to maintain both live weight and weight associated with the growth of gravid uterus. This could be attributed to both an increase in dietary energy utilization and decreases in animal maintenance requirements. Decreased intake has been shown to increase the extent of ruminal digestibility (Ellis 1978; Murphey et al., 1994; Trubenbach et al., 2019), effectively increasing NE value of the diet. Loerch (1990) and Zinn et al. (1995) both observed increases in digestibility when restricting intake of high energy diets. Similarly, Trubenbach et al. (2019) fed an energy dense diet to cows at 80 or 120% of maintenance requirements, and observed a 4% increase in diet ME value when cows were fed at 80% compared to 120%. While limited intake has been shown to increase digestibility and the subsequent dietary ME value, in the current study the ME value of the diet would need to increase by nearly 20% to be solely responsible for cows being able to achieve maintenance when being fed at only 82% of predicted requirements. Therefore, it is most likely that a combination of both increased diet energy utilization and decreased maintenance requirements occurred that resulted in achievement of maintenance when fed at 82% of expected requirements. Similarly, Trubenbach et al. (2019) found that feeding cows a high energy diet at 76% of the energy requirement predicted by NASEM (2016) was sufficient to achieve maintenance, and Freetly and Nienaber (1998) reported a 22% reduction in maintenance energy requirements when intake of mature cows was restricted to 65%.

The quadratic effect observed in weight change could be attributed to behavioral tendencies of cattle. Wagnon (1965) evaluated social dominance in range cows and its effect on supplemental feed intake, and suggested that optimum feeding conditions (cows spend equal amount of time at the bunk) occur when cows have to stand close together at the trough (or bunk), presumably only seeing the cows on each side. Wagnon (1965) observed less fighting and position changing when trough space was decreased from 182.9 cm to 91.4 cm of trough space per cow. Conversely, the dairy literature suggests that increased animal densities (less bunk space/cow) increases aggressive behavior and variability of within pen intake (Kondo et al., 1989; DeVris et al., 2004; Huzzey et al., 2006); however, it is important to keep in mind that all of the dairy studies fed *ad libitum*.

Cows were not individually fed; therefore, standard deviation of within pen weight change was used as a proxy for the variation of feed intake within the pen. We hypothesized that increased competition, fighting, and social dominance resulting from reduced bunk space allowance would result in greater variation in DMI per animal within a pen, and this increase in variance in intake would manifest as greater deviation of individuals from mean BW change. Consistent with this hypothesis, we observed a tendency for standard deviation in gross weight change to decline as bunk space allowance increased; this tendency was not detected when gross BW change was corrected by estimates of gravid uterine weight. Although there was an effect on net BW change, the lack of effect on standard deviation in net BW change may suggest that suboptimal bunk space allowance may not have resulted in differences in intake but rather increases in energy expenditure.

The reduction in net weight gain observed in cows when bunk space allowance increased from the most restricted scenario to those receiving 61.0 cm/cow could be attributed to a greater energy expenditure associated with increased movement. Wagnon (1965) observed less fighting and position changing upon reducing bunk space; however, he reduced bunk space to only 91.4 cm/cow (the same as highest treatment in our study). DeVries et al. (2004) compared bunk space allowance of 50 cm/cow (similar to our lowest treatment) to 100 cm/cow (similar to our highest treatment) and found that fighting and position changing at the bunk was reduced as bunk space increased from 50 to 100 cm/cow. Perhaps cows receiving 61.0 cm of bunk space per cow spent more time fighting and changing positions at the bunk compared to cows with more restricted bunk space (45.7 cm); therefore, increasing their energy expenditure associated with movement reducing energy available for gain.

Conclusion

In limit-fed systems for gestating beef cows, intermediate bunk space allowance had the least positive effects on BW change. The most restrictive bunk space allowance may have reduced displacement effort and energy expenditure, without measurable increases in the variance in individual weight change within pen. These results suggest that intermediate spacing may be the least optimal for cow performance, while less restrictive space may result in less efficient utilization of assets. Overall, limit-feeding cows and allowing 45.7 cm of bunk space per cow will allow each cow to consume sufficient amounts to meet her requirements while also reducing the variable costs associated with feed and the fixed costs associated with pen and bunk space.

CHAPTER V

VIABILITY OF TRITICALE AS AN ALTERNATE WINTER FORAGE FOR STOCKER GRAZING SYSTEMS

Introduction

Stocker cattle production is prevalent in the Southern Great Plains of the United States due to the availability of weaned calves and environmental conditions favoring production of small grains as a source of high-quality forage during the fall, winter, and spring. In these systems, sufficient forage biomass is produced to support grazing for greater than 90 days a year (Rouquette, 2017) and can produce average daily gain in excess of 0.91 kg/d with greater gains observed when implants and ionophores are provided (Horn et al., 2005; Beck 2013). Wheat (*Triticum aestivum*) is the most common small-grain species for winter forage production with 12.2 million acres planted in the Southern Great Plains in 2017 (USDA, 2017), followed by oats, rye, and triticale. At lower latitudes in the region, oat (*Avena sativa*) pasture may be more prevalent than wheat. Oats are less cold tolerant (Redmon et al., 1998); however oats have the potential to produce more forage per acre (Coblentz and Walgenbach, 2010) and has similar forage quality to wheat.

Triticale (×*Triticosecale Wittm. ex A. Camus [Secale* × *Triticum]*), a hybrid grain crop produced by crossing wheat and rye (*Secale cereal*), was developed to combine the quality and productivity of wheat with the vigor and disease resistance of rye. Triticale is similar to high-yielding rye; however, it has a higher quality grain similar to wheat (Lorenz and Pomeranz, 1974), with greater tolerance to drought than both wheat and oats (Lelley, 2006). Comparisons of the nutritional value and yields of wheat, oats, and triticale have been made (Brown, 1976; Coblentz et al., 2010); however, fewer comparisons of performance from cattle grazing triticale are available in the published literature (Mullenix et al., 2014).

Therefore, our objectives were to compare cattle performance when grazing wheat, oats, or triticale and determine triticale's viability as an alternate winter forage.

Materials and Methods

Experimental protocols were approved by the Agricultural Animal Care and Use Committee of Texas A&M Agrilife Research.

A two year study was conducted during the winter and spring growing seasons of 2008 and 2009 in Burleson County, Texas (30°31'13.55" N, 96°24'54.44" W). Annual precipitation averages 990mm. Average maximum daily temperatures range from 35° C in July to 3.8° C in January. Soils on the study area were Weswood silt loam (0-1% slopes) and Weswood silty clay loam (0-1% slopes) with rare flooding.

