THESIS

EVALUATION OF THE ALL HEIFER, NO COW BEEF PRODUCTION SYSTEM TO IMPROVE BEEF PRODUCTION EFFICIENCY

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ABSTRACT

EVALUATION OF THE ALL HEIFER, NO COW BEEF PRODUCTION SYSTEM TO IMPROVE BEEF PRODUCTION EFFICIENCY

Maintaining a mature cowherd year-round requires costly feed inputs that do not contribute to overall herd productivity, but simply are expended on unproductive, maintenance energy for cows. Alternative herd management strategies with no cows and all heifers may increase feed and economic efficiency, yet prior research addressing these response variables is scarce. The overall objective of this research was to evaluate performance and efficiency of the All Heifer, No Cow (**AHNC**) beef production system. The AHNC beef production system involves insemination of nulliparous heifers with female sex-selected semen to produce primarily female calves that are early-weaned 3 mo after birth. Dams are finished on a high concentrate ration and harvested before reaching 30 mo of age to produce high quality carcasses. Objectives of this study were two-fold: 1) manage a live AHNC demonstration herd to characterize herd performance, and 2) use data collected from the AHNC demonstration herd to parameterize a system dynamic model to evaluate biological and economic efficiency of the system.

Specific objectives of Chapter II were to: 1) document reproductive, feedyard, calf, and carcass performance of a 5-cohort AHNC demonstration herd; 2) evaluate effects of carcass maturity on carcass quality variables; and 3) determine if performance of initial cohorts (i.e., cohorts 1 and 2) differed from sustaining cohorts (i.e., cohorts 3 through 5).To evaluate system performance, 273 heifers were enrolled in the AHNC beef production system via 5 annual cohorts over a 6-yr period. The system was initiated with the purchase of 51 yearling, Angus-based commercial heifers (initial BW = 354 ± 39 kg). Cohort 2 was started with a similar set of

purchased heifers (n = 56; initial BW = 307 ± 30 kg) 12 mo after cohort 1. Heifers enrolled in cohorts 3 (n = 53), 4 (n = 56), and 5 (n = 56) were primarily offspring of prior cohorts (e.g., cohort 3 heifers were born to cohort 1 dams, etc.), but some heifers were acquired in a similar manner as cohorts 1 and 2 to ensure maintenance of annual inventory.

Ovulation was synchronized, and heifers were artificially inseminated with female sex-selected semen. In cohorts 2 through 5, heifers were resynchronized, and a second AI was performed approximately 18 to 21 d after the first AI. Following insemination, heifers were placed with 1 natural service sire. Overall, heifers achieved a pregnancy rate of 50.4 ± 9.8% approximately 30 d after AI and a pregnancy rate of 93.0 ± 1.5% at 140 d post AI. Across 5 cohorts, percent calf crop was 85.7 ± 8.2%, and 61.0 ± 6.5% of females replaced themselves with a heifer. For cohorts 4 and 5, 67.8% of females replaced themselves with a heifer, requiring remaining heifers to be purchased from outside the system.

Calves produced in the system were early-weaned at 105 ± 21 d and weighed 125 ± 28 kg at weaning. After weaning, dams were fed a corn-based finishing ration for 72 ± 8 d. While on the finishing ration, dams gained 1.9 ± 0.4 kg • d^{-1} and consumed 14.9 ± 1.9 kg DM • d^{-1}. Although dams gained rapidly, their feed conversion was poor. Overall G:F for the 5 cohorts was 0.123 ± 0.025. Body weight at harvest was 637 ± 57 kg.

A total of 222 AHNC females were harvested. Across cohorts, HCW and dressing percent were 367 ± 35 kg and 58.8 ± 1.9%, respectively. The packer classified 68.3 ± 5.3% of carcasses as over 30 mo of age based on dentition. Overall USDA yield grade (**YG**) was 2.6 ± 0.7. Marbling score (**MA**) was 457 ± 87, which coincided with a marbling level of small[57]. Overall, 62.4 ± 29.1% of carcasses graded USDA Choice and greater.

Carcasses were pooled across cohorts and performance variables associated with carcass quality were compared between youthful (i.e., A and B maturity) and mature (i.e., C maturity

and greater) carcasses. Overall, 177 carcasses were classified as youthful (80.5%) and 43 were classified as mature (19.5%) by USDA grading personnel. There were no differences between maturity groups for ribeye area ($P = 0.13$), USDA YG ($P = 0.67$), MA ($P = 0.26$), or lean maturity score ($P = 1.00$). Mature carcasses had greater ($P < 0.001$) bone maturity scores and greater ($P < 0.001$) overall maturity scores compared to youthful carcasses. Additionally, mature carcasses had heavier ($P < 0.01$) HCW and greater ($P < 0.001$) dressing percentages. For cohorts 3 through 5, mature carcasses (919 ± 11 d) were older ($P < 0.001$) than youthful carcasses (902 ± 11 d) at harvest.

Performance variables between initial (i.e., cohorts 1 and 2) and sustaining cohorts (i.e., cohorts 3 through 5) were compared. Logistic regression models were used to evaluate reproductive performance. There were no differences for 30 ($P = 0.17$) or 140 d ($P = 0.48$) pregnancy rates between initial and sustaining cohorts. Multiple linear regression models were used to evaluate growth and carcass performance. Models indicated ADG ($P = 0.88$), USDA YG ($P = 0.25$), and MA ($P = 0.44$) did not differ between cohorts. Daily DMI was greater ($P < 0.001$) for sustaining cohorts. Carcasses produced by initial cohorts had heavier ($P < 0.001$) HCW and greater ($P < 0.001$) dressing percentages. Lean maturity and bone maturity scores were greater ($P < 0.01$; $P < 0.01$) for carcasses produced by sustaining cohorts, but overall maturity scores were greater ($P < 0.05$) for carcasses produced by initial cohorts.

Specific objectives of Chapter III were to: 1) build a dynamic model of an AHNC beef production system using data collected from an AHNC demonstration herd to quantify system biological and economic efficiency; 2) compare effects of utilizing female sex-selected semen vs. conventional semen on system biological and economic efficiency; 3) evaluate what-if scenarios to determine effects of first AI conception rate, percent of female calves born, and percent USDA Choice and greater carcasses had on system biological and economic efficiency;

4) evaluate effects that changing conception rate to first AI, percent of female calves born, and HCW ±10% from observed values had on biological efficiency (**BE**) and evaluate effects of changing corn, hay, feed, and replacement heifer prices and the percent of carcasses over 30 mo of age, HCW, conception rate to first AI, and percent of female calves born ±10% from observed values had on economic efficiency. Biological efficiency was defined on a system basis as the ratio of *output* (i.e., kg of HCW) to *input* (i.e., lifetime kg of TDN consumed). Biological efficiency was evaluated as lifetime G:F. Economic efficiency was measured via a benefit-cost ratio (**BCR**) and cost-effectiveness ratio (**CER**).

The model included several different modules: 1) production herd 1, 2) production herd 2, 3) harvest, 4) marketing, 5) variable costs, 6) revenues, and 7) biological and economic efficiency which worked in unison to create model output. There were 2 production units, coinciding with the 2 initial purchased sets of heifers (i.e., cohorts 1 and 2), that were started 12 mo apart to garner annual income. Within production unit 1, there was an initial herd track (i.e., cohort 1) sustaining herd track (i.e. cohorts 3, 5, etc.), and steer calf track. Biological model parameters were calibrated using values observed in the 5-cohort AHNC demonstration herd. Initial and sustaining herds were parameterized differently; initial cohorts were parameterized with data from cohorts 1 and 2 and sustaining cohorts were parameterized with data from cohorts 3 through 5. Parameterization for production herds 1 and 2 was identical. The model included 10 yr of historical price data from 2008 to 2017.

All results were reported on a system basis, combining production herds 1 and 2. Over 40 simulation runs, the model predicted an average BE of 0.070 ± 0.001. Economic efficiency was 0.842 ± 0.006 and \$4.60 ± 0.06 for BCR and CER, respectively. Results of the simulations showed only a small amount of run-to-run variation between biological and economic efficiencies. The small amount of run-to-run variation was due to the inability to randomize

conception rates, culling rates, death loss, and assignment of carcass grades. The run-to-run variation observed was due to price variation, randomized animal feed intake, and randomized biological performance.

When evaluating the female sex-selected and conventional semen scenarios in the model, heifer replacement rates were 64.7% and 41.0% for female sex-selected and conventional semen scenarios, respectively. Predicted G:F were 0.070 ± 0.001 and 0.073 ± 0.001 for female sex-selected and conventional semen scenarios, respectively. Predicted BCR were 0.842 ± 0.006 and 0.929 ± 0.006 for female sex-selected and conventional semen scenarios, respectively. The conventional semen scenario was more biologically and economically efficient. However, based on BCR the system was not profitable in either scenario.

Results of what-if scenarios showed that greatest BE was achieved using a high conception rate to first AI, a low female replacement rate, and greater percent of USDA Choice and greater carcasses. Greatest economic efficiency was achieved using a high conception rate to first AI, a low female replacement rate, and a high percentage of USDA Choice and greater carcasses. Generally, economic efficiency was consistent with BE, indicating the most biologically efficient option was also the most economically efficient option.

Sensitivity analyses were conducted by changing selected variables ±10% from observed values. Overall, biological and economic efficiencies were most sensitive to HCW. Increasing HCW resulted in improvements to both biological and economic efficiencies. High feed costs and replacement heifer prices negatively affected system profitability. Reducing the percent of carcasses classified as over 30 mo of age at harvest positively impacted AHNC beef production system profitability.

In conclusion, the AHNC beef production system was capable of achieving reproductive rates similar to conventional cow/calf production and producing carcasses that are similar to

conventionally raised and finished steers and heifers. The AHNC beef production system does not breakeven in most years due primarily to discounts of some carcasses that were classified as over 30 mo of age at harvest based on dentition and C maturity based on bone maturity. An important question for future exploration is how biological and economic efficiency of AHNC beef production compares to conventional cow/calf-based beef production systems.

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"For those who encouraged me to fly towards my dreams: Let's soar."

—Unknown

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DEDICATION

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I:

REVIEW OF LITERATURE

Economic pressures and increasing demand to improve beef production efficiency, particularly via a reduction in feed and water use and methane output relative to beef output, have prompted evaluation of alternative beef production systems. The Single-Calf Heifer System (**SCHS**) proposed by Brethour and Jaeger (1989) involves breeding nulliparous heifers to produce a single calf, then subsequently feeding and harvesting dams to produce carcasses before reaching 30 mo of age. Conventional thinking is to maximize cow longevity, thus amortizing the cost of replacement heifer development (Ritchie, 1995). However, optimal system efficiency is achieved through reducing calvings per cow, or using the SCHS (Taylor et al., 1985; Bourdon and Brinks, 1987; Brethour and Jaeger, 1989). The SCHS offers improved efficiency through elimination of the mature cowherd and their excessive maintenance energy requirements.

In beef production, nutrients are partitioned accordingly: maintenance energy, growth/ development, lactation, reproduction, and fat accretion (Noble Research Institute, 1997; Radunz, 2012). A reproducing cowherd requires energy for lactation, gestation, and maintenance energy (Short et al., 1990). Collectively considering the cows' requirements, combined with energy requirements of replacement heifers and bulls, about 70% of all nutrients consumed for beef production are expended by the cow/calf segment (Ferrell and Jenkins, 1985). The remaining 30% accounts for the post-weaning growth of both the stocker and final finishing phases (Fig. 1.1). Bourdon and Brinks concluded efficiency was improved in younger females due to a decreased maintenance energy requirement (1987).

Modifying the SCHS can accelerate the system timeline, ensuring a calf is produced and dams are finished and harvested in a timely manner (Riggs, 2000). The All Heifer, No Cow (**AHNC**) beef production system is a modified version of the Single-Calf Heifer (**SCH**) beef production system. The AHNC beef production system involves insemination of nulliparous heifers with female sex-selected semen to produce primarily female calves that are early-weaned 3 mo after parturition. Dams are finished on a high concentrate ration and harvested before reaching 30 mo of age to produce high quality carcasses (Seidel and Whittier, 2015). Use of female sex-selected semen and retention of subsequent female calves reduces the number of replacements purchased annually.

The AHNC beef production system is a management scheme that may be more biologically efficient than conventional cow/calf-based beef production. While components of the AHNC beef production system (i.e., AI with female sex-selected semen, crossbreeding, early-weaning, and feeding once-calved females on a high concentrate ration) have been well researched independently, there have been limited studies evaluating these strategies as cohesive system. The AHNC beef production system has potential of producing high quality carcasses for beef, while reducing feed inputs (Seidel and Whittier, 2015).

SINGLE-CALF HEIFER SYSTEM

The SCH beef production system has been studied as an alternative to conventional cow/calf-based production. The SCHS is an intensive management strategy that relies on breeding heifers and harvesting once-calved females (**OCF**) at a young age (Brethour and Jaeger, 1989). The SCHS is an effective management strategy because the system is best suited to large-framed heifers destined for harvest that typically are not suitable for use as replacements due to excessive maintenance energy requirements after reaching mature BW (Brethour and Jaeger, 1989). Unlike conventional cow/calf-based production, animals in the SCHS produce both a calf

and carcass annually. Compared to conventional cow/calf production, the SCHS offers improved biological efficiency due to more effective nutrient utilization (Taylor et al., 1985; Bourdon and Brinks, 1987; Brethour and Jaeger, 1989). Energy is used for growth, pregnancy, lactation, and fat accretion, so proportionally less feed is used for maintenance energy (Sell et al., 1988; Seidel and Whittier, 2015).

In the early 1970s, Europe had a beef shortage (Owen, 1973). Use of OCF was proposed as a means of increasing beef production (Owen, 1973). In Belgium, dairy production was extensive, and it was hypothesized that beef production could be intensified by breeding cull dairy heifers to a beef breed (Owen, 1973; Boucqué et al., 1980). An experiment, conducted by Boucqué and colleagues (1980), used Belgian red and white dual-purpose calves that were divided into 3 groups: a control group that was not exposed to a bull, but fed extensively, and 2 experimental groups that both were exposed to Charolais bulls and fed intensively; one experimental group was maintained on pasture and the other was managed indoors. Heifers were reared from 8 d of age and programmed to calve at 2 yr of age, and dams were fattened post calving (Boucqué et al., 1980). Both control and OCF groups were harvested at roughly 30 mo of age, and there were no differences in dressing percentages between treatment groups, but the intensive-indoor group produced heavier, longer carcasses (Boucqué et al., 1980). Results showed the SCHS could improve meat production, but feed conversion of OCF was poor, and resulted in unfavorable economics (Boucqué et al., 1980).

There are many technical considerations for a SCH beef production system. Conception rate, calving difficulty, calf survival rate, and progeny performance are key considerations. However, arguably the most important consideration is carcass age and quality (Riggs, 2000). It is critical to ensure dams are harvested before reaching 30 mo of age to avoid age associated carcass discounts. There are carcass discounts for advanced carcass physiological maturity scores of “C”

or greater and additional discounts for those identified as over 30 mo of age based on dentition (USDA, 2016). An OCF carcass that grades USDA Choice, may be worth as much as 30% more per pound than a cull cow on a weight basis (Brethour and Jaeger, 1989).

Dystocia and breed selection. Calving difficulty is a common problem when calving heifers at 2 yr of age; however, availability of accurate EPD for calf birth weight (**BWT**) and calving ease has helped mitigate this problem. Incidence of dystocia in 2-yr-old heifers was 36% greater than in 3-yr-olds and 45% greater than in 4- and 5-yr-olds (Laster et al., 1973). The predominant type of dystocia that impacts 2-yr-old heifers is feto-maternal disproportion, the calf is too large relative to size of the dam's pelvis (Hickson et al., 2006). Other common causes of dystocia are improper calf position, posture, or presentation (e.g., backwards, transverse) at the time of birth. Ultimately, dystocia has a negative impact on calf morbidity and mortality, which in turn has a negative impact on system profitability (Laster et al., 1973; Keeling et al., 1990; Hickson et al., 2006). Results of a SCHS modeling study yielded profitability was more sensitive to the percent of live calves than an increase in rate of gain (Keeling et al., 1991).

One effective way to reduce dystocia is through close supervision during parturition. However, a more proactive approach should also be taken. Naazie et al. (1989) and Hickson et al. (2006) reported BWT had the largest effect on dystocia. Specifically, the ratio of BWT to dam BW was the most important factor (Naazie et al., 1989). Thus, dam BW at calving and BWT are important considerations when selecting breeds used in a SCHS. Brethour and Jaeger (1989) noted young, small-framed heifers should not be used in a SCHS due to not reaching puberty in sufficient time. Contrary to the theory of Brethour and Jaeger (1989), Dickerson (1976) determined that rapid growth was associated with an increased mature BW, increased age at puberty, and longer gestation length. Furthermore, Dickerson (1970) emphasized that in many production systems, an increased growth rate is associated with greater levels of dystocia and

calf mortality. Likewise, Bagley (1993) reported larger mature BW coincided with reaching puberty at an older age. Cundiff et al. (1986) reported significant breed effects for gestation length, BWT, and calf mortality from a study involving 14 breeds of cattle. Breeds with heavier mature BW experienced an increased rate of dystocia and calf death loss (Cundiff et al., 1986).

With this in mind, careful consideration should be given when selecting maternal and paternal breeds for a SCHS. The aforementioned OCF experiment by Boucqué et al. (1980) used Belgian red and white heifers that were bred to Charolais bulls to calve at approximately 2 yr of age. Roughly 35% of calvings required caesarean sections and 25% of calves were deceased within the first 24 h after parturition. Surprisingly, the authors contributed the high rate of dystocia to heifers' young age at parturition, not breed effects (Boucqué et al., 1980). Smith et al. (1976) demonstrated a relationship between Continental breeds and calving difficulty. Calves born to primiparous heifers sired by Continental breeds experienced greater levels of dystocia than those sired by British breeds. Multiparous dams have much less difficulty calving high BWT calves (Laster et al., 1973; Smith et al., 1976). Breed of sire also has a relationship with gestation length and BWT. Smith and colleagues (1976) reported Limousin sired calves had the longest gestation length (i.e., 288.1 d), and Simmental, Charolais, and South Devon sired calves had similar gestation lengths.

High BWT can be mitigated through use of bulls with low estimated breeding values for BWT. However, this practice should be used judiciously due to the positive correlation between BWT and mature BW (Hickson et al., 2006). Low BWT calves may be lighter at harvest, producing a less desirable carcass. Bagley (1993) reported calves born to OCF had slightly lighter weaning weights (**WWT**) than those born to multiparous dams. In a SCHS, few calves, if any, are retained. Consequently, lighter WWT are offset by higher market prices on a weight basis for lighter weight calves (Brethour and Jaeger, 1989). However, bull selection should

receive further consideration when using the AHNC beef production system since most heifer calves are retained and subsequently bred.

Heifers can be managed to facilitate growth, ultimately increasing pelvic size to help minimize calving difficulty. Bagley (1993) reported that using anabolic implants increased rate of gain, facilitating growth and increasing pelvic size. Additionally, ionophores improved growth rate and most importantly, decreased age at puberty (Bagley, 1993). Excessive feeding can result in overweight heifers at time of parturition, which contributes to dystocia (Laster et al., 1973; Boucqué et al., 1980; Brethour and Jaeger, 1989).

Lastly, calf sex may impact BWT ultimately impacting calving difficulty. Laster et al. (1973) reported an increase in calving difficulty for every 2.3% increase in BWT. Specifically, dams with male progeny experienced greater levels of dystocia, 28%, versus 17% for dams with female progeny (Laster et al., 1973). On average, male progeny had 1.7 d longer gestation lengths when compared to female progeny (Smith et al., 1976). Naazie et al. (1989) used multiple regression modeling to predict calving difficulty and reported calf sex did not influence calving difficulty. However, Tubman et al. (2004) concluded heifer calves had an average birth weight of >2 kg less than their male contemporaries. This suggests that use of female sex-selected semen in the AHNC would help mitigate dystocia.

Early-weaning. The SCH and AHNC beef production systems both employ the strategy of early-weaning. Early-weaning was developed as a tool to improve cow BCS (Rasby, 2007). Rasby (2007) defined early-weaning as weaning a calf at less than 180 d of age. Conventional weaning usually occurs between 180 and 220 d (Rasby, 2007). Early-weaning calves is an effective strategy to improve conception rate when rebreeding cows (Lusby et al., 1981; Lalman, 2017). Early-weaning is effective in improving conception because cow nutrient requirements are reduced and BCS improves. Lactation greatly increases cow energy and protein requirements

(Ferrell and Jenkins, 1985; Rasby, 2007; Lalman, 2017). In addition to facilitating an increased BCS at the time of breeding, research has shown removal of the suckling calf can elicit hormonal changes that stimulate resumption of estrous cycles (Short et al., 1990; Rasby, 2007). A study conducted by Lusby et al. (1981) showed early-weaning improved reproductive performance in OCF. Percentages of dams cycling at 85 d postpartum were 34 and 90% and conception rates were 59 and 97%, for conventionally- and early-weaned dams, respectively.

Considering female offspring in the AHNC beef production system are retained and subsequently inseminated, performance of early-weaned calves is important. Peterson et al. (1987) reported early-weaned calves gained more than conventionally-weaned calves and were heavier at the time of conventional weaning than conventionally-weaned calves. Increased calf gain coupled with a 45.3% reduction in hay use by their dams, resulted in early-weaned pairs achieving a 43% improvement in converting feed energy into calf gain (Peterson et al., 1987). A lifetime evaluation of early-weaned calves by Fluharty et al. (1996) concluded early-weaned animals were heavier at harvest, dressed more desirably, and showed an improvement in lifetime feed efficiency. Similar results were reported by Myers et al. (1999a,b,c). Early-weaned calves had improved overall ADG, decreased daily feed intake, improved quality grades, and were younger at harvest (Myers et al., 1999a,b,c).

Early-weaning can improve dam reproductive performance and calf efficiency. However, this requires an increase in concentrate feeding (Myers et al., 1999b; Rasby, 2007). Myers et al. (1999b) reared early-weaned calves on grazed endophyte infected fescue or concentrate. The concentrate group had increased ADG and efficiency and yielded a larger proportion of carcasses that graded USDA Choice, however increased feeding of concentrate increased break-even prices (Myers et al., 1999b). Break-even prices per 45.4 kg of calf BW for calves weaned at 150, 210, and 270 d were $113.18, $86.81, and $82.76, respectively (Story et al., 2000). In addition to

an increased break-even price, heavier weights were penalized in the market. Average dollar values per calf at weaning for the 150-, 210-, and 270-d-old calf groups were $325.33, $393.75, and $430.19, respectively (Story et al., 2000). Early-weaning reduced cow-costs; cow costs were $410.16 for early-weaned dams, $421.21 for conventionally-weaned dams, and $443.32 for late-weaned dams (Story et al., 2000). At the cow/calf level, conventionally-weaned calves were more profitable, however when increased ADG and improvements in efficiency post-weaning were considered, the early-weaned steers were most profitable (Story et al., 2000).

The scientific literature indicated early-weaned calves can produce carcasses of equal quality to carcasses produced by conventionally-weaned calves, but early-weaned animals converted feed to beef more efficiently (Myers et al., 1999b; Story et al., 2000; Rasby, 2007). To ensure high quality carcasses are produced, early-weaned calves must be fed concentrate post-weaning, increasing costs (Myers et al., 1999b; Story et al., 2000; Rasby, 2007). However, these costs will be realized in retention of calves through the feedyard (Story et al., 2000). Consequently, early-weaning is a profit increasing strategy for an AHNC producer.

Carcass characteristics. The 2016 National Beef Quality Audit reported consumers desire a beef product that is safe, tender, and palatable (NCBA, 2016). However, to remain competitive with pork and poultry, beef must be produced efficiently. If beef produced from AHNC females is palatable (i.e., tender, juicy, and flavorful) and economically viable, the AHNC beef production system may be able to satisfy consumer needs and improve overall beef production efficiency.

The U.S. Standards for Grades of Beef Carcasses include 5 classes of maturity: A, B, C, D, and E (USDA, 2016). The following ages correspond to maturities A, B, C, D, and E: 9 to 30 mo, 30 to 42 mo, 42 to 72 mo, 72 to 96 mo, and >96 mo, respectively (USDA, 2016). These overall maturity (**OM**) classifications are determined through assessment of lean maturity (**LM**)

and bone maturity (**BM**). Specifically, LM is evaluated in the exposed ribeye at the interface of the 12th and 13th rib. In young animals, the lean texture is very fine, and the color is a light, grayish red (Tatum, 2011; USDA, 2016). Older animals will have a very coarse lean texture and exhibit a very dark red lean color (Tatum, 2011; USDA, 2016). However, LM score is much less important than BM in the calculation of OM. Bone maturity is assessed by evaluating the size and shape of ribs and the degree of ossification in bones and cartilage along the vertebral column of halved carcasses. Emphasis is placed on ossification of the thoracic buttons because bone fusion and ossification generally start in the sacral region and continue through the forequarter of the carcass (Tatum, 2011). According to the USDA (2016), BM is more indicative of age, and thus receives greater emphasis in the calculation of OM. A carcass of "A" LM and "C" BM would receive an OM score of C. Overall maturity cannot be adjusted more than 1 maturity group different than indicated by BM (USDA, 2016).

Dentition is more indicative of chronological age than physiological maturity (Tatum, 2011). Dentition is assessed on the harvest floor, but it is not used for grading purposes. Animals with an erupting third permanent incisor are deemed over 30 mo of age. Dentition is used a surrogate criterion to quantify chronological age, but it is a crude predictor. However, dentition is still frequently used to classify cattle as over or under 30 mo of age to prevent human exposure to bovine tissue at increased risk of infection from prions that cause bovine spongiform encephalopathy (Tatum, 2011). Currently, third party age and source verification of cattle will override dentition, but dentition has no effect on assessment of OM which is used with marbling score (**MA**) to determine QG.

It has been documented that estrogen enhances skeletal ossification. Thus, females typically exhibit more advanced BM than their male contemporaries (Grumbach and Auchus, 1999). As a result, when comparing steers and heifers of the same age at harvest, heifer carcasses are more

likely to receive the classification of B maturity. Further complicating the issue, more accelerated bone ossification is observed in OCF due to greater hormone concentrations associated with pregnancy, calving, and nursing (Waggoner et al., 1990; Kreikemeier and Unruh, 1993; Field et al., 1996).

Kreikemeier and Unruh (1993) evaluated carcasses of finished, pregnant and non-pregnant heifers of unknown ages and discovered carcasses produced by pregnant heifers harvested during their last trimester had significantly more advanced BM than non-pregnant heifers. Seven and a half percent of pregnant heifers were classified as B maturity or older based on carcass maturity, and 3.5% of non-pregnant heifers were classified as B maturity or older based on carcass maturity (Kreikemeier and Unruh, 1993). A comparison of carcasses produced by 31- to 35-mo-old females—either spayed, virgin, or once-calved—fed a high concentrate ration for 100 d, resulted in physiological maturity differences (Field et al., 1996). Moreover, 5.6, 37.5, and 77.8% of carcasses were classified B maturity or older based on carcass maturity for the spayed, virgin, and OCF, respectively (Field et al., 1996).

This implies despite an OCF being under 30 mo of age at harvest, her carcass likely will be classified as B or C maturity. Interesting research conducted by Schackelford and colleagues (1995) found maturity scores increased with age much more rapidly than the USDA indicated. Schackelford et al. (1995) suggested guidelines for age and physiological maturity correspondence should be: A – 9 to 24 mo, B – 4 to 36 mo, C – 36 to 48 mo, D – 48 to 60 mo, and E – > 60 mo. Both the SCHS and the AHNC beef production systems target a harvest age of 30 mo, and therefore an OM of B is anticipated, and C maturity discounts would be avoided.

Generally, beef produced from OCF is thought to be of poorer quality than that of a conventionally raised and fed heifer or steer. Generally, OCF exhibit more advanced physiological maturity than typical calf- or yearling-fed animals, thus decreasing likelihood of

carcasses produced by OCF achieving a desirable QG (i.e., USDA Choice or better). However, OCF are sometimes over 1 yr older than conventionally raised and finished animals at harvest. The relationship between age and tenderness has been well documented. Shorthose and Harris (1990) compared 12 different muscles from 8 different age groups of carcasses ranging from about 1- to 60-mo-old, and concluded meat tenderness decreased with age, and the greatest increase in muscle toughness occurred in muscles with high concentrations of connective tissue (e.g., Biceps femoris). Older cattle become tougher due to increased mechanical and thermal stability of collagen (Shorthose and Harris, 1990). Beef from youthful carcasses (e.g., 12- to 18-mo-old) also contains collagen, however collagen in younger animals is formed by immature crosslinks, thus collagen more readily hydrolyzes to form gelatin in the cooking process, minimizing toughness effects (Tatum, 2011). With increasing age, crosslinks begin to stabilize, causing collagen to become heat resistant and insoluble, resulting in increased meat toughness (Shorthose and Harris, 1990; McCormick, 1994; Tatum, 2011).

When comparisons were made in animals widely disparate in chronological age, tenderness and age generally had an inverse relationship; increasing age coincided with decreased tenderness (Shorthose and Harris, 1990; Purslow, 2005). However, when evaluating fed cattle typically produced in the mainstream U.S. beef market (i.e., 12 to 24 mo of age), age generally had little to no effect on beef tenderness (Field et al., 1966). Field and colleagues (1966) compared beef produced by steers and heifers ranging 300 to 699 d of age at harvest. Field and colleagues (1966) determined when MA was held constant, age did not impact meat tenderness.

Perhaps most relevant to AHNC and OCF beef production systems is how A and B maturity beef carcasses compare to C maturity carcasses. Miller et al. (1983) examined beef from youthful (e.g., A and B maturity) and mature (e.g., C and D maturity) carcasses produced by steers finished 185 d on a high concentrate ration and detected no differences in meat tenderness

between the 2 groups. A second study conducted by Tatum et al. (1980) yielded similar results. Sensory panel ratings and Warner-Bratzler shear force (**WBSF**) values indicated no differences for steaks produced by steers that were harvested after 100 or 160 d on feed. Interestingly, a small number of C maturity carcasses produced steaks with superior sensory qualities (Tatum et al., 1980). Field and colleagues (1997) were specifically examining differences between A and C maturity carcasses produced by finished, beef females of similar chronological age (i.e., both groups consisted of heifers 31 to 35 mo of age) and determined there were no differences between mature collagen crosslinks or steak tenderness. The authors concluded collagen maturation was independent of skeletal maturation (Field et al., 1997).

A review conducted by Reddy et al. (2015) compared beef produced by heifers to beef produced by steers, bulls, and cows. Key findings of the review included: beef produced by heifers had superior eating quality characteristics, a healthier fatty acid profile, and an increased propensity to marble (Reddy et al., 2015). These results indicated beef produced by heifers has the ability to be equally palatable, if not more palatable, than beef produced by steers. However, Tatum et al. (2007) reported beef produced by females is tougher due to increased 24-hr calpastatin activity. In the early postmortem aging period, μ-calpains break down muscle fiber proteins, compromising their structural integrity and causing increased tenderness as carcass ages (Tatum et al., 2007). Calpastatin limits the enzymatic activity of μ-calpains, decreasing tenderization in the postmortem aging period (Tatum et al., 2007).

There have been several studies that specifically investigated the quality of beef produced by OCF. The first study conducted by Joseph and Crowley (1971) compared beef from 12 maiden and 24 Hereford OCF that were harvested at 27 to 30 mo of age. Results of a taste panel showed no differences between the 2 groups (Joseph and Crowley, 1971). Additionally, the authors

determined the length of time calves were allowed to suckle (e.g., 2, 42, or 70 d) had no effect on beef tenderness (Joseph and Crowley, 1971).

Waggoner et al. (1990) evaluated carcass traits of Simmental × Hereford maiden heifers that were harvested at 1- or 2-yr-old and OCF that were harvested at 30 mo of age, and both groups were fed a high concentrate diet for 137 d before harvest. Carcasses produced by OCF exhibited more advanced BM and OM than both groups of maiden heifers (Waggoner et al., 1990). For the OCF average OM was 205 ± 3, average BM was 216 ± 4, and average LM was 180 ± 3 and, 3 of the 84 carcasses were classified as C maturity based on carcass maturity (Waggoner et al., 1990). There were no differences in MA between groups (Waggoner et al., 1990). Sensory panelists and WBSF values indicated beef produced by OCF was tougher than beef produced by yearling heifers, but of similar tenderness to beef produced by 24-mo-old heifers (Waggoner et al., 1990). Ultimately, Waggoner et al. (1990) concluded beef produced by. OCF was comparable to beef produced by heifers of similar chronological age.

A recent study conducted by Nogalski et al. (2016), indicated beef produced by OCF is of equal value, if not greater value, than beef produced by their maiden contemporaries. The authors reported that maiden heifers were harvested at 18 mo of age and OCF were harvested at 24 mo. Carcasses produced by OCF were heavier, exhibited a lower dressing percentages by an average of 2.57 percentage points, had greater percentages of intramuscular fat (i.e., 3.99 versus 2.97%), and had a larger portion of the 5 most valuable cuts when compared to maiden heifers (Nogalski et al., 2016). Results from the study conducted by Nogalski et al. (2016) were consistent with Vincent et al. (1991). Three groups of OCF were harvested at 3, 5, or 7 mo post-calving and 1 set of conventionally raised and finished heifers was harvested at 15 mo and evaluated (Vincent et al., 1991). Carcasses produced by OCF were heavier with greater MA, but had lean tissue, fat, and bone proportions that were similar to conventionally raised and finished

heifers (Vincent et al., 1991). Lean color was slightly darker for OCF, but sensory panels concluded all carcasses were of similar eating quality (Vincent et al., 1991).

