OPTIMAL BEEF COW STOCKING RATES IN THE U.S. SOUTHERN PLAINS

By

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SOUTHERN PLAINS

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Title of Study: OPTIMAL BEEF COW STOCKING RATES IN THE U.S. SOUTHERN PLAINS

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Abstract: This research investigates optimal beef-cow stocking rates under common drought management scenarios in the U.S. Southern Plains. An Angus spring calving herd utilizing native range forage and hay was modeled. The relationship of weather variables, calf birth weight, and calf weaning weight was estimated using data from two Oklahoma research stations. Historical county hay yields for the counties associated with the two research stations were used for forage yields. Data for the cattle range from 2002 to 2016 including 3,020 observations and data for the hay yields range from 1960 – 2017, including 115 observations. The simulation used historical cull cow and calf prices, and feed prices to evaluate the economics of various stocking rates ranging from six to 14 acres per head for the 30-year period. Management strategies assessed included normally culling cows and weaning calves, early weaning and culling ten-year-old cows, early weaning and culling nine- and ten-year old cows, and early weaning and culling eight-, nine- and ten-year-old cows. Results indicated that lighter stocking (10 – 12 acres/cow) has the highest expected profit because the producer is better able to mitigate adverse effects of severe drought. Further, strategies employing deeper culling during forage-deficit years were found to be higher returning by reducing purchased forages as compared to maintaining a constant herd size.

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CHAPTER I

INTRODUCTION

U.S. Southern Plains beef producers frequently experience severe drought during the agricultural growing season. According to the Palmer Drought Severity Index, Oklahoma had moderate to extreme drought conditions in 101 out of 445 months from July 1998 – July 2017 – the longest drought lasted from 2011 to 2013 (NOAA – NCEI 2018). Drought has substantial economic implications for beef producers due to increased production costs and reduced output. Oklahoma's beef cattle industry lost about $702 million from the 2011 drought (Elliot 2012). Of the $702 million, pasture production costs exceeded $153 million and added feed costs were nearly $332 million (Elliot 2012).

Rawlins and Bernardo (1991) argue forage production variability is one primary production risk faced by Oklahoma cow-calf producers. When forage quantity and quality fall below cattle needs, cow-calf producers may sell calf crops early and deeply cull cows (Elliot 2012; Painter 2012; Doye et al. 2013). At times in 2011, producer interviews revealed some having to schedule an appointment to sell their cattle due to auctions experiencing sales increases of 56% for feeder cattle and 205% for cull cows and bulls (Stotts 2011a, Painter 2012). Moreover, producers hauled in hay and grain from neighboring states to supplement extremely reduced forage production (Painter 2012). In all, Oklahoma's beef cow herd decreased by 16.4%

between January 2011 and January 2013 (Livestock Market Information Center 2018). Smaller breeding herds and higher feed costs decreased profits leading to diminishing cash reserves (Painter 2012; Doye et al. 2013).

These diminished cash reserves and reduced free cash flows cause financial stress for producers. Rebuilding the cow herd and rejuvenating pasture forages can also be financially difficult (Torell et al. 2010; Doye et al. 2013). Since pasture recovery may span over several years, the producer potentially incurs several years of high feed costs and/or reduced output of beef calves (Torell et al. 1991). As a result, producer operating debt increases rapidly. Thus, producers need to consider drought-mitigation strategies when making management decisions about stocking rates, retention, purchasing feed or purchasing stockers to reduce farm loses.

The purpose of this research is to determine the optimal drought-mitigation strategies for Oklahoma cow-calf producers. Several articles review the economic and biological benefits from stocking rate selection and drought management. However, destocking due to drought and rebuilding post drought is intrinsically a multi-year dynamic economic issue. This research adds to cow-calf economic research by developing a model of cow-calf herd dynamics to evaluate the economic outcomes associated with alternative responses to drought under varying stocking rates.