Year 1

A 53.4-ha field was divided with two-strand electric fence into six 8.9-ha paddocks. Pastures were planted the second and third weeks of October 2008, in clean tilled prepared seed beds using a conventional grain drill at the rate of 112.1 kg/ha. No pre-plant fertilization was applied. Pastures were planted in wheat forage (*Triticum aestivum* var. Heavy Grazer TX 7306), oats (*Avena sativa* var. Heavy Grazer 76-30), and triticale (*X Triticosecale wittmack* var. Triplecale), with two separate paddocks per species of forage. Pastures were fertilized (top-dressed) in mid-December with nitrogen at 224.2 kg per hectare.

Two hundred and nine non-implanted crossbred heifers (266.6 kg initial BW) were stratified by weight within similar breed composites (¾ Angus and ¼ Nellore or 7/8 Angus and 1/8 Nellore). Heifers were randomly assigned within strata to one of six groups, five groups of 35 and one group of 34. Stocking rate was determined using historical wheat forage production (5,614 kg wheat forage/ ha) for the area, an expected average heifer weight of 318 kg, and estimated intake of 2.5% of body weight. Prior to weighing, cattle were gathered in the afternoon, penned and restricted from feed and water overnight to equalize shrink across paddocks. Cattle were weighed individually on d 0, 21, 42, 63, and 84 to calculate average daily gain. Cattle were allowed *ad libitum* access to medicated mineral (1,584 mg of lasolocid/kg of mineral mixture). Energy supplement (14% high-energy cube) was hand fed twice a week (average daily intake 0.65 kg/heifer).

At 14-d intervals, forage samples were collected by clipping herbage in 2 paired caged and grazed plots randomly placed within each paddock. Wire cages were 1.22-m^2. A frame (0.1 m^2) was randomly placed inside the cage and forage was clipped from ground level in each cage and averaged within paddocks. A paired sample was then immediately clipped approximately 3 m in a random direction away from the cage. Samples were placed in paper bags, weighed and dried in a forced-air oven at 60°C for 72 h then re-weighed to determine herbage mass of each paddock, forage growth, forage disappearance, and forage allowance. The difference of the paired samples was used to calculate forage utilization. All samples were composited by collection type (caged vs. non-caged) within each paddock then further composited by treatment and ground with a Wiley Mill (Thomas Wiley, Laboratory Mill Model 4, Thomas Scientific Co. Philadelphia, PA) to pass a 1-mm screen. Sub-samples were dried for an additional 24 h at 105°C in a forced-air oven to determine laboratory DM, then combusted for 8 h at 450°C in a muffle furnace for OM determination. Nitrogen content of forage was determined by total combustion (Rapid-N-Cube, Elementar Americas Inc. Mt. Laurel, NJ). Crude protein was calculated N × 6.25. All samples were analyzed for NDF and ADF with the ANKOM-Fiber Analyzer (ANKOM-Technology, Fairport, NY). Paired plots were moved to alternative sites after each 14-day measurement.

Year 2

A 48.55-ha portion of the same field used in year 1 was divided with two-strand electric fence into five 8.9-ha paddocks and one 4.05-ha paddock. Pastures were planted the fourth week of October, 2009, in clean tilled prepared seed beds via a conventional grain drill at the rate of 112.1 kg per hectare. No pre-plant fertilization was used. Pastures were planted in the same three forages used during year 1 with two separate paddocks per species of forage.

One hundred thirty-seven non-implanted crossbred heifers (184.2 kg initial BW) were stratified by weight prior to being randomly assigned within strata to one of six groups, one group of 26, four groups of 25 and one group of 11. Stocking rate was determined using the same methods described in year 1. Cattle were gathered in the afternoon, penned and restricted from feed and water overnight to standardize shrink across paddocks then weighed individually on days 0, 28, 56, and 84 to calculate average daily gain. Cattle were allowed *ad libitum* access to medicated mineral (1,584 mg of lasolocid/kg of mineral mixture). Energy supplement (14% high-energy cube) was hand fed twice a week (average daily intake 0.65 kg/hd). Forage samples were collected and analyzed using the same methods described in year 1.

Diet Selection

In year 2, twelve ruminally fistulated steers were used to determine diet selection by ruminal evacuation. Steers were stratified by weight and randomly assigned, two to each paddock, remaining on the same treatment for the duration of the study. Steers were gathered on d 0, 28, 56, and 84 and rumen contents were emptied manually by hand. After ruminal contents were removed, rumens were rinsed with water to prevent the possibility of sample contamination by previous ingesta. Steers were allowed to graze in their respective treatment pastures for 45 min. After grazing, steers were gathered and the selected forage was manually mixed in the rumen. Duplicate samples were collected and placed in individually marked containers. Rumen contents were replaced after the completion of the diet selection sampling. Steer selection samples were dried in a forced-air oven at 60°C for 96 h and composited by steer. A 1 kg subsample of each of the composites was taken and manually separated by anatomical parts and weighed to determine diet composition (leaf:stem ratio). The remaining sample was ground with a Wiley Mill (Thomas Wiley, Laboratory Mill Model 4, Thomas Scientific Co. Philadelphia, PA) to pass a 1-mm screen. A subsample was dried for an additional 24 h at 105°C in a forced-air oven to determine lab DM and combusted for 8 h at 450°C in a muffle furnace for OM determination. Nitrogen content of the diet selection was determined by total combustion (Rapid-N-Cube, Elementar Americas Inc. Mt. Laurel, NJ), crude protein was then calculated (N × 6.25). All samples were subsequently analyzed for NDF and ADF with the ANKOM-Fiver Analyzer (ANKOM-Technology, Fairport, NY).

Statistical Analysis

Data were analyzed using the MIXED procedure of SAS (SAS Institute, Inc., Cary, NC) as a repeated measures analyses. Model effects for animal performance included treatment, year, and treatment × year with pasture ID within treatment as a random effect. Model effects for forage yield and forage quality included year, collection day, treatment, treatment × year, and treatment × day.

Results

Monthly rainfall over the forage growing period (October – May) was below average for 6 of the 8 trial months during year one. Specifically, the first 5 months of the growing period experienced well below average rain fall. In year two, 5 of the 8 trial months experienced less than average rain fall, however, the first two months were above average and the following two were just below average (Table 14).

There was no treatment × year interaction effect on measures of cattle performance (P =0.16); however there were significant year effects for all responses (P > 0.01), therefore results are presented as simple effects by year. Year 1 total ADG was greatest (P = 0.05; Table 15) for heifers grazing triticale while ADG did not differ

Table 14. Monthly mean temperatures and total precipitation during year 1 and year 2 winter growing seasons near College Station, Texas.