Arce-Cordero (2016) specifically evaluated meat quality of females managed in an AHNC beef production system. A total of 86 AHNC carcasses were evaluated and 34% were classified as C maturity based on carcass maturity (Arce-Cordero, 2016). For youthful carcasses, measurements were OM = 192 ± 39, BM = 211 ± 53, LM = 165 ± 29, MA = 446 ± 84, slice shear force = 25.4 ± 8.6 kg, WBSF = 4.94 ± 1.19 kg, and cooking loss = 25.4 ± 4.1%, and mature carcass measurements were OM = 305 ± 18, BM = 346 ± 46, LM = 167 ± 27, MA = 462 ± 78, slice shear force = 27.6 ± 9.1 kg, WBSF = 4.96 ± 0.84 kg, and cooking loss = 26.1 ± 4.2% (Arce-Cordero, 2016). There were no differences between maturity groups with the exception of OM and BM; therefore, there were no palatability differences between youthful and mature AHNC carcasses (Arce-Cordero, 2016).

Overall, SCH and/or AHNC beef production systems are capable of producing quality beef that is of acceptable marbling, tenderness, and flavor (Joseph and Crowley, 1971; Waggoner et al., 1990; Vincent et al., 1991; Arce-Cordero, 2016; Nogalski et al., 2016). However, carcass quality is variable and dependent on management. Feeding a high concentrate ration and timing of harvest are key factors in producing high quality carcasses; this will help ensure an adequate amount of marbling is produced while mitigating the occurrence of advanced carcass maturity.

BEEF PRODUCTION EFFICIENCY

Dickerson (1970) defined efficiency in food animal production systems as the ratio of total costs to total animal product produced from both reproducing females and their progeny. However, this definition confounds boundaries of biological and economic efficiency. It is important to note biological and economic efficiencies do not always align. Bourdon and Brinks (1987) provided a definition for biological efficiency, the ratio of TDN input (kg) to product

output (kg). Similar biological efficiency indicators have been used by Taylor et al. (1985), Kress et al. (1988), Van Oijen et al. (1993), Naazie et al. (1997), and Pang et al. (1999). Economic efficiency has been defined as the ratio of income to expenses (Van Oijen et al., 1993) or the ratio of cost to 100 kg product (Bourdon and Brinks, 1987).

Considering interactions between biological and economic efficiency, it is critical to understand that one does not necessarily equate the other. Economic efficiency can only be sustained if it is built on biological advantage (i.e., improved conception rate, improved ADG, increased weaning weight). Consequently, simultaneous evaluation of biological and economic efficiency is usually required. However, understanding biological efficiency is difficult because different segments of the beef industry define efficiency differently (Johnson et al., 2010). An efficient cow is small to moderate in size, reaches sexual maturity early, consistently weans a healthy calf, rebreeds in a timely manner, possesses longevity, and attains the aforementioned attributes at a low cost (Dickerson, 1970; Ritchie, 1995). However, an efficient feedlot animal is typically moderate to large in size, and emphasis is placed on growth, carcass characteristics, and feed efficiency (Cundiff et al., 1993; Jenkins and Ferrel, 2006). To simplify, reproduction is the most important trait in the cow/calf segment, but growth and carcass characteristics are most important in feedlot settings.

Achieving balance between the 2 is critical for an operation to remain viable. Over emphasis on small-framed, low maintenance cows may result in progeny producing small, light-weight carcasses that are heavily discounted by packers. Similarly, using large-framed cows with high milking ability will produce calves with heavier weaning weights, but their increased maintenance energy requirements may be too costly to offset increased weaning weights (Ritchie, 1995; Johnson et al., 2010). This agrees with research of Melton (1994) that ranked beef industry traits according to their importance. Reproduction traits accounted for nearly half

of the total (47%), and growth traits (23%) and carcass traits (30%) made up the remainder (Melton, 1994).

Further complicating the issue, optimums vary greatly by environment, especially the availability of feed resources. Smith and colleagues (1987a,b) maintained 3 breed types (i.e., Angus × Hereford, Charolais × British, and Simmental × British) in 2 varying climate regions. The Simmental × British group most profitable in a climate with abundant feed resources, but under restricted feed resources, the group of Charolais × British cows emerged as most profitable (Smith et al., 1987a,b). Armstrong et al. (1990) evaluated 4 mating systems (e.g., purebred Herefords, small rotational cross, large rotational cross, and large rotational cross cows) under 2 scenarios—feed supply constraint (i.e., 198 t DM/yr) or, herd size restriction (i.e., 100 cows). Interestingly, when feed resources were constrained, the large rotational cross system was most profitable, and the large rotational cross cowherd was least profitable, but there was little variation between systems (Armstrong et al., 1990). When the restriction was herd size, the large rotational cross system ranked first, and the purebred Hereford program was last, but a greater variation in the range of profit was observed (Armstrong et al., 1990). These results are somewhat surprising because it was expected that the smaller Hereford would be preferred under a constrained feed supply. Rankings may have been different depending on the level of feed restriction.

Van Oijen et al. (1993) conducted a similar study to evaluate biological and economic efficiency of beef production through points of weaning and slaughter using different breeds of cows with differing levels of milk production (e.g., low [L] = Hereford × Angus, moderate [M] = Red poll × Angus, and high [H] milking ability = Shorthorn × Angus). With the ratio of calf weight to total feed energy consumed as a measure of biological efficiency, weaning and harvest efficiencies were 28.1, 27.2, 27.5 g of weaning weight and 22.0, 20.4, and 20.3 g of carcass

weight per megacalorie of ME for the L, M, and H milking groups, respectively (Van Oijen et al., 1993). Economic efficiencies (ratio of income to expenses) to weaning were L = 90.3, M = 89.2, and H = 88.1, and to harvest economic efficiencies were 100.0, 95.7, and 95.1 for L, M, and H groups, respectively (Van Oijen et al., 1993). The low milking group always emerged as most profitable (Van Oijen et al., 1993). This study illustrated the close relationship between biological and economic efficiency.

A 3 yr experiment involving cows and their calves was designed to evaluate resource inputs, animal performance, and carcass characteristics of 2 production systems: 1) a control system (**CON**) where 99 cows grazed pasture, were fed hay during the winter, and steer progeny were weaned and finished in the feedyard for 211 d; and 2) a treatment system (**TRT**) where 100 cows grazed pasture and crop residue, were fed hay in winter, and calves were backgrounded on crop residue and pasture before entering the feedyard for 90 d (Anderson et al., 2005). Calving rates were similar between groups, however in the feedyard, TRT steers had decreased ADG and DMI but were more efficient than CON steers (Anderson et al., 2005). At harvest, TRT steers had greater live BW, HCW, ribeye area, but decreased MA (Anderson et al., 2005). Break-even calf price was greater for the CON group ($455.12/animal), than the TRT group ($421.43/animal; Anderson et al., 2005). There were no differences in revenue between groups when steers were sold on a grid-basis, however when sold on a live BW basis, the TRT steers were more profitable (Anderson et al., 2005).

Newman et al. (1993) designed a study to compare feed efficiency of OCF to conventionally raised and finished heifers with 120 crossbred, OCF that were programmed to calve at 2 yr of age. An 80% calf crop was achieved, and females were harvested at 3, 5, or 7 mo post calving (Newman et al., 1993). Feed efficiency of OCF was compared to the feed efficiency of conventionally raised and finished heifers that were harvested at 457 d (Newman et al., 1993).

When conception failure (11.7%), calf death loss (7.5%), and dam death loss (0.8%) were accounted for, the OCF became slightly less efficient than conventional heifers, but it was not statistically significant (Newman et al., 1993). Post-calving, the OCF groups consumed inordinate amounts of feed, negatively impacting the overall system efficiency, but all groups produced carcasses of similar quality (Newman et al., 1993). The authors concluded that if conception failure and death loss could be controlled, OCF could produce beef as equally efficient as conventionally produced beef (Newman et al., 1993). It is worth noting this study did not consider the feed efficiency of calves, which would have likely resulted in superior efficiency for the OCF system.

Due to difficulty obtaining feed intake while grazing, experiments involving cow feed efficiency have been limited. Davis et al. (1983) collected BW and individual feed consumption on 160 dams and their progeny and estimated lifetime cow efficiency. However, their study considered progeny weaning weight and cull cow BW as the output and did not include efficiency losses from harvest (Davis et al. 1983). Cows were assigned to individual self-feeders, randomly assigned to a high or low energy diet, and individual feed consumption was measured in 28 d intervals from the beginning of the experiment until dams had weaned 3 calves or reached 5 yr of age (Davis et al. 1983). Feed efficiencies were similar between high and low energy diets, but dams fed the high energy ration had greater BW at the time of culling (Davis et al., 1983). Davis et al. (1983) concluded efficiency improved as number of progeny weaned increased, contrary to conclusions of Brethour and Jaeger (1989) and Taylor et al. (1985).

To mitigate high costs and ineffectiveness of collecting feed intake data on a grazing cowherd, computer-based simulations are often used to estimate feed efficiency. A 1988 study conducted by Kress and colleagues studied the effect cow culling age had on system efficiency. Both biological (e.g., kg TDN/kg HCW) and economic (e.g., $ cost/45.4 kg of HCW)

efficiencies were estimated as a function of cow age at culling (Kress et al., 1988). Conclusions of this study were consistent with results published by Davis et al. (1983). This study demonstrated stayability has economic value; under both biological and economic efficiency measures, and the cost of production declined the longer a cow remained in the herd (Kress et al., 1988).

Davis et al. (1994) completed a life cycle evaluation of 5 biological cattle types (purebred Herefords, Angus × Hereford F_1, Simmental × Hereford F_1, 75% Hereford × 25% Simmental, and 25% Hereford × 75% Simmental) to evaluate biological and economic efficiency. Davis et al. (1994) used 4 biological efficiency indicators: 1) number of lifetime matings, 2) calves weaned, 3) kg of calf weight sold per cow exposed, and 4) ME consumed per kg of calf weight sold and per kg of total BW sold. Economic performance was measured via break-even steer prices, total production costs, net profit per cow exposed, and net profit for a ranch of a fixed size (Davis et al., 1994). Interestingly, straight Hereford and 75% Hereford × 25% Simmental cows consumed the least amount of ME per kg of total BW sold but had the highest break-even price and lowest profits (Davis et al., 1994). The F_1 dams consistently achieved the greatest profitability (Davis et al., 1994). Results of this study illustrated the need for simultaneous evaluation of biological and economic efficiency due to confounding results.

Theoretical work of Taylor et al. (1985) evaluated feed efficiency of several different beef production systems: 1) conventional cow/calf, 2) single-sex OCF like AHNC, 3) all-male progeny system, and 4) modified conventional system with bred heifers. Greatest feed efficiency was achieved using the single-sex OCF system (Taylor et al., 1985). Conventional system feed efficiency values ranged from 2.3 to 3.5 g of lean tissue per MJ of ME, and the feed efficiency of the single-sex OCF system was 5.2 g, exceeding feed efficiency of the conventional cow/calf system by over 50% (Taylor et al., 1985). Reproductive performance was a major factor

affecting success of the single-sex OCF system, however even using a more conservative reproductive rate (e.g., 85%), efficiency was 4.8 g, still surpassing efficiency of the conventional cow/calf system (Taylor et al., 1985).

Bourdon and Brinks (1987) used a modified version of the Texas A&M Beef Cattle Production Model to simulate biological and economic efficiency of various culling strategies and nontraditional beef production systems. Bourdon and Brinks (1987) defined biological efficiency as the ratio of TDN input (kg) to product output (kg) and economic as the ratio of income to the ratio of cost to 100 kg product where products were live BW at weaning, empty BW at harvest, and fat-free weight at harvest. Culling cows at a younger age increased biological efficiency, but not necessarily economic efficiency (Bourdon and Brinks, 1987). The model indicated 8 yr was the optimal culling age and finishing cull cows in the feedyard generally improved economic efficiency, but not biological efficiency (Bourdon and Brinks, 1987). The optimal combination of biological and economic efficiency was achieved using the single-sex OCF beef production system with feeding of 2-yr-old cows (i.e., AHNC; Bourdon and Brinks, 1987). This combination was markedly more biologically efficient, but only slightly more profitable than conventional cow/calf production (Bourdon and Brinks, 1987).

Several studies have specifically evaluated economic efficiency of beef production. A review by Melton and Colette (1993) cautioned using output:input ratios as indicators of economic efficiency. The authors stated using such ratios to evaluate breeds could cause errors due to the narrow range of input use values under which most breeds are evaluated and the inability for output:input ratios to consistently reflect economic objectives of commercial cow/calf producers (Melton and Colette, 1993). Instead, the authors recommended using economic theories relating to optimal investment and asset replacement; for example, net present value computed under alternative marketing scenarios (Melton and Colette, 1993).

A review conducted by Sell et al. (1988) compared the profitability of 11 different beef production systems: 1) conventional cow/calf; 2) OCF; 3) surplus heifer; 4) cow/calf plus backgrounding; 5) cow/calf plus wintering; 6) cow/calf, wintering, and pasturing; 7) cow/calf plus custom backgrounding; 8) cow/calf plus custom weaned calf feeding; 9) cow/calf; backgrounding, and custom feeding; 10) cow/calf, wintering, and custom feeding; and 11) cow/calf, wintering, pasturing, and custom feeding. Budgets and revenues were created for the various enterprises for the yrs 1958 to 1986 using price indices (Sell et al., 1988). For the OCF beef production system, the model assumed an 83% calf crop and that 85% of carcasses graded USDA Choice (Sell et al., 1988). The conventional cow/calf system calf crop was 92% (Sell et al., 1988). The OCF system was much more profitable than any other systems and had the least year-to-year variation in profit (Sell et al., 1988). The authors attributed the reduced profitability of the conventional cow/calf system to the significant price risk associated with cow/calf beef production.

Lastly, the discussion of beef production efficiency would not be complete without comparing beef to its major competitors—pork and poultry. In terms of raw weight of feed to food conversion efficiency, beef is very poor. Feed to gain ratios for chickens, pork, and beef were 2.5, 5.0, 10.0 on a kg of corn equivalents to kg of live weight gain, respectively (Smil, 2002). However, when accounting for only the edible portion of meat, beef becomes more inefficient. Feed to gain ratios for chicken, pork, and beef on a kg of feed to kg of edible meat basis were 5.4, 9.4, and 25.0, respectively (Smil, 2002). Beef producers are at an inherent disadvantage due to length of the production cycle, and typically only producing a single offspring annually. However, it is worth noting beef production relies on grazing cattle on land that would not be suitable for cropping and feeding by-products (e.g., cornstalks, beet pulp);

whereas hogs and poultry typically consume grain that could be used for human consumption, convoluting efficiency comparisons between various livestock proteins.

With the goal of quantifying the environmental footprint of beef production systems, cow/calf, feedyard, and farm enterprises of the Meat Animal Research Center in Clay Center, Nebraska were simulated and managed as a cohesive ranching system (Rotz et al., 2013). The farm enterprise grew 841 hectares of alfalfa and 1,160 hectares of corn which was used to feed the 5,500 cows, 1,180 replacement heifers, and 3,724 feedyard cattle (Rotz et al., 2013). A 25-yr simulation of the current production system predicted an average annual carbon footprint of 10.9 ± 06 kg of CO_2 equivalent units per kg BW sold, energy required to produce the beef was 26.5 ± 4.5 MJ/kg BW, and predicted cost of production was \$2.11 ± 0.05/kg BW (Rotz et al., 2013). Results of the simulation indicated there has been a 6% reduction in the carbon footprint required to produce beef since 1970, but there has been no change in the energy footprint (Rotz et al., 2013).

Pelletier et al. (2010) completed an ISO-compliant life cycle assessment to compare cumulative energy use, ecological footprint, greenhouse gas emissions and eutrophying emissions from 3 beef production strategies: 1) calf-fed system, 2) yearling-fed system, and 3) a solely pasture based production system. Results of this cradle-to-farm gate analysis indicated feedyard produced beef was more environmentally friendly than pasture beef (Pelletier et al., 2010). Ecological footprints were 370, 119, 198, and 208 ha for cow/calf, feedyard, feedyard/pasture combination, and pasture systems, respectively (Pelletier et al., 2010). Not surprisingly, cow/calf production has the greatest environmental impact, indicating there is a tremendous amount of opportunity to improve overall efficiency of beef production systems via the cow/calf segment. Further investigation needs to be completed to determine the ecological footprint of an SCH and AHNC beef production systems.

To summarize the efficiency literature, beef production efficiency is a complicated issue that is impacted by many different factors. The SCH and AHNC beef production systems are currently estimated to be the most viable strategy to produce beef with less feed (Taylor et al., 1985; Bourdon and Brinks, 1987). If reproductive failure and death loss can be controlled, OCF and AHNC beef production systems can be economically viable. Considering the relationship and trade-offs between biological and economic efficiencies, a robust evaluation of the AHNC beef production system must consider biological and economic efficiency simultaneously.

SYSTEM DYNAMICS AND BEEF PRODUCTION

To understand system dynamics and their role in beef production systems, it is critical to first define a system. Merriam-Webster (2018) defined a system as "a regularly interacting or interdependent group of items forming a unified whole." To put this in context of a beef production system, cows, bulls, replacement heifers, laborers, facilities, etc. are integral, interacting components that work together to produce the final product of weaned calves, or carcasses in the case of SCH and AHNC beef production systems.

Modeling dynamic systems often starts with mental models. A mental model is an individual's view and understanding of a system and its components (Forrester, 1961). It is critical to understand mental models because descriptions of process relationships are not generally available from traditional data sources but are stored in mental models of process experts in the field (Ford and Sterman, 1997). A sound mental model is essential to modeling processes because mental models serve as the template, outlining key structures and feedbacks mechanisms. Considering the dynamic nature and feedback mechanisms associated with beef production systems, it is critical to have an understanding of biological processes and management of the cattle as well as economics, carbon footprint, etc. depending on model objectives.

Within systems modeling, the dynamic nature of a system is characterized by constant change over time and is represented through feedback processes, stock and flow structure, time delays, and non-linearities (Sterman, 2000). Considering the dynamic nature of a system, actions and solutions are rarely isolated in a linear fashion, but rather exist in cause and effect relationships, forming feedback loops (Senge, 1990). Feedback can be defined as chains of causal relationships where a decision or event changes the system, often in an unintended way (Hopper and Stave, 2008; Turner, 2011). Stocks are variables that are measured or accumulated at/over a specific period of time. They represent an existing quantity that can appreciate or depreciate overtime (Waters Foundation, 2003). Stocks are often considered the "nouns" of the system and are analogous to a bath tub. Stocks can only be manipulated through flows, "verbs" of the system. Flows are akin to the faucet and drain of a bath tub. The Waters Foundation (2003) describes flows as actions or processes that transport units of stocks. A time delay can best be described as time between when a decision is made and the eventual outcome that occurs as a result of a decision (Turner, 2011). Time delays are major contributors to unforeseen consequences that result from feedback processes.

Beef production systems are complex and involve decisions driven by a variety of factors such as: resource availability, market prices, and cattle performance. Due to the interrelatedness and non-linearity of beef production systems, a robust understanding can only be achieved through simultaneous assessment of decisions and associated consequences that affect final outcomes (Jonadet and Cartwright, 1975). The complexity and interrelatedness of beef production systems coupled with the capital and time intensity required to raise beef livestock, elicits a need for dynamic modeling of beef systems.

Jonadet and Cartwright (1975) pioneered the first beef production models. Their work focused on defining mental models and describing various applications of beef production

models including: 1) optimizing a particular function, 2) determining effects of changes to specific variables and how they affect final outcomes, 3) providing insight into relationships among model components, and 4) simulating experiments. The work of Jonadet and Cartwright (1975) was the foundation for many beef system models, influencing system dynamics research in beef reproduction and genetics (Sanders, 1974; Sanders and Cartwright, 1979; Shafer et al., 2007), beef nutrition and growth (Tess and Kolstad, 2000a,b; Tedeschi et al., 2004; Tedeschi et al., 2006), beef production efficiency (Davis et al., 1983; Bourdon and Brinks, 1987; and Pang et al., 1999), and marketing and economics (Clarke et al., 1982; Werth et al., 1991; and Turner, 2011).

Considering goals of this literature review, specific emphasis was placed on models that evaluated beef production efficiency and economics. Keeling et al. (1991) modeled a SCHS. The spreadsheet-based simulation evaluated system profitability. The model indicated the SCHS was more profitable than conventional cow/calf production (Keeling et al., 1991). Market price for finished heifers was a major determinant in profitability of the SCHS and profitability was more sensitive to an increase in the calving rate than an increase in ADG (Keeling et al., 1991). Additionally, the authors identified providing pasture of sufficient quality was a major challenge in reaching target harvest weight (Keeling et al., 1991).

Tess and Kolstad (2000a) built a mathematical computer model to simulate the dynamic relationship among cattle genotype, physiological state, forage quality, and management in range environments. The model was designed to track a variety of biological and economic efficiency measures (e.g., DM, CP, ME, dollars) to outputs (e.g., kg of BW and lean tissue), break-even prices, and annual gross margin per cow or ranch (Tess and Kolstad, 2000a). In their second paper, Tess and Kolstad (2000b) stated that the model provided insight on physiological processes and mechanisms that were not well understood with conventional experimentation.

Specifically, their model addressed 4 key issues: 1) life-cycle BW and body condition changes for different genotypes raised in a northern range environment; 2) response in forage intake and BW to changes in forage quality, protein supplementation, and cow physiological state; 3) responses in reproduction, weight, body condition, and calf growth to differences in pre- and postpartum nutrition; and 4) differences in enterprise efficiency and profit for different genotypes and mating systems (Tess and Kolstad, 2000b). Insights from this model helped to better explain animal performance in a range environment (Tess and Kolstad, 2000b).

Naazie and colleagues (1997) created a deterministic beef model to evaluate beef production efficiency, defined as the ratio of total output (i.e., lean meat equivalent) to total input (i.e., feed ME). The model consisted of 3 submodels: 1) growth and feed intake, 2) herd structure, and 3) enterprise efficiency (Naazie et al., 1997). The cow and her offspring were the basic herd unit and efficiency was evaluated in relation to culling age and age of her offspring at harvest (Naazie et al., 1997). Sensitivity analyses indicated the model was most sensitive to dam maturity. Increasing dam age by 10% resulted in a large (i.e., up to 35% depending on breed) decrease in overall system efficiency (Naazie et al., 1997). These results reiterate the theoretical work of Taylor et al. (1985). Increasing growth rate or carcass lean by 10% resulted in up to an 8.7% improvement in efficiency (Naazie et al., 1997).

Two models—a stochastic dynamic model of reproduction and a deterministic cowherd economic simulation model—were used to evaluate effects of management decisions and reproductive performance on net income of a cow/calf enterprise (1,000 cows) for a single production yr (Werth et. al., 1991). The stochastic model predicted herd performance using 3 key metrics: length of breeding season (i.e., 45, 70, or 120 d), length of postpartum anestrus (48, 65, or 90 d), and 3 conception rates at first service (i.e., 60, 70, or 80%), and heifers were bred 3 wk before cows (Werth et. al., 1991). Length of postpartum anestrus was used to reflect differences

in reproductive performance. The model calculated feed requirements separately for each postpartum interval to reflect 3 different BCS; thin, moderate, and good; to correspond to long, moderate, and short postpartum lengths; respectively (Werth et. al., 1991). The economic model included herd performance, feed requirements, non-feed costs, and livestock and feed prices for 1 yr of production (Werth et. al., 1991). Fifty-four simulations were generated, and net income was greatest when cows were managed to have postpartum intervals of moderate length (Werth et. al., 1991). Breeding heifers before cows had economic benefit, but the most benefit was realized when postpartum interval was long and cows were thin (Werth et. al., 1991).

Pang et al. (1999) built a dynamic system model consisting of composed of 4 tandem submodels—herd inventory, nutrient requirements, forage production, and economics—to evaluate the effects that production traits and management decisions had on bioeconomic efficiency of beef production systems. Bioeconomic efficiency was measured as net return per cow (Pang et al., 1999). Sensitivity analyses determined mature cow BW, milk production, calf weaning weight, and feed prices had greatest impact on system profitability, but due to lack of sufficient data, the model could not be validated (Pang et al., 1999). Nonetheless, this simulation model contributed to the body of knowledge and influenced development of later models.

A system dynamic model was built to evaluate the relationship between level of cow sales (e.g., low = 10%, medium = 20%, and high = 30% of the total cow herd) and profitability (Turner, 2011). Specifically, the model was built to examine whether the same decisions would have been made if rewards were based on return of investment (**ROI**), rather than net income (**NI**; Turner, 2011). The model showed NI was sensitive to cow pregnancy rate, but not heifer pregnancy rate, and the model predicted as cow culling rate increased, so did ROI and NI, suggesting the same marketing decisions would have been made with either incentive (Turner, 2011).

It is important to remember that models are just depictions of reality and no model is perfect, but they still are useful. Validated models are most useful. A model is determined valid if the predicted output matches the "real" system output within a specified range of accuracy. There must be little to no uncertainty in model output (Barlas, 1996). However, there are no formal rules for model validation in system dynamics, and the field has been criticized for lack of formal model validation methods.

Validation is important to eliminate uncertainty. There are 2 main sources of uncertainty within dynamic models: 1) parameter uncertainty (i.e., inaccurate parameters values), and 2) structural uncertainty (i.e., incorrect relationships between stocks, flows, and feedback structures within the model). The second source of uncertainty will have a greater impact on model results, eliciting a greater need for model validation. It is impossible to validate all components of a system dynamics model (Oreskes et al., 1994; Sterman, 2002). But considering the model for its intended use, output can be assessed as reasonable or unreasonable (Tess and Kolstad, 2000b).

Beef production models can be an effective way to predict beef cattle performance and efficiency. When calibrated with robust data, a simulation model can be used as a decision support tool to evaluate the effect of alterative management decisions. A system dynamics model would be a useful tool to predict biological and economic efficiencies of the AHNC beef production system.

CONCLUSIONS

The AHNC beef production system appears to be a viable strategy to improve beef production efficiency. Based on several computer models, the SCH beef production system, a modified AHNC system, has been identified as the most biologically efficient means of beef production (Taylor et al., 1985; Bourdon and Brinks, 1987; and Keeling et al., 1991). The literature indicated SCHS can effectively reduce nutrient requirements necessary to produce

beef, however these models were theoretical and relied on data from previously published cow/calf models and intake models outlined in the National Research Council for Beef Cattle, but previous models did not include experimental data that was unique to SCH beef production. Additionally, the use of female sex-selected semen and early-weaning in an AHNC beef production system may offer additional efficiency improvements. Based on results of this literature review, there is need to manage and an AHNC demonstration herd and collect performance and economic data. Data collected from the demonstration herd could be used to create a dynamic simulation model to quantify the biological and economic efficiency of producing beef without mature cows via the AHNC beef production system.

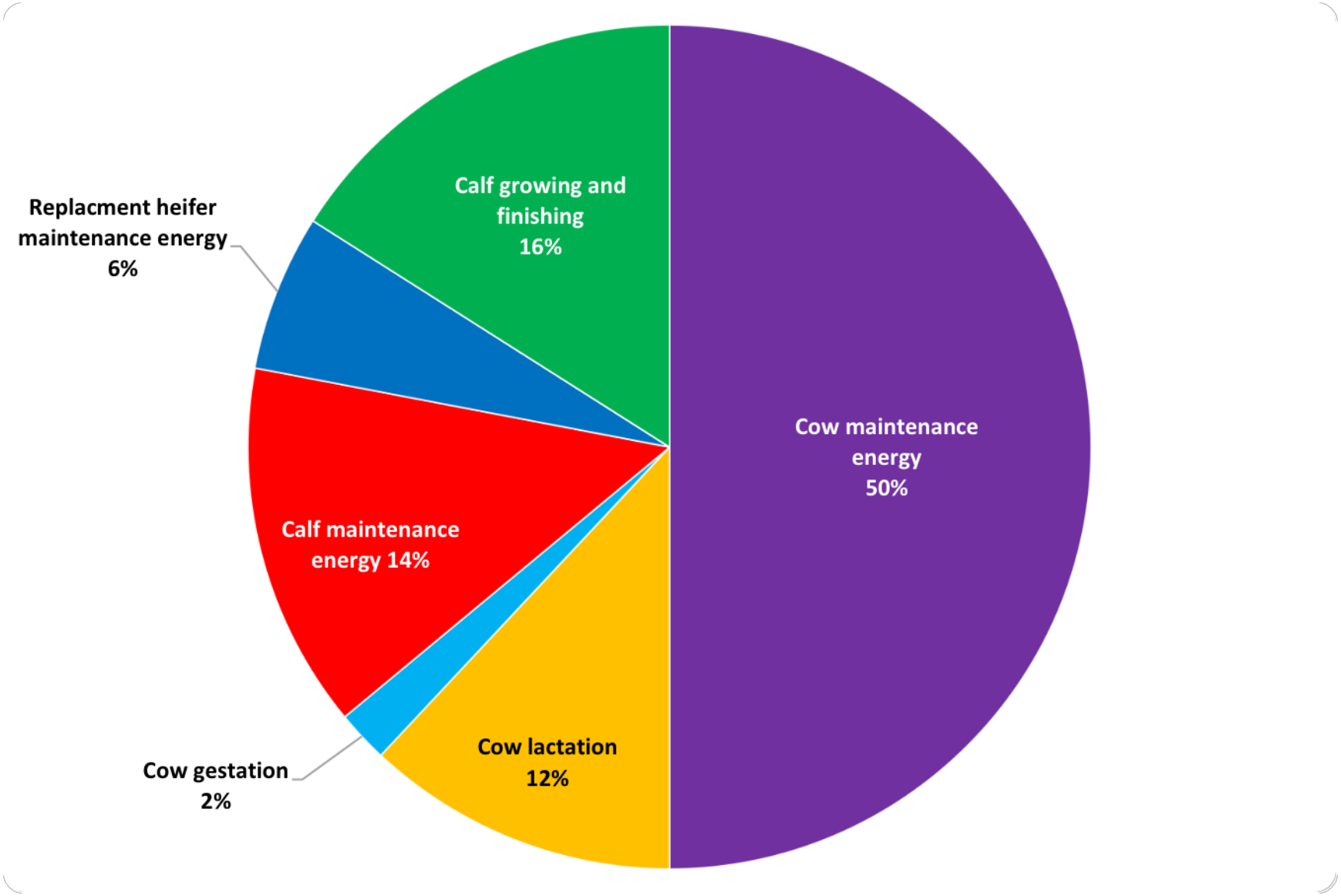

Figure 1.1. Conceptual illustration of intake energy devoted to physiological functions associated with typical beef production in the United States

LITERATURE CITED

Anderson, R.V., R.J. Rasby, T.J. Klopfenstein, and R.T. Clark. 2005. An evaluation of production and economic evaluation of two beef systems from calving to slaughter. J. Anim. Sci. 83:694–704.

Arce-Cordero, J.A. 2016. Evaluation of management strategies to improve efficiency and sustainability of beef and dairy cattle operations. MS Thesis. Colorado State Univ., Fort Collins, CO.

Armstrong, S.L., J.W. Wilton, W.C. Pfeiffer, and L.R. Schaeffer, 1990. Influence of variations in biological and economic parameters on beef production net returns. J. Anim. Sci. 68:1857–1866.

Bagley, C.P. 1993. Nutritional management of replacement beef heifers—A review. J. Anim. Sci. 71:3155–3163.

Barlas, Y. 1996. Formal aspects of model validity and validation in system dynamics. System Dynamics Review. 12:183–210.

Boucqué, Ch. V., L.O. Fiems, B.G. Cottyn, and F.X. Buysse. 1980. Beef production with maiden and once-calved heifers. Livestock Prod. Sci. 7:123–133.

Bourdon, R.M., and J.S. Brinks. 1987. Simulated efficiency of range beef production. III. Culling strategies and nontraditional management systems. J. Anim. Sci. 65:963–969.

Brethour, J.R., and J.R. Jaeger. 1989. The single-calf heifer system. Kansas Agric. Sta. Rept. of Progress. 570.

Clarke, S.E., C.T. Gaskins, and J.K. Hillers. 1982. Systems analysis of beef production effects on culling criteria on net income. J. Anim. Sci. 55:489–497.

Cundiff, L.V., S. Szabo, K.E. Gregory, R.M. Koch, M.E. Dikeman, and J.D. Crouse. 1993. Breed comparisons in the germplasm evaluation program at MARC. Proc. Beef Improvement Federation. Asheville, NC.

Cundiff, L.V., K.E. Gregory, R.M. Koch, and G.E. Dickerson. 1986. Between- and within-breed genetic analysis of calving traits and survival to weaning in beef cattle. J. Anim. Sci. 64:27. Abstract.