Objectives

The overall goal of this research is to improve economic well-being of Oklahoma cow-calf producers by determining optimal management strategies given the historical distribution of weather-driven forage production. Specifically, this research

1. Evaluated cow-calf returns for rangeland in Oklahoma under a 30-year timeframe with episodes of drought; and
2. Evaluated the economic impact of alternative stocking rates from light to heavy stocking and under four culling strategies under historical weather

These culling strategies were normally cull, early culling of ten-year-old cows, early/deep culling of nine- and ten-year-old cows, and early/deep culling of eight-, nine-, and ten-year-old cows.

Methods

An optimization model utilizing historical Payne County, Oklahoma hay production data was used to compare the economics of alternative stocking rates and drought management strategies for producers in Oklahoma. Cow weight, calf birth weight, and calf weaning weight data was used to estimate the relationship between cow weight and calf weaning weight for an Angus spring calving herd grazing native forage from two Oklahoma research stations. Rations were developed under the forage nutrient conditions using CowCulator software, (Lalman and Gill 2010) for spring calving. The model maximized discounted expected returns by choosing stocking rates, culling rates, feed purchases, stock-piled forages, and weaning dates. The results allow extension personnel to make drought management recommendations. The optimization model is developed using GAMS (GAMS Development Corporation 2017) and Microsoft Excel (Microsoft Office 2019) to model economic outcomes associated with each management strategy simulated.

Outline of study

The remaining portions of this study are outlined in the following order. Chapter two reviews past literature on the relationships between forage production and stocking rates and herd profitability. Chapter three expands the explanation of the methods to include the conceptual framework, empirical models and data collection. Chapter four presents the study results. Chapter five includes the summary and conclusions from the study, and closes with study limitations.

CHAPTER II

LITERATURE REVIEW

Producer's Willingness to Adopt Drought Management Practices

Drought is a problem impacting beef producers throughout the western United States. Karchergis et al. (2014) conducted a mail survey of producer members of the Wyoming Stock Growers Association. Most respondents experienced some form of drought within the last decade with about 60% of the respondents reporting having a drought plan in place during the most recent drought.

Further, larger ranches were more likely to incorporate half or more of five management strategies such as shorter grazing periods, other activities like hunting or conventional energy development, or yearling livestock grazing, but the most popular practices consisted of building forage reserves, reducing herd size, and buying feed. Due to recent droughts, about 40% reported drought planning would be a more extensive consideration in their ten-year management decisions (Kachergis et al. 2014).

Forage Production

The method of calculating forage yields to incorporate drought scenarios varies across studies Some optimization models used primary historical weather patterns as factors for measuring forage production such as Carande et al. (1995)

Bastian et al. (2009) quantified shocks to the grazing forage supply and demand in the overall model for Fremont County, Wyoming, for a three- and four-year drought cycle. The estimates were used in the multi-period linear programming model for the two drought cycles incorporating a 12- year peak-to-peak price cycle and a 12-year trough-to-trough price cycle because like drought, cattle prices of a given year might affect ranch income and savings. Results indicated a partial liquidation typically provided better returns under forage constraints than purchasing feed in the short run for both drought scenarios (Bastian et al. 2009).

Parsch et al. (1997) simulated stocker steer performance on intensively grazed common Bermuda grass summer pasture in western Arkansas to evaluate how both management and environmental variables affect forage production. The model consisted of three major components: “a biophysical plant growth and composition model; a physiological feed intake and animal growth model and a plant-animal interface model which describes the logic of selective grazing as a function of the environment” (Parsch et al. 1997, p.542). Each year was an independent study depending on daily weather variation, so the authors' ignore long-term impacts of heavy grazing and pasture depletion, or sustainability. They found steer average daily gain (ADG) increased rapidly and plateaued when stocking rates were lower per hectare because the animal does not have to compete for palatable forage. The study concluded moderate stocking rates (10 head/hectare) for the 126-day grazing period resulted in the highest expected returns, but the highest expected weight gains per hectare were from higher stocking rates (12 head/hectare) for the 126-day grazing period.

Torell et al. (2010) employed a multi-period linear programming model utilizing a herd mix to incorporate more flexibility in stocking rates from the different animal classes. The model accounted for rainfall, but the authors were more interested in the distribution of mean annual herbaceous production. They concluded a flexible stocking decision of adding productive animals when producers experience favorable forage conditions with high amounts of carryover forage and removing animals in drought suppressed years had more economical potential for increasing cow-calf profitability.