	Mean temperature, °C			Total precipitation, mm		
Month	YR1	YR2	Normal[1]	YR1	YR2	Normal[1]
October[2]	20.56	20.78	21.39	43.94	206.76	107.19
November	16.17	16.39	15.56	34.29	87.38	80.77
December	11.44	8.89	11.22	20.32	71.37	82.04
January	11.56	14.61	10.11	17.78	74.68	84.33
February	15.78	8.17	12.50	17.27	70.36	60.45
March	16.78	14.61	16.44	128.78	66.55	72.14
April	19.83	20.50	19.94	155.19	28.19	81.28
May	25.33	26.33	24.06	35.81	50.80	128.27

[1]Normal temperature and precipitation is the average from 1971-2000 for College Station, TX (Easterwood Field, College Station, TX, Texas Climate Data, http://atmo.tamu.edu/osc/).
[2]Planting dates: Year 1: October 7 -14and Year 2: October 21-23.

Table 15. Average daily gain by period, total ADG, and total gain of heifers grazing wheat, oats, and triticale.

	Treatment[1]				
Item	Wheat	Oats	Triticale	SEM	*P*-Value
Year 1					
ADG, kg/d					
D 21	0.19	0.28	0.26	0.05	0.45
D 42	1.22	0.96	1.08	0.07	0.16
D 63	1.03	1.30	1.29	0.10	0.23
D 84	0.58	0.55	0.83	0.09	0.19
Total	0.75[b]	0.77[b]	0.86[a]	0.02	0.05
Total Gain, kg					
Animal	63.40[b]	64.90[b]	72.40[a]	1.51	0.05
Hectare	249.20	251.70	276.50	5.77	0.08
Year 2					
ADG, kg/d					
D 21	1.16	1.11	0.96	0.11	0.49
D 42	1.09	0.71	0.85	0.18	0.43
D 63	0.86	1.00	1.12	0.10	0.29
D 84	1.04	0.94	1.00	0.04	0.30
Total	1.01	0.97	1.01	0.07	0.26
Total Gain, kg					
Animal	87.10	78.90	83.40	3.40	0.30
Hectare	257.00	250.80	256.60	4.06	0.55

[a,b,c]Within a row, values with different superscript differ, ($P < 0.05$)

[1]Treatments included heifers grazing wheat, heifers grazing oats, or heifers grazing triticale

[2]Treatment × Year ($P = 0.16$)

[3]Year ($P < 0.01$)

Table 16. Total standing crop (kg/ha) for wheat, oats, and triticale in year 1 and 2.

	Treatment[1]				
Item	Wheat	Oats	Triticale	SEM	*P*-Value
Total Standing Crop kg/ha					
Year 1					
D 14	3271[ab]	4413[a]	2097[b]	1020	< 0.01
D 28	5731[a]	5533[a]	2935[b]	1020	0.02
D 42	5039[ab]	5891[a]	3352[b]	1020	0.03
D 56	6719[a]	4871[ab]	3447[b]	1020	< 0.01
D 70	5334[b]	7543[a]	3012[c]	1020	< 0.01
D 84	3306[b]	6116[a]	3127[b]	1020	0.01
Mean	4900[a]	5728[a]	2995[b]	523	0.01
Year 2					
D 14	3697	3993	2079	1618	0.25
D 28	4092	4468	3542	1618	0.57
D 42	3580	4200	2774	1618	0.39
D 56	3050	4655	3360	1618	0.34
D 70	3647	3750	3631	1618	0.94
D 84	1732	3135	1720	1618	0.39
Mean	3300	3993	2079	1045	0.34

[a,b,c]Within a row, values with different superscripts differ, ($P < 0.05$)
[1]Treatments included heifers grazing wheat, heifers grazing oats, or heifers grazing triticale
[2]Treatment × Year ($P = 0.39$)
[3]Year ($P = 0.05$)
[4]Treatment × Day ($P \geq 0.13$)

Table 17. Forage allowance (kg DM·100 kg BW^{-1}·d^{-1}) for wheat, oats, and triticale in year 1 and 2.

	Treatment[1]				
Item	Wheat	Oats	Triticale	SEM	*P*-Value
Forage Allowance (kg DM·100 kg BW^{-1}·d^{-1})					
Year 1					
D 14	22.11^{ab}	30.10^{a}	14.48^{b}	6.02	0.02
D 28	37.37^{a}	36.56^{a}	19.59^{b}	6.02	0.01
D 42	30.93^{ab}	37.20^{a}	21.23^{b}	6.02	0.02
D 56	39.36^{a}	28.89^{ab}	20.51^{b}	6.02	< 0.01
D 70	30.17^{a}	42.83^{a}	17.13^{b}	6.02	< 0.01
D 84	18.22^{a}	34.00^{b}	17.23^{a}	6.02	0.01
Mean	29.69^{a}	34.93^{a}	18.36^{b}	3.16	0.02
Year 2					
D 14	44.83	46.04	34.47	15.05	0.45
D 28	44.91	47.42	33.56	15.05	0.37
D 42	36.66	43.10	35.88	15.05	0.64
D 56	29.24	45.52	36.57	15.05	0.29
D 70	33.37	34.60	17.39	15.05	0.31
D 84	15.11	27.25	17.20	15.05	0.43
Mean	33.85	40.65	29.17	11.21	0.38

[a,b,c]Within a row, values with different superscripts differ, ($P < 0.05$)

[1]Treatments included heifers grazing wheat, heifers grazing oats, or heifers grazing triticale

[2]Treatment × Year ($P = 0.84$)

[3]Year ($P = 0.20$)

[4]Treatment × Day ($P \geq 0.15$)

between wheat and oats ($P = 0.55$). Because grazing period duration was the same for all forages, total weight gain per head mirrored ADG and was greatest ($P = 0.05$) in heifers grazing triticale and was not different between wheat or oats ($P = 0.57$). There was a tendency ($P = 0.08$) for gain per hectare to be greater for triticale than both wheat and oats, which were not different ($P = 0.61$). In Year 2 total ADG, total weight gain, and weight gain per hectare were not different among the three treatments ($P \geq 0.30$).