Davis, M.E., J.J. Rutledge, L.V. Cundiff, and E.R. Hauser. 1983. Life cycle efficiency of beef production: I. Cow efficiency ratios for progeny weaned. J. Anim. Sci. 57:832–851.

Davis, K.C., M.W. Tess, D.D. Kress, D.E. Doornbos, and D.C. Anderson. 1994. Life cycle evaluation of five biological types of beef cattle in a cow/calf range production systems. J. Anim. Sci. 72:2591–2598.

Dickerson, G.E. 1970 Efficiency of animal production—molding the biological components. J. Anim. Sci. 30:849. Abstract.

Dickerson, G.E. 1976. The choice of selection objectives in meat producing animals. p. 449–462 in Meat Animals, Plenum Pub. Corp., New York City, NY.

Ferrell, C.L., and T.G. Jenkins. 1985. Cow type and nutritional environment: Nutritional aspects. J. Anim. Sci. 61:725–741.

Field, R.A., G.E. Nelms, and C.O. Schoonover. 1966. Effects of age, marbling and sex on palatability of beef. J. Anim. Sci. 25:360–366.

Field, R., R. McCormick, V. Balasubramanian, D. Sanson, J. Wise, D. Hixon, M. Riley, and W. Russell. 1996. Growth, carcass, and tenderness characteristics of virgin, spayed, and single-calf heifers. J. Anim. Sci. 74:2178–2186.

Field, R., R. McCormick, V. Balasubramanian, D. Sanson, J. Wise, D. Hixon, M. Riley, and W. Russell. 1997. Tenderness variation among loin steaks from A and C maturity carcasses of heifers similar in chronological age. J. Anim. Sci. 75:693–699.

Fluharty, F.L., T.B. Turner, S.J. Moeller, and G.D. Lowe. 1996. Effect of weaning and diet on growth of calves. Research and Reviews. The Ohio State University Dept. of Anim. Sci. Columbus, OH.

Ford, D.N., and J.D. Sterman. 1997. Expert knowledge elicitation to improve mental and formal models. Cambridge, Mass.—Massachusetts Institute of Technology. p. 18–23.

Forrester, J.W. 1961. Industrial dynamics. Cambridge, Mass. MIT Press.

Grumbach, M.M., and R.J. Auchus. 1999. Estrogen: Consequences and implications of human mutations in synthesis and action. J. Clin. Endocrinol. Metab. 84:4677–4694.

Hickson, R.E., S.T. Morris, P.R. Kenyon, and N. Lopez-Villalobos. 2006. Dystocia in beef heifers: A review of genetic and nutritional influences. New Zealand Vet. J. 54:256–264.

Hopper, M., and K.A. Stave 2008. Assessing the effectiveness of systems thinking interventions in the classroom. In The 26th International Conference of the System Dynamics Society. Athens, Greece. p. 1–26.

Jenkins, T.G., and C.L. Ferrell. 2006. Matching genetics with the production environment. Proc., Beef Improvement Federation. Choctaw, MS.

Johnson, J.J., B.H. Dunn, and J.D. Radakovich. 2010. Understanding cow size and efficiency. Proceedings Beef Improvement Federation Annual Research Symposium and Annual Meeting. Columbia, MO. p. 52–70.

Joandet, G.E., and T.C. Cartwright. 1975. Modeling Beef Production Systems. J. Anim. Sci. 41:1238–1246.

Joseph, R.L., and J.P. Crowley. 1971. Meat quality of once-calved heifers. Irish J. of Agric. Res. 10:281–285.

Keeling, P.C.B., S.T. Morris, D.I. Gray, and W.J. Parker. 1991. A modeling study of once-bred heifer beef production. Proc., of the New Zealand Soc. of Anim. Prod. 51:389–393.

Kreikemeier, K.K., and J.A. Unruh. 1993. Carcass traits and the occurrence of dark cutters in pregnant and non-pregnant feedlot heifers. J. Anim. Sci. 71:1699–1703.

Kress, D.D., M.D. MacNeil, and G.E. Dickerson, 1988. Effect of mating system, cow culling strategy, and maximum cow age on beef cattle biological and economic efficiency. J. Anim. Sci. 66:175. Abstract.

Lalman, D.L. 2017. Early weaning the beef herd. Oklahoma Cooperative Extension Service. Oklahoma State Univ. Stillwater, OK.

Laster, B.D., H.A. Glimp, L.V. Cundiff, and K.E. Gregory. 1973. Factors affecting dystocia and the effects of dystocia on the subsequent reproduction in beef cattle. J. Anim. Sci. 36:695.

Lusby, K.S., R.P. Wetteman, and E.J. Turman. 1981. Effects of early weaning calves from first-calf heifers on calf and heifer performance. J. Anim. Sci. 53:1193–1197.

McCormick, R.J. 1994. The flexibility of the collagen compartment of muscle. J. Meat Sci. 36:79–91.

Melton, B.E., and W.A. Colette, 1993. Potential shortcomings of output-input ratios as indicators of economic efficiency in commercial beef breed evaluations. J. Anim. Sci. 71:579–586.

Melton, B.E. 1994. Relative genetic emphasis for profitable beef production. Natl. Cattlemen's Assn., Midyear Conf., 22 July 1994, Denver, CO.

Merriam-Webster. 2018. Merriam-Webster Dictionary. https://www.merriam- webster.com/ dictionary/system (Accessed 31 May 2018).

Miller, R.K., J.D. Tatum, H.R. Cross, R.A. Bowling, and R.P. Clayton. 1983. Effects of carcass maturity on collagen solubility and palatability of beef from grain-finished steers. J. Food Sci. 48:484-486.

Myers, S.E., D.B. Faulkner, F.A. Ireland, L.L. Berger, and D.F. Parrett. 1999a. Production systems comparing early weaning to normal weaning with or without creep feeding for beef steers. J. Anim. Sci. 77:300. Abstract.

Myers, S.E., D.B. Faulkner, F.A. Ireland, and D.F. Parrett. 1999b. Comparison of three weaning ages on cow/calf performance and steer carcass traits. J. Anim. Sci. 77:323. Abstract.

Myers, S.E., D.B. Faulkner, T.G. Nash, L.L. Berger, D.F. Parrett and F.K. McKeith. 1999c. Performance and carcass traits of early weaned steers receiving either a pasture growing period or finishing diet at weaning. J. Anim. Sci. 73:311. Abstract.

Naazie, A., M.M. Makarechian, and R.T. Berg. 1989. Factors influencing calving difficulty in beef heifers. J. Anim. Sci. 67:3243–3249.

Naazie, A., M.M. Makarechian, and R.J. Hudson. 1997. Efficiency of beef production systems: Description and preliminary evaluation of a model. Agric. Syst. 54:357–380.

NCBA. 2017. Navigating Pathways to Success: Executive Summary of the 2016 National Beef Quality Audit. Centennial, CO.

Newman, J.A., S.D.M. Jones, M.A. Price, and B.C. Vincent. 1993. Feed efficiency in once-calved and conventional systems of heifer beef production. Can. J. Anim. Sci. 73:915–930.

Nogalski, Z., M. Sobczuk-Szul, P. Pogorzelska-Przybylek, Z. Wielgosz-Groth, C. Purwin, and M. Modzelewska-Kapitula. 2016. Comparison of slaughter value for once-calved heifers and heifers of Polish Holstein-Friesian x Limousine crossbreds. J. Meat Sci. 117:1–6.

Oreskes, N., K. Shrader-Frechette, and K. Belitz. 1994. Verification, validation, and confirmation of numerical models in the earth sciences. Science 263:641–646.

Owen, J.B. 1973. The maiden female—a means of increasing meat production. Proc., Symp. on the Use of Once Bred heifers and Gilts, 11 October 1972, School of Agriculture, Aberdeen, Scotland. p. 71.

Pang, H., M. Makatechian, J.A. Basarab, and R.T. Berg. 1999. Structure if a dynamic simulation model for beef cattle production systems. Can. J. Anim. Sci. 79:409–417.

Pelletier, N., R. Pirog, and R. Rasmussen. 2010. Comparative life cycle environmental impacts of three beef production strategies in the Upper Midwestern United States. Agric. Syst. 103:380–389.

Peterson, G.A., T.B. Turner, K.M. Irvin, M.E. Davis, H.W. Newland, and W.R. Harvey. 1987. Cow and calf performance and economic considerations of early weaning of fall - born beef calves. J. Anim. Sci. 65:15–22.

Purslow, P.P. 2005. Intramuscular connective tissue and its role in meat quality. J. Meat Sci. 70:435–447.

Radunz, A.E. 2012. Back to basics: biological use of nutrients. Univ. of Wisconsin Extension Services. https://fyi.uwex.edu/wbic/2012/02/28/back-to-basics-biological-use-of-nutrients/. (Accessed 22 April 2018.)

Rasby, R.J. 2007. Early weaning beef calves. Vet. Clin. Food Anim. 23:29–40.

Reddy, B.V., A.S. Sivakumar, D.W. Jeong, Y.B. Woo, S.J. Park, S.Y. Lee, J.Y. Byun, C.H. Kim, S.H. Cho, and I. Hwang. 2015. Beef quality traits of heifer in comparison with steer, bull, and cow at various feeding environments. J. Anim. Sci. 86:1–16.

Riggs, B. 2001. Integration of early weaning and use of sexed semen in a single-calf heifer

system to increase value of non-replacement heifers. MS Thesis. Colorado State Univ., Fort Collins, CO.

Ritchie, H.D. 1995. The optimum cow - what criteria must she meet? Proc., Beef Improvement Federation Annual Research Symposium and Annual Meeting. Sheridan, WY.

Rotz, C.A., B.J. Isenberg, K.R. Stackhouse-Lawson, and E.J. Pollak. 2013. A simulation-based approach for evaluating and comparing the environmental footprints of beef production systems. J. Anim. Sci. 91:5427–5437.

Sanders, J.O. 1974. A model of reproductive performance in the bovine female. M.S. Thesis, Texas A&M University, College Station, TX. Abstract of Thesis.

Sanders, J.O., and T.C. Cartwright. 1979. A general cattle production systems model. I: Structure of the model. Agric. Syst. 79:217–227.

Seidel, G.E. Jr., and J.C. Whittier. 2015. Beef species symposium: Beef production without mature cows. J. Anim. Sci. 93:4244–4251.

Sell, R.S., D.L. Watt, R.D. Little, and T.A. Petry. 1988. Single-calf heifer system profitability compared to other North Dakota beef production systems. Agric. Econ. Report No. 240, North Dakota State Univ., Fargo, ND.

Senge, P.M. 1990. The Fifth Discipline: the art and practice of the learning organization. New York: Doubleday/Currency. Print.

Shackelford, S.D., M. Koohmaraie, and T.L. Wheeler. 1995. Effects of slaughter age on meat tenderness and USDA carcass maturity scores of beef females. J. Anim. Sci. 73:3304–3309.

Shafer, W.R., R.M. Bourdon, and R.M. Enns. 2007. Simulation of cow/calf production with and without realistic levels of variability. J. Anim. Sci. 85:332–340.

Short, R.E., R.A. Bellows, R.B. Staigmiller, J.G. Berardinelli, and E.E. Custer. 1990. Physiological mechanisms controlling anestrus and infertility in postpartum beef cattle. J. Anim. Sci. 68: 799–816.

Shorthose, W.R. and P.V. Harris. 1990. Effect of animal age on the tenderness of selected beef muscles. J. Food Sci. 55:1–8.

Smil, V. 2002. Transformation of diets, burdens of meat production and opportunities for novel food proteins. J. of Enzyme and Microb. Tech. 30:305–311.

Smith, G.M., D.B. Lester, and K. E. Gregory. 1976. Characterization of biological types of cattle I. Dystocia and preweaning growth. J. Anim. Sci. 43:27–36.

Smith, E.G., G.W. Rahnefeld, J.E. Lawson, and K.K. Klein, 1987a. Cow-calf production returns in the parkland region. Agric. Canada Res. Branch Tech. Bull. No. 12107.1. Ottawa, ON.

Smith, E.G., J.E. Lawson, G.W. Rahnefeld, and K.K. Klein, 1987b. Cow-calf production returns in the short-grass prairie region. Agric. Canada Res. Branch Tech. Bull. No. 12107.2. Ottawa, ON.

Sterman, J.D. 2000. The choice of selection objectives in meat producing animals. p. 449–462 in Business Dynamics: Systems Thinking for a Complex World., Irwin-McGraw Hill Pub. Corp., USA.

Sterman, J.D. 2002. All models are wrong: reflections on becoming a systems scientist. Syst. Dynamics Rev. 18:501–531.

Story, C.E., R.J. Rasby, and R.T. Clarke. 2000. Age of calf at weaning of spring-calving beef cows and the effect on cow and calf performance and production economics. J. Anim. Sci. 78:1403–1413.

Tatum, J.D, G.C. Smith, B.W. Berry, C.E. Murphey, F.L. Williams, and Z.L. Carpenter. 1980. Carcass characteristics, time on feed and cooked beef palatability attributes. J. Anim. Sci. 50:833–840.

Tatum, J.D., S.L. Gruber, and B.A. Schneider. 2007. Pre-harvest factors affecting beef tenderness in heifers. Handbook National Cattlemen's Beef Assoc., Centennial, CO.

Tatum, J.D. 2011. Animal Age, Physiological Maturity, and Associated Effects on Beef Tenderness. White Paper for National Cattleman's Beef Assoc., Centennial, CO.

Taylor, C.S., A.J. Moore, R.B. Thiessen, and C.M. Bailey. 1985. Efficiency of food utilization in traditional and sex-controlled systems of beef production. J. Anim. Prod. 40:401–440.

Tedeschi, L.O., M.L. Chizzotti, D.G. Fox, and G.E. Carstens. 2006. Using mathematical nutrition models to improve beef cattle efficiency. p. 461–484 in International Symposium of Beef Production, V., Viçosa, M.G., Brazil. Suprema Gráfica e Editora Ltda.

Tedeschi, L.O., D.G. Fox, and P.J. Guiroy. 2004. A decision support system to improve individual cattle management. 1: A mechanistic, dynamic model for animal growth. Agric. Syst. 79:171–204.

Tess, M.W., and B.W. Kolstad. 2000a. Simulation of cow/calf production systems in a range environment: Model evaluation. J. Anim. Sci. 78:1159–1169.

Tess, M.W., and B.W. Kolstad. 2000b. Simulation of cow/calf production systems in a range environment: Model development. J. Anim. Sci. 78:1170–1180.

Tubman, L.M., Z. Brink, T.K. Suh, and G.E. Seidel Jr. 2004. Characteristics of calves produced with sperm sexed by flow cytometry/cell sorting. J. Anim. Sci. 82:1029–1036.

Turner, B.L. 2011. Analyzing past ranch profitability from varying marketing scenarios for cow/calf production using system dynamics. M.S. Thesis, King Ranch Institute of Texas A&M, Kingsville, TX.

USDA. 2016. United States Standards for Grades of Beef Carcasses. Agric. Marketing Serv., USDA. Washington, DC.

Van Oijen, M., M. Montano-Bermudez, and M.K. Nielsen. 1993. Economical and biological efficiencies of beef cattle differing in level of milk production. J. Anim. Sci. 71:44–50.

Vincent, B.C., S.D.M. Jones, L.E. Jeremiah, M.A. Price, and J.A. Newman. 1991. Carcass characteristics and meat quality of once-calved heifers. Can. J. Anim. Sci. 71:311–319.

Waggoner, A.W., M.E. Dikeman, J.R. Brethour, and K.E. Kemp. 1990. Performance, carcass, cartilage calcium, sensory, and collagen traits of longissimus muscles of open versus 30-month-old heifers that produced one calf. J. Anim. Sci. 68:2380–2386.

Waters Foundation, 2003. Systems thinking in Schools: A Waters Foundation Project. http://watersfoundation.org. (Accessed 4 June 2018).

Werth, L.A., S.M. Azzam, M.K. Nielsen and J.E. Kinder. 1991. Use of a simulation model to evaluate the influence of reproductive management decisions on net income in beef production. J. Anim. Sci. 69:4710–4721.

CHAPTER II:

EVALAUTION OF PERFORMANCE AND CARCASS TRAITS FOR A 5-COHORT ALL HEIFER, NO COW BEEF PRODUCTION SYSTEM DEMONSTRATION HERD

INTRODUCTION

Conventional beef production in the U.S. is typically a specialized system that encompasses forage-based cow/calf production through intensively managed feedyards that finish cattle on grain or other concentrates. Often there is an intermediary, grass-based stocker segment between cow/calf and feedyard segments. In beef production, feed nutrients are partitioned to growth/development, lactation, reproduction, fat accretion, and maintenance (Ferrell and Jenkins, 1985). A reproducing cowherd requires energy for maintenance, lactation, and gestation. Collectively, considering cows' requirements combined with energy requirements of replacement heifers and bulls, 70% of all nutrients consumed for beef production are expended by the cow/calf segment (Ferrell and Jenkins, 1985). The remaining 30% account for post-weaning growth of calves during both stocker and feedyard segments. Thus, integrated over the entire U.S. beef production system, nearly one-half of all nutrients consumed are utilized for cowherd maintenance (Ferrell and Jenkins, 1985).

Researchers analyzing beef production feed efficiency have reported greatest efficiency can be achieved by harvesting females shortly after the birth of their first calves (Taylor et al., 1985; Bourdon and Brinks, 1987). The All Heifer, No Cow (**AHNC**) beef production system produces beef without mature cows. Nulliparous heifers are inseminated with female sex-selected semen to produce primarily female calves that are early-weaned 3 mo after parturition. Post-weaning,

dams are finished on a high concentrate ration and harvested before reaching 30 mo of age (Seidel and Whittier, 2015).

Objectives of this study were to: 1) document reproductive, feedyard, calf, and carcass performance of a 5-cohort AHNC demonstration herd; 2) evaluate effects of carcass maturity on carcass quality variables; and 3) determine if performance of initial cohorts (i.e., cohorts 1 and 2) differed from sustaining cohorts (i.e., cohorts 3 through 5).

MATERIALS AND METHODS

A total of 273 heifers were enrolled in the AHNC beef production system via 5 annual cohorts over a 6-yr period. The herd was initiated March of 2013 (i.e., cohort 1) with the purchase of 51 yearling, Angus-based commercial heifers (initial BW = 354 ± 39 kg). A replicate set of similar heifers (n = 56; initial BW = 307 ± 30 kg) was purchased and enrolled the following yr. With this system, annual income requires 2 herds, 12 mo apart in age from each other. One herd is being bred approximately the same time the dams and calves from the other set enter the feedyard (Seidel and Whittier, 2015).

Exact ages of heifers in cohorts 1 and 2 were not known, but heifers were estimated to be 1 yr of age at purchase. Upon arrival, heifers were weighed, body condition scored, ear tagged, and assigned reproductive tract scores (Lefever and Odde, 1986). Heifers enrolled in cohorts 3 (n = 53), 4 (n = 56), and 5 (n = 56) were primarily offspring of prior cohorts (i.e., cohort 3 heifers were born to cohort 1 females, etc.), but some heifers were acquired in a similar manner as cohorts 1 and 2 to ensure maintenance of annual inventory. Animals were maintained at East Rabbit Creek Ranch in Livermore, CO and the feedyard at the Colorado State University Agricultural Research Development Education Center (**ARDEC**; Fort Collins, CO).

Ovulation synchronization to weaning. Ovulation was synchronized with a 14-d controlled internal drug releasing insert (**CIDR**; Eazi-Breed; Zoetis, Parsippany, NJ). On d 17, estrus

detection patches (Estrotect; Rockway Inc., Spring Valley, WI) were placed in front of tail heads and heifers received an i.m. injection containing 25 mg of $PGF_{2\alpha}$ (Lutalyse; Zoetis, Parsippany, NJ). Approximately 66 h post $PGF_{2\alpha}$ injection, patch status was assessed. Heifers with tripped patches were inseminated with a 0.25 cc dose of female sex-selected semen. Heifers with inactivated patches at 66 h post $PGF_{2\alpha}$ injection received an i.m. injection of 100 μg of GnRH (Factrel; Zoetis, Parsippany, NJ) and were inseminated 18 h later with female sex-selected semen. Cohorts 1 and 2 were inseminated with semen from polled Hereford bulls resulting in predominantly Angus-Hereford crosses. Cohorts 3 and 4 were inseminated with semen from a polled, black Simmental bull. Cohort 5 was inseminated with semen from an Angus, polled Hereford, or Simmental sire used in previous cohorts. Purchased replacement heifers for cohorts 3 through 5 were all black Angus-based.

Cohorts 2 through 5, had ovulation re-synchronized after timed AI. Resynchronization of estrous was initiated 12 d after timed AI with insertion of intra-uterine CIDR. After 7.5 d, CIDRs were removed and estrus detection patches were applied. Heifers were observed for behavioral signs of estrus at least twice daily (e.g., am and pm). Heifers displaying standing estrus in am were inseminated the same evening. Heifers displaying standing estrus in the pm were inseminated the following evening. On average, heifers were inseminated approximately 3.5 d after CIDR removal. Generally, heifers that were inseminated a second time were bred to the same sire as their first insemination. Heifers that did not exhibit estrus were assumed pregnant to the first AI and were not inseminated a second time. Immediately following the second AI, heifers were placed with a natural service sire. For cohorts 1 and 2, a polled Hereford bull was used. In cohorts 3 and 4, a Gelbvieh × Angus bull was used. In cohort 5, a black Angus bull was used. Heifers remained with the bull uninterrupted for approximately 100 d. Since cohort 1 did

not receive a second AI, the natural service sire was immediately placed with the heifers after the first AI.

Pregnancy rate to the first AI was diagnosed 33 to 36 d after the first AI via ultrasound (Aloka 500; Corometrics Medical Systems, Wellington, CT) fitted with a 5-MHz rectal probe. A second pregnancy diagnosis was performed by rectal palpation 140 d after the first timed AI to determine season-long pregnancy rate. Following the second pregnancy diagnosis, non-pregnant heifers and heifers that conceived late in the breeding season (i.e., pregnancy determined to be less than 90 d) were sold. Heifers were maintained on native range May through November and were fed hay December through April. At parturition, date of birth, calving ease score, calf birth weight (**BWT**), and sex were recorded. Post-calving, dams were supplemented with 15% CP range cubes at a level of 1.4 kg per dam per d.

Weaning to harvest. Two weeks prior to early-weaning, dams and calves were jointly shipped 45 km to ARDEC and placed into a single pen with a concrete bunk and ad libitum access to water. Dams and calves received ad libitum grass hay for the first 3 d. For the next 2 to 3 wk, dams and calves in cohorts 1 and 3 through 5 were fed a receiving diet and cohort 2 was fed grass hay and a transitioning ration (Tables 2.1 and 2.2), offered as a TMR. Calves produced by the 5 cohorts were early-weaned at 105 ± 21 d. Cohorts 2 through 4 were weaned using the fence-line weaning technique (Price et al., 2003). In cohorts 1 and 5, calves were weaned by placing them in a pen at the opposite end of the feedyard. Dams were weighed and implanted in the right ear with 200 mg of trenbolone acetate and 20 mg of ß-estradiol (Revalor®-H; Intervet, Madison, NJ). Dams in cohorts 4 and 5 were implanted at weaning, dams in cohorts 1 and 2 were implanted 6 wk after weaning, and cohort 3 was not implanted (Table 2.2). Calves were retagged and weighed at weaning.

Post weaning, calves in all cohorts remained in the feedyard an average of 50 ± 10 d on a moderate energy growth ration (Table 2.1) until shipped back to Rabbit Creek Ranch. After weaning, dams in cohorts 1 and 3 through 5 were fed a moderate energy, transitioning ration for approximately 3 wk (Tables 2.1 and 2.2). Cohort 2 was not fed the receiving ration and was transitioned directly from grass hay to the transitioning ration. The remaining time in the feedyard, dams were fed a high energy, finishing ration (Tables 2.1 through 2.3). Post-weaning rations for dams in cohorts 2 through 5 were formulated to provide 0.5 mg of melengestrol acetate per cow per d until harvest. Across the 5 cohorts, dams received the finishing ration for 72 ± 8 d, until they reached a target harvest BW of 636 kg. While dams and calves were in the feedyard, individual animal BW were collected at least every 3 wk early in the morning prior to feeding.

In cohorts 1 and 2, individual cow feed intake evaluations were conducted in ARDEC's Feed Intake Unit (**FIU**)**.** Dams were individually tagged with a radio frequency identification tag (TFIW/GESMW, Allflex®; Airport, TX) that was placed on their left ear. Dams were sorted and placed in two 25-animal pens equipped with free access to water and concrete bunks (Arce-Cordero, 2016). Dams remained in the FIU for 42 and 48 d in cohorts 1 and 2, respectively (Table 2.2). Dams in cohorts 1 and 2 were weighed upon entry to the FIU, and again on d 14, 28, and 42 (Arce-Cordero, 2016). Dams in cohort 2 remained in the FIU for an additional wk and were also weighed on d 48 when exiting the FIU (Arce-Cordero, 2016). Individual daily feed intake data were collected by an automated feed intake monitoring system (GrowSafe®; Calgary, Alberta, Canada; Arce-Cordero, 2016). Individual simple linear regressions were performed using animal BW data, and ADG was predicted and individual DMI and G:F values were calculated (Arce-Cordero, 2016). On days cattle were weighed, feed intake data were omitted from analyses to ensure external factors did not influence feed intake. After conclusion of feed

intake measurements, dams remained in the feedyard on the finishing ration until harvest (Arce-Cordero, 2016).

For cohorts 2 through 5, 3 wk prior to harvest dams were individually mouth scored to quantify the number of permanent incisors. A second mouth score was taken the d prior to harvest. In cohort 1, only a single mouth score was taken the d prior to harvest. Exit BW was individually calculated by averaging BW measured the final 2 d at the feedyard. Shrunk BW was calculated using a 4% pencil shrink between the feedyard and packing plant. Table 2.2 describes variation in management of the 5 cohorts while at the feedyard.

Harvest. Across all 5 cohorts, a total of 222 AHNC females were harvested at a commercial packing plant located 48 km from the feedyard. In cohorts 1 and 5, 1 carcass was unavailable for measurements. Researchers from Colorado State University Center for Meat Quality and Safety recorded the following carcass measurements: preliminary yield grade (**PYG**), adjusted preliminary yield grade (**APYG**), HCW, ribeye area (**REA**), KPH, marbling score (**MA**), lean maturity score (**LM**), skeletal maturity score (**BM**), and overall maturity score (**OM).** Yield grade (**YG**) and quality grade (**QG**) were calculated and USDA YG and QG were recorded when assigned by USDA grading personnel. Yield and quality grades were calculated using standards outlined in USDA Beef Quality and Yield Grades (Hale et al., 2013). Dressing percentages were calculated using shrunk BW and HCW. For cohorts 3 through 5, age at harvest was calculated using available birth dates. Since no birth dates were available for cohorts 1 and 2, age at harvest was not known.

Overall carcass maturity was calculated using LM and BM. Maturity scores of 100, 200, 300, and 400 coincided with maturities of A^{00}, B^{00}, C^{00}, and D^{00}, respectively. Marbling score was assessed at the interface of the 12^{th} and 13^{th} ribs and corresponded with the following

marbling levels: practically devoid^{00} = 100, traces^{00} = 200, slight^{00} = 300, small^{00} = 400, modest^{00} = 500, moderate^{00} = 600, and slightly abundant^{00} = 700.

Weaning to ovulation synchronization. Recently-weaned calves were transported from the feedyard back to Rabbit Creek Ranch to graze fall pasture and were supplemented daily with 15% CP range cubes at a level of 1.3 kg per animal. In all cohorts, steer calves were removed from the study and sold at a local auction market. Heifers diagnosed as non-pregnant or late-pregnant were removed from the study and sold. Due to imperfections in accuracy of sex-selected semen, use of a natural service sire following AI, and calf and dam death loss, the AHNC beef production system was unable to derive 100% of its replacements from within the system. Thus, replacement heifers were purchased annually for cohorts 3 through 5. A total of 80 Angus-cross, replacement-quality heifers were purchased in cohorts 3 (n = 26; initial BW = 180 ± 6 kg), 4 (n = 26; initial BW = 222 ± 21 kg) and 5 (n = 28; initial BW = 228 ± 22 kg). In each cohort, the new set of heifers, including replacements, were transported to ARDEC in early winter. Heifers were fed a moderate energy ration overwinter (99 ± 5 d; Table 2.1). Subsequently, heifers returned to the ranch and were fed hay until May, when native range was available. Ovulation was synchronized as previously described.

Data analyses. Data analyses were done using R (version 3.5.1). Descriptive statistics were used to calculate means and SD of key production parameters for reproducing females, calves, dams in the feedyard, and carcasses. Pregnancy diagnoses, calving records, and production records from first and second inseminations were used to calculate percentages of heifers that conceived to first fixed-time AI and remained pregnant, percentages of heifers that conceived to second fixed-time AI, and percentages of heifers that conceived to natural service sires.

To evaluate differences in meat quality between youthful (i.e., A and B maturity) and mature (i.e., C maturity and greater) as classified by USDA grading personnel based on carcass maturity,

a t-test was conducted. Carcasses were pooled across cohorts and sorted into 2 groups—youthful (i.e., OM < 300) and mature (i.e., OM ≥ 300) carcasses based on assigned USDA grades. The resultant means for HCW, REA, YG, MA, LM, BM, OM, and dressing percent were compared.

To test for performance differences between initial and sustaining cohorts, regression analyses were used. Group referred to whether an animal was from initial (i.e., cohorts 1 and 2) or sustaining (i.e., cohorts 3 through 5) cohorts. Logistic regression and contrasts were used for 30 and 140 d conception rates, and pregnancy was treated as the response variable. Prebreeding BW and BCS and group were considered as dependent variables. In the case of the 140 d regression, the categorical predictor repeat AI was also used (i.e., whether or not a heifer received a second AI). Age was not used as a predictor variable because ages were unknown for the initial cohorts.

Multiple linear regression models were fit to data to evaluate growth and carcass performance. Response variables considered were ADG, DMI, HCW, dressing percent, USDA YG, MA, LM, BM, and OM. Predictor variables included for consideration were BCS and BW at prebreeding, conception to first AI, second AI exposure, live calf weaned, days on feed, ADG, G:F, HCW, MA, LM, BM, OM, USDA YG, and group. Model selection was performed using backwards selection. Data collected on animals that died were not used in analyses. Means were calculated using the emmeans package and reported as least squares means. Significance was declared at $P \leq 0.05$

RESULTS AND DISCUSSION

Reproductive performance. At prebreeding, BW for the 5 cohorts was 346 ± 45 kg, and BCS was 5.5 ± 0.6 (Table 2.4). Overall pregnancy rate at 30 d post fixed-time AI with sex-selected semen was 50.8 ± 9.4%. Considering the reduced fertility of sex-selected semen due to decreased sperm numbers, these results were expected (Garner and Seidel, 2008). Seidel et al.

(1999) evaluated effects of breed, sperm concentration, and semen deposition site on conception rates for beef heifers inseminated with sex-selected semen and reported that pregnancy rates ranged from 26 to 86%, and conception rates with sexed semen were typically 70 to 90% of conventional semen controls. In a follow up study, average pregnancy rate for beef heifers inseminated with sexed semen 12 to 24 h after standing estrus was 55.9% (range: 47 to 80%), and sex-selected semen conception rates were typically 80% of conventional semen, but management played a key role in success of breeding (Seidel and Schenk, 2008). In the current study, conception rates were within the reported range, but lower than average. However, conception rates improved in later cohorts.

Riggs (2001) evaluated an integrated production system that included use of early-weaning, early-breeding (i.e., 10 mo of age), and insemination with sex-selected semen. Conception rates to fixed-time AI with sex-selected semen were 19 and 8% in cohorts 1 and 2, respectively. However, at the conclusion of the breeding season after both AI and natural service, conception rates were 58 and 16% for cohorts 1 and 2, respectively (Riggs, 2001). The author attributed low conception rates to the fact only a small percentage of heifers were cycling prior to first the AI, which was likely caused by the young age of the heifers. Results from the current study suggest there are external management factors that also impact success of insemination with sex-selected semen. In cohort 1, there was a numerical reduction in 30 d post fixed-time AI pregnancy rate (41.2%) compared to other cohorts (Table 2.4). The reduced conception rate for cohort 1 was attributed to lack of fertility information on bulls used, incomplete history on purchased heifers (e.g., age or previous implant status), and other management factors.

At the conclusion of the 5 breeding seasons, 93.0 ± 1.5% of heifers were pregnant. In accordance with this, a small number of heifers failed to conceive (19/273 = 7.0%) and were sold from the system (Table 2.4). Percentages of heifers that conceived to first AI (47.1 ± 6.5%),

repeat AI (12.2 ± 5.1%), and natural service (36.6 ± 10.3%) were calculated (Table 2.4). A relatively small percentage of animals (69/273 = 25.3%) received a second AI. Less than half of repeat inseminations resulted in conception. There was a numerical reduction between pregnancy rate at 30 d post AI (50.8%) and those pregnant to first AI that remained pregnant (47.1%; Table 2.4). This loss was due to early embryonic death.