Cow-Calf Dynamics

There is little literature examining the relationship between droughts and stocking rates of cow-calf operations. Cow-calf models are more dynamic than stocker models since the nutritional requirements for brood stock change over time. Gillard and Monypenny (1984) described such complexities in their analysis of stocking rates and droughts in semi-arid tropics.

Andales et al. (2005) and Fang et al. (2014) simulated cow-calf operations on native rangeland in a dynamic cow-calf and forage production model with parameters for the most common cattle breeds. Andales et al. (2005) simulated management scenarios effects on monthly cow and calf weights from Wyoming cattle. Herd size estimates included bred, open, replacement heifers, steer and heifer calves, and bulls. The production component consisted of estimates for the average daily gain or loss for each cattle class, milk production for lactating cows, and produced calf crop for annual sale. Andales et al. (2005) found the model was biased overpredicting cow weights and under-predicting calf weights, but predicted yearly trends in weights rather well. Fang et al. (2014) focused more on the economic implications of the model and concluded the model reasonably predicted peak standing forage from long-term weather forecasts before the growing season, so ranchers can set a stocking rate reasonable for stocker weight gains, potentially improving economic profits.

King (1979) and Trapp (1986) viewed the relationship between cattle price cycles and the cow herd size instead of drought. King (1979) found culling older cows should occur when the beef price cycle is in the downward phase or hits bottom, but when the beef price cycle experienced an upward phase or peaked younger cows could be culled. Ultimately, the study found varying the culling age of cows between ages five and eleven was the best strategy to keep a relatively constant herd size. Trapp (1986) found optimal returns came from a flexible culling and addition strategy for the cattle price cycle.

Setting Stocking Rates

Researchers utilize both static and dynamic modeling to determine optimal stocking rates for stocker cattle. Static models have lower data needs but fail to capture intertemporal variability in contrast to dynamic models. Torell et al. (1991) developed a multi-period dynamic economic model incorporating current and future effects of stocking rate decisions for an eastern Colorado stocker cattle operation. They found years with small price discounts for heavier cattle allowed for a stocking rate nearly twice that of larger price discount years. The objective function value increased from minus $63 per hectare to minus $48 per hectare, an increase of 24%, when flexible stocking rates were used compared to the recommended constant utilization rule (Torell et al. 1991). These results suggested flexible stocking rates were more economically optimal.

Ritten et al. (2010a) analyzed long-term tradeoffs typical stocker grazing systems, when stockers are purchased in early summer and sold in the fall, impacted future forage production in central Wyoming. The model considered the ecological effects of the modeling system by stabilizing steady states in the grazing subject to a constant herd size constraint. Results suggested optimal levels of standing forage are reliant on growth rates of forage and consumption characteristics of animals at a 50% herbage utilization with a long-run equilibrium of 195 kg of standing forage per hectare and associated stocking rate of 1.66 head per hectare for the 120-day grazing period (Ritten et al. 2010a). The results also suggested a stocker operation with the long-run objective of maximizing the value of land optimally improve rangeland health when incurring initial lower returns from lighter stocking.

Other studies used dynamic modeling to determine optimal stocking rates for cow-calf operations since producers retain the brood stock and the herd's nutritional requirements change over time. Ritten et al. (2010b) developed a dynamic model comparing “economic relationships among forage growth, stocking rate decisions, animal performance, and price differentials associated with weight and financial returns over time” (p. 1244) in response to stochastic weather events. Under the four simulations tested, when the authors analyzed adaptive stocking and available average standing forage to a moderate stocking with higher averages standing forage, the adaptive stocking had higher annual returns and less standing forage variability than the moderate stocking approach due to weather variability.