There were no treatment × year interactions ($P \geq 0.39$) for total standing crop (kg/ha; Table 16) or forage allowance (kg DM·100 kg $BW^{-1}·d^{-1}$; Table 17). There was also no treatment × day interactions ($P \geq 0.13$) for total standing crop or forage allowance in year 1 or year 2. There was a year effect ($P = 0.05$) on total standing crop, but because stocking rates were lower in year 2, there was no year effect ($P = 0.20$) on forage allowance. Average standing crop in year 1 was least ($P = 0.01$) for triticale and greatest for oats and wheat which were not different from each other ($P = 0.21$). Year 2 average standing crop was not different between treatments ($P \geq 0.21$). Forage allowance in year 1 was not different between wheat and oats ($P = 0.20$) and were both greater than forage allowance of triticale ($P \leq 0.04$). Similar to standing crop, forage allowance in year 2 was not different between treatments ($P \geq 0.38$) for the entirety of year 2.

There was no treatment × year interaction ($P = 0.40$) for CP concentration. There was also no year effect ($P = 0.57$); however, there was a treatment × day interaction ($P < 0.01$) during year 1. Initial CP in year 1 (Figure 9) was greatest ($P <$

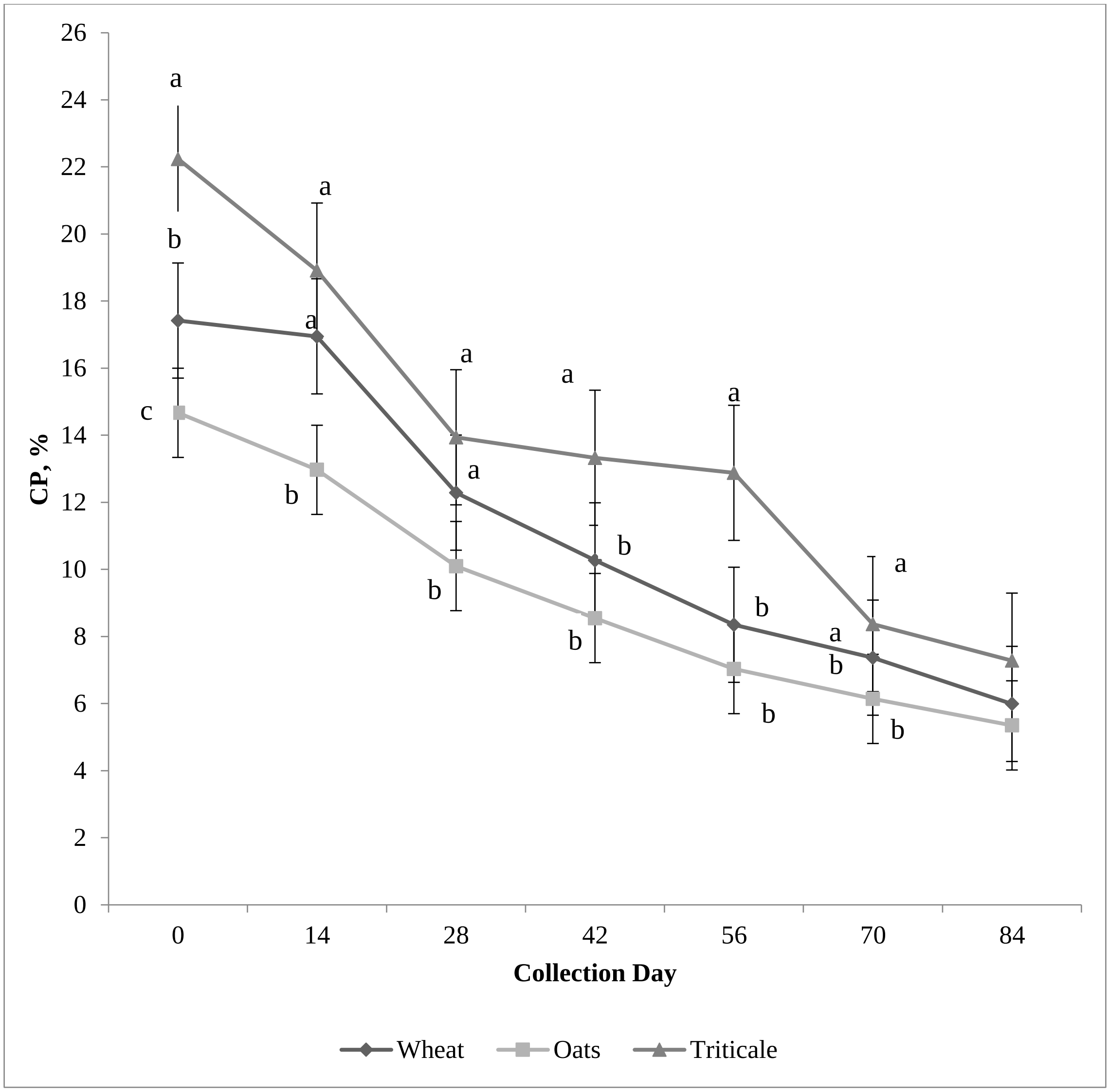

Figure 9. Crude protein concentrations for wheat, oats, and triticale by collection day for year 1. Treatment × Year: P = 0.40; Year: P = 0.57; Treatment × Day: P = 0.01; Treatment: P = 0.02; Day: P < 0.01

0.01) for triticale, intermediate for wheat, and least for oats. On d 14 and 28 CP was similar ($P \geq 0.09$) between triticale and wheat which were both greater ($P < 0.01$) than oats. Crude protein on d 42 and 56 was greater for triticale ($P < 0.01$) than both wheat and oats which were not different ($P \geq 0.12$). On d 70 CP of triticale was greater ($P = 0.05$) than oats and CP of wheat did not differ ($P \geq 0.25$) from either triticale or oats. On d 84 CP of triticale tended ($P = 0.08$) to be greater than oats, while wheat did not differ ($P \geq 0.23$) from either triticale or oats. Average CP for the entire growing period in year 1 was greatest ($P \leq 0.03$) for triticale (13.4%), and wheat (11.2%) tended ($P = 0.06$) to be greater than oats (9.3%). There was no treatment × day interaction ($P = 0.77$) or treatment ($P = 0.20$) effect on CP concentration in year 2 (Figure 10); however, there was an effect of day ($P < 0.01$) on CP. Average crude protein concentration decreased from 14.8% on d 0 to 10.0% on d 84. Average CP for the entire growing period in year 2 was not different between treatments ($P \geq 0.12$) and averaged 11.1%.