The hastened system timeline (Fig. 2.1) in the current study requires timely conception. Overall, 6.9 ± 4.1% of exposed heifers achieved pregnancy, but were sold because the projected calving date was outside the desired calving season (i.e., pregnant less than 90 d at season-long pregnancy diagnosis; Table 2.4). Heifers that calve late in the calving season will have difficulty achieving target harvest weight prior to reaching 30 mo of age. Additionally, calves born later in the season would be younger and lighter at weaning and thus may struggle to achieve puberty in sufficient time for conception to the first AI. Although these pregnant heifers are not suitable for this system, selling them as pregnant females is a viable strategy for offsetting the lengthy time to income associated with this system.

As shown in Table 2.4, percent calf crop was 85.7 ± 8.3%. The 2007-08 National Animal Health Survey for the cow/calf segment conducted by the USDA (2009) reported an average percent calf crop of 83.2% for primiparous females and 91.5% for all females. The authors of the Cow Herd Appraisal Performance Software (CHAPS, 2017) reported a combined female calf crop of 91.0%. An evaluation conducted by Laster and Gregory (1973) evaluated parturition and calf death loss in a variety of cattle breeds and concluded calf losses were greater in primiparous females than cows. This difference was attributed to the greater number of assisted births with primiparous females (Laster and Gregory, 1973). Similar results were reported by Patterson et al. (1987) who documented greatest calf mortality rates in primiparous females. Results showed

AHNC heifers were able to perform reproductively and achieved reproductive rates similar to those of conventional cow/calf production.

Calf performance. Over the 5-cohort study, a total of 213 calves were weaned. Combining across sexes and cohorts, calf BWT was 33 ± 5 kg (Table 2.5). There was a difference ($P <$ 0.001) in BWT between male (n = 51; 35 ± 10 kg) and female (n = 173; 32 ± 9 kg) calves. These results were consistent with Tubman et al. (2004) who concluded heifer calves weighed an average of 1.9 kg less than their male contemporaries. The difference between male and female BWT was also partly due to sire differences. Most female calves were conceived via AI and sired by bulls with accurate EPDs for calving ease; most male calves were sired by natural service sires with less accurate EPDs for calving ease. Decreased calf BWT likely contributed to the low incidence of dystocia. The reduction in number of calves born (n = 224) and calves weaned (n = 213) was due to calf death loss.

At the time of early-weaning, calves had a weaning weight (**WWT**) of 125 ± 28 kg (Table 2.5). Calves from cohorts 1 and 2 were heavier ($P < 0.001$) at weaning than calves in cohorts 3 through 5. Increased WWT for cohorts 1 and 2 was attributed to the increased ($P < 0.001$) age of cohort 1 and 2 calves at weaning, but also the unknown genetic history and age of dams in the initial cohorts. Post-weaning, calves gained 0.9 ± 0.3 kg • d^{-1} in the dry lot (Table 2.5). Similar results were reported by Reiling et al. (1995). The authors reported calves of crossbred Angus once-calved females (**OCF**) were early-weaned at 117 d of age at a WWT of 159 kg with an ADG of 1.1 kg • d^{-1}. Similarly, Peterson et al. (1987) reported average WWT and ADG for crossbred calves weaned at 110 d were 109 kg and 0.76 kg • d^{-1}, respectively. However, it is worth noting that ADG in these 2 studies were indicative of the period from birth to weaning, not post-weaning as in the current study.

An important measure for the AHNC beef production system is percent females weaned. This will influence the number of replacements that must be purchased annually to maintain consistent inventory. Overall, 61.1 ± 6.5% of females replaced themselves with a heifer, although the last 2 cohorts averaged a replacement rate of 67.9% (Table 2.5). This number was slightly below initial expectations; the goal was to achieve a replacement rate of 75%. The reduced accuracy and fertility of sex-selected semen, calf death loss, and use of natural service sires following AI reduced the percent of female calves weaned. The high replacement rate indicated the AHNC beef production system may function with conventional semen, in which about 40% of females would replace themselves with a heifer, but management burdens and insemination costs would be reduced.

Feedyard performance. Entering the feedyard initial BW was 464 ± 54 kg for the 5 cohorts. Dams in cohort 1 were heavier upon entry to the feedyard (518 ± 49 kg; Table 2.6), but dams in this cohort were assumed to have been slightly older than those in other cohorts since their ages were unknown. This theory was supported by the greater percentage of C maturity carcasses based on carcass maturity in cohort 1. Dams in cohort 1 were also heavier ($P < 0.01$) at harvest. Overall, dams remained in the feedyard 102 ± 10 d prior to harvest and majority of the time (72 ± 8 d), dams were fed a high-energy finishing ration (Table 2.3). The length of the feeding period in the current study was consistent with previously reported feeding periods for primiparous and multiparous females. Schnell et al. (1997) concluded feeding a grain-based diet for 56 d was a sufficient amount of time to convert yellow fat to white fat. A longer feeding period of 105 d was reported by Pritchard and Berg (1993) for culls cows ranging 4 to 10 yr of age.

While on the finishing ration, overall ADG for dams was 1.9 ± 0.4 kg • d^{-1} (Table 2.6). The ADG observed in the current study was greater than ADG previously reported for OCF. Field et al. (1996) fed a grain-based diet to crossbred OCF (entry BW = 525 kg) for 100 d after early-

weaning of their calves at 120 d of age. Dams gained 1.3 kg • d^{-1} and had an average exit BW of 656 kg (Field et al., 1996). A similar study by Waggoner et al. (1990) evaluated Simmental × Hereford OCF that calved at 24 mo of age and were implanted and fed a grain-based diet for 137 d prior to harvest. Live BW at harvest was 539 kg and ADG was 1.0 kg • d^{-1} (Waggoner et al., 1990). The ADG achieved by dams in the current study exceeded ADG values reported for conventionally raised and finished heifers (1.5 kg • d^{-1}) and steers (1.7 kg • d^{-1}; Kansas State Research and Extension, 2017).

The high ADG reported in this study is likely a combination of several factors. Dams experienced some compensatory gain upon entering the feedyard. After calving in late winter, the combination of lactation and growth/development facilitated a negative energy balance. The increased plane of nutrition and early-weaning resulted in a faster than normal rate of gain. Over the past 20 yr the beef cattle industry has seen considerable improvement in ADG and harvest weights through genetic selection (CHAPS, 2017).

Overall dams consumed 14.9 ± 1.9 kg • d^{-1} of DM. The G:F ratio of dams was 0.120 ± 0.023, and G:F ratios continued to improve in later cohorts (Table 2.6). Although dams in the current study were able to gain weight rapidly, their conversion of feed to BW was poor. There was a numerical reduction in G:F for cohort 4 when compared to other cohorts, especially other sustaining cohorts (e.g., cohorts 3 and 5). In cohort 4, fence-line weaning was unsuccessful, and half of the dams were still lactating up to a few wk prior to harvest. Increased energy requirements of lactation likely contributed to the decreased feed efficiency (Ferrell and Jenkins, 1985).

Kansas State Research and Extension (2016) reported average G:F ratios of 0.166 and 0.159 for conventionally raised and finished steers and heifers, respectively. Wertz et al. (2001) analyzed feed efficiency of conventionally raised and finished 2 yr-old Angus heifers and

determined a F:G ratio of 7.6. The F:G ratio of AHNC females was reduced when compared to nulliparous contemporaries. It was assumed reduced efficiency was due to recent parturition and lactation (e.g., presence of mammary tissue), and reduced feed efficiency is often associated with heavy animals at the start of the finishing period (Nkrumah et al., 2006). Although feed efficiency of AHNC dams was poorer than conventionally raised and finished steers and heifers, AHNC dams received the finishing ration a fewer number of days than animals in conventional finishing systems. Additionally, elimination of the highly inefficient mature cowherd may offset decreased feed efficiency during the short finishing phase. All heifer, no cow dams gained rapidly in the feedyard but, were slightly less efficient than conventionally raised and finished steers and heifers.

Carcass performance. Table 2.7 includes carcass characteristics of the 222 AHNC females that were harvested. For cohorts 3 through 5, age at harvest was 904 ± 20 d (i.e., just under 30 mo of age based on chronological age). The packing plant did not use birth dates to determine chronological age, even when cohort 3 was third party age and source verified. The packing plant used dentition as a surrogate criterion to determine chronological age. Dams with 3 or more permanent incisors were declared over 30 mo of age. Dentition classified 68.3% of carcasses as over 30 mo of age. However, based on documented birth dates for cohorts 3 through 5, only 29.5% of carcasses exceeded 30 mo of age. This indicated dentition was a crude measure of chronological age (Shorthose et al., 1990; Schönfeldt and Strydom, 2011). Cattle that are over 30 mo based on dentition of age are perceived to be of greater risk of infection from prions that cause bovine spongiform encephalopathy (Tatum, 2011). Discounts for carcasses classified as over 30 mo of age based on dentition was costly (e.g., $100 per animal in the current study). Third party age and source verification of cattle may override dentition scores and would help

mitigate occurrence of carcass discounts for animals declared over 30 mo of age based on dentition.

Overall, the 5 cohorts had an HCW of 367 ± 35 kg and dressing percent of 58.8 ± 1.9% (Table 2.7). Finding an industry average for dressing percent of similar cattle was difficult, but generally 62% is used as an industry benchmark for dressing percent, considering both conventionally raised and finished steers and heifers (Nold, 2013; Content, 2018). Decreased dressing percentages observed in the current study were likely due to increased reproductive and mammary tissue associated with calving and lactation (Waggoner et al., 1990; Nkrumah et al., 2006; Nogalski et al., 2016). Additionally, dressing percent decreases as animal age increases, so increased age at harvest likely decreased dressing percentages (Pritchard and Berg, 1993; Content, 2008). Dressing percentages of females in the current study exceeded values reported for OCF in the literature. Nogalski et al. (2016) harvested 2 sets of females: maiden heifers harvested at 18 mo after being conventionally raised and finished and OCF with calves early-weaned that were subsequently finished and harvested at 28 mo of age. Noglaksi et al. (2016) reported that OCF had heavier live BW at harvest (570 ± 17 kg) but, decreased dressing percent (54.5 ± 0.4%) when compared to conventionally raised and finished heifers (BW = 482 ± 13 kg; dressing percent = 57.1 ± 0.3%). Additional comparisons of OCF carcasses to conventionally raised and finished carcasses have also reported decreased yields for OCF (Joseph and Crowley, 1971; Boucqué et al., 1980;). Waggoner et al. (1990) reported an average HCW of 406 kg and dressing percent of 62.7% for OCF. Hot carcass weights of AHNC dams in the current study were only slightly lower than HCW of conventionally raised and finished steers and heifers (394 kg) reported in the 2016 National Beef Quality Audit (NCBA, 2017).

In the current study, all carcasses were sold on a value-based grid, in which YG and QG were important attributes. Yield grade-related attributes are included in Table 2.8. Across the 5

cohorts, mean USDA YG was 2.6 ± 0.7, and calculated YG was 2.9 ± 0.7. An interesting comparison of USDA YG and calculated YG showed similar YG variance, but dissimilar means; mean USDA YG was less (P = 0.001) than calculated YG. This difference was expected considering USDA yield grading does not use standard rounding rules (i.e., YG 2.6 is classified as a YG 2, not a YG 3). Overall, REA measured 88.2 ± 11.0 cm squared, back fat thickness measured 1.20 ± 0.37 cm, and percent KPH was 1.96 ± 0.38%. (Table 2.8). Based on results from the 2016 National Beef Quality Audit, mean REA was 83.2 cm squared, and mean back fat thickness was 1.42 cm (NCBA, 2017). Carcasses in the current study were leaner than conventionally raised and finished steers and heifers based on the objective measures of REA and back fat thickness. Performance of these carcasses resembled carcass performance from females managed in an integrated system where heifers were bred young, calves were early-weaned, and dams were finished and slaughtered at 24 mo of age (Riggs, 2001). Integrated system females (n = 22) had similar HCW (361 ± 28 kg), dressing percent (60.0 ± 2.2%), and USDA YG (3.1 ± 0.7) to females in the current study (Riggs, 2001).

The distribution of USDA YG assigned to AHNC carcasses closely resembled the YG distribution for conventionally raised and finished beef cattle reported in the 2016 National Beef Quality Audit (NCBA, 2017). The authors reported 9.5, 36.5, 39.4, 12.1, and 2.5% of carcasses graded YG 1, YG 2, YG 3, YG 4, and YG 5, respectively (NCBA, 2017). Table 2.8 shows percentages of AHNC carcasses that were represented in the 5 YG categories. The AHNC dams graded similarly to conventionally raised and finished steers and heifers. In the current study, the predominant USDA YG was 3 and included 52.3 ± 9.2% of all graded carcasses. In the current study, YG 4 and 5 only represented 3.6 ± 3.7% and 0.9 ± 1.3% of total harvested carcasses, respectively (Table 2.8).

Overall, based on carcass maturity the packer classified 20.5 ± 18.7% of carcasses as mature and remaining were classified as youthful. Combining youthful and mature carcasses, LM for AHNC carcasses was 166 ± 26 and BM was 236 ± 81 (Table 2.9). It is important to note in cohort 3 there were no C maturity carcasses based on carcass maturity. Females in cohort 3 did not receive an estrogenic implant during the feedyard phase, likely contributing to the absence of mature carcasses. In beef carcasses, estrogens enhance skeletal ossification (Grumbach and Auchus, 1999; Tatum, 2011).

When calculating OM, BM is more influential than LM. Across the 5 cohorts, OM was 213 ± 54 (Table 2.9). The young age of these females coupled with accelerated levels of ossification supports the theory that hormones associated with pregnancy, calving, and lactation cause accelerated bone ossification (Waggoner et al., 1990; Kreikemeier and Unruh, 1993; Field et al., 1996). Waggoner et al. (1990) reported the following maturity scores for OCF: LM = 180 ± 3, BM = 216 ± 4, and OM = 205 ± 3. These maturities are comparable to maturities observed in the current study.

Mean MA of AHNC carcasses was 457 ± 87 and corresponded with a marbling level of small^{57} (Table 2.9). The 2016 National Beef Quality Audit reported an average MA of small^{70} for conventionally raised and finished steers and heifers (NCBA, 2017). Reiling et al. (1995) and Shackleford et al. (1995) reported MA of small^{75} and small^{27} for conventionally raised and finished heifers and OCF, respectively. Marbling scores of AHNC carcasses in the current study were within the range of MA previously reported for beef produced by OCF (Reiling et al., 1995; Shackleford et al., 1995; Riggs, 2001; Nogalski et al., 2016). Carcasses produced by AHNC females were able to sufficiently marble, but advanced carcass maturity penalized carcasses when QG was assigned. Overall, 62.4 ± 29.1% of carcasses were classified as USDA Choice by USDA graders (Table 2.9). This was only slightly less than the percent USDA Choice carcasses

(68.78%) reported in the 2016 National Beef Quality Audit (NCBA, 2017). The integrated system studied by Riggs (2001) resulted in 68.2% of carcasses grading USDA Choice. It is worth noting that in the current study, 4.9 ± 5.5% of all carcasses were USDA Prime (Table 2.9). On average, only 4.6% of conventionally raised and finished carcasses grade USDA Prime (NCBA, 2017). Although, the combined percentages of standard and ungraded carcasses in the current study (23.3 ± 21.0%) greatly exceeded that of conventionally raised and finished carcasses (3.6%; NCBA, 2017). Carcasses that were ungraded in the current study were mostly ineligible for grading due to advanced ossification of thoracic buttons.

In this study, even though birth dates were unknown for cohorts 1 and 2, it was very unlikely any harvested females exceeded 42 months of age at harvest (i.e., OM = C or greater). Overall, 177 carcasses were classified as youthful and 43 were classified as mature based on carcass maturity assessed by USDA grading personnel. There were no differences between maturity groups for REA ($P = 0.13$), USDA YG ($P = 0.67$), MA ($P = 0.26$), or LM ($P = 1.00$). Mature carcasses had greater ($P < 0.001$; $P < 0.001$) BM and OM when compared to youthful carcasses (Table 2.10). These results were expected since BM is the major determinant of OM (Hale et al., 2013). The mature group had greater ($P < 0.01$) HCW and greater ($P <0.001$) dressing percent. The increased HCW for the mature group was likely due to an increased age at harvest. For cohort 3 through 5, mature carcasses (n = 12; 919 ± 11 d) were older ($P = 0.001$) than youthful carcasses (n = 120; 903 ± 20 d) at harvest. The reduced dressing percent for youthful carcasses was surprising because generally older animals have decreased dressing percentages (Content, 2018). However, decreased dressing percentages in the youthful group was likely due a small number of animals not reaching target harvest BW. Arce-Cordero (2016) specifically evaluated meat quality of females managed in an AHNC beef production system, and 86 AHNC carcasses were evaluated; 34% were classified as C maturity based on carcass maturity. Tenderness

differences were assessed by Warner-Bratzler (**WBSF**) and slice shear force (**SSF**; Arce-Cordero, 2016). The WBSF and SSF scores were 4.9 ± 1.2 kg and 25.4 ± 8.6 kg for mature carcasses and were 5.0 ± 0.8 kg and 27.6 ± 9.1 kg for youthful carcasses, respectively (Arce-Cordero, 2016). There were no differences between WBSF and SSF (Arce-Cordero, 2016). This indicated discounts for advanced carcass maturity were unjustified based on the objective evaluation of tenderness.

Field et al. (1997) compared A and C maturity carcasses based on carcass maturity that were produced by grain-finished, OCF harvested at 32.5 mo of age. These results were similar to those observed in the current study and Arce-Cordero (2016). There were no differences in comparisons of LM, MA, WBSF, and muscle collagen concentration between the different carcass maturities, however, there were differences in BM across maturities (Field et al., 1997). The authors concluded that collagen maturation, a major determinant of beef tenderness, was independent of skeletal maturation (Field et al., 1997). Waggoner et al. (1990) compared maiden and OCF and also concluded OCF had greater BM than 2-yr-old maiden heifers, but MA were the same. Waggoner et al. (1990) reported that sensory panelists and WBSF values indicated beef produced by OCF was tougher than beef produced by a yearling heifer, but similar to beef from conventionally raised and finished 24-mo-old heifer. Ultimately, the study concluded beef from OCF was comparable to beef produced by maiden heifers of similar chronological age (Waggoner et al., 1990). This demonstration herd indicated the AHNC beef production system is a viable system for producing beef. Carcasses produced by AHNC females are of similar quality to carcasses produced by conventionally raised and finished steers and heifers. Secondly, with exceptions of BM and OM, beef produced by youthful, AHNC carcasses was the same quality as beef produced by mature carcasses.

Comparison of cohorts. Seidel and Whitter (2015) hypothesized the AHNC beef production system will not reach equilibrium until later cohorts due to the influence of purchased heifers with little background information, comprising performance of initial cohorts. Thus, it was anticipated that performance of sustaining cohorts would exceed that of initial cohorts. However, results of regression analyses yielded conflicting results. Average 30 d pregnancy rates were 47.1 and 55.6% for initial and sustaining cohorts, respectively. At the 140 d pregnancy diagnosis, 94.1 and 92.6% of heifers were pregnant in initial and sustaining cohorts, respectively. There were no differences in 30 d ($P = 0.17$) and 140 d ($P = 0.48$) pregnancy rates between in initial and sustaining cohorts (Table 2.11).

Table 2.12 summarizes differences in carcass and growth performance for initial and sustaining cohorts. Analyses showed ADG ($P = 0.88$), YG ($P = 0.25$), and MA ($P = 0.44$) did not differ between cohorts. However, females in sustaining cohorts consumed more ($P < 0.001$) feed than females in initial cohorts, but carcasses in initial cohorts had heavier ($P < 0.001$) HCW and improved ($P < 0.001$) dressing percentages when compared to carcasses in the sustaining cohorts. These results were somewhat surprising, however increased DMI for sustaining cohorts was likely due to females in cohort 4 lactating longer than females in other cohorts. Carcasses produced by the initial cohorts were more ($P < 0.01$; $P < 0.01$) youthful based on comparisons of LM and BM, but carcasses produced by initial cohorts had greater ($P < 0.05$) OM, indicating carcasses in cohorts 1 and 2 were older at harvest based on carcass maturity. These results indicated that generally, performance of an AHNC herd will improve overtime. However, performance of initial cohorts was only slightly decreased, so producers can easily enter and exit the AHNC beef production system without compromised performance.

Limitations and improvements. This was an observational study and did not allow for a comparison of AHNC vs. conventional cow/calf-based beef production. An ideal evaluation

would entail managing an AHNC and conventional cow/calf herd (i.e., control) under similar management, climate, market conditions, etc. This would provide a baseline for AHNC production parameters and allow for more sophisticated statistical analyses.

It was difficult to effectively evaluate feed intake and feed efficiency of AHNC dams when they were not maintained in the FIU. Individually measuring animal feed intake is the only reliable method for determining feed efficiency. Dams in cohorts 1 and 2 were in the FIU, but in an ideal analysis, all dams would have had feed intake measured the entire length of the feeding period. Reported efficiency measures are less robust than feed intake tracked in the FIU. Measuring intake when grazing would have been extremely difficult, but the amount of hay fed daily should be thoroughly documented to allow for more accurate estimation of lifetime intake. The unknown history and ages of the initial sets also made statistical analyses and conclusions more difficult. By purchasing heifers from known sources, birth dates and management and genetic history could be known, helping to explain some variation that was observed between the initial and sustaining herds. However, from a performance standpoint, performance is not compromised by purchasing heifers with unknown history.

A fair system evaluation should attempt to mitigate occurrence of advanced maturity carcasses based on both dentition and carcass maturity. Some possible strategies include: 1) third party age and source verification of females, and 2) not using an estrogenic implant which has been shown to accelerate bone ossification. Age and source verification of cattle would override dentition and would eliminate many of the discounts for carcasses over 30 mo of age. Finally, this system warrants evaluation in a grass-based finishing system, since grass-finished animals are typically older at harvest and not assigned QG or evaluated in markets or countries where discounts for 30-mo-old animals and C maturity carcasses are not present.

CONCLUSIONS

Over 30 years ago, several studies evaluated single-calf heifer beef production. At the time, the consensus based on theoretical simulations was the system was the most efficient means of producing beef. This study indicated the AHNC beef production system can effectively produce female calves and high quality carcasses at harvest. The AHNC beef production system offers flexibility. Performance of cohorts 1 and 2 was very similar to cohorts 3 through 5, indicating the producer can easily enter and exit the system. The system could be started with calves, yearling heifers, or bred heifers, and similarly, producers could exit the system by selling yearling heifers, bred heifers, pairs or cows after calving, depending on market conditions and the goals of the producer.

Additionally, the program envisioned is especially appropriate to increase beef production over the next several decades. The combination of increasing world population from the current 7.6 billion to a projected 9.8 billion people, plus the increasing standard of living in most developing countries, is predicted to result in an increased demand for meat. With the studied system, an increase in beef production may be possible without increasing the net amount of feed required, and greenhouse gases generated.

Table 2.1. Nutrition content of rations fed to All Heifer, No Cow animals in feedyard and dry lot phases by cohort[1,2]

Nutrient composition (DM basis)		Receiving ration (low energy)	Transition ration (moderate energy)	Finishing ration (high energy)
Cohort 1[3]	DM, %	-	63.91	67.48
	NE_g, MCal • kg^{-1}	-	0.48	0.64
	CP, %	-	16.48	12.58
	ADF, %	-	25.16	8.48
Cohort 2[4]	DM, %	n/a	63.91	67.48
	NE_g, MCal • kg^{-1}	n/a	0.48	0.64
	CP, %	n/a	16.48	12.58
	ADF, %	n/a	25.16	8.48
Cohort 3[5]	DM, %	70.20	71.24	-
	NE_g, MCal • kg^{-1}	0.36	0.58	-
	CP, %	14.74	14.43	-
	ADF, %	32.73	15.06	-
Cohort 4	DM, %	71.24	67.09	73.37
	NE_g, MCal • kg^{-1}	0.48	0.52	0.56
	CP, %	15.61	17.81	14.45
	ADF %	18.31	14.09	8.90
Cohort 5	DM, %	80.00	69.46	77.52
	NE_g, MCal • kg^{-1}	0.53	0.46	0.57
	CP, %	16.52	15.50	12.15
	ADF, %	20.01	20.77	7.17

[1] Ration information for cohorts 1 and 2 was obtained from Arce-Cordero, 2016.
[2] Nutrient percentages were reported on a DM basis.
[3] Proximate analysis for the receiving ration from Cohort 1 was unavailable.
[4] Cohort 2 was not fed the receiving ration.

[5] Proximate analysis for the finishing ration from Cohort 3 was unavailable.

Table 2.2. Description of variation in management across the 5-cohort All Heifer, No Cow demonstration herd during the feedyard phases[1]

Management factor	Cohort 1	Cohort 2	Cohort 3	Cohort 4	Cohort 5
Time on grass hay, d	1	8	3	2	2
Time on receiving ration, d	6	-	22	12	9
Time on transitioning ration, d	11	21	16	21	15
Time on finishing ration, d	72	80	61	79	70
Total time in the feedyard, d	90	109	102	115	96
Time in the feed intake unit, d	42	48	-	-	-
Steam-flaked corn used in TMR in place of cracked corn	-	-	-	YES	-
Implanted with Revolar®-H[2]	YES	YES	-	YES	YES
Fed melengestrol acetate in the finishing TMR	-	YES	YES	YES	YES
Calves fence-line weaned	-	YES	YES	YES	-
Lactation continued in some females prior to harvest	-	-	-	YES	-

[1] Information for cohorts 1 and 2 was obtained from Arce-Cordero, 2016.
[2] Intervet, Madison, NJ.

Table 2.3. Ingredient composition of finishing rations fed to All Heifer, No Cow females by cohort[1,2]

Item	Cohort 1	Cohort 2	Cohort 3	Cohort 4	Cohort 5
Alfalfa hay, %	8.1	8.1	-	-	-
Wheat straw, %	-	-	-	-	4.6
Hay treat, %	3.3	3.3	-	-	5.9
Corn silage, %	30.0	30.0	28.6	24.7	24.0
Cracked corn, %	35.0	35.0	-	56.2	58.0
Steam flaked corn, %	-	-	63.3	-	-
Dried distillers grains, %	7.8	7.8	-	11.3	6.5
Limestone, %	0.3	0.3	-	-	1.0
Salt, %	0.1	0.1	-	-	0.1
Rumensin®(g • ton^{-1})[3]	149	149	-	-	-
Melengestrol acetate (g • ton^{-1})	1.0	1.0	1.0	1.0	1.0
Liquid supplement	-	-	4.3	3.6	-
Mineral supplement	-	-	3.8	4.2	-

[1]All ingredients are reported on a DM basis.
[2] Ration information for cohorts 1 and 2 was obtained from Arce-Cordero, 2016.
[3] Elanco Animal Health, Indianapolis.

Table 2.4. Summary statistics (mean ± SD) for reproductive performance of females managed in the All Heifer, No Cow beef production system by cohort and overall [1]

Parameter	Cohort 1	Cohort 2	Cohort 3	Cohort 4	Cohort 5	Overall
Females exposed, n =	51	56	54	56	56	273
BW at estrus synchronization, kg	354 ± 39	307 ± 30	390 ± 44	336 ± 32	348 ± 38	346 ± 45
BCS at estrus synchronization[2]	5.1 ± 0.8	5.1 ± 0.5	6.0 ± 0.3	5.7 ± 0.5	5.5 ± 0.5	5.5 ± 0.6
Pregnancy rate 30 d post fixed time AI, %	41.2	48.2	51.9	46.4	66.1	50.8 ± 9.4
Pregnancy rate 140 d post fixed time AI, %	94.1	92.9	90.7	92.9	94.6	93.0 ± 1.5
Heifers—failed to conceive[3], %	5.9	3.5	7.4	7.1	3.6	5.5 ± 1.9
Heifers—AI and remained[4], %	39.2	44.6	48.1	46.4	57.1	47.1 ± 6.5
Heifers—repeats[5], %	.	16.1	11.1	16.1	5.4	12.2 ± 5.1
Heifers—bull[6], %	54.9	32.1	33.3	32.1	30.4	36.6 ± 10.3
Heifers—late and sold[7], %	7.8	10.7	0.0	7.1	8.9	6.9 ± 4.1
Calf crop[8], %	94.1	85.7	74.1	81.8	92.9	85.7 ± 8.3
Calves born alive[9], %	100.0	88.9	81.6	88.2	98.1	91.4 ± 7.6

[1] Data from cohorts 1 and 2 were obtained from Arce-Cordero, 2016.

[2] BCS were on a 9 pt scale and included half scores (Herd and Sprott, 1996).
[3] Percent of heifers that were open at the 140 d pregnancy diagnosis.
[4] Percent of heifers that conceived to the first AI and remained pregnant.
[5] Percent of heifers that received a repeat AI; only a single AI was performed on cohort 1.
[6] Percent of heifers that conceived via natural service.
[7] Percent of heifers that conceived late (i.e., pregnancy less than 90 d at the 140 d pregnancy diagnosis) and were sold.
[8] (N◦ weaned calves/ N◦ exposed females) • 100; heifers sold pregnant were assumed to wean a live calf.
[9] (N◦ weaned calves/ N◦ pregnant females) • 100; heifers sold pregnant were assumed to wean a live calf.

Table 2.5. Summary statistics (mean ± SD) for performance of early-weaned calves managed in the All Heifer, No Cow beef production system by cohort and overall[1]

Parameter	Cohort 1	Cohort 2	Cohort 3	Cohort 4	Cohort 5	Overall
Birth weight, kg	33 ± 3	34 ± 4	33 ± 4	32 ± 6	35 ± 6	33 ± 5
Age at weaning, d	108 ± 20	120 ± 21	101 ± 21	97 ± 18	100 ± 19	105 ± 21
Weaning weight, kg	147 ± 24	133 ± 25	111 ± 26	118 ± 22	115 ± 28	125 ± 28
ADG, kg • d^{-1}	0.8 ± 0.2	1.0 ± 0.3	0.9 ± 0.3	1.1 ± 0.2	1.2 ± 0.4	0.9 ± 0.3
Post-weaning dry lot period, d	43	40	55	61	58	51 ± 9
Female calves weaned, %	58.8	57.1	53.7	67.9	67.9	61.1 ± 6.5

[1] Data from cohorts 1 and 2 were obtained from Arce-Cordero, 2016.

Table 2.6. Summary statistics (mean ± SD) for feedyard performance of females managed in the All Heifer, No Cow beef production system by cohort and overall[1]

Parameter	Cohort 1	Cohort 2	Cohort 3	Cohort 4	Cohort 5	Overall
Entry BW, kg	518 ± 49	453 ± 41	481 ± 45	421 ± 40	451 ± 50	464 ± 54
Exit BW, kg	664 ± 55	620 ± 64	626 ± 50	645 ± 55	631 ± 52	637 ± 57
ADG[2], kg • d^{-1}	1.6 ± 0.3	1.8 ± 0.4	1.9 ± 0.3	1.9 ± 0.3	2.0 ± 0.4	1.9 ± 0.4
DMI[2], kg • d^{-1}	14.3 ± 1.3	14.6 ± 1.7	14.1 ± 1.2	17.5 ± 1.4	14.0 ± 1.0	14.9 ± 1.9
Gain:Feed[2]	0.112 ± 0.022	0.123 ± 0.023	0.133 ± 0.019	0.109 ± 0.016[3]	0.123 ± 0.025	0.120 ± 0.023

[1] Data from cohorts 1 and 2 were obtained from Arce-Cordero, 2016.
[2] ADG, daily DMI, and G:F were calculated for the time for the time on the finishing ration.
[3] Weaning time was delayed in over half of the dams in this cohort.

Table 2.7. Summary statistics (mean ± SD) for general characteristics of females and carcasses managed in the All Heifer, No Cow beef production system by cohort and overall [1]

Parameter	Cohort 1	Cohort 2	Cohort 3	Cohort 4	Cohort 5	Overall
Females harvested, n =	43	43	46	44	46	222
Age at harvest[2], d	-	-	898 ± 14	919 ± 16	895 ± 20	904 ± 20
Shrunk BW[3], kg	638 ± 53	596 ± 62	602 ± 48	620 ± 53	607 ± 50	613 ± 55
HCW, kg	389 ± 33	366 ± 36.3	351 ± 28.1	372 ± 31.7	358 ± 32.1	367 ± 35
Dressing percent, %	61.0 ± 1.5	61.0 ± 2.0	58.3 ± 1.6	59.8 ± 1.2	59.0 ± 1.6	59.8 ± 1.9
Carcasses classified over 30 mo of age[4], %	71.4	69.8	63.0	75.0	63.0	68.3 ± 5.3

[1] Data from cohorts 1 and 2 were obtained from Arce-Cordero, 2016.
[2] Unable to calculate for cohorts 1 and 2 since birth dates were unknown.
[3] Live shrunk BW, using 4 % pencil shrink.
[4] Assessed via dentition by the packer; carcasses with 3 or more permanent incisors were declared over 30 mo of age.