There was no treatment × year interaction ($P = 0.33$) for NDF concentration in clipped forage composites; however, there was a year effect ($P < 0.01$). There was also a treatment × day interaction ($P \leq 0.01$) for both year 1 and year 2 NDF concentration in clipped forage composites. During year 1, NDF concentration was greatest for wheat ($P < 0.01$) and not different for oats and triticale for the first four collection periods (D 0 - 42). During the fifth and sixth sampling periods (D 56, 70), there was no differences in forage NDF; however, by d 84 triticale was less than that of both wheat and oats ($P < 0.01$; Figure 11). Neutral detergent fiber concentration averaged across the entire growing period in year 1 was greater ($P \leq 0.02$) for wheat (44.3%) compared to oats

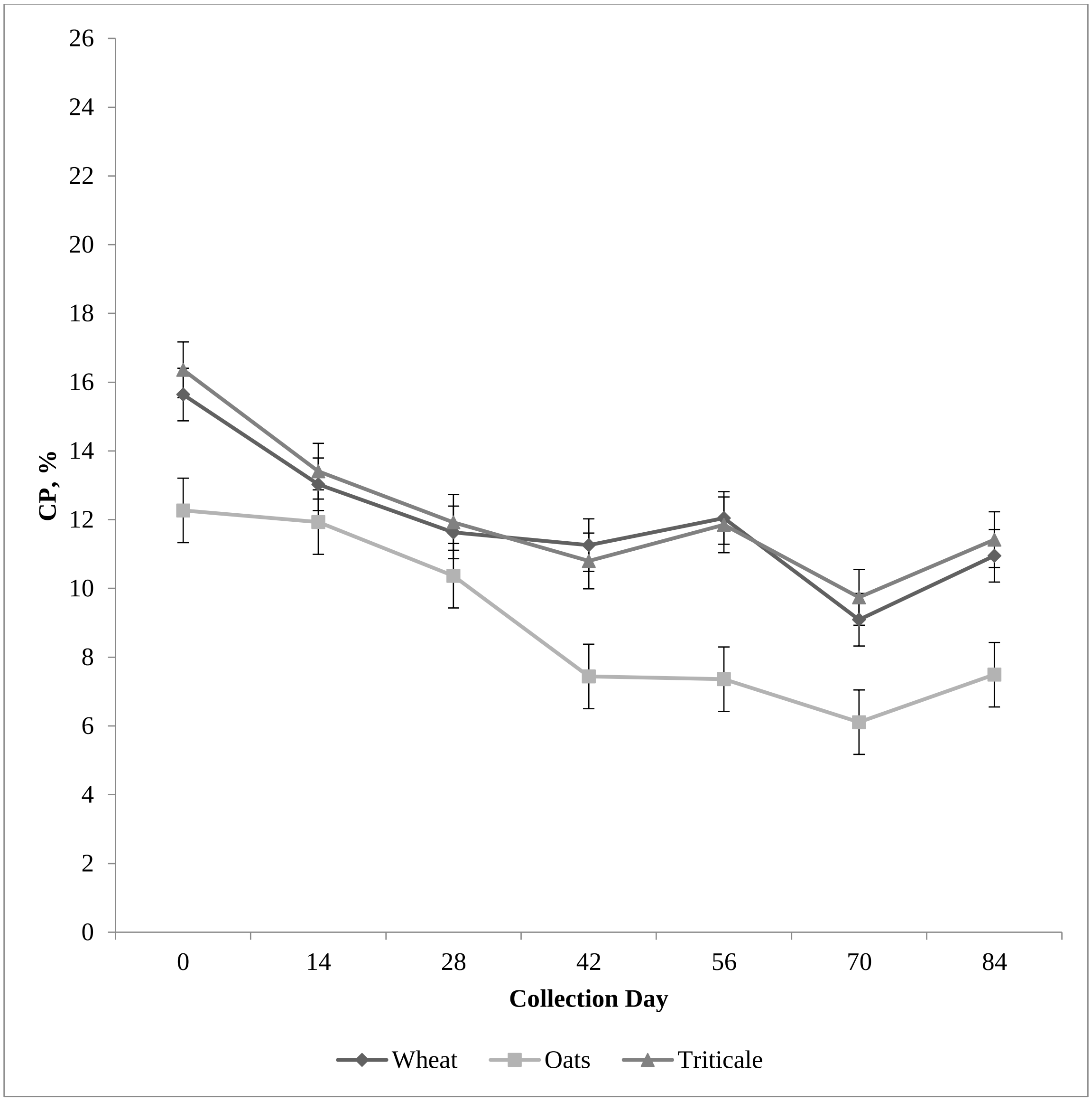

Figure 10. Crude protein concentrations for wheat, oats, and triticale by collection day for year 2. Treatment × Year: P = 0.40; Year: P = 0.57; Treatment × Day: P = 0.77; Treatment: P = 0.20; Day: P < 0.01.

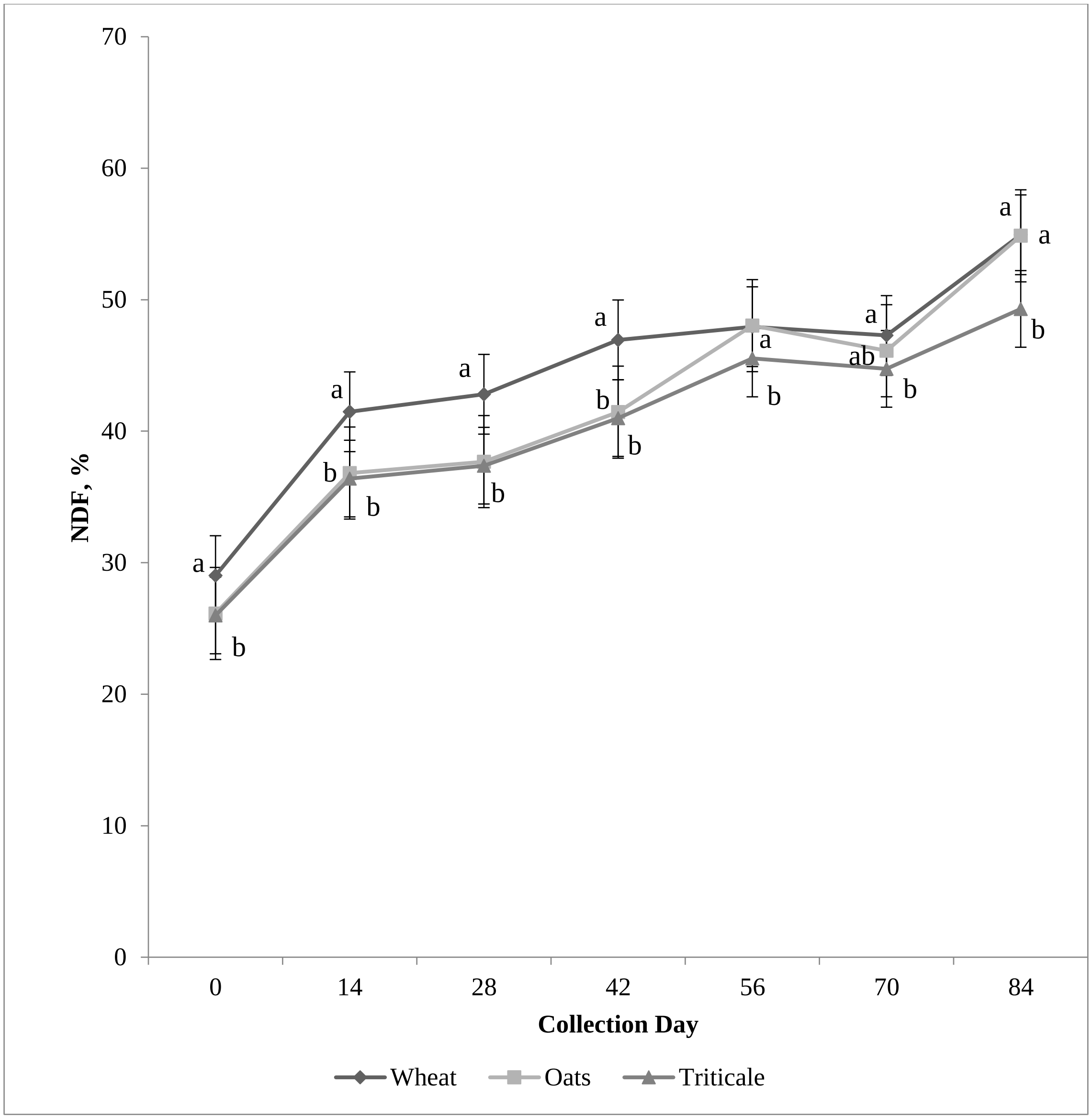

Figure 11. Neutral detergent fiber concentrations for wheat, oats, and triticale by collection day for year 1. Treatment × Year (P = 0.33; Year: P < 0.01; Treatment × Day: P < 0.01; Treatment: P = 0.01; Day: P < 0.01

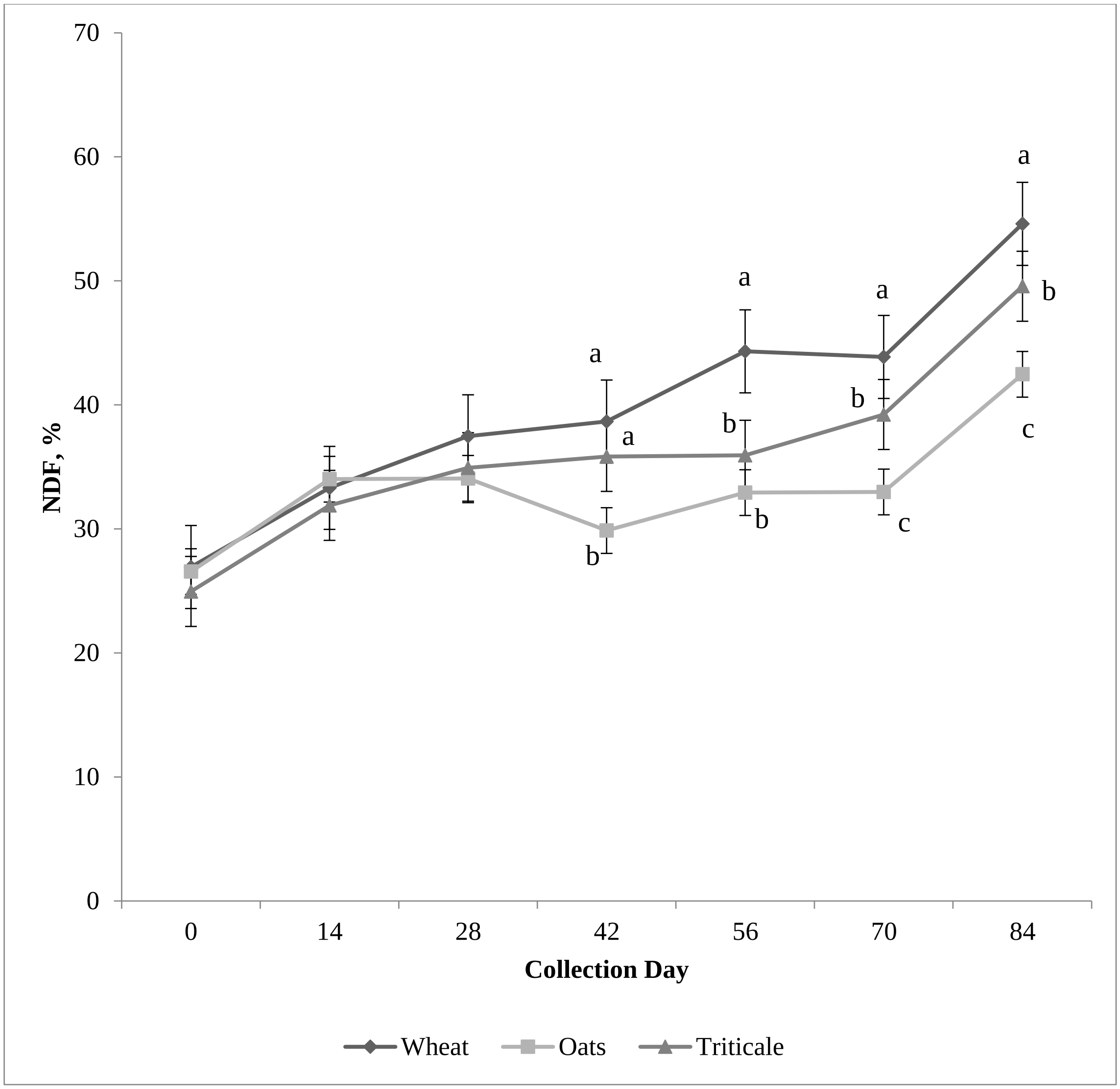

Figure 12. Neutral detergent fiber concentrations for wheat, oats, and triticale by collection day for year 2. Treatment × Year: $P = 0.33$; Year: $P < 0.01$; Treatment × Day: $P < 0.01$; Treatment: $P = 0.05$; Day: $P < 0.01$

Table 18. Table 18 in text. Percent of leaf and stem from clipped forage samples of wheat, oats, and triticale during year 2.