Table 2.8. Summary statistics (mean ± SD) for yield grade-related attributes of carcasses produced by females managed in the All Heifer, No Cow beef production system and percentages of carcasses in each USDA yield grade category by cohort and overall[1]

Parameter	Cohort 1	Cohort 2	Cohort 3	Cohort 4	Cohort 5	Overall
REA, sq. cm.	89.8 ± 11.7	86.9 ± 9.6	80.5 ± 6.7	90.3 ± 11.9	91.9 ± 4.7	88.2 ± 11.0
Calculated Yield Grade	2.9 ± 0.7	2.9 ± 0.8	3.2 ± 0.5	2.8 ± 0.7	2.5 ± 0.7	2.9 ± 0.7
KPH, %	1.62 ± 0.29	2.00 ± 0.45	2.12 ± 0.26	1.85 ± 0.29	2.20 ± 0.27	1.96 ± 0.38
Back fat thickness, cm[2]	1.30 ± 0.25	1.21 ± 0.42	1.26 ± 0.30	1.29 ± 0.39	0.97 ± 0.36	1.20 ± 0.37
USDA Yield Grade	2.3 ± 0.8	2.6 ± 0.8	2.5 ± 0.6	2.9 ± 0.6	2.6 ± 0.7	2.6 ± 0.7
USDA Yield Grade 1, %	16.7	4.7	2.2	0.0	2.2	5.2 ± 6.7
USDA Yield Grade 2, %	33.3	39.5	47.8	22.7	44.4	37.5 ± 9.9
USDA Yield Grade 3, %	50.0	48.8	50.0	68.2	44.4	52.3 ± 9.2
USDA Yield Grade 4, %	0.0	4.7	0.0	4.5	8.9	3.6 ± 3.7
USDA Yield Grade 5, %	0.0	2.3	0.0	2.3	0.0	0.9 ± 1.3

[1] Data from cohorts 1 and 2 were obtained from Arce-Cordero, 2016.
[2] Measured at a point three-fourths of the distance of the outer length of the ribeye (USDA, 2017).

Table 2.9. Summary statistics (mean ± SD) for quality grade-related attributes of carcasses produced by females managed in the All Heifer, No Cow beef production system and percentages of carcasses in each USDA quality grade category by cohort and overall[1]

Parameter	Cohort 1	Cohort 2	Cohort 3	Cohort 4	Cohort 5	Overall
Marbling score[2]	475 ± 75.7	430 ± 85.8	490 ± 89.4	428 ± 95.3	460 ± 71.8	457 ± 87.1
Lean maturity score[3]	170 ± 14.1	161 ± 37.1	173 ± 13.0	155 ± 20.7	170 ± 32.1	166 ± 26.0
Bone maturity score[3]	281 ± 55.5	229 ± 101.7	215 ± 31.3	245 ± 110.8	213 ± 60.7	236 ± 80.7
Overall maturity score[3]	249 ± 40.8	213 ± 75.8	201 ± 22.4	205 ± 56.2	202 ± 47.5	213 ± 53.9
C maturity carcasses[4], %	47.6	27.9	0.0	20.5	6.7	20.5 ± 18.7
Calculated C maturity carcasses[5], %	35.7	32.6	0	13.6	13.3	19.0 ± 14.9
USDA Choice and greater, %	42.9	25.6	97.8	63.6	82.2	62.4 ± 29.1
USDA Prime, %	0.0	0.0	6.5	4.6	13.3	4.9 ± 5.5
USDA CAB, %	0.0	2.3	6.5	4.6	22.2	7.1 ± 8.8
USDA Choice, %	42.9	23.3	84.8	54.6	46.7	50.5 ± 22.4
USDA Select, %	9.5	32.6	2.2	15.9	11.1	14.3 ± 11.4
Other[6], %	47.6	41.9	0.0	20.5	6.7	23.3 ± 21.0

[1] Data from cohorts 1 and 2 were obtained from Arce-Cordero, 2016.
[2] Marbling score (slight^{00} = 300, small^{00} = 400, modest^{00} = 500, etc.).
[3] Maturity score (A^{00} = 100, B^{00} = 200, C^{00} = 300, etc.).
[4] Carcasses classified as C maturity by the USDA grader.
[5] Carcasses classifies as C maturity based on overall maturity calculated by Colorado State University.
[6] Other included: Standard, Commercial, Utility, dark cutter, blood splash, and advanced bone maturity.

Table 2.10. Comparison (mean ± SD) of key carcass attributes between A and B maturity carcasses versus C maturity carcasses produced by females in the All Heifer, No Cow beef production system across cohorts[1]

	Overall maturity		
Parameter	A and B maturity	C maturity[2]	P > |t|
Carcasses, n =	177	43	-
HCW, kg	363 ± 32	383 ± 39	<0.01
Dressing percent, %	58.4 ± 2.9	60.6 ± 2.2	<0.001
REA, cm sq.	87.74 ± 10.3	90.1 ± 13.2	0.13
USDA Yield Grade	2.6 ± 0.7	2.5 ± 0.8	0.67
Marbling score[3]	459 ± 89	450 ± 76	0.25
Lean maturity score[4]	166 ± 26	166 ± 25	0.99
Bone maturity score[4]	213 ± 68	330 ± 62	<0.001
Overall maturity score[4,5]	197 ± 43	283 ± 39[4]	<0.001
Age at harvest[6], d	902 ± 20	919 ± 11	<0.001

[1] Data from cohorts 1 and 2 were obtained from Arce-Cordero, 2016.
[2] C maturity carcasses classified by the USDA grader.
[3] Marbling score (slight^{00} = 300, small^{00} = 400, modest^{00} = 500, etc.).
[4] Maturity score (A^{00} = 100, B^{00} = 200, C^{00} = 300, etc.).
[5] Average overall maturity score for the C maturity group was not over 300 because the number over C maturity was classified by the USDA grader, but Colorado State University took the bone measurements and determined some of the carcasses classified as C maturity were B maturity.
[6] Age at harvest was only evaluated for cohorts 3 though 5 since birth dates were unknown for cohorts 1 and 2.

Table 2.11. Comparison of reproductive performance between initial and sustaining cohorts of the All Heifer, No Cow beef production system[1]

Parameter	Initial cohorts[2]	Sustaining cohorts[3]	SE	P > |t|
Females, n =	102	162	-	-
Pregnant 30 d post fixed time AI, %	47.1	55.6	26.2	0.17
Pregnant 140 d post fixed time AI	94.1	92.6	52.5	0.48

[1]Animals with missing data were omitted from analysis.
[2] Cohorts 1 and 2.
[3] Cohorts 3 through 5.

Table 2.12. Comparison of growth and carcass performance between initial and sustaining cohorts of the All Heifer, No Cow beef production system[1,2]

Parameter	Initial cohorts[3]	Sustaining cohorts[4]	SE	P > |t|
Carcasses, n =	85	135	-	-
ADG, kg • d^{-1}	1.83	1.83	0.03	0.88
Daily DMI, kg • d^{-1}	14.6	15.1	0.33	<0.001
HCW, kg	385	355	8.41	<0.001
Dressing percent, %	62.3	58.3	0.31	<0.001
USDA Yield Grade	2.5	2.6	0.09	0.25
Marbling score[5]	451	460	12.60	0.44
Lean maturity score[6]	159	164	3.07	<0.01
Bone maturity score[6]	230	239	3.35	<0.01
Overall maturity score[6]	218	213	2.42	<0.05

[1]Animals with missing data were omitted from analyses.
[2] Least squares means were reported.
[3] Cohorts 1 and 2.
[4] Cohorts 3 through 5.
[5] Marbling score (slight^{00} = 300, small^{00} = 400, modest^{00} = 500, etc.).
[6] Maturity score (A^{00} = 100, B^{00} = 200, C^{00} = 300, etc.) assessed by carcass maturity.

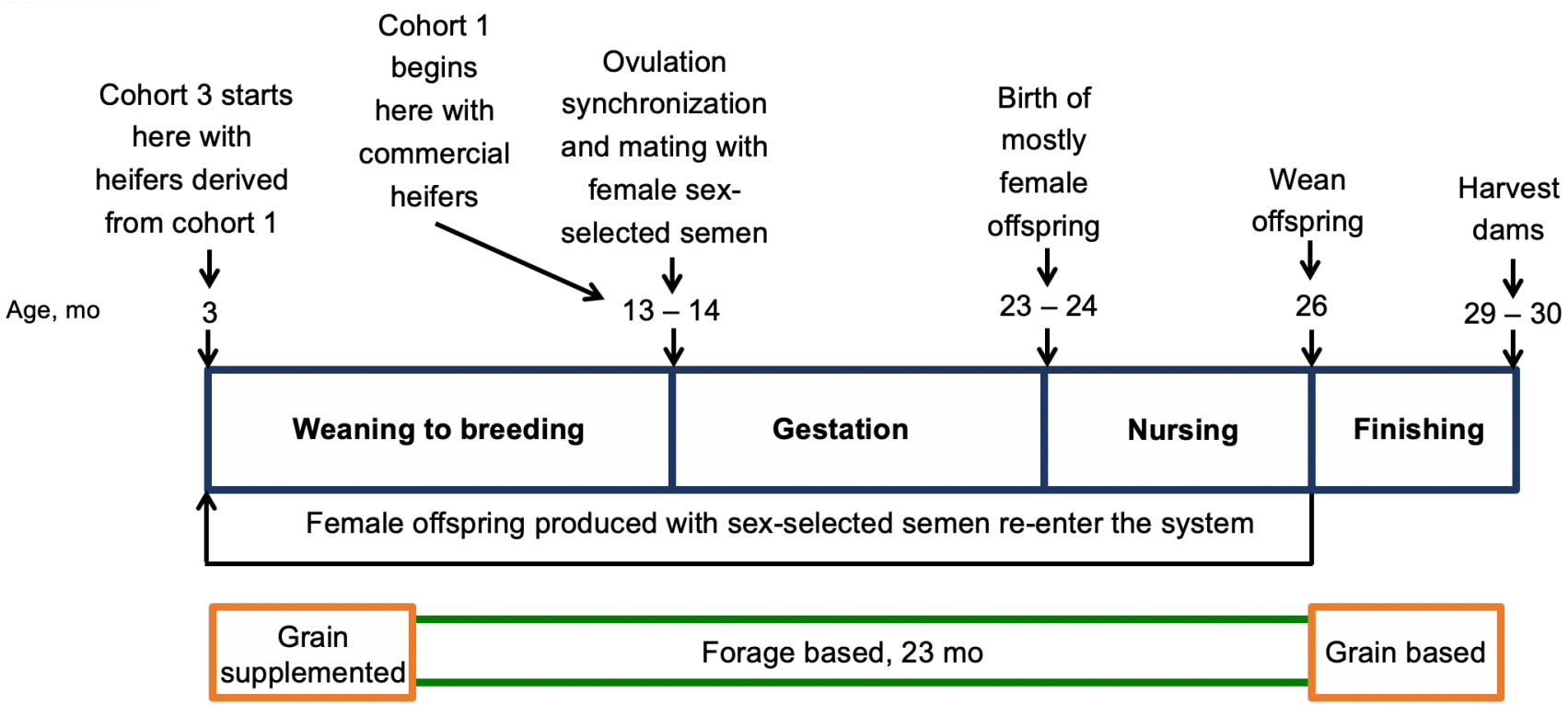

Figure 2.1. General timeline for the All Heifer, No Cow beef production system
[1]Annual income requires a second set of heifers (i.e., cohort 2) started 12 mo after the first.
[2] During subsequent years, a few additional commercial heifers enter the system prior to breeding to maintain system inventory.

LITERATURE CITED

Arce-Cordero, J.A. 2016. Evaluation of management strategies to improve efficiency and sustainability of beef and dairy cattle operations. MS Thesis. Colorado State Univ., Fort Collins, CO.

Boucqué, Ch. V., L.O. Fiems, B.G. Cottyn, and F.X. Buysse. 1980. Beef production with maiden and once-calved heifers. Livestock Prod. Sci. 7:121–133.

Bourdon, R.M., and J.S. Brinks. 1987. Simulated efficiency of range beef production. III. Culling strategies and nontraditional management systems. J. Anim. Sci. 65:963–969.

CHAPS, 2017. Cow Herd Appraisal Performance Software Program: Most recent benchmarks. North Dakota State University Extension Service. https://www.ag.ndsu.edu/DickinsonREC/chaps-software-1 (Accessed 15 September 2018).

Content, S.T. 2018. Economics and marketing: understanding dressing percentage of slaughter cattle. Agricultural Marketing Guide, Alberta, CA. https://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sis12389. (Accessed 28 Aug. 2018).

Field, R.A., G.E. Nelms, and C.O. Schoonover. 1996. Effects of age, marbling and sex on palatability of beef. J. Anim. Sci. 25:360–366.

Field, R., R. McCormick, V. Balasubramanian, D. Sanson, J. Wise, D. Hixon, M. Riley, and W. Russell. 1997. Tenderness variation among loin steaks from A and C maturity carcasses of heifers similar in chronological age. J. Anim. Sci. 75:693–699.

Ferrell, C.L., and T.G. Jenkins. 1985. Cow type and nutritional environment: Nutritional aspects. J. Anim. Sci. 61:725–741.

Garner, D.L., and G.E. Seidel Jr. 2008. History of commercializing sexed semen for cattle. Therio. 69:886–995.

Grumbach, M.M., and R.J. Auchus. 1999. Estrogen: Consequences and implications of human mutations in synthesis and action. J. Clin. Endocrinol. Metab. 84:4677–4694.

Hale, D.S., K. Goodson, and J.W. Savell. 2013. USDA Beef Quality and Yield Grades. Texas A&M University Research and Extension. https://meat.tamu.edu/beefgrading/ (Accessed 30 Aug. 2018).

Herd, D.B., and L.R. Sprott. 1996. Body condition, nutrition and reproduction of beef cows. Texas Agric. Ext. Serv. Bull. 1526, College Station, TX.

Joseph, R.L., and J.P. Crowley. 1971. Meat quality of once-calved heifers. Irish J. of Agric. Res. 10:281–285.

Kansas State Research and Extension. 2017. Focus on Feedlots: Kansas feedlot performance and feed cost summary, 2016 annual review. Manhattan, KS. https://www.asi.k-state.edu/about/newsletters/focus-on-feedlots/ (Accessed 28 May 2018).

Kreikemeier, K.K., and J.A. Unruh. 1993. Carcass traits and the occurrence of dark cutters in pregnant and non-pregnant feedlot heifers. J. Anim. Sci. 71:1699–1703.

Laster, D.B., and K.E. Gregory. 1973. Factors influencing peri- and early postnatal calf mortality. J. Anim. Sci. 37:1092–1097.

Lefever, D. G. and K.G. Odde, 1986. Predicting reproductive performance in beef heifers by reproductive tract evaluation before breeding. CSU Beef Program Report, Fort Collins, CO. p. 5–13.

NCBA. 2017. Navigating Pathways to Success: Executive Summary of the 2016 National Beef Quality Audit. Centennial, CO.

Nkrumah, J.D., E.K. Okine, G.W. Mathison, K. Schmid, C. Li, J.A. Basarab, M.A. Price, Z. Wang, and S.S. Moore. 2006. Relationships of feedlot feed efficiency, performance, and feeding behavior with metabolic rate, methane production, and energy partitioning in beef cattle. J. Anim. Sci. 84:145–153.

Nold, R. 2013. How much can you expect from a fed steer? South Dakota State Univ. Extension Service. http://igrow.org/livestock/beef/how-much-meat-can-you-expect-from-a-fed-steer/ (Accessed 1 October 2018).

Patterson, D.J., R.A. Bellows, P.J. Burfening, and J.B. Carr. 1987. Occurrence of neonatal and postnatal mortality in range beef cattle. I. Calf loss incidence from birth to weaning, backward and breech presentations and effects of calf loss on subsequent rate of dams. Therio. 28:557–571.

Peterson, G.A., T.B. Turner, K.M. Irvin, M.E. Davis, H.W. Newland, and W.R. Harvey. 1987. Cow and calf performance and economic considerations of early weaning of fall-born beef calves. J. Anim. Sci. 65:15–22.

Price, E.O., J.E. Harris, R.E. Borgwardt, M.L. Sween, and J.M. Connor. 2003. Fenceline contact of beef calves with their dams at weaning reduces the negative effects of separation on behavior and growth rate. J. Anim. Sci. 81:116–121.

Pritchard, R.H., and P.T. Berg. 1993. Feedlot performance and carcass traits of culled cows fed for slaughter. South Dakota Beef Report. p. 101–107.

Reiling, B.A., L.L. Berger, D.B. Faulkner, F.K. McKeith, and T.G. Nash. 1995. Effect of prenatal androgenization on performance, lactation, carcass, and sensory traits of heifers in a single-calf heifer system. J. Anim. Sci.73:986–992.

Riggs, B. 2001. Integration of early weaning and use of sexed semen in a single-calf heifer system to increase value of non-replacement heifers. MS Thesis. Colorado State Univ., Fort Collins, CO.

Schnell, T.D., K.E. Belk, J.D. Tatum, R.K. Miller, and G.C. Smith. 1997. Performance, carcass, and palatability traits for cull cows fed high-energy concentrate diets for 0, 14, 28, 42, or 56 days. J. Anim. Sci. 75:1195–1202.

Schönfeldt, H.C., and P.E. Strydom. 2011. Effect of age and cut on tenderness of South African beef. Meat Sci. 87:206–218.

Seidel, G.E. Jr., J.L. Schenk, L.A. Herickhoff, S.P. Doyle, Z. Brink, R.D. Green, and D.G. Cran. 1999. Insemination of heifers with sexed sperm. Therio. 52:1407–1420.

Seidel, G.E. Jr., and J.L. Schenk. 2008. Pregnancy rates in cattle with cryopreserved sexed sperm: Effects of sperm numbers per inseminate and site of sperm deposition. Anim. Reprod. Sci. 105:129–138.

Seidel, G.E. Jr., and J.C. Whittier. 2015. Beef species symposium: Beef production without mature cows. J. Anim. Sci. 93:4244–4251.

Shackelford, S.D., M. Koohmaraie, and T.L. Wheeler. 1995. Effects of slaughter age on meat tenderness and USDA carcass maturity scores of beef females. J. Anim. Sci. 73:3304–3309.

Shorthose, W.R., and P.V. Harris. 1990. Effect of animal age on the tenderness of selected beef muscles. J. Food Sci. 55:1–8.

Tatum, J.D. 2011. Animal Age, Physiological Maturity, and Associated Effects on Beef Tenderness. White Paper for National Cattleman's Beef Assoc. Centennial, CO.

Tubman, L.M., Z. Brink, T.K. Suh, and G.E. Seidel Jr. 2004. Characteristics of calves produced with sperm sexed by flow cytometry/cell sorting. J. Anim. Sci. 82:1029–1036.

USDA. 2009. Part II: Reference of beef cow/calf management practices in the United States, 2007-08. USDA:APHIS:VS, CEAH. Fort Collins, CO.

USDA. 2017. United States Standards for Grades of Beef Carcasses. Agric. Marketing Serv., USDA. Washington, DC.

Vincent, B.C., S.D.M. Jones, L.E. Jeremiah, M.A. Price, and J.A. Newman. 1991. Carcass characteristics and meat quality of once-calved heifers. Can. J. Anim. Sci. 71:311–319.

Waggoner, A.W., M.E. Dikeman, J.R. Brethour, and K.E. Kemp. 1990. Performance, carcass, cartilage calcium, sensory, and collagen traits of longissimus muscles of open versus 30-month-old heifers that produced one calf. J. Anim. Sci. 68:2380–2386.

Wertz, A.E., L.L. Berger, P.M. Walker, D.B. Faulkner, F.K. McKeith, and S. Rodriguez-Zas. 2001. Early weaning and post weaning nutritional management affect feedlot performance,

carcass merit, and the relationship of 12th-rib fat, marbling score, and feed efficiency among Angus and Wagyu heifers. J. Anim. Sci. 80:28–37.

CHAPTER III:

EVALUATION OF BIOLOGICAL AND ECONOMIC EFFICIENCY OF THE ALL HEFIER, NO COW BEEF PRODUCTION SYSTEM USING A SYSTEM DYNAMICS MODEL

INTRODUCTION

Beef production systems are a multiplex of technological, biological, and economic relationships that are impacted by management decisions and external factors. Recently, there has been increasing demand for more efficiently produced beef, including a reduction in grain use, water use, and greenhouse gas emissions (Rotz et al., 2013; Clark and Tilman, 2017). The All Heifer, No Cow (**AHNC**) beef production system may be a viable strategy to reduce feed energy required to produce a unit of beef (Seidel and Whittier, 2015). The AHNC beef production system involves breeding nulliparous heifers with female sex-selected semen to produce primarily female calves. Offspring are early-weaned, and dams are fed a finishing ration prior to harvest at 30 mo of age to produce high quality carcasses. Female offspring re-enter the system and are subsequently synchronized and bred.

Most studies evaluating feed efficiency of beef production have been limited to individual animal efficiency (Davis et al., 1983; Ferrel and Jenkins, 1985), and few inferences about system efficiency have been made. Individual animals are not a suitable production unit for study since eliminating animal-to-animal interactions oversimplifies production systems (Jonadet and Cartwright, 1969). Computer-based modeling is an inexpensive and valuable alternative to conventional experimentation for an evaluating system efficiency. Previous models have compared efficiency of the single-calf heifer system (**SCHS**) to conventional cow/calf-based beef production (Taylor et al., 1985; Bourdon and Brinks, 1987; Sell et al., 1988). In both

instances, the authors concluded the SCHS was more biologically efficient than conventional cow/calf-based production. However, most previous research has been theoretical, and models were not calibrated with actual production data, and little emphasis was placed on economic efficiency.

Objectives of this research were to: 1) build a dynamic model of an AHNC beef production system using data collected from an AHNC demonstration herd to quantify system biological and economic efficiency; 2) compare effects of utilizing female sex-selected semen vs. conventional semen on system biological and economic efficiency; 3) evaluate what-if scenarios to determine effects of first AI conception rate, percent of female calves born, and percent USDA Choice and greater carcasses had on system biological and economic efficiency; 4) evaluate effects that changing conception rate to first AI, percent of female calves born, and HCW ±10% from observed values had on biological efficiency (**BE**) and evaluate effects of changing corn, hay, feed, and replacement heifer prices and the percent of carcasses over 30 mo of age, HCW, conception rate to first AI, and percent of female calves born ±10% from observed values had on economic efficiency.

MATERIALS AND METHODS

A dynamic systems model of AHNC beef production over a 21-yr horizon was built using Stella Architect © (iSee Systems, Inc.; Lebanon, NH). The simulation was designed to emulate management and performance of an AHNC demonstration herd that included 5 cohorts of females (n = 277; Harrison et al., 2019). Since calving and significant income generation occurred every 2 yr in this system, achieving annual income required beginning a second set of heifers 12 mo after the first. The model was initiated with the purchase of 2 sets of 100 yearling heifers. Production parameters were randomized (mean ± SD). Biological parameters were based on values observed in the demonstration herd (Harrison et al., 2019). Key response variables

were biological and economic efficiency. Biological efficiency was defined on a system basis as G: F, the ratio of *output* (i.e., kg of HCW produced) to *input* (i.e., lifetime kg of feed TDN consumed). Economic efficiency was measured using a benefit-cost ratio (**BCR**) and cost effectiveness ratio (**CER**).

Key assumptions. To define boundaries of the model, several key assumptions were made. The model was initiated with pulsing 100 purchased, yearling heifers into the system in March of 1998, and the second set was started in March of 1999. Although the demonstration herd only included an average of 55 ± 2.2 females in each cohort, the simulation herd included 100 animals in each cohort for evaluation of a larger, commercially-viable herd (Harrison et al., 2019). The cost to purchase initial sets of yearling heifers was not included in economic analyses because at the end of the simulated time frame (i.e., 1998 to 2018), a valuable asset (i.e., AHNC females) would remain available and could be sustained or sold for an amount similar and possibly more than the amount of the initial purchase.

Although the model was simulated over a 21-yr period, only results from the final 11 yr were used for evaluation. Initial results from the first 10 yr of the simulation were omitted to allow herd dynamics to settle and reach equilibrium. Each cohort herd carried an operating loan at 4% interest with payments due every 12 mo. The loan was repaid over 2.5 yr, the length of the production cycle since harvest occurred at or before 30 mo of age. The operating loan for cohorts 1 and 2 was repaid after 18 mo since the system started with yearling heifers, decreasing time from initial purchase to initial income generation in initial cohorts compared to subsequent cohorts.

A single bull was leased annually for the 100 d breeding season. The leasing fee included: use of the bull and costs (i.e., health and feed) during the time used. Only TDN consumed by the bull during breeding seasons was included in the BE calculation, but beef that resulted from his

harvest was not. To account for TDN consumed by the initial sets of heifers (i.e., cohorts 1 and 2) and annual replacement heifers prior to purchase, it was assumed they consumed the same amount of TDN as if they would have been raised within the AHNC beef production system. Thus, the amount of TDN assigned to replacements heifers was equivalent to the amount of TDN consumed by females raised in the system. For calves born in the AHNC beef production system, TDN was not tracked until post-weaning since it was assumed majority of pre-weaning energy was consumed by each calf's dam and delivered to the calf in the form of milk. In the model, timing of animal purchases and sales were made at the same time of yr as the demonstration herd (Fig. 3.1).

Data collection and estimation. Production records were collected from 5 cohorts of females managed in the AHNC beef production system (Harrison et al., 2019). These records included BW and BW gain, reproductive performance, feedyard performance of dams, dry lot performance of calves, daily feed provided in the feedyard and dry lot phases, carcass performance, and some financial data. Available financial records included: feed costs incurred in the feedyard and dry lot phases, medical and breeding expenses, livestock supply costs, and other expenses. Only feed, yardage, and labor expenses for time in the feedyard and dry lot were documented. Actual hay, grazing, and labor expenses during the time on the ranch were not available because the AHNC demonstration herd was managed with a commercial cowherd and partitioning of these expenses between enterprises was not possible. Other costs that were estimated included: freight, gas/diesel, and labor (Colorado State University Extension, 2016). Tables 3.1 through 3.3 describe medical and breeding, livestock supply, and other costs.

Regression analyses were used to estimate daily feed intake during phases of hay feeding and grazing since hay usage records were not available and inability to obtain individual feed intake data for grazing cattle. Simple linear regression models were individually fit for each

female in the demonstration herd using the lm function from R (version 3.5.1). Average R^2 value was 0.91. Body weight was regressed on d using BW data collected from the demonstration herd at regular intervals. Body weight for the median d of each lifetime phase was calculated using the intercept (i.e., birth weight) and ADG was predicted by the regression. Lifetime phases are listed in Table 3.4. Generally, production phase breaks coincided with changes in diet. Production phases were dictated by management of the AHNC demonstration herd, however a commercial producer utilizing the AHNC beef production system typically would not have so many changes in diet, eliminating many of the production phases, simplifying management.

Dry matter intake was calculated for each phase by allocating 2.6% of predicted BW (SRM, 1989; USDA, 2003). When animals were lactating, 2.9% of BW was used (Streeter et al., 1974; Kartchner, 1975). A sub-phase was defined as a smaller portion of a lifetime phase. In phases that lasted over 30 d, BW was predicted for the median d in each sub-phase that were no more than 31 d in length. Feed intake data during these sub-phases were averaged to calculate average phase DMI. This methodology was used to estimate DMI while grazing pasture and during winter hay feeding since daily individual animal feed intake records were not available during these times. To estimate DMI in the feedyard and dry lot, total BW of the pen was calculated. The proportion of each animal's individual BW to pen BW was calculated. Individual animal DMI was allocated by multiplying the proportion of individual animal BW to pen BW by the total amount of feed delivered to the pen daily. The proportion of individual animal BW to pen BW was recalculated when animal BW were updated every 3 wk. For cohorts 1 and 2, individual DMI measurements were collected by an automated feed intake monitoring system (GrowSafe®; Calgary, Alberta, Canada) and used when available (Arce-Cordero, 2016). Sub-phases were also used when calculating average daily TDN intake for time on the finishing ration, phases 12 and 16 for initial and sustaining herds, respectively (Table 3.4). Individual animal DMI estimates

were averaged for each lifetime phase and sub-phase. Average estimate for each phase DMI was multiplied by percent TDN of the feed, which varied depending on feed type and time of year for pasture. Percentages of TDN for the TMR were obtained by laboratory analyses from the demonstration herd (Harrison et al., 2019).

Steers were removed from the system after the fall grazing period and sold when cull yearling heifers were sold (Fig. 3.1). Based on the demonstration herd, average steer calf BW exiting the dry lot after the short post-weaning gain period was 153 ± 31 kg (Harrison et al., 2019). Similar to the demonstration herd, the model sold all steer calves at the time of fall pregnancy diagnoses. Feed intake data and BW were not collected on steers in the demonstration herd after the post-weaning dry lot phase. Thus, feed intake for time after exiting the dry lot but prior to sale was estimated. Steers were assumed to have grazed fall pasture for 75 d at an ADG of 0.68 kg ● d^{-1} to reach 205 kg prior to sale at the time of fall pregnancy diagnosis (Sell et al., 1988; Mathis et al., 2008). Average daily TDN requirement (2.8 kg ● d^{-1}) was calculated for the presale gain phase using values outlined in the literature; however, an SD was not available (Lalman, 2007). To randomize TDN intake for steers during the presale gain phase, an SD of 1.0 kg was used in model parameterization. Average steer feedyard entry BW was 369 kg for Kansas feedyards (Kansas State Research and Extension, 2017). At time of sale, steers were too light to enter the feedyard directly. Steers were assumed to have been backgrounded for 64 d at an ADG of 1.1 kg ● d^{-1} until reaching the aforementioned entry BW (Lawrence and Ostendorf, 2006; Mathis et al., 2008). Average daily TDN requirement calculated for the backgrounding phase was 4.7 kg ● d^{-1}, and an SD of 1.0 kg was used in model parameterization (Lalman, 2007).

Daily DMI of steers while in the feedyard post-sale was calculated using 3 yr averages for steer exit BW (640 kg), d on feed (161 d), ADG (1.7 kg ● d^{-1}), and G:F (0.166) for Kansas feedyards (Kansas State Research and Extension, 2017). It was assumed steers consumed a

finishing ration with the same percent TDN as AHNC females in the demonstration herd (Harrison et al., 2019). Thus, average daily TDN intake (8.2 ± 2.27 kg ● d^{-1}) was estimated by multiplying average DMI calculated from the Kansas State feedyard data by average percent TDN of all finishing rations fed to the AHNC demonstration herd (Kansas State Research and Extension, 2017; Harrison et al., 2019).

Similar to the demonstration herd, the model allowed culling of AHNC breeding females at 2 points (Fig. 3.1). Non-pregnant and late-bred heifers (i.e., pregnant less than 90 d at 140 d pregnancy diagnosis) were culled following the 140 d pregnancy diagnosis. Percentages of females culled at pregnancy diagnoses and percentages of non-pregnant and late-bred heifers were based on performance of the demonstration herd (Table 3.5; Harrison et al., 2019). Additionally, dams that lost their calves were sold as postpartum cows 2 wk after calving.

Culled non-pregnant heifers and dams were fed a finishing ration for a period prior to harvest to reach a suitable harvest BW. For non-pregnant females culled at pregnancy diagnosis, feed intake was estimated using the same methodology as steers. Data used to estimate DMI on the finishing ration were 3-yr averages for exit BW, d on feed, ADG, and G:F reported for heifers in Kansas feedyards (Kansas State Research and Extension, 2017). For dams culled postpartum, it was assumed their feedyard performance would be similar to finished AHNC females that were harvested in the demonstration herd. Thus, the amount of TDN consumed by dams culled postpartum while receiving the finishing ration was the same as AHNC dams harvested in the system. All feed energy inputs were expressed as kg of TDN (mean ± SD) per animal per d.

Model prices. The model included 10 yr of historical U.S. annual average prices for hay, Animal Unit Months (**AUM**) for grazing costs, feedstuffs used in feedyard and dry lot rations (e.g., corn, corn silage, wheat straw, dried distillers' grains, salt, and limestone), cattle prices,

and carcass prices. Prices for AUM, hay, and ration feedstuffs were obtained from historical USDA Agricultural Price Reports (USDA, 2008—2017). Corn silage price was computed by multiplying 7.65 by shelled corn price per bushel (Berger, 2017).

All cattle and carcass prices were obtained from the Livestock Marketing Information Center (LMIC, 2017). Cattle prices in the model were 273 to 318 kg heifers, 365 to 409 kg heifers, 409 to 455 kg heifers, finished heifers, pregnant heifers, and 182 to 227 kg steers. These weight classes were used as they corresponded to BW at which animals were purchased into or sold from the system. Non-pregnant heifers weighed 420 ± 20 kg and 435 ± 36 kg at the time of fall pregnancy diagnosis for initial and sustaining cohorts, respectively (Harrison et al., 2019). Thus, heifer price corresponding to that weight class (i.e., 409 to 455 kg heifers) was used as the price for selling non-pregnant heifers. It was difficult to price culled postpartum cows that lost calves and were sold, due in part to limited availability of market information for this class of cattle. At 2 yr of age these animals were more valuable than a cull cow or typical finished heifer on a weight basis. At the time of sale, average BW for cows culled after calving was 485 ± 55 kg and 451± 50 kg for initial and sustaining cohorts, respectively (Harrison et al., 2019). For consistency, price corresponding to heifer BW 409 to 455 kg was used for both initial and sustaining herds. Culled females were priced according to their BW exiting the demonstration herd, not the harvest weight after the brief finishing phase to accurately reflect system income. U.S. historical carcass prices included: base price (i.e., USDA Choice, YG 3), QG premiums [i.e., USDA Prime and Certified Angus Beef (**CAB**)] and discounts (i.e., USDA Select and ungraded), YG premiums (i.e., USDA YG 1 and 2) and discounts (i.e., USDA YG 4 and 5), and over 30 mo of age discounts based on dentition (Table 3.6).