	Treatment[1]				
Item	Wheat	Oats	Triticale	SEM	*P*-Value
% of Clipped Forage					
D 0					
Leaf	71.6^{b}	79.5^{a}	74.8^{ab}	3.18	0.04
Stem	28.4^{a}	20.5^{b}	25.2^{ab}	3.19	0.04
D 28					
Leaf	69.8^{b}	77.9^{ab}	80.8^{a}	3.87	0.01
Stem	30.2^{a}	19.3^{b}	22.1^{ab}	3.88	0.01
D 56					
Leaf	56.6^{c}	75.4^{a}	65.7^{b}	3.40	< 0.01
Stem	43.4^{a}	24.6^{c}	34.3^{b}	3.88	< 0.01
D 84					
Leaf	38.2^{b}	47.6^{a}	42.0^{ab}	3.87	0.02
Stem	61.9^{a}	52.4^{b}	58.0^{ab}	3.88	0.02

[a,b,c]Within a row, values with different superscripts differ, ($P < 0.05$)

[1]Treatments included heifers grazing wheat, heifers grazing oats, or heifers grazing triticale

[2]Treatment × Day ($P \geq 0.31$)

(41.6%) or triticale (40.1%), which did not differ (*P* = 0.09). During the first three collection periods (d 0, 14, 28) of year 2 there were no differences ($P \geq 0.14$) in NDF concentration (Figure 12). On d 42 NDF concentration of oats was less ($P \leq 0.01$) then both wheat and triticale which were not different (*P* = 0.22). On d 56 wheat had a greater ($P < 0.01$) NDF concentration then both oats and triticale which were not different (*P* = 0.19). Neutral detergent fiber concentration on d 70 and 84 was different ($P \leq 0.05$) amongst the three treatments with wheat being greatest, triticale intermediate, and oats least. Averaged across the entire growing period NDF concentration was greater (*P* = 0.02) in wheat (39.9%) than oats (33.3%); NDF in triticale (36.1%) did not differ ($P \geq 0.09$) from either.

Clipped forage samples were taken in year 1 and there was no treatment × day interaction ($P \geq 0.31$; Table 18) for percent leaf and stem in clipped forage. From d 0 to 84 the percent leaf in clipped wheat forage decreased from 71.6 to 38.2% and the percent stem increased from 28.4 to 61.9%. Similarly, percent leaf in oats decreased from 79.5 to 47.6% during the 84 d growing period and the percent stem increased from 20.5 to 52.4%. Clipped triticale followed a similar pattern with 74.8% leaf decreasing to 42.0% leaf by d 84 and the percent stem increased from 25.2 to 58.0%.

In samples collected via ruminal evacuation during year 2, there was a treatment × day interaction ($P \leq 0.05$; Table 19) for CP, NDF, leaf, and stem selection. On d 0, there were no differences among forages in CP and NDF of the diet selected ($P \geq 0.11$; Table 19). Steers grazing wheat consumed a greater (*P* = 0.03) percent leaf than stem were intermediate ($P \geq 0.17$). On d 28, steers grazing wheat harvested a diet greater (*P*

Table 19. Table 19 in text. Diet selection of ruminally cannulated steers grazing wheat, oats, and triticale in Year 2.

	Treatment[1]				
Item	Wheat	Oats	Triticale	SEM	*P*-Value
D 0					
Nutritive Value, % DM					
CP	18.0	17.3	19.8	1.39	0.11
NDF	31.2	36.6	35.4	3.10	0.12
% of selected forage					
Leaf	99.9[a]	96.6[b]	98.5[ab]	0.01	0.03
Stem	0.06[b]	3.38[a]	1.53[ab]	1.26	0.03
D 28					
Nutritive Value, % DM					
CP	19.0[a]	14.7[b]	16.5[ab]	1.39	0.01
NDF	44.7	43.5	45.8	3.10	0.47
% of selected forage					
Leaf	99.9	99.6	99.9	0.01	0.97
Stem	0.04	0.04	0.07	1.26	0.97
D 56					
Nutritive Value, % DM					
CP	16.4[a]	12.3[b]	18.2[a]	1.39	< 0.01
NDF	49.1	45.0	49.6	3.10	0.17
% of selected forage					
Leaf	99.8	99.7	99.9	0.01	0.87
Stem	0.16	0.35	0.15	1.26	0.87
D 84					
Nutritive Value, % DM					
CP	15.5	17.0	15.0	1.39	0.16
NDF	56.2[a]	47.7[b]	51.3[ab]	3.10	0.02
% of selected forage					
Leaf	94.7[b]	97.2[ab]	98.4[a]	0.01	0.02
Stem	5.33[a]	2.82[ab]	1.57[b]	1.26	0.02

[a,b,c]Within a row, values with different superscript differ, ($P <$ 0.05)
[1]Treatments included heifers grazing wheat, heifers grazing oats, or heifers grazing triticale
[2]Treatment × Day ($P \leq 0.05$)

= 0.01) in CP compared to steers grazing oats, and steers grazing triticale harvested an intermediate CP concentration ($P \geq 0.11$). There were no differences ($P \geq 0.47$) in the concentration of NDF in the diet harvested by steers grazing wheat, oats, and triticale on d 28. There was also no differences among forage types ($P \geq 0.87$) in the percentage of leaves and stems selected on d 28. On d 56, steers grazing triticale and wheat selected diets with a greater ($P \leq 0.02$) CP compared to oats. There were no differences ($P \geq$ 0.17) in NDF, or percent of leaf and stem selected by steers grazing wheat, oats, and triticale on d 56. On d 84, there was no differences in the percent CP selected among forage types ($P \geq 0.16$); however, steers grazing wheat selected a diet with greater (P = 0.02) NDF content compared to steers grazing oats, while steers grazing triticale selected a diet intermediate in NDF content, not different ($P \geq 0.15$) from either wheat or oats. Steers grazing triticale on d 84 selected a greater percent leaf (P = 0.02) compared to steers grazing wheat, while steers grazing oats selected an intermediate percent of leaf, not different ($P \geq 0.08$) from either triticale or wheat.

Discussion

Total ADG was 26%, 21%, and 15% greater in year 2 compared to year one for wheat, oats, and triticale, respectively. Daily and total gains in year two were not different between forages and are consistent with those presented in the literature (Beck et al., 2005; Fieser et al., 2007; McCartney et al., 2008). In contrast, in year one when rainfall was 31.6% of normal for the first 5 months after planting, heifers grazing triticale gained 13% more per day and 10% more per hectare than heifers grazing wheat or oats. Data comparing wheat and triticale during drought years is minimal; however, the current study demonstrates that growth rates of cattle grazing wheat and oats in years of below average rainfall were less than cattle grazing triticale, suggesting that triticale may afford more resilience in supporting production during drier periods.

Forage allowance (expressed as kg DM·100 kg $BW^{-1}\cdot d^{-1}$) required for maximum gain has a reported critical level between 22 and 27 kg DM·100 kg $BW^{-1}\cdot d^{-1}$ (Redmon et al., 1995, Pinchak et al., 1996). In year one of the current study, heifers grazing either wheat or oats had a forage allowance greater than or equal to the critical levels reported by Redmon et al. (1995) and Pinchak et al. (1996) in each of the six collection periods, and an average forage allowance of 29.7 and 34.9 kg DM·100 kg $BW^{-1}\cdot d^{-1}$, respectively. Forage allowance for heifers grazing triticale in year 1 was below the critical value of 22 kg DM·100 kg $BW^{-1}\cdot d^{-1}$ reported by Redmon et al. (1995) in each of the six collection periods and averaged 18.4 kg DM·100 kg $BW^{-1}\cdot d^{-1}$. Redmon et al. (1995) suggest that the initial reductions in ADG as forage allowance falls are due to declines in forage quality as opposed to forage intake. However, results of the current study suggest it is likely that the observed greater ADG by heifers grazing triticale in year 1 was due to greater forage quality, and thus it is unlikely that intake was substantially impacted by the forage allowance being slightly below reported critical values. Forage nutritive value, or the ability of a forage to elicit a productive response, is primarily affected by intake and digestibility. Forage allowance for heifers grazing wheat and oats was sufficient to expect that intake was not likely to have been restricted; therefore, the lower growth rate observed compared to heifers grazing triticale is attributed to lower measures of quality of the available forage.

As forages increase in physical maturity the leaf to stem ratio decreases (Merchen and Bourquin, 1994). Forage clippings in year 2 of the current study (Table 18) show a decrease in the percent leaf and an increase in the stem with each sampling period. As plants become more mature leaves become proportionally less available than stems, increasing NDF content, thereby decreasing digestibility. While there was a significant reduction in the leaf to stem ratio as forages became more mature, cannulated steers were able to select a diet consisting of at least 95% leaf in year 2. Along with advancing maturity, the decrease from nearly 100% leaf on d 0 to around 95% on d 84 account for the increased NDF and decreased CP intake.

Cool season annuals are typically high in CP especially early in the growing season (> 25% DM basis; Mader et al., 1983, Beck et al., 2007; Morgan et al., 2012) however, in both years of the current study CP averaged only 11.2%. Coblentz et al. (2002) reported mean CP values of 24.1% in wheat, 17.4% in oats, and 23.1% in triticale, all of which are greater than the CP values observed in both years of the current study. Forage intake is positively related to CP content when forage CP content is less than 7% (low quality forage); however, there is no relationship when forage CP is greater than 7% (Moore and Kunkle (1995). In the current study average CP levels were all greater than 7%. While CP content of triticale was slightly greater in year 1 compared to wheat and oats, it likely does not fully account for the observed increase in performance.

Less mature forages typically have lower NDF values and are of higher nutritional quality. Mertens (1985) used NDF concentration to predict DMI as a % of

BW and found that as NDF increased from 38 to 52%, DMI as a % of BW decreased from 3.16 to 2.31%. Coblentz et al. (2002) reported mean NDF values of 40.7% in wheat, 43.7% in oats, and 44.8% in triticale. These NDF values are similar to those observed in year 1 of the current study; however, NDF values in year 2 averaged only 39.9% in wheat, 33.3% in oats, and 36.1% in triticale. According to Mertens (1985), the 4% increase in NDF concentration of wheat compared to triticale would result in a 9% decrease in DMI as a % of BW. Midpoint BW of heifers in the current study was 300 kg, and heifers grazing triticale consumed 2.5% of BW (DM basis), heifers grazing wheat would be consuming 2.3% of BW (9% reduction in DMI); resulting 0.6 kg/d difference in intake. Using the Beef Cattle Nutrient Requirements Model (NASEM, 2016) the 0.6 kg/d difference in intake of a forage of this quality would result in 0.12 kg/d decrease in ADG, similar to the difference in overall ADG observed in this study. Therefore, even though forage availability was greater for both wheat and oats in year 1, the increased NDF concentration potentially reduced forage intake and ADG.

Because heifers in both years were supplemented (Horn et al., 2005), it is also possible that the observed difference in ADG was due to variation in the substitution of forage intake by supplement intake. If forage allowance was lower for triticale, then heifers grazing triticale may not have substituted forage intake for the supplement intake to the same degree as those consuming wheat, and thus converted supplement more efficiently than heifers with greater forage availability and a larger substitution decreasing the value of the supplement. If heifers who had forage availability greater than the critical value had a substitution of 100%, and the supplement had a similar TDN to forage, then there would be no effect of supplement on gain. If heifers grazing triticale had a substitution of only 50% then the 0.65 kg of supplement (75% TDN) adds 0.49 kg of TDN and because forage intake (75% TDN) is reduced 0.34 kg/d it removes 0.23 kg of TDN. Therefore, net TDN of heifers grazing triticale is increased by 0.23 kg/d which is enough to add close to 0.1 kg/d of gain.

Overall, the 0.1 kg/d increase in ADG observed in heifers grazing triticale could be attributed to increased quality (greater CP content and lower NDF concentrations) compared to both wheat and oats; however, it is also important to consider the substitution of forage for supplement. While it appears that the increased ADG in heifers grazing triticale in year 1 was due to increased quality, it can also be attributed to increased efficiency of supplementation.

Conclusion

The current study suggests that animal performance among the three forage sources evaluated in this study was similar during years of adequate precipitation or when stocking rate allows for an excess of forage available for grazing. When early growing season rainfall was below average, animal performance was greater in heifers grazing triticale compared to wheat or oats. This improvement was likely a result of differences in forage quality under those growing conditions, but may also have resulted from an unanticipated difference in substitution rates of forage for supplements provided. Regardless, triticale is a viable alternate winter forage to wheat or oats with similar forage quality and yield

CHAPTER VI

CONCLUSIONS

Declining production base coupled with increasing demand for beef suggest a need for innovation in production. In order to improve the overall sustainability of beef production, gains in both production efficiency and land-use efficiency need to be observed. Overall, intensification of beef cow production appears to be a reasonable solution for increasing cow-calf system efficiency and also shows potential to increase production per unit of land. However, it is important to remember that cow-calf systems reliant upon managed feed consumption require enhanced management of nutrition, health, and space relative to more typical confinement dairy or beef finishing systems designed for *ad libitum* feed consumption.

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