Model description. The model consisted of several distinct, yet highly interconnected modules. Modules included: 1) production herd 1, 2) production herd 2, 3) harvest, 4) marketing,

5) variable costs, 6) revenues, and 7) biological and economic efficiency. There were 2 production herds, coinciding with the 2 initial purchased sets of heifers (i.e., cohorts 1 and 2) that were started 12 mo apart to garner annual income. Production herd 1 included a single initial cohort (i.e., cohort 1), sustaining cohorts (i.e., cohorts 3, 5, etc.), and steer calves produced by initial and sustaining cohorts (Fig. 3.1). Similarly, production herd 2 included a single initial cohort (i.e., cohort 2), sustaining cohorts (i.e., cohorts 4, 6, etc.), and steer calves produced by initial and sustaining cohorts. These modules are visually represented in Fig. 3.2. Working in unison, modules generated output.

Production herd modules. Parameterization and structure of the 2 production herds was identical. In each of the 2 production herds, there were 3 separate animal groups—an initial cohort, sustaining cohorts, and steer calves produced within the system. Initial cohorts reflected averaged performance data from cohorts 1 and 2, and sustaining herds used averaged performance data from cohorts 3 through 5 in the demonstration herd (Harrison et al., 2019). Animals in the model only flowed through initial cohort tracks once. At weaning, offspring from initial cohorts were transferred to sustaining cohort tracks or steer calf tracks for female and male calves, respectively (Fig. 3.1). Females in sustaining cohorts moved through sustaining cohort tracks, and at weaning, female offspring repopulated the sustaining cohort. Male offspring were transferred to the steer track (Fig. 3.1). The model accounted for 3.2% calf death loss, based on average percent calf death loss reported for primiparous heifers (USDA, 2009). For breeding females, 1.0% annualized death loss was used, and annualized 1.3 and 1.6% were as the percent death loss for fed steers and heifers, respectively (USDA, 2009; Kansas State Research and Extension, 2017).

Animals moved through the model via stocks and flows. Each stock represented a change in a lifetime production phase. Stocks used in production herd modules were conveyors, each with

its own individually-specified transit time, the length of time (d) spent in each stock (Table 3.4). Each time animals entered a stock, average daily TDN consumed during that phase (i.e., stock) was dynamically calculated in a coflow. It is important to note animals in a cohort move through stocks and flows simultaneously. Total TDN consumed while in a stock was calculated using daily animal TDN requirements, number of animals in the stock, and duration of the stock (Fig. 3.3). This calculation was individually done for all stocks containing animals—including steers, culled heifers, culled cows, and bulls. All coflows calculating total TDN were summed to calculate lifetime TDN consumption, on a herd basis.

The model allowed for 3 different conception opportunities—2 attempts at AI with female sex-selected semen and exposure to a natural service sire. At time of breeding, the parent track separated into 3 separate tracks for each conception group (Fig. 3.3). Each track lost animals to culling and death loss annually. The female fraction dictated the percent of female calves weaned. Female fractions were calculated independently for initial and sustaining herds. The female fraction accounted for conception rates to first and second AI, bull exposure, culling late-bred heifers and postpartum cows, calf death loss, dam death loss, and percent of female calves born. For first and second AI tracks, 90% was used as percent females born and for bull conception 50% was used as percent females born (Seidel, 2014). The female fraction dictated the number of replacement heifers required annually to maintain herd inventory (i.e., 100 females for each production herd at the start of the breeding season). A basic equation for calculating female fraction was:

$$\begin{aligned} \textit{Female fraction} = &((1-P^1) \bullet (1-C^1) \bullet (1-C^2) \bullet (1-D^1) \bullet F^1) + \\ &(P^1 \bullet (1-P^2) \bullet (1-C^{11}) \bullet (1-C^2) \bullet (1-D^1) \bullet F^1) + \\ &(P^1 \bullet P^2 \bullet (1-C^{111}) \bullet (1-C^2) \bullet (1-D^1) \bullet F^2) \end{aligned}$$

Where, P^1 was pregnancy rate to first AI, C^1 was fall culling rate for heifers from the first AI track, C^2 was culling rate for postpartum cows, D^1 was dam death loss, F^1 was percent of female calves born to AI with female sex-selected semen, P^2 was pregnancy rate to second AI, C^{11} was fall culling rate for heifers from the second AI track, C^{111} was fall culling rate for heifers from the bull track, and F^2 was percent of female calves born to natural service. A list of parameter values is shown in Table 3.5. The number of replacements required to maintain an inventory of 100 breeding females was dynamically calculated for each cohort using the female fraction. Replacements were added in the fall (Fig. 3.1). Unfortunately, to ensure the number of replacements was accurately calculated, pregnancy rate, culling rate, and death loss were not randomized. Subsequently, AHNC females were transferred to the harvest module.

Harvest module. Within the harvest module, carcasses from production herds 1 and 2 were assigned YG and QG based on percentages observed in the demonstration herd. Percentages of carcasses in each YG-QG combination were calculated independently for initial and sustaining cohorts (Tables 3.7 and 3.8; Harrison et al., 2019). Carcasses were assigned a numerical USDA YG of 1 through 5 and USDA QG of Prime, CAB, Choice, Select, or other. Other included: Standard, Commercial, Utility, dark cutter, blood splash, and advanced bone maturity carcasses. Unfortunately, to ensure that percentages of carcasses in YG-QG categories summed to 100, percentages of carcasses assigned to YG and QG categories were not randomized.

The model predicted HCW, a major determinant of carcass value, using average HCW for each YG-QG combination calculated from demonstration herd data (Harrison et al., 2019). In addition to predicting YG and QG, the model also classified carcasses as over 30 mo of age at harvest based on dentition of demonstration herd carcasses assessed on the harvest floor (Harrison et al., 2019). Percentages of animal over 30 mo of age were randomized based on standard deviations observed in the demonstration herd. Figure 3.4 shows carcasses in the model

being assigned YG and QG. Steers and culled females were not graded but sold as live animals at pregnancy diagnosis or post-calving.

Revenue module. Within the revenue module, sale prices for all animals and carcasses were calculated. Prices used in calculations were historical LMIC prices contained in the marketing module. Average BW at time of sale and price corresponding to that weight were used. All prices were reported on a dollars per 45.4 kg basis, so animal BW was adjusted accordingly. A generic equation for animal revenue was:

$$\textit{Animal revenue} = N \bullet (W/45.4\ \text{kg}) \bullet P$$

Where N was number of animals sold, W was average BW at time of sale, and P was price corresponding to animal class and weight. This equation was used to calculate revenue for non-pregnant heifers, postpartum cull cows, and steer calves. Pregnant heifer prices were reported on a dollars per animal basis (LMIC, 2017). Prices for all animals and carcasses were historical prices from 2008 to 2017. Figure 3.5 depicts a calculation for steer revenue in the model.

Carcass revenue assumed grid, value-based pricing. Grid-pricing was accommodated using arrayed stocks and flows, allowing different carcass grades (e.g., USDA Prime, USDA CAB, USDA Choice, USDA Select, and other carcasses) to flow through simultaneously. Carcass revenue was calculated using carcass base price, premiums, discounts, and HCW since prices were reported on a dollars per 45.4 kg basis. Figure 3.6 depicts grid-based pricing calculations in the model for USDA Prime carcasses from an initial cohort. Revenue for all YG-QG combinations were summed to calculate total carcass revenue. All revenue calculations were dynamic, changing with animal numbers and historical prices.

Revenue from the sale of non-pregnant heifers, pregnant heifers, postpartum culled cows, steer calves, and carcasses were summed to calculate total revenue. Revenues were incurred over

the length of the production cycle (i.e., 2.5 yr) and were tracked independently for production herds 1 and 2. Revenue from all 5 sources for production herds 1 and 2 were accumulated in a single stock. To calculate annual revenue, the pulse function was used to empty the cumulative revenue stock every 12 mo.

Variable costs module. Variable costs included feed, medical and breeding, livestock supplies, other (e.g., labor, freight, and yardage), annual heifer replacements, and interest on operating loans. Medical and breeding, livestock supply, and other costs were reported on a dollars per animal basis and held constant over the simulated time frame. These costs are shown in Tables 3.1 through 3.3.

Amount of hay fed was calculated using average daily TDN consumption estimated for hay feeding phases. Hay values were converted from kg of TDN to kg of as-fed hay using 55% TDN and 88% DM (NRC Beef Cattle, 2016). Hay waste was assumed, so total kg of as-fed hay was increased by 10%. Herd AUM consumption was calculated using average TDN consumed during grazing phases. Total Digestible Nutrient intake was converted to kg of DM using percent TDN of native range. It was assumed an AUM contained 364 kg of DM (SRM, 1989; USDA, 2003). Historical hay and AUM prices were multiplied by respective amounts fed to calculate total hay and AUM costs.

Ration costs were calculated using total as-fed kg of the ration. Compositions of TMR fed during feedyard and dry lot phases were included in demonstration herd production records (Harrison et al., 2019). Amounts of ration feedstuffs (e.g., kg of corn, kg of corn silage) were calculated using ration composition and total as-fed kg of the ration. Ration costs were calculated for 5 TMR feeding phases: 1) post-weaning dry lot gain, 2) overwinter dry lot gain, 3) receiving ration, 4) transitioning ration, and 5) finishing ration. Feedstuff costs were calculated by

summing calculated ingredient amounts for all 5 rations and multiplying by historical prices reported in the marketing module.

Cost of purchased replacement heifers was determined using the average system entry BW (210 ± 28 kg) from the demonstration herd and historical prices for 182 to 273 kg heifers (LMIC, 2017; Harrison et al., 2019). Hay, AUM, ration, and replacement heifer costs were dynamically calculated using animal numbers and historical prices. Operating loan interest and feed, medical and breeding, livestock supply, other, and annual replacement purchase costs for both production herds were accumulated in a single stock. To calculate annual variable costs, the pulse function was used to empty the cumulative variable cost stock every 12 mo.

Biological efficiency. The BE calculation included beef produced by AHNC females, non-pregnant and pregnant heifers culled at pregnancy diagnosis, cows culled postpartum, and steers. Although heifers culled at pregnancy diagnosis, culled postpartum cows, and steers were sold from the system, TDN consumed post-sale was tracked and accounted for in BE calculations; however, only TDN consumed pre-sale was accounted for in economic efficiency calculations. The number of animals in each category was multiplied by animals' respective average HCW to calculate total kg of beef produced by animals in the AHNC beef production system. Different HCW were used for initial (378 ± 37 kg) and sustaining (360 ± 32 kg) cohorts. Hot carcass weight used for steers was 392 kg, but no SD was available, so a conservative SD of 11.4 kg was used (NCBA, 2017). Cull heifers that were harvested for beef in the model would have likely performed similar to AHNC carcasses harvested in the demonstration herd, so the 5-cohort average HCW (367 ± 35 kg) was used. Total kg of beef produced by AHNC females, steers, cull heifers, and cull cows were calculated independently for production herds 1 and 2. The equation used to calculate total kg of beef produced on a HCW basis (i.e., denominator in the BE calculation and denominator in the CER calculation) was:

Total kg of beef (on a HCW basis) = $(X^1 \bullet HCW^1) + (X^2 \bullet HCW^2) + (X^3 \bullet HCW^3) + (X^4 \bullet HCW^4)$

Where X^1 was the combined number of AHNC carcasses produced by all 3 conception tracks, HCW^1 was average HCW for X^1 carcasses, X^2 was the number carcasses produced by heifers culled at the fall pregnancy diagnosis, HCW^2 was average HCW for X^2 carcasses, X^3 was the number carcasses produced by cows culled postpartum, HCW^3 was average HCW for X^3 carcasses, and X^4 was the number carcasses produced by steers, and HCW^4 was average HCW for X^4 carcasses.

Economic efficiency. System economic efficiency was measured using a BCR and CER. A BCR is an indicator of economic efficiency that attempts to summarize the overall value of money for a system or project. A BCR considers the relationship between system benefits and costs in monetary terms. The calculation for BCR used in the AHNC beef production system model was:

Benefit-cost ratio = Total revenue/Total variable costs

Benefit-cost ratios are often used in conjunction with cost-effectiveness analysis when conducting cost-benefit analyses. Cost-effectiveness analysis compares relative costs and outcomes (i.e., effects) of different systems or projects. The main difference between a BCR and CER is a BCR uses monetary value to measure effects. Cost-effectiveness analysis is useful when the effect is difficult to monetize. With regard to the AHNC beef production system, the effect was kg of beef produced. The CER measured the cost per unit of effectiveness, or dollars spent per kg of beef produced. The calculation for CER used in the AHNC beef production system model was:

Cost-effectiveness ratio = Total variable costs/total kg of beef produced (on a HCW basis)

Calibration and validation procedures. Model parameters were calibrated using comprehensive biological data from the AHNC demonstration herd (Harrison et al., 2019). After parameterization, model behavior and outputs were evaluated to ensure feedback structures were accurately portrayed. This model was developed to evaluate biological and economic efficiency of an AHNC beef production system, but lack of available data made model validation difficult. It is impossible to validate all components of a system dynamics model (Oreskes et al., 1994; Sterman, 2002). But by considering the model for its intended use, output can be assessed as reasonable or unreasonable (Tess and Kolstad, 2000b).

For some models, validation is straightforward when predicted results can be compared against experimental results. In the current study, validation of model profitability was difficult due to incomplete financial data. Costs and fringe revenues (i.e., cull females and steers) were not accurately documented in the demonstration herd. Additionally, BE was unable to be validated due to the inability to collect accurate feed intake measurements during hay feeding and grazing phases. However, Harrison (1990) showed that statistical tests are often not appropriate for model validation and that subjective tests are more useful to build confidence in model performance.

Validation is a lengthy and tedious process in theoretical models where relationships are not well understood (Oreskes et al., 1994; Barlas, 1996). This particular model was not feedback dependent, but rather, was mechanistic in nature. Model validation was less important because parameters were accurately calculated using demonstration herd data, and relationships were well understood, eliminating structural uncertainty.

Model evaluation. Herd performance was evaluated by completing a total of 40 simulation runs. Key output variables included: BE and economic efficiency measured via BCR and CER. An alternate breeding scenario was simulated to evaluate use of conventional semen and its

effects on biological and economic efficiency. In the alternate scenario, breeding included a single AI with conventional semen and bull exposure, but the second AI was eliminated. For the conventional semen scenario, percent of female calves born was 50% for both AI and bull conceptions, AI costs were reduced, and conception rates were slightly increased to reflect those reported in the literature for heifers bred to fixed time AI following synchronized estrus. Cost of AI in the conventional semen scenario was $45.00 per heifer vs. $62.00 with sex-selected semen. The cost of insemination with female sex-selected semen was obtained from the demonstration herd (Harrison et al., 2019), and conventional semen cost was reported by Johnson and Jones (2004) and was adjusted for inflation. Conception rates to first AI were kept different for initial (55%) and sustaining (65%) cohorts in the conventional semen scenario.

What-if scenarios and sensitivity analyses. To further evaluate model predictions of system efficiency, conception rate to first AI, percent of female calves born, and percent of USDA Choice and greater carcasses were tested at levels ±5, 10, 15, and 20% from observed, calibrated values, but not to exceed 99% when applicable. All other variables were held constant to ensure results were not influenced by variation in intake, weight, or price.

A similar process was used when conducting sensitivity analyses. Hot carcass weight, percent of female calves born, and conception rate to first AI were changed ±10% from observed values to determine effects on BE. Corn, hay, feed, and replacement heifer prices and percent of carcasses over 30 mo, HCW, percent of female calves born, and conception rate to first AI were changed ±10% from observed values to determine effects on economic efficiency. The methodology used in sensitivity analyses was that followed by Pang et al. (1999). For sensitivity analyses, no variables were randomized, and all prices were held constant at 10-yr averages. This eliminated variation caused by year-to-year price change, allowing for assessment of model sensitivity. A baseline measurement was taken first. Individual runs were made adjusting

selected variables ±10% from observed values. Percent changes of biological and economic efficiencies were calculated using results of sensitivity runs and baseline values.

RESULTS AND DISCUSSION

All results were reported on a system basis, combining production herds 1 and 2. Initial cohorts were parameterized differently than sustaining cohorts to reflect performance differences between initial and sustaining cohorts that were reported by Harrison et al. (2019). Table 3.9 depicts predicted overall mean biological and economic efficiencies. Converting revenues and costs to an annual basis created results that were difficult to interpret. Thus, biological and economic efficiencies were calculated as previously described using a cumulative stock. Mean BE predicted by the model was 0.070 ± 0.001 (Table 3.9). To interpret this ratio, on average, each kg of TDN consumed resulted in 0.07 kg of HCW.

Mean (± SD) BCR predicted by the model was 0.842 ± 0.006 (Table 3.9). A BCR greater than 1 suggests system cashflows outweigh system variable costs, and the investment should be made. A BCR less than 1 indicates system variable costs outweigh system cashflows, and the investment should not be made. A BCR equal to 1 suggests expected profits equal expected costs. However, in the current BCR calculation the denominator is total variable costs and does not account for fixed costs of the system. Thus, a BCR equal to 1 did not equate system profitability. Mean (± SD) CER predicted by the model was $4.60± 0.06 (Table 3.9). When comparing different CER, the smaller CER indicates the more cost-effective option.

Table 3.10 lists mean total revenues, total variable costs, and total kg of beef produced on a HCW basis predicted by the model that were associated with biological and economic efficiency outputs listed in Table 3.9. Mean (± SD) revenue, variable costs, and beef produced predicted by the model were $161,306 ± 1,069, $191,576 ± 797, and 41,647 ± 536 kg on a HCW basis, respectively. There was a relatively small amount of run-to-run variation between biological and

economic efficiency, variable costs, and kg of beef produced. The low variation was due in part to the inability to randomize conception rates, culling rates, death loss, and assignment of USDA yield and quality grades. Observed run-to-run variation was due to historical price variation, randomized animal feed intake, and randomized biological performance (e.g., HCW, percent carcasses over 30 mo of age based on dentition).

Biological efficiency predicted by the model in the current study was similar to BE reported by Bourdon and Brinks (1987). The authors built a model to compare biological (i.e., kg TDN/kg of product) and economic efficiency (i.e., $/100 kg product) of various culling strategies and alternate management scenarios where product was defined as live BW at weaning, empty BW at harvest, and fat free weight (**FFW**) at harvest. Fat free weight at harvest was a measure of body weight excluding fat but including muscle, organs, and bone. Biological efficiencies reported for conventional cow/calf and sex-selected, once-calved female (**OCF**) production systems were 0.095 and 0.110 for live BW at weaning, 0.095 and 0.093 for empty BW at harvest, and 0.071 and 0.067 for FFW for conventional cow/calf and sex-selected OCF production systems, respectively (Bourdon and Brinks, 1987). Biological efficiency of the AHNC beef production model in the current study was estimated on a HCW basis. Biological efficiency predicted by the current AHNC model seemed reasonable based on BE reported for FFW for the sex-selected OCF system (i.e., 14.06) by Bourdon and Brinks (1987). The authors reported that prior to weaning, the sex-selected OCF system was more efficient, but conventional cow/calf production was most efficient through harvest. Reduced efficiency through harvest was attributed to reduced empty BW at harvest (Bourdon and Brinks, 1987). However, methods for accounting TDN consumed by feedyard steers and heifers in the conventional system was unclear.

Biological efficiency predicted for FFW in the sex-selected OCF system predicted by Bourdon and Brinks (1987) was likely too low. Based on parameterization of their model and

results from the AHNC demonstration herd, it seems that Bourdon and Brinks (1987) underestimated dam feed intake post-weaning (Harrison et al., 2019). Additionally, it was unclear how they accounted for TDN of purchased replacement heifers. The authors reported that the sex-selected OCF system was identified as the most economically efficient system ($226 /100 kg FFW), but the cost and reduced fertility of sex-selected semen was not considered, likely due to the fact that it was not commercially available at the time. When inflated 2018-dollar values, the cost to produce 100 kg of FFW was $500. In the model for the current study, the cost to produce 100 kg of HCW was $460.

The SCHS was estimated as the most profitable system in an analysis conducted by Sell et al. (1988). The authors considered 11 beef production systems and estimated profitability for 27 yr (1958 to 1985). The SCHS was calculated to be over twice as profitable than the second most profitable system. Over the 27-yr period, the SCHS had the least year-to-year variation in profit. The authors concluded that conventional cow/calf production exposes producers to significant price risk, but a well-operated SCHS could mitigate price risk and increase profits.

Without a complementary cow/calf model in the current study, it was difficult to make direct comparisons of biological and economic efficiencies between AHNC and conventional cow/calf-based beef production systems. However, a life cycle analysis (**LCA**) of conventional beef production published by Pelletier et al. (2010a) estimated lifetime feed intake and could be used as a comparison. Additional data (i.e., percent TDN, ration composition) were reported in supplemental materials (Pelletier et al., 2010b). Biological efficiency for conventional cow/calf-based beef production was calculated using parameters outlined in the LCA and supplemental materials (Pelletier et al., 2010a,b). Based on reported values and calculations, BE of conventional cow/calf-based beef production was 22.4. When comparing BE predicted by the model in the current study, the AHNC beef production system was 35.5% more efficient than the

conventional cowherd reported by Pelletier et al. (2010a,b). However, the AHNC model in the current study was not validated, and inputs were not identical to the LCA completed by Pelletier et al. (2010a,b) making this comparison less robust.

Sexed versus conventional semen. Percent females weaned observed in the demonstration herd using female sex-selected semen was low (61.1 ± 6.5%; Harrison et al., 2019), indicating the AHNC beef production system may function well with conventional semen. The current management practice in the AHNC demonstration herd, use of female sex-selected semen, was compared to an alternative scenario using conventional semen. The model reported divergent results for biological and economic efficiencies for the 2 scenarios. Table 3.11 summarizes key model output associated with the switch from female sex-selected to conventional semen.

In the female sex-selected semen scenario modeled, 64.6% females were weaned from the total number of exposed heifers, and in the conventional semen scenario only 41.0% females were weaned. Predicted G:F values were 0.070 ± 0.001 and 0.073 ± 0.001 for female sex-selected and conventional semen, respectively (Table 3.11). Based on G:F values, BE improved 4.6% using conventional vs. female sex-selected semen. This was not surprising since steers are more efficient than heifers at converting feed to gain (Kansas State Research and Extension, 2017). Considering the reduced harvest age of steers, coupled with improved feed efficiency compared to OCF in the AHNC beef production system, it was expected that the scenario with a larger percent of harvested beef produced by steers vs. AHNC females would be more biologically efficient.

Predicted BCR were 0.842 ± 0.006 and 0.929 ± 0.006 for female sex-selected and conventional semen scenarios, respectively (Table 3.11). Based on BCR, the model predicted superior economic efficiency for the conventional semen scenario. By using conventional semen, the BCR improved by 10.3% over female sex-selected semen. The conventional semen scenario

improved economic efficiency, indicating the same amount of beef could be produced with fewer monetary inputs. However, in both instances the BCR indicated the system was losing money; it is unclear to what extent conventional cow/calf-based production would make or lose money with similar assumptions.

Predicted CER were $4.60 ± 0.06 and $4.07 ± 0.06 for female sex-selected and conventional semen scenarios, respectively (Table 3.11). Based on CER, the conventional semen scenario was more cost effective. In the conventional semen scenario, the CER was positively impacted by a decrease in total variable costs and an increase in kg of beef produced on a HCW basis. More beef could be produced at a lower cost when conventional semen was used. This suggested greater biological and economic efficiency could be achieved using conventional semen, indicating the AHNC beef production system may not reduce feed requirements as indicated in the literature (Taylor et al., 1985; Bourdon and Brinks, 1987).

Revenue generated by the conventional semen scenario exceeded revenue generated by the female sex-selected semen scenario (Table 3.11). Additionally, variable costs were greater for the sex-selected semen scenario. Variable costs for the conventional semen scenario were impacted by a decrease in percent of females weaned, which increased the number of annual purchased replacements required, thus increasing annual heifer replacement costs. This indicated that under current model parametrization and historical prices, heifer development and feed costs were more expensive than costs to purchase replacement heifers. However, if replacement heifer costs were high, different results may have been observed. In an actual production system, a producer must also consider genetics, resource availability, and feed costs when deciding between sex-selected and conventional semen.

Results of the current study contradicted results reported by Taylor et al. (1985) who concluded efficiency of beef production was greatest in a female sex-selected OCF system.

Specifically, the model evaluated efficiency of conventional cow/calf, all male sex-selected, and female sex-selected OCF systems. The model predicted efficiency values of 2.3 to 3.5 g of lean tissue per MJ of ME, 3.6 to 4.0 g of lean tissue per MJ of ME, and 4.8 to 5.2 g of lean tissue per MJ of ME for conventional cow/calf, all male sex-selected, and female sex-selected OCF systems, respectively (Taylor et al., 1985). However, results may have differed because the authors model did not consider reduced fertility of sex-selected semen, less than 100% accuracy of sex-selected semen, or less desirable feed efficiency during the post-weaning finishing period for OCF.

What-if scenarios. Figure 3.7 shows a graphical representation between G:F and BCR at varying levels of first AI conception rates. From this graph we can conclude that increasing conception rate to first AI improved both biological and economic efficiency. Considering G:F, there were improvements in BE when changing conception rate to first AI from −10 to −5% and an equal improvement when changing from 10 to 15%, but interestingly, there was no change in BE when conception rate to the first AI changed from −5 to 10%. This indicated a small (i.e., 5%) decrease in first AI conception rate will not affect BE. However, it would take a 10% improvement in first AI conception rate to improve biological efficiency. Based on predictions of this model, changes in conception rate to first AI have little effect on improving BE. There was a strong linear relationship between conception rate to first AI and BCR that indicated as conception rate to first AI increased, economic efficiency increased. These results illustrated the high economic value of conception rate to first AI. Cundiff et al. (1974) conducted a study with crossbred and straight bred beef females and found calf crop improved 6.6% in crossbred females due to an improvement in first service conception rate. Similarly, Wells (2015) reported improved overall profitability for producers utilizing AI due to a larger percentage of females conceiving early in the breeding season which resulted older, heavier calves at the time of

weaning. In the context of the AHNC beef production system, this would be beneficial because heifers would be older and heavier at the time of breeding, thus increasing the likelihood of conception to the first AI.

Figure 3.8 illustrates the relationship between CER and BCR at varying levels of first AI conception rates. For Fig. 3.8, it is important to remember that a lower CER is more desirable. The CER and BCR have a positive relationship, meaning an increase in first AI conception rate made both CER and BCR more desirable, indicating more kg of beef can be produced at a lower cost. It is important to note that BCR accounted for quality of beef produced (i.e., YG and QG were considered), whereas CER only accounted for kg of beef produced on a HCW basis. These results were expected because improving conception rate to first AI will minimize the percent of heifers that are sold from the system due to failure to achieve pregnancy in a timely manner.

The effect that changing percent of female calves born had on G:F and BCR is shown in Fig. 3.9. As percent of female calves born increased, BCR increased, and G:F improved. These were the same results demonstrated in the comparison of female sex-selected and conventional semen. Results suggest using conventional semen would be preferred over female sex-selected semen. Figure 3.10 depicts the relationship between CER and BCR at varying percentages of female calves born. This graph showed that greater economic efficiency in the case of both CER and BCR were achieved when replacement rates (i.e., purchasing outside heifers to maintain inventory) were lowest. Notice in Figs. 3.9 and 3.10 that G:F, BCR, and CER begin to taper off at +10% from the observed value. This occurred due to reaching a maximum percent of female calves born (i.e., 99%) for AI conception. The change was only driven by an increased percent of female calves from bull conception, which only made up a small percentage of total weaned calves.

Figure 3.11 displays effects that percent of USDA Choice and greater carcasses had on carcass revenue. Results of this what-if scenario were expected since higher quality carcasses will result in more quality premiums and ultimately more revenue. The upward trend of the line indicated that revenue increased as the percent of USDA Choice and greater carcasses increased. This sensitivity analysis only evaluated effects of changing percent of USDA Choice and greater carcasses and did not account for increased days on feed or feed intake. However, by genetically selecting for marbling, it would be possible to increase percent of USDA Choice and greater carcasses without increasing days on feed on feed intake. The decreased generation interval of the AHNC beef production system will allow for markedly faster genetic progress when compared to conventional cow/calf-based production systems (Seidel and Whittier, 2015). Ultimately, producers should strive to produce as many quality carcasses (i.e., USDA Prime, CAB, and Choice) and minimize the occurrence of USDA Select and ungraded carcasses.

Sensitivity analyses. Sensitivity analysis can be defined as "the study of the relative importance of different input factors on the output" (Saltelli, 2017). Dent and Blackie (1979) described sensitivity analysis for agriculture systems as assessing operation and performance of a model. Results of sensitivity analyses are shown in Tables 3.12 and 3.13. The baseline BE estimate used in percent change calculations was 0.071. Baseline economic efficiency estimates used in percent change calculations were 0.785 and $4.55 for BCR and CER, respectively.

Biological efficiency was most sensitive to HCW. A −10% change in HCW caused a 9.9% decrease in G:F and a +10% change in HCW resulted in an 8.5% increase in G:F (Table 3.12). To summarize, increasing HCW, assuming feed intake was held constant, will positively impact system BE, and a decrease in HCW will negatively impact BE. A decrease in percent of female calves born caused BE to improve and an increase in the percent of female calves born caused BE to worsen, reiterating results from the female sex-selected vs. conventional semen scenarios.

Conception rate to first AI did not have the effect on BE that was anticipated. A ±10% change in conception rate first AI, resulted in percent changes of −1.4 and 0.0% for a 10% decrease and 10% increase, respectively. However, it is important to note the model did not consider increased BW at weaning due to a larger portion of heifers calving earlier in the season which would have increased TDN requirements. Other variables (e.g., carcasses over 30 mo of age) were unable to be tested because TDN requirement was not based on animal age.

Economic efficiency was also most sensitive to HCW (Table 3.13). A 10% decrease in HCW resulted in −6.41 and −11.65% changes in BCR and CER, respectively. A 10% increase in HCW resulted in 8.97 and 9.23% changes in BCR and CER, respectively. A 10% increase in HCW had the greatest impact on BCR, but still did not indicate the system would be profitable. These results were not realistic as an increase in HCW would likely be accompanied by an increase in the feed intake which the model did not consider. However, results of this sensitivity analysis are valuable as they demonstrate the value that total kilograms of beef produced carries, indicating a terminal cross may be a valuable strategy for an AHNC producer. Further, genetic selection for improved feed efficiency and HCW could result in improved carcass weights without increasing in feed intake on days on feed.

Not surprisingly, economic efficiency was extremely sensitive to feed prices. Decreasing prices 10% from observed values resulted in 4.31 and 2.31% increases in BCR for hay and corn, respectively, and increasing prices 10% from observes values resulted in 3.85 and 1.03% decreases in CER for hay and corn, respectively (Table 3.13). This was not surprising considering the large amount of hay fed during winters. Hay price is a major risk for producers using the AHNC beef production system. An AHNC producer has more feeding burdens than a conventional cow/calf producer, since they bear burdens of feeding breeding females year-round and also have to periodically finish dams in a feedyard and feed early-weaned calves in a dry lot.

This exposes AHNC producers to a variety of price risks. The impact of feed costs was not surprising since feed costs represent of 73% of total operating costs. Based on these results, it seems the AHNC beef production system would economically perform poorly in a drought. Additionally, this system may perform better in a warmer climate that is conducive to year-round grazing, thus eliminating hay feeding during the winters.

As seen in Table 3.13, replacement heifer price did not have as great as an effect as anticipated. A 10% decrease in replacement heifer price caused BCR to increase 2.56% and CER to decrease 1.54%, and a 10% increase in replacement heifer price caused BCR to decrease 1.28% and ECR to increase 1.32%. Similar results were observed when evaluating percent change in percent of female calves born. A 10% decrease in percent of female calves born resulted in a 2.05% increase in BCR and a 3.74% increase in CER, and a 10% increase in the percent of female calves born resulted in a 0.90% decrease in BCR and 3.96% increase in CER. These results were anticipated based on the previous comparison of female sex-selected and conventional semen. Decreasing conception rate to first AI by 10% from the observed value resulted in 1.91% decrease and 0.44% increase to BCR and CER, respectively. Increasing conception rate to first AI by 10% from the observed value resulted in 1.28 increase and 0.88% decreases to BCR and CER, respectively.

Carcasses over 30 mo of age based on dentition also negatively impacted system profit. (Table 3.13). Decreasing percent of carcasses classified as over 30 mo of age by 10% resulted in a 1.4% increase in BCR, while increasing percent of carcasses classified as over 30 mo age by 10% resulted in a 2.31% decrease to BCR. There were no changes to CER because as previously mentioned individual animal feed intake did not change in the model based on age at harvest. However, in a real production system there would also likely be changes to the percent of carcasses classified as USDA Choice because animals 30 to 42 mo must achieve a higher level of

marbling to classify for USDA Choice (USDA, 2017). Late in 2017, USDA changed rules for assigning beef QG. With the change, carcasses that are identified as under 30 mo of age at harvest based on dentition or age and source verification will no longer have bone ossification assessed when assigning USDA QG (USDA, 2017). Thus, presumably fewer carcasses would be classified as C maturity based on carcass maturity. However, the model did not take this new grading system into account.

During this study, age and source verification of animals could have been used to override dentition assessment by the packing facility on the harvest floor; unfortunately, due to a shortage of supply and demand for age and source verified carcasses, this option was not available on days that cattle were harvested. Harrison et al. (2019) reported only 29.5% of females in cohorts 3 through 5 of the demonstration herd were over 30 mo of age at harvest based on documented birthdates. A what-if scenario was conducted using 29.5% as the parameter value for percent of carcasses over 30 mo of age for sustaining cohorts while the percent of carcasses over 30 mo of age for initial cohorts was not changed. With this alternate parametrization, the model predicted BCR improved by 3% (0.94). This suggested that use of age and source verification could have saved reduced discounts and may have been worth the investment as long as cattle were chronologically under 30 mo of age. However, beef produced by the AHNC production system would be an excellent candidate for a branded beef program where beef production efficiency is emphasized. In the case of a branded beef program, carcasses over 30 mo of age would be irrelevant and discounts could be avoided.

CONCLUSIONS

Both biological and economic efficiency were affected by HCW. The system's high feed costs resulted in the model's output being greatly impacted by feed prices. Furthermore, economic efficiency of the AHNC beef production system was dependent on percent females

weaned, conception rate to first AI, replacement heifer price, and percent of carcasses over 30 mo of age. An understanding of variables affecting BE is critical to ensure appropriate management decisions are made. Additionally, biological and economic efficiencies were possibly correlated, indicating a producer could select the most biologically efficient system without negatively impacting profit margins.

Payment received for beef produced in the AHNC beef production system did not reflect the improved BE marked by a reduction in energy consumed to produce beef compared to conventional cow/calf-based production system estimates. Discounts applied to carcasses due to being over 30 mo of age based on dentition and C maturity based on carcass maturity had a negative impact on system profitability. Opportunities for alternative marketing options outside of the mainstream U.S. beef supply chain should be explored to avoid such discounts, including acquiring a retail-level label claim that indicates improved efficiency from beef produced in the AHNC beef production system, which may be desirable among consumers willing to pay a premium for such a claim. Biological and economic efficiencies could be improved with the use of conventional semen; however, under both scenarios, female sex-selected semen and conventional semen, BCR was less than 1, indicating both would fail to return a profit. Further research should be completed to evaluate more complex relationships between variables in the model and to compare biological and economic efficiency of the AHNC beef production system to conventional cow/calf-based beef production.

Table 3.1. Medical and breeding costs held constant for the simulated time frame in the All Heifer, No Cow beef production model[1]

Description	Unit	Quantity[2]	Price per unit, $	Cost per heifer, $	Cost per herd, $
Calf care					
Bovashield Gold 5[3]	calf	82	1.31	1.31	105.193
Ultrbac 8[3,6]	calf	160.6	0.51	0.51	81.91
Bovishield Gold One Shot[3]	calf	80.3	4.16	4.16	334.05
Deworming	calf	80.3	0.25	0.25	20.08
Heifer care					
Lepto/vibrio vaccine	heifer	100	1.11	1.11	111.00
Bos scours 4[4]	heifer	85.3	2.64	2.64	225.19
Bos scours 9[4]	heifer	85.3	3.90	3.90	332.67
Deworming[6]	heifer	170.6	2.55	5.10	870.06
Pregnancy test	heifer	100	2.50	2.50	250.00
Semen + AI service	insemination	133	62.00	82.46	8,246.00
Bull lease (includes feed)	bull	1	1,500.00	15.00	1,500.00
Total medical and breeding costs				118.94	12,076.15

[1] Costs were derived from the All Heifer, No Cow beef production system demonstration herd records.
[2] Quantities of animals subject to change annually and between production herds due to randomization of production parameters.
[3] Zoetis, Parsippany, NJ.
[4] Elanco Animal Health, Indianapolis, IN.
[5] Received treatment twice.

Table 3.2. Livestock supply costs held constant for the simulated time frame in the All Heifer, No Cow beef production system model[1]

Description	Unit	Quantity[2]	Price per unit, $	Cost per heifer, $	Cost per herd, $
Ear tags steers	steer	19.1	0.80	15.28	291.85
Ear tags heifers[3]	heifer	184	2.75	2.75	504.90
Controlled internal drug releasing devices	heifer	100	12.78	12.78	1,278.00
Melangesterol acetate	dam	78.7	2.56	2.56	201.47
Ralgro® implant[4]	steer	19.1	1.67	1.67	31.90
Revolar®-H implant[4]	dam	78.7	3.47	3.47	273.09
Total livestock supply costs				38.51	2,581.21

[1] Costs were derived from the All Heifer, No Cow beef production system demonstration herd records.
[2] Quantities of animals subject to change annually and between production herds due to randomization of production parameters.
[3] Received 3 ear tags.
[4] Intervet, Madison, NJ.

Table 3.3. Other costs held constant for the simulated time frame in the All Heifer, No Cow beef production system model[1]

Description	Unit	Quantity[2]	Price per unit, $	Cost per heifer, $	Cost per herd, $
Freight and Trucking	miles	150	4.50	8.44	675.00
Yardage	head/day	272	0.40	108.80	8,582.00
Gasoline/Fuel	heifer	100	3.00	3.00	300.00
Maintenance/Repairs	heifer	100	20.00	20.00	2,000.00
Labor	hours	400	15.00	60.00	6,000.00
Total other expenses				200.24	17,557.00

[1] Costs were estimated using a Colorado cow/calf budget (Colorado State University Extension, 2016)
[2] Quantities of animals subject to change annually and between production herds due to randomization of production parameters.

Table 3.4. Description of lifetime phases and daily TDN (± SD) intake for All Heifer, No Cow females in initial (i.e., cohorts 1 and 2) and sustaining (i.e., cohorts 3 through 5) cohorts based on the demonstration herd

Initial cohorts					Sustaining cohorts				
Phase (stock)	Length[1], d	Event[2]	Diet	TDN, kg • d^{-1}	Phase (stock)	Length, d	Event	Diet	TDN, kg • d^{-1}
					Dry lot post-weaning	60	Calves transfer from parent line; start: Jun 7	Bull ration	2.9 ± 0.6
					Fall grazing	106	Steer calves sold; Start: Aug. 7	Pasture	3.0 ± 0.4
					Dry lot overwinter	113	Replacements added; start: Nov. 22	Weaning ration	4.8 ± 0.6
Purchase heifers	21	Initial heifers purchased; start: Mar. 25	Hay	4.9 ± 0.5	Spring feeding	30	Start: Mar. 16	Hay	4.4 ± 0.4
Estrus Synchroni-zation	30	Start: Apr. 16	Pasture	6.0 ± 0.6	Estrus synchroni-zation	30	Start: Apr. 16	Pasture	5.5 ± 0.5
Breeding	30	1st and 2nd AI; start: May 17	Pasture	6.7 ± 0.6	Breeding	4[3]	1st and 2nd AI; start: May 17	Pasture	6.3 ± 0.6
Summer pasture	110	Bull exposure; start: Jun. 17	Pasture	5.7 ± 0.6	Summer pasture	110[4]	Bull exposure; start: Jun. 17	Pasture	6.0 ± 0.7

Table 3.4 continued. Description of lifetime phases and daily TDN (± SD) intake for All Heifer, No Cow females in initial (i.e., cohorts 1 and 2) and sustaining (i.e., cohorts 3 through 5) cohorts based on the demonstration herd

Initial cohorts					Sustaining cohorts				
Phase (stock)	Length[1], d	Event[2]	Diet	TDN, kg • d^{-1}	Phase (stock)	Length, d	Event	Diet	TDN, kg • d^{-1}
Pregnancy diagnosis	15	Culling heifers; start: Oct. 6	Pasture	5.6 ± 0.5	Pregnancy diagnosis	15	Culling heifers; start: Oct. 6	Pasture	5.4 ± 0.5
Fall pasture	29	Start: Oct. 22	Pasture	6.3 ± 0.6	Fall pasture	29	Start: Oct. 22	Pasture	6.2 ± 0.6
Winter feeding	96	Assumes 283 gestation; start: Nov. 21	Hay	6.9 ± 0.7	Winter feeding	96	Assumes 283 d gestation; start: Nov. 21	Hay	6.7 ± 0.7
Postpartum feeding	52	Culling dams that lost calves; start: Feb. 26	Hay + range cube	8.2 ± 0.8	Postpartum feeding	52	Culling dams that lost calves; start: Feb. 26	Hay + range cubes	8.1 ± 0.8
Postpartum grazing	26	Start: Apr 20	Pasture	9.8 ± 1.0	Postpartum grazing	26	Start: Apr 20	Pasture	10.0 ± 1.0
Receiving ration	20	Pairs to feedyard; Start: May 17	Weaning ration	10.4 ± 1.1	Receiving ration	20	Pairs to feedyard; Start: May 17	Weaning ration	10.7 ± 1.0
Transition-ing ration	11	Calves weaned; start: Jun. 18	Bull ration	10.1 ± 1.1	Transition-ing ration	11	Calves weaned; start: Jun. 18	Bull ration	10.9 ± 1.0

Table 3.4 continued. Description of lifetime phases and daily TDN (± SD) intake for All Heifer, No Cow females in initial (i.e., cohorts 1 and 2) and sustaining (i.e., cohorts 3 through 5) cohorts based on the demonstration herd

Initial cohorts					Sustaining cohorts				
Phase (stock)	Length[1], d	Event[2]	Diet	TDN, kg • d^{-1}	Phase (stock)	Length, d	Event	Diet	TDN, kg • d^{-1}
Finishing ration	69	Harvest dams; start: Jun. 19	Finishing ration	11.7 ± 1.3	Finishing ration	69	Harvest dams; start: Jun. 19	Finishing ration	12.0 ± 1.1

[1] Length refers to number of days in the stock.
[2] Start dates were determined by mean event dates from the demonstration herd.
[3] Length of breeding stock was 4 d for first AI, 25 d for second AI, and 25 d for bull conception; age at harvest is different for the 3 conception groups.
[4] Length of summer pasture stock was 110 d for first AI, 118 d for second AI, and 143 d for bull conception; age at harvest is different for the 3 conception groups.

Table 3.5. Description of key biological parameters used in the All Heifer, No Cow beef production system model for initial (i.e., cohorts 1 and 2) and sustaining (i.e., cohorts 3 through 5) cohorts based on the demonstration herd

		Cohort value	
Parameter	Description	Initial	Sustaining
Cohort size, n =	Cohort size was constant and annually replacements were purchased to return to constant size	100	100
Pregnancy rate first AI[1], %	Percent of heifers pregnant to first AI based on 30-d pregnancy diagnosis data	44.7	54.8
Exposure to second AI[1], %	Percent of heifers that didn't conceive to first AI and received a second AI	50.2	33.8
Exposure to bull[1], %	Percent of heifers that didn't conceive to the first AI and conceived to the bull	49.8	66.2
Total heifers culled[2], %	Percent of heifers culled after pregnancy diagnosis	14.0 ± 1.9	11.3 ± 3.4
Non-pregnant heifers[2], %	Percent of cull heifers culled due failure to achieve pregnancy	36.8 ± 8.5	43.1 ± 16.8
Total postpartum cows culled[2,3], %	Percent of post-partum cows culled after the death of their calf	5.5 ± 7.6	10.7 ± 8.3
Percent of female calves born AI with sexed semen, %	Percent of calves born to AI that were female	90.0	90.0
Percent of female calves born natural service, %	Percent of calves born to natural service that were female	50.0	50.0
Calf death loss, %	Percent death loss post-weaning prior to sale or entry replacement purchase	3.2	3.2
Dam death loss, %	Annualized percent death loss on breeding females	1.6	1.6

[1] Pregnancy rate and percent of heifers exposed to second AI and bull were unable to be randomized to ensure herd size at a consistent 100 females.

[2] Mean (± SD)
[3] Percent of calves that died preweaning.

Table 3.6. Ten year mean yield grade and quality grade premiums and discounts used to calculate carcass revenue in the All Heifer, No Cow beef production system model

Parameter	Premium or Discount[1], $/ 45.4 kg
Yield grade related pricing	
Yield Grade 1	+3.33
Yield Grade 2	+1.54
Yield Grade 3[1]	base price
Yield Grade 4	-11.78
Yield Grade 5	-17.55
Quality grade related pricing	
USDA Prime	+12.02
USDA CAB	+3.27
USDA Choice[2]	base price
USDA Select	−8.73
Other[3]	−30.11
Over 30 mo of age at harvest based on dentition[4]	−16.71

[1] Prices were 10-yr U.S. annual averages obtained from LMIC, 2017.
[2] Ten yr average base price was $182.83/45.4 kg and assumed USDA Choice, Yield Grade 3.
[3] Other included: Standard, Commercial, Utility, dark cutter, blood splash, and advanced bone maturity.
[4] Discount for carcasses over 30 mo of age based on dentition was based on an average U.S. discount reported by LMIC (2017), not the exact grid that carcasses in the demonstration herd were priced on.

Table 3.7. Percent of carcasses in initial cohorts (i.e., cohorts 1 and 2) by USDA yield and quality grade used in model parameterization[1]

	Yield Grade 1, %	Yield Grade 2, %	Yield Grade 3, %	Yield Grade 4, %	Yield Grade 5, %
USDA Prime, %	0.00	0.00	0.00	0.00	0.00
USDA CAB, %	0.12	0.43	0.58	0.03	0.01
USDA Choice, %	3.49	12.01	16.28	0.78	0.39
USDA Select, %	2.24	7.72	10.46	0.50	0.25
Other[2], %	4.73	16.30	22.09	1.05	0.53

[1] Data were obtained from USDA yield and quality grades reported by Harrison et al. (2019).
[2] Other includes: Standard, Commercial, Utility, dark cutter, blood splash, and advanced bone maturity.

Table 3.8. Percent of carcasses in sustaining cohorts (i.e., cohorts 3 through 5) by USDA yield and quality grade used in model parameterization[1]

	Yield Grade 1	Yield Grade 2	Yield Grade 3	Yield Grade 4	Yield Grade 5
USDA Prime, %	0.25	0.36	2.55	0.7	1.36
USDA CAB, %	1.88	2.74	19.21	5.32	8.57
USDA Choice, %	2.61	3.8	26.61	7.37	11.88
USDA Select, %	0.2	0.3	2.08	0.58	0.93
Other[2], %	0.05	0.07	0.46	0.21	0.21

[1] Data was obtained from USDA yield and quality grades reported by Harrison et al. (2019).
[2] Other included Standard, Commercial, Utility, dark cutter, blood splash, and advanced bone maturity.

Table 3.9. Mean (± SD) biological and economic efficiency for 40 simulation runs predicted by the calibrated All Heifer, No Cow beef production system model combining production herds

	Biological efficiency	Economic efficiency	
	Gain:Feed[1]	BCR[2]	CER, $[3]
Mean	0.070	0.842	4.60
SD	0.001	0.006	0.06

[1] Among animals in the All Heifer, No Cow beef production system, ratio of kg of HCW produced to lifetime kg of TDN consumed.
[2] Benefit-cost ratio = total revenues/total variable costs.
[3] Cost-effectiveness ratio = total variable costs/total kg of beef produced (on a HCW basis).

Table 3.10. Mean (± SD) total revenues, total variable costs, and total kg of beef produced for 40 simulation runs predicted by the calibrated All Heifer, No Cow beef production system model combining production herds

	Total revenues, $	Total variable costs, $	Total beef produced[1], kg
Mean	161,306	191,576	41,647
SD	1,069	797	536

[1] Total kg of beef produced on a HCW basis.

Table 3.11. Mean (± SD) predicted for key biological and economic efficiency parameters from the female sex-selected and conventional semen scenarios for 40 simulation runs predicted by the calibrated All Heifer, No Cow beef production system model combining production herds

	Sex-selected		Conventional	
Parameter	Mean	SD	Mean	SD
Gain:Feed[1]	0.070	0.001	0.073	0.001
Weaned females, %	64.7	-	41.0	-
Benefit-cost ratio[2]	0.842	0.006	0.929	0.006
Cost-effectiveness ratio[3]	4.60	0.06	4.07	0.06
Total revenue, $	161,306	1,069	177,250	1,114
Total variable costs, $	191,576	797	190,743	1,139
Total replacement cost, $	29,642	766	40,012	7,655
Total beef produced (on a HCW basis), kg	41,647	536	46,918	654

[1] Among animals in the All Heifer, No Cow beef production system, ratio of kg of HCW produced to lifetime kg of TDN consumed.
[2] Benefit-cost ratio = total revenue/total variable costs.
[3] Cost-effectiveness ratio = total variable costs/total kg beef produced (on a HCW basis).

Table 3.12. Sensitivity analyses evaluating parameter effects on biological efficiency in the calibrated All Heifer, No Cow beef production system model combining production herds

	–10% observed value		+10% observed value	
Variable	Gain:Feed[1]	%Δ[2]	Gain:Feed	%Δ
Conception rate to first AI	0.070	(1.4)	0.071	0.0
Percent of female calves born[3]	0.072	1.4	0.069	(2.8)
HCW	0.064	(9.9)	0.077	8.5

[1] Among animals in the All Heifer, No Cow beef production system, ratio of kg of HCW produced to lifetime kg of TDN consumed.
[2] Percent change calculated from a base Gain:Feed: 0.071.
[3] Percent of female calves born.

Table 3.13. Sensitivity analyses evaluating parameter effects on economic efficiency in the calibrated All Heifer, No Cow beef production system model combining production herds

	–10% observed value				+10% observed value			
Variable	BCR[1]	%Δ[2]	ECR[3]	%Δ[4]	BCR	%Δ	ECR	%Δ
Conception rate to first AI	0.80	1.91	4.57	0.44	0.77	(1.28)	4.51	(0.88)
Percent of female calves born	0.796	2.05	4.38	(3.74)	0.773	(0.90)	4.73	3.96
Percent of carcasses over 30 mo of age	0.789	2.31	4.55	0.0	0.780	(0.64)	4.55	0.0
Hay prices	0.827	6.41	4.31	(5.27)	0.746	(3.85)	4.78	5.05
Corn prices	0.798	2.31	4.47	1.76	0.772	(1.03)	4.62	1.54
Replacement heifer prices	0.796	2.56	4.48	(1.54)	0.773	(1.28)	4.61	1.32
HCW	0.83	(6.41)	5.08	(11.65)	0.71	8.97	4.13	9.23

[1] Benefit-cost ratio = total revenue/total variable costs.
[2] Percent change calculated from base benefit-cost ratio: 0.785.
[3] Cost-effectiveness ratio = total variable costs/total kg of beef produced (on a HCW basis).
[4] Percent change calculated from base cost-effectiveness ratio: $4.55.

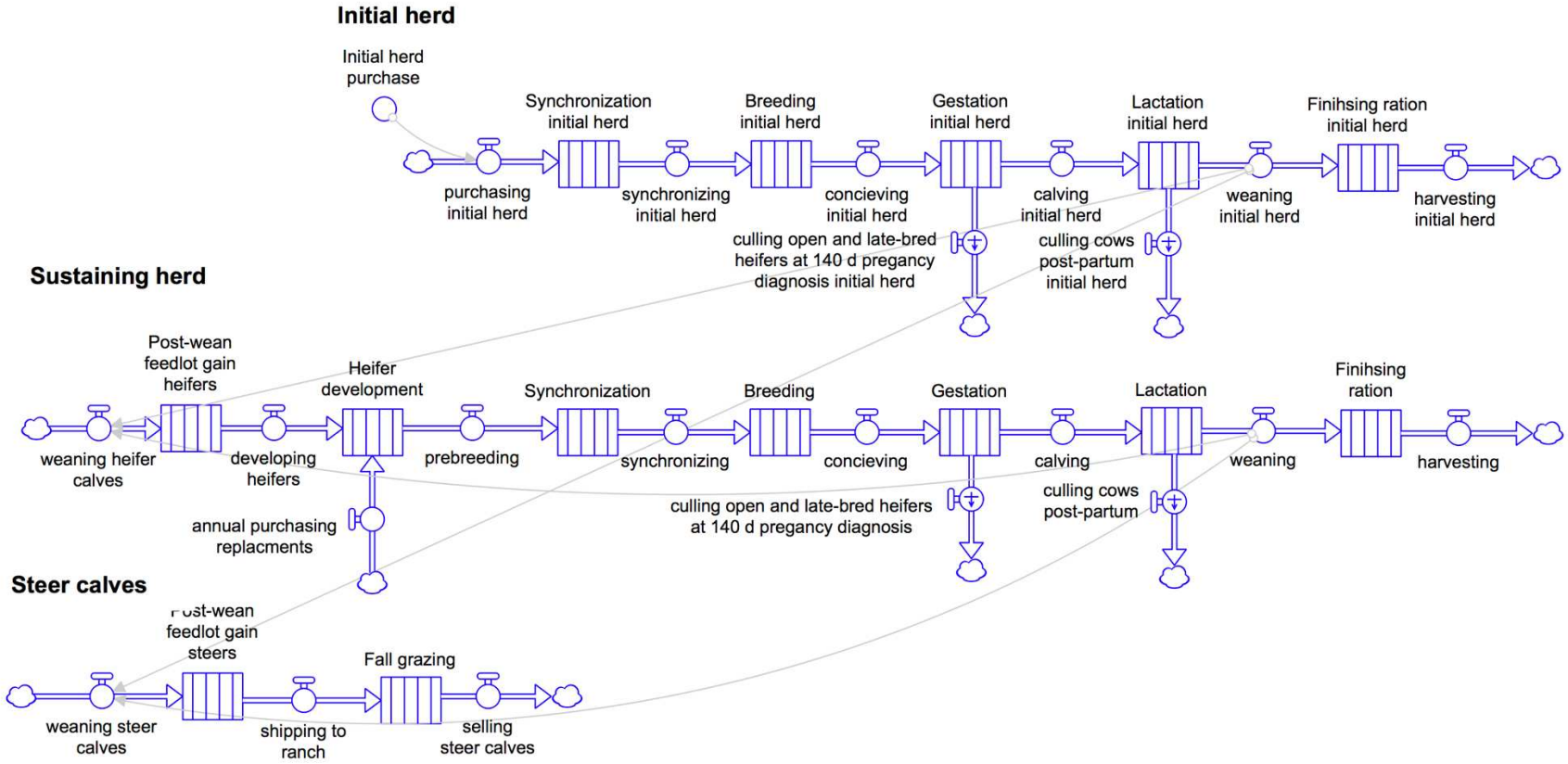

Figure 3.1. Simplified schematic of the All Heifer, No Cow beef production system model herd dynamics depicting when animals enter and exit the system

[1] Initial herd track included data collected from demonstration herd cohorts 1 and 2.

[2] Sustaining herd track included data collected from demonstration herd cohorts 3 through 5.

[3] Steer track included steer calves born in both initial and sustaining herds.

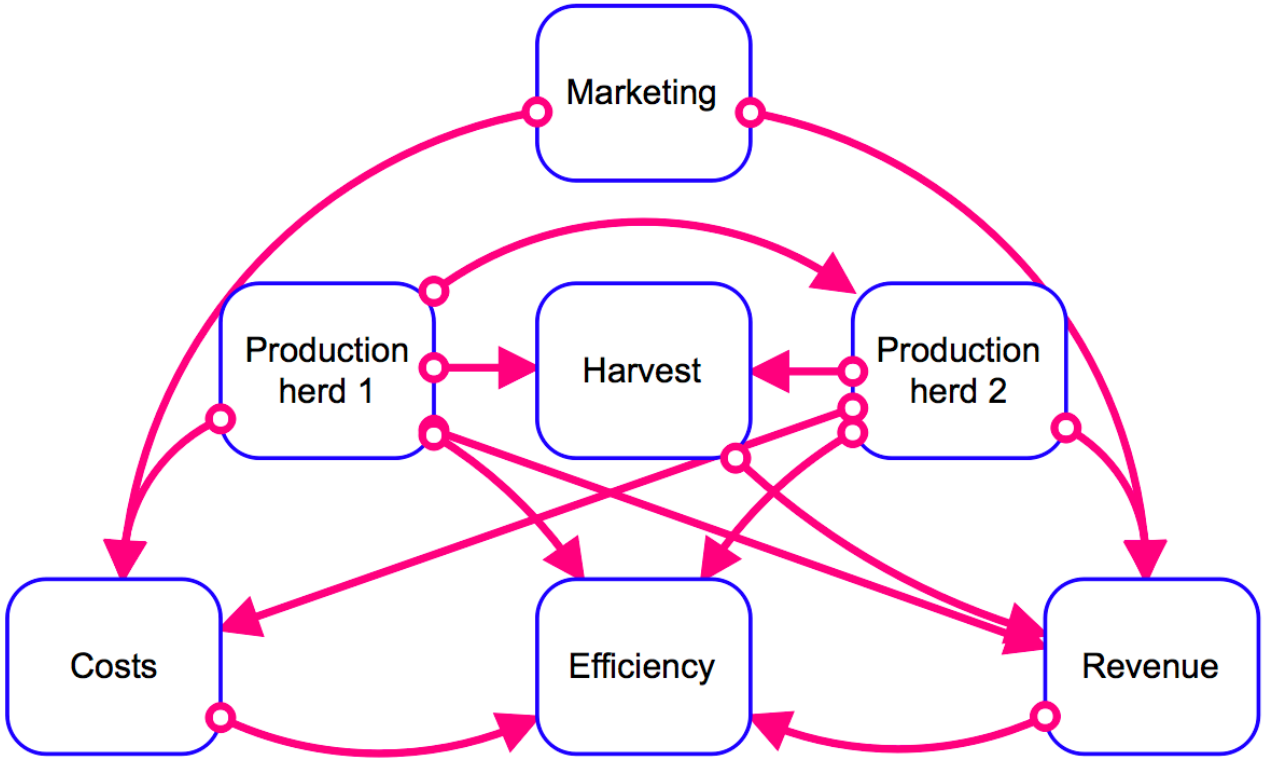

Figure 3.2. Visual representation of the top-level of the All Heifer, No Cow beef production system model depicting the various modules and arrows denoting interactions

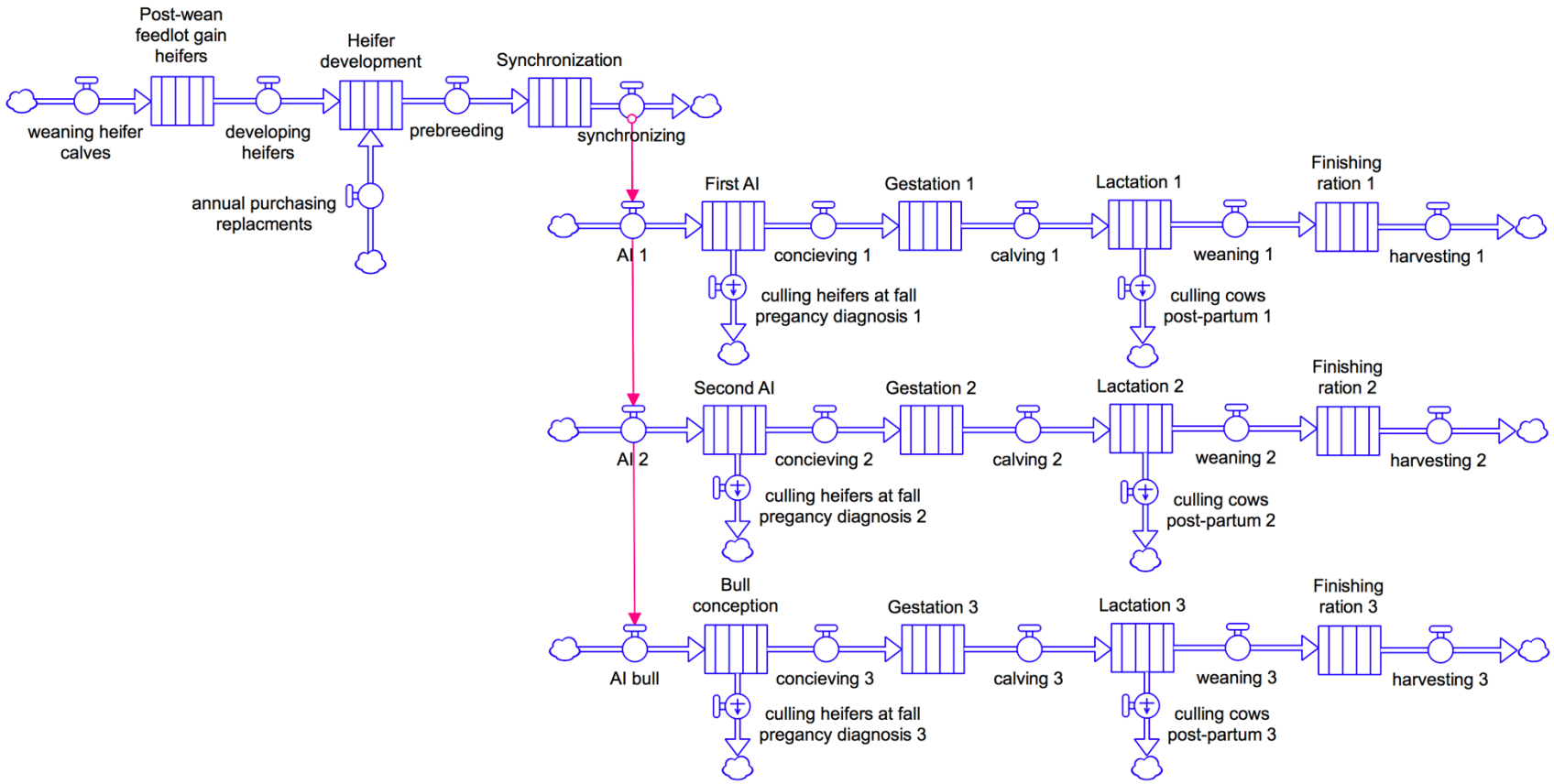

Figure 3.3. Simplified schematic depicting the 3 conception tracks (i.e., first AI, second AI, and bull conception) in the All Heifer, No Cow beef production system model

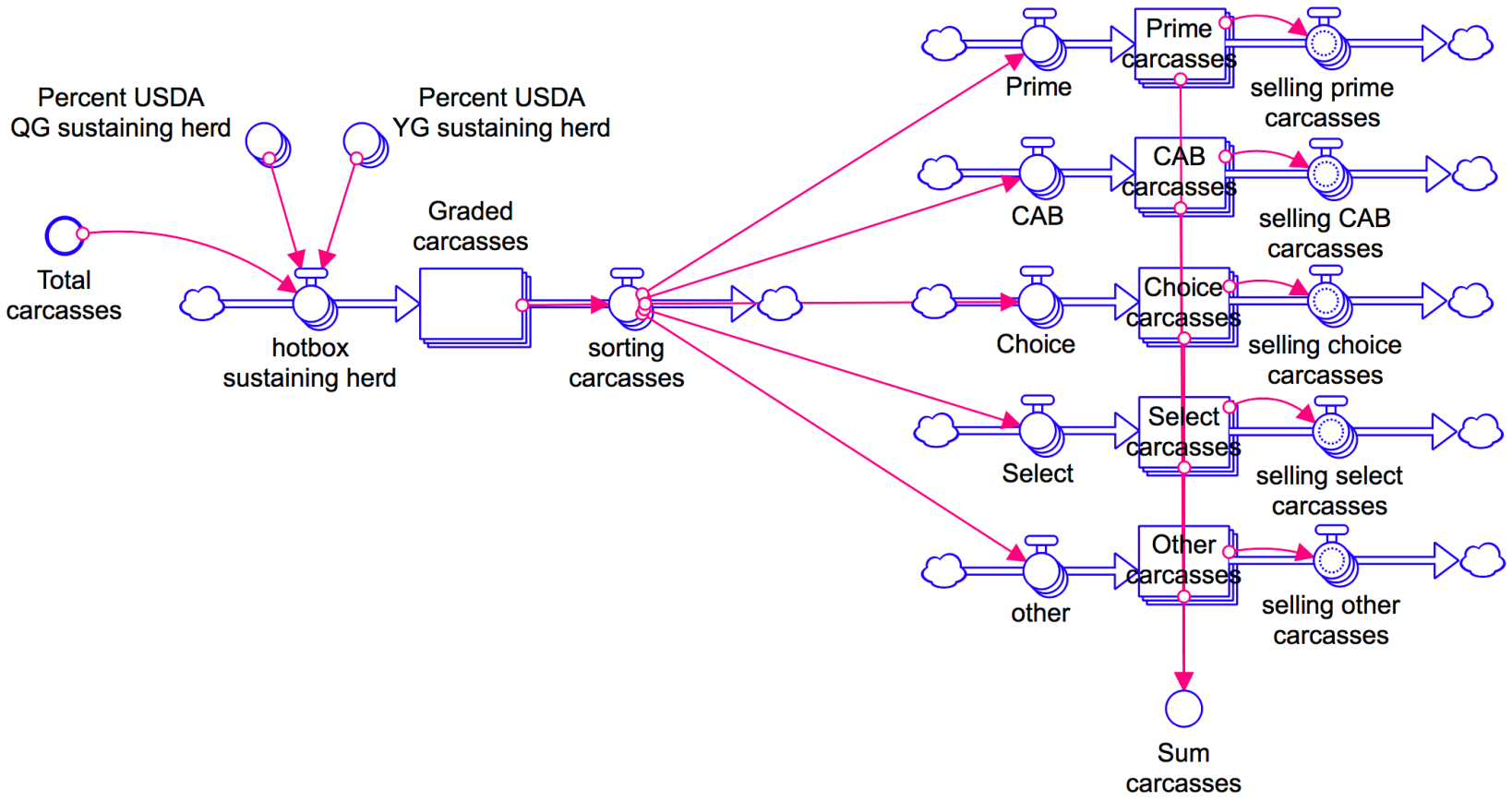

Figure 3.4. Assignment of USDA yield and quality grades in the All Heifer, No Cow beef production system model

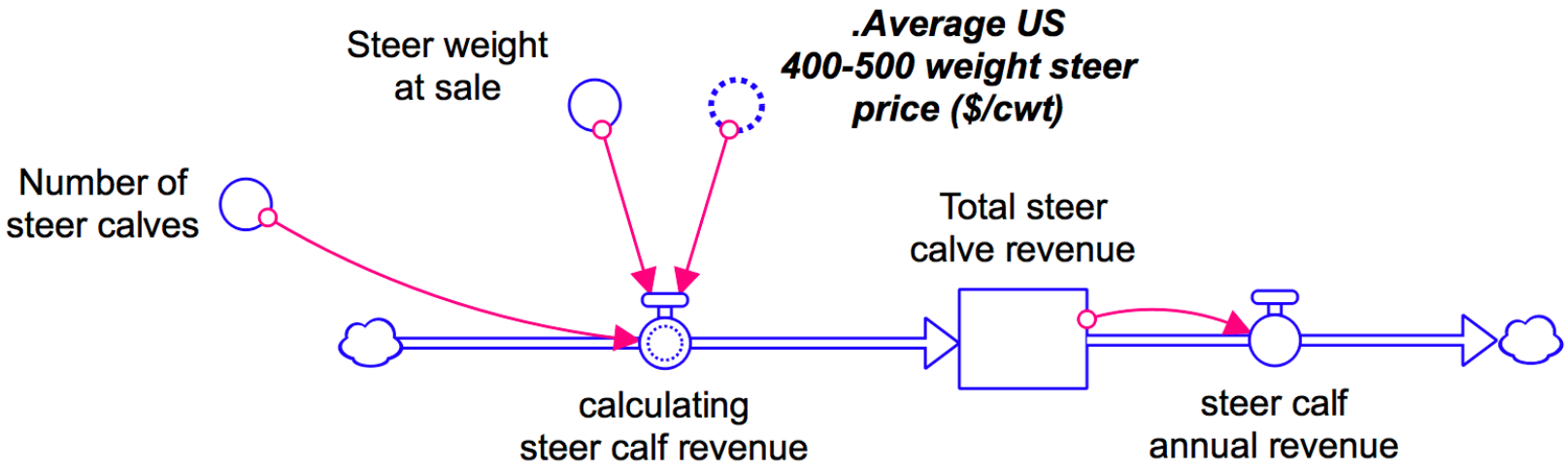

Figure 3.5. Revenue calculation for the sale of steer calves in the All Heifer, No Cow beef production system model

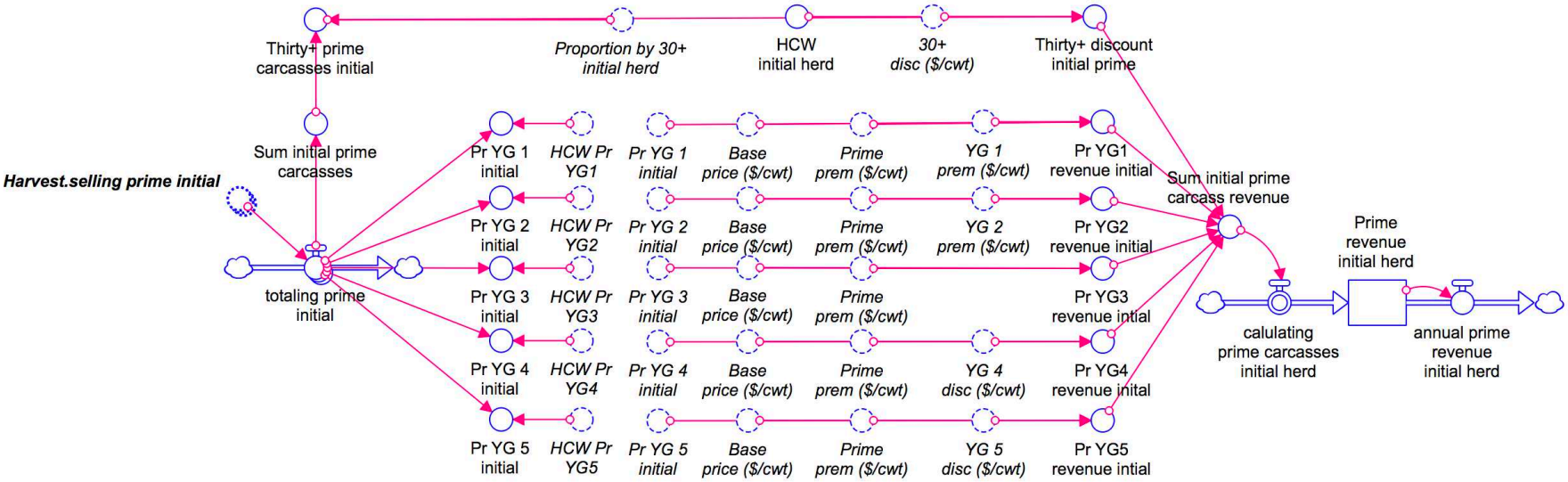

Figure 3.6. Depiction of calculating revenue using grid-based pricing for USDA Prime carcasses in the initial cohort of production herd 1 in the All Heifer, No Cow beef production system model

[1] Harvest selling prime initial represented the total number of graded prime carcasses being transferred from the harvest module in an initial herd.

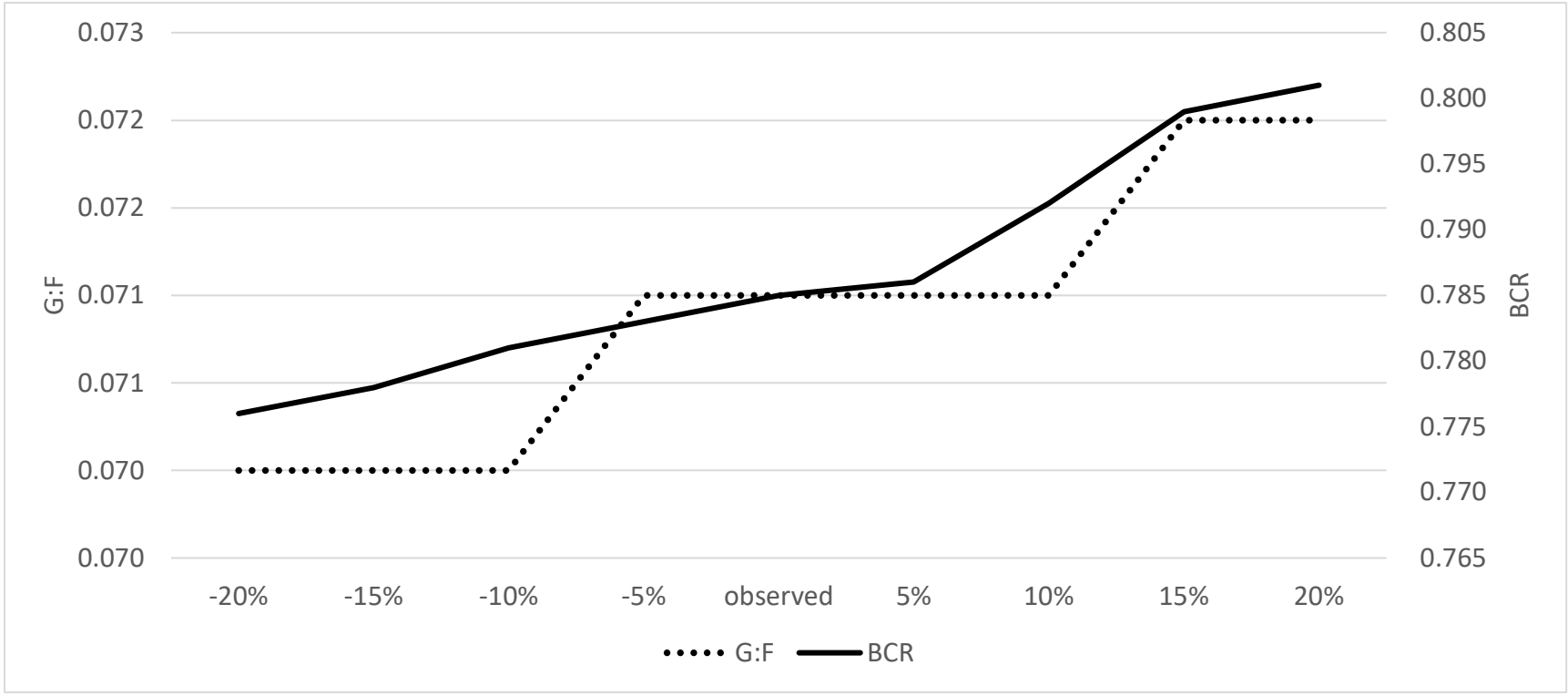

Figure. 3.7. Gain:feed (**G:F**) and benefit-cost ratio (**BCR**) for a what-if scenario evaluating effects of changing conception rate to first AI in the calibrated All Heifer, No Cow beef production system model

[1] G:F = Among animals in the All Heifer, No Cow beef production system, ratio of kg of HCW produced to lifetime kg of TDN consumed.

[2] BCR = total revenue/total variable costs.

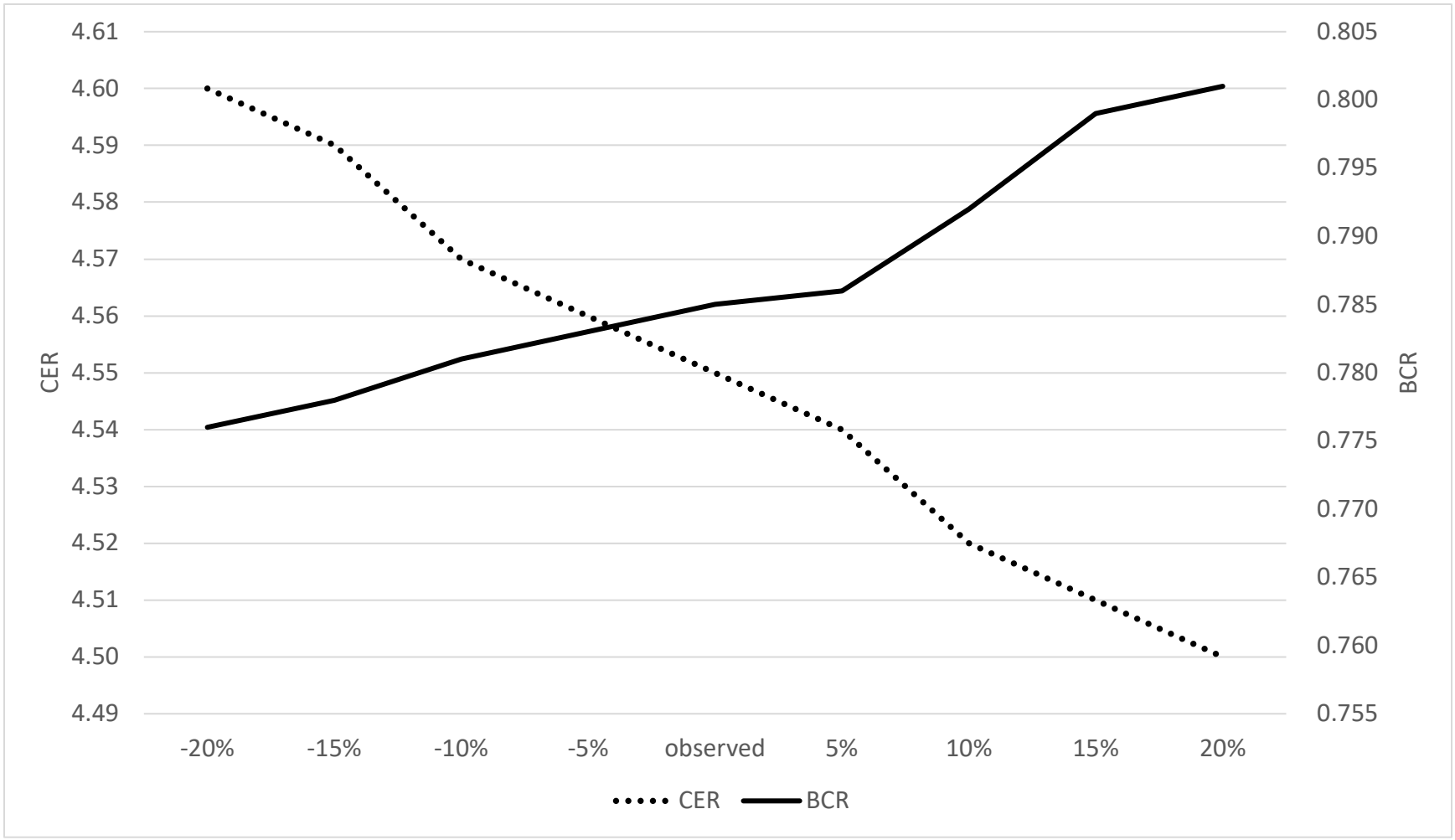

Figure 3.8. Cost-effectiveness ratio (**CER**) and benefit-cost ratio (**BCR**) for a what-if scenario evaluating effects of changing conception rate to first AI in the calibrated All Heifer, No Cow beef production system model

[1] CER = total variable costs/total kg of beef produced (on a HCW basis).

[2] BCR = total revenue/total variable costs.

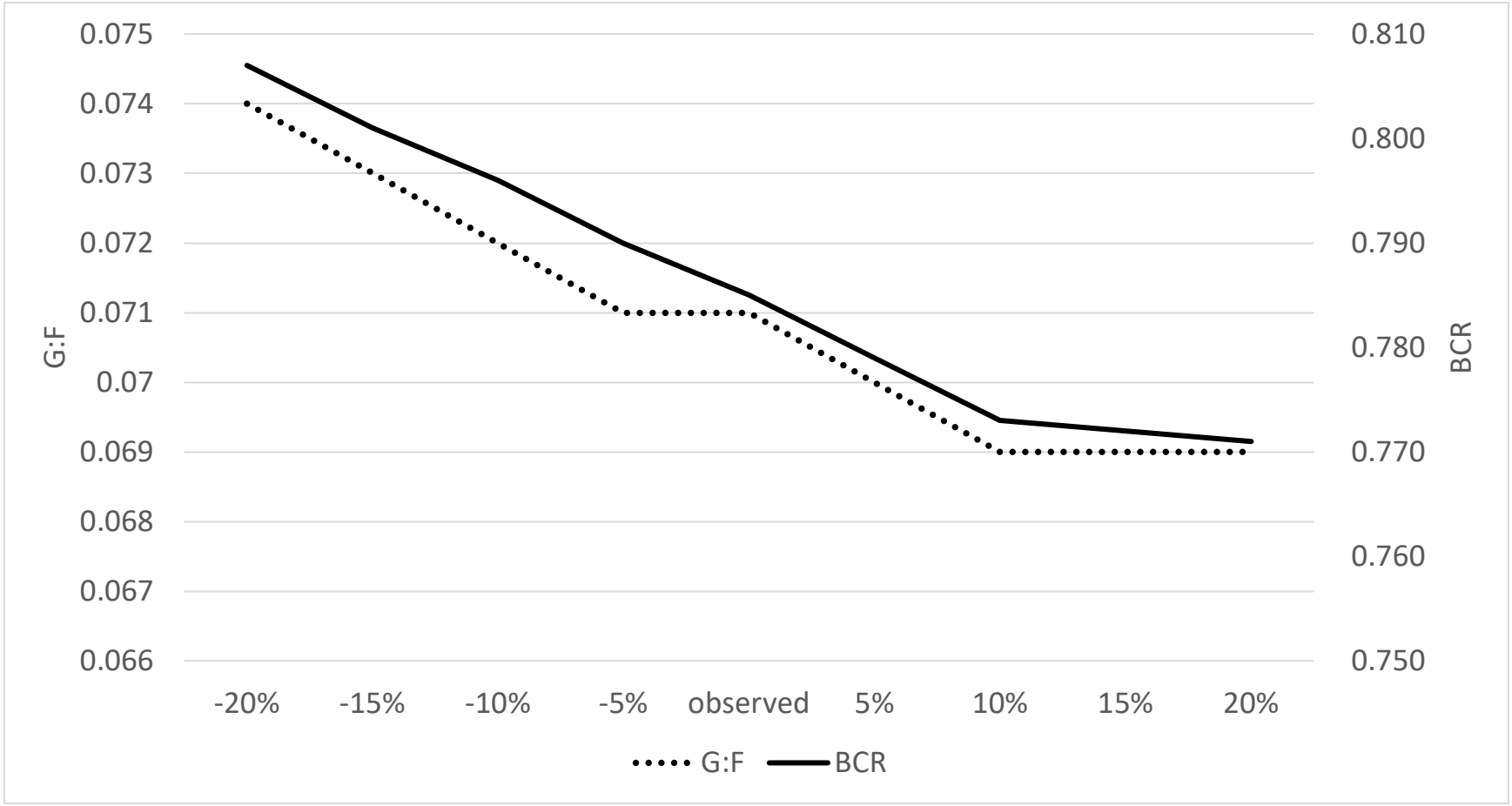

Figure. 3.9. Gain:feed (**G:F**) and benefit-cost ratio (**BCR**) for a what-if scenario evaluating effects of changing percent of female calves born in the calibrated All Heifer, No Cow beef production system model

[1] G:F = Among animals in the All Heifer, No Cow beef production system, ratio of kg of HCW produced to lifetime kg of TDN consumed.

[2] BCR = total revenue/total variable costs.

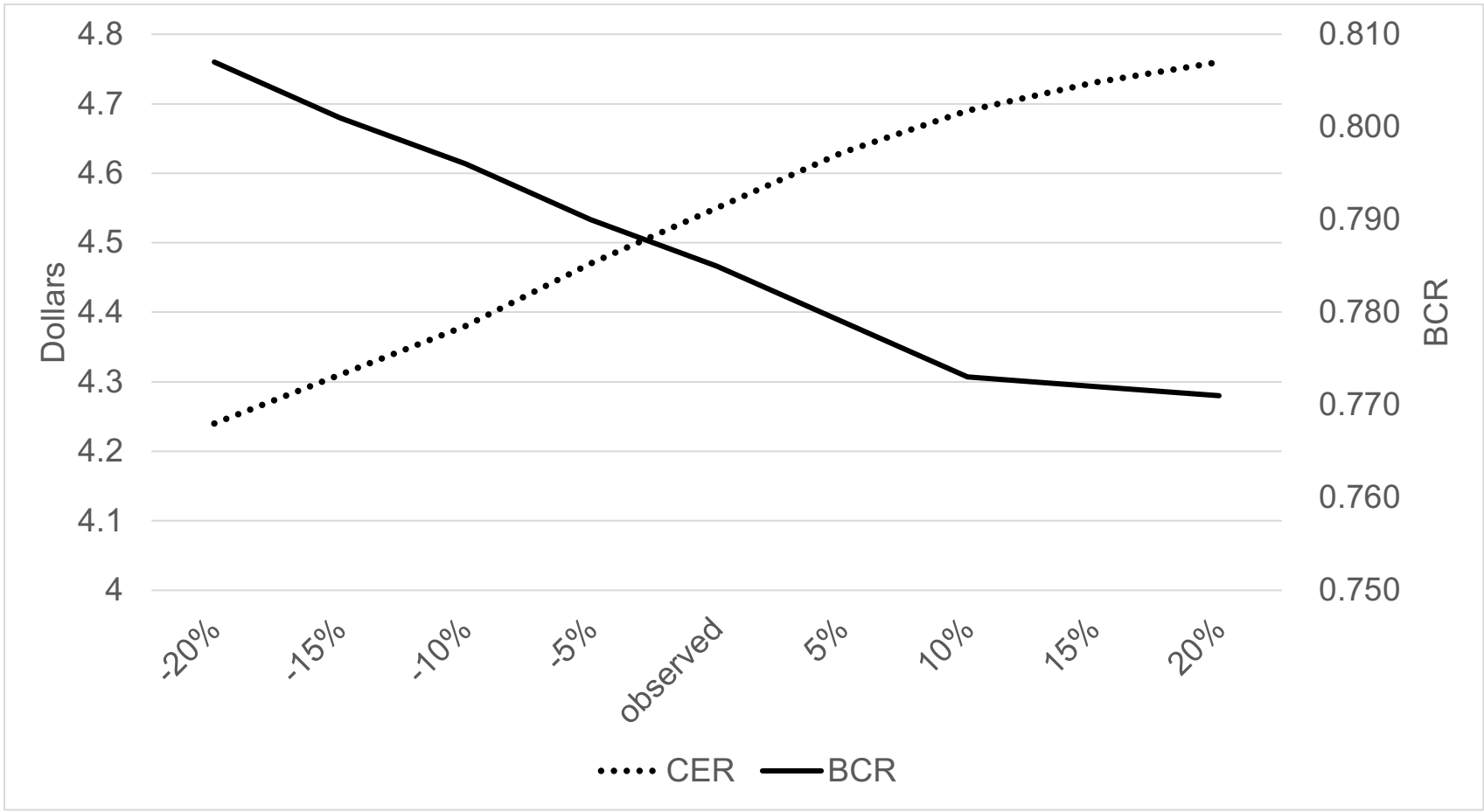

Figure 3.10. Cost-effectiveness ratio (**CER**) and benefit-cost ratio (**BCR**) for a what-if scenario evaluating effects of changing percent of female calves born in the calibrated All Heifer, No Cow beef production system model

[1] CER = total variable costs/total kg of beef produced (on a HCW basis).

[2] BCR = total revenue/total variable costs.

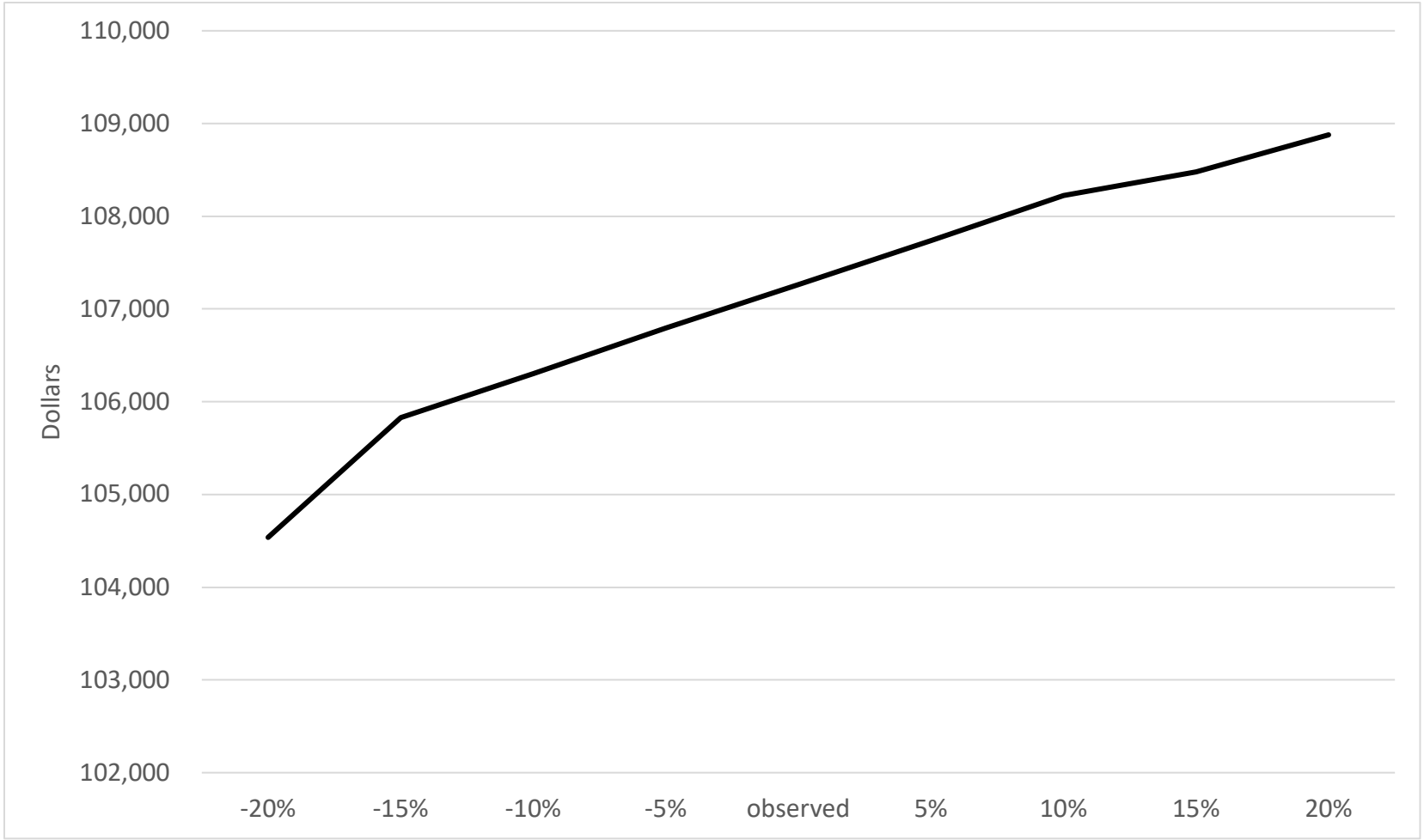

Figure 3.11. Carcass revenue for a what-if scenario evaluating effects of changing percent of USDA Choice and greater carcasses in the calibrated All Heifer, No Cow beef production system model

LITERATURE CITED

Arce-Cordero, J.A. 2016. Evaluation of management strategies to improve efficiency and sustainability of beef and dairy cattle operations. MS Thesis. Colorado State Univ., Fort Collins, CO.

Barlas, Y. 1996. Formal aspects of model validity and validation in system dynamics. System Dynamics Review. 12:183–210.

Berger, A. 2017. Is that corn worth more as silage or grain? Panhandle Research and Extension Center. University of Nebraska-Lincoln.

Bourdon, R.M., and J.S. Brinks. 1987. Simulated efficiency of range beef production. III. Culling strategies and nontraditional management systems. J. Anim. Sci. 65:963–969.

Clark, M., and D. Tilman. 2017. Comparative analysis of environmental impacts of agricultural production systems, agricultural input efficiency, and food choice. Environ Res Lett 12:064016.

Colorado State University Extension. 2016. Cow-calf budget San Luis Valley. Colorado Livestock enterprise budgets. Colorado State Univ., Agricultural and Business Mgt.

Cundiff, L.V., K.E. Gregory and R.M. Koch. 1974. Effects of heterosis on reproduction in Hereford, Angus and Shorthorn Cattle. J. Anim. Sci. 38:711–7 27

Davis, M.E., J.J. Rutledge, L.V. Cundiff, and E.R. Hauser. 1983. Life cycle efficiency of beef production: I. Cow efficiency ratios for progeny weaned. J. Anim. Sci. 57:832–851.

Dent, J.B., and M.J. Blackie, 1979. J.B. Dent, M.J. Systems simulation in agriculture. Applied Science Publishers Ltd., London, UK.

Ferrell C.L., and T.G. Jenkins. 1985. Cow type and nutritional environment: Nutritional aspects. J. Anim. Sci. 61:725–741.

Harrison, M.A., J.A. Arce-Cordero, G.E. Seidel Jr., S.L. Archibeque, R.D. Rhoades, and J.K. Ahola. 2019. Evaluation of performance and carcass traits for a 5-cohort all heifer, no cow beef production system demonstration herd. *In review.*

Harrison, S.R. 1990. Regression of a model on real-system output: an invalid test of model validity. Agric. Syst. 34:183−190.

Johnson, S.K., and R. Jones. 2004. Comparisons of estrus synchronization systems. Proceedings, Applied Reproductive Strategies in Beef Cattle. Sept. 1 and 2. North Platte, NE.

Joandet, G.E., and T.C. Cartwright. 1969. Estimation of efficiency of beef production. J. Anim. Sci. 29:862–868.

Kansas State Research and Extension. 2017. Focus on Feedlots: Kansas feedlot performance and feed cost summary, 2016 annual review. Accessed May 28, 2018: *https://www.asi.k-state.edu/about/newsletters/focus-on-feedlots/*

Kartchner, R.J., L.R. Rittenhouse, and R.J. Raleigh. 1975. Forage and animal management implications of spring and fall calving. J. Anim. Sci. 48:425–430.

Lalman, D.L. 2007. Nutrient requirements of beef cattle. Oklahoma Cooperative Extension Service. Oklahoma State Univ. Stillwater, OK.

Lawrence, J.D., and C. Ostendorf. 2006. How profitable is backgrounding beef cattle? Staff general research papers. Iowa State Univ., Ames, IA.

Livestock Marketing Information Center. 2017. Historical Beef Cattle Prices. Littleton, CO.

Mathis, C.P., S.H. Cox, C.A. Loest, M.K. Petersen, R.L. Endecott, A.M. Encinias, and J.C. Wenzel. 2008. Comparison of low-input pasture to high-input dry lot backgrounding of beef calves through harvest. Prof. Anim. Sci. 24:169–174.

National Academies of Sciences, Engineering, and Medicine. 2016. *Nutrient Requirements of Beef Cattle: Eighth Revised Edition*. Washington, DC: The National Academies Press. https://doi.org/10.17226/19014.

NCBA. 2017. Navigating Pathways to Success: Executive Summary of the 2016 National Beef Quality Audit. Centennial, CO.

Oreskes, N., K. Schrader-Frechette, and K. Belitz. 1994. Verification, validation, and confirmation of numerical models in the earth sciences. Science. 263:641–646.

Pang, H., M. Makatechian, J.A. Basarab, and R.T. Berg. 1999. Structure if a dynamic simulation model for beef cattle production systems. Can. J. Anim. Sci. 79:409–417.

Pelletier, N., R. Pirog, and R. Rasmussen. (2010a). Comparative life cycle environmental impacts of three beef production strategies in the Upper Midwestern United States. Agric. Syst. 103:380–389.

Pelletier, N., R. Pirog, and R. Rasmussen. (2010b). Supplemental materials: comparative life cycle environmental impacts of three beef production strategies in the Upper Midwestern United States. Agric. Syst. 103:380–389.

Rotz, C.A., B.J. Isenberg, K.R. Stackhouse-Lawson, and E.J. Pollak. 2013. A simulation-based approach for evaluating and comparing the environmental footprints of beef production systems. J. Anim. Sci. 91:5427–5437.

Saltelli, A. 2017. Present challenges in sensitivity analysis. Uncertainty Quantification Seminar. January 17. Trondhiem, Norway.

Seidel, G.E. Jr. 2014. Update on sexed semen technology in cattle. Animal 8(Suppl. 1):160–164.

Seidel, G.E. Jr., and J.C. Whittier. 2015. Beef species symposium: Beef production without mature cows. J. Anim. Sci. 93:4244–4251.

Sell, R.S., D.L. Watt, R.D. Little, and T.A. Petry. 1988. Single-calf heifer system profitability compared to other North Dakota beef production systems. Agric. Econ. Report No. 240, North Dakota State Univ., Fargo, ND.

SRM, 1989. A glossary of terms used in range management. Society for Range Management. Denver, Colo. p. 1.

Streeter, C.L., C.B. Rumburg, T.H. Hall, and E.G. Siemer.1974. Meadow forage quality, intake, and milk production of cows. J. Range Manage. 27:133–135.

Sterman, J.D. 2002. All models are wrong: reflections on becoming a systems scientist. Syst. Dynamics Rev. 18:501–531.

Taylor, C.S., A.J. Moore, R.B. Thiessen, and C.M. Bailey. 1985. Efficiency of food utilization in traditional and sex-controlled systems of beef production. J. Anim. Prod. 40:401–440.

Tess, M.W., and B.W. Kolstad. 2000b. Simulation of cow-calf production systems in a range environment: II. Model evaluation. J. Anim. Sci. 78:1170–1180.

USDA. 2003. Nutrient management technical note no. 2: Feed and animal management for beef cattle. USDA:NRCS. Washington, D.C.

USDA. 2008–2018. Agricultural Prices. USDA:NASS. Washington, D.C.

USDA. 2009. Beef 2007–08, Part IV: Reference of Beef Cow-calf Management Practices in the United States, 2007–08. USDA:APHIS:VS, CEAH. Fort Collins, CO.

USDA. 2017. United States Standards for Grades of Beef Carcasses. Agric. Marketing Serv., USDA. Washington, DC.

Wells, R. 2015. Artificial insemination increases profits. Noble Research Institute. Ardmore, OK. Accessed Feb. 24, 2019. https://www.noble.org/news/publications/ag-news-and-views/2015/january/artificial-insemination-increases-profits/