Hamilton et al. (2016) used a multilinear programming model to evaluate management strategies. The model incorporated forage constraints and animal production constraints. The results showed southeastern Wyoming cow-calf producers are more adversely impacted by precipitation-induced forage production variability and suggest enterprises prepare for drought by maintaining a smaller herd rather than destocking and restocking in drought years and wet years respectively. They report expected gross returns variability increases at 20% or more precipitation variation because herd size varies as precipitation levels vary forage production. In most cases, more flexible practices of changing stocking rates were needed to mitigate annual precipitation variability.

Pope and McBryde (1984) modeled continuous grazing systems. They found shortsighted stocking rate approaches often lead ranchers to stock the range at levels exceeding safe carrying capacities possibly stunting range recovery, so producers often experience lower net returns in those situations. However, if economically- and ecologically- sound range improvement treatments are used, an optimal strategy could be to periodically apply treatments to allow for methodical heavier stocking rates.

Hart et al. (1988) evaluated management strategies for pasture systems combining native range and crested wheatgrass or irrigated bromegrass-alfalfa. They reported as increasing grazing pressure on irrigated bromegrass pastures occurred cattle gains decreased linearly. Higher gains were experiences on crested wheatgrass, brome-alfalfa and native range at intermediate, high or low, and low grazing pressures respectively. The improved pastures retained highest conception rates until the stocking rates were above the maximum net returns level.

Drought Affecting Cow-Calf Profitability

The consensus of the literature is producers can improve discounted net returns when frequently experiencing moderate to severe drought by one or two options: moderate stocking rates (Torell et al. 1991; Ritten et al. 2010b; Parsch et al. 1997; and Gillard and Monypenny 1990) or incorporate flexible stocking practices (Torell et al. 2010; Pope and McBryde 1984; and Hamilton et al. 2016). Few articles considered long-term effects of extended drought periods, such as rebuilding the cow herd as in Doye et al. (2013). They analyzed three cow herd rebuilding strategies: 1) slow rebuilding using summer stockers, 2) fast rebuilding by purchasing bred cows or cow-calf pairs, and 3) cow leasing with heifer retention. Each strategy considered three land tenure positions: owned land with debt, owned land without debt, and leased land. The authors found producers who liquidated their entire breeding herds face the most cash flow challenges to rebuild.

Incorporating stockers into the enterprise mix as a source of income (similar to Rawlins and Bernardo 1991; Torell et al. 2010; and Hamilton et al. 2016) increased cash flows for producers rebuilding cow herds in four years. Under the fast rebuilding scenario, producers reached targeted cow-calf herd sizes by the end of the third year but had cashflow difficulties. Leasing scenarios took six years to reach target herd size and cash flows were much lower than in other scenarios (Doye et al. 2013). Other management suggestions for optimizing discounted net returns or discounted land returns include purchased hay (Bastian et al. 2009 and Hamilton et al. 2016), retaining heifers over drought cycles (Torell et al. 2010 and Doye et al. 2013), and forage carryover (Torell et al. 2010).

Research thus far has examined either the economically- or ecologically- optimal relationship between stocking rate and drought. Primarily, literature reviews stocker cattle production due to less variation in production practices. However, few articles review the relationship between cow-calf stocking rates and weather variation in the western United States. The consensus of the literature is producers can improve discounted net returns by one or two options: moderate stocking or incorporate flexible stocking practices. This research expands on previous research to review the economic relationship between common cow-calf drought management practices and weather variation for the U.S. Southern Plains.

CHAPTER III

METHODS

Conceptual Framework

Cow-calf producers were assumed to maximize discounted expected profit subject to a herd size constraint and resource constraints, similar to Ramsey et al. (2005) and Ward et al. 2008). A simulation model was developed and used to estimate birth and weaning weights varying with stocking rates and weather for central Oklahoma. Historical forage production data were used to create scenarios accounting for drought reduced forage yields and surplus forage yields. The model incorporates a baseline stocking rate ($S^{stkrate}$) and selects for early or typical fall weaning, and deep or typical culling.

Behavioral model

To calculate the expected profit of the various stocking rates and forage management strategies, a cow herd was developed for Payne County, Oklahoma. The baseline herd is assumed to have 100 mature females with a mature weight of 1,300 pounds and spring calving production cycle.

Assuming the producers' goal is maximize net present value of expected profits as in equation (1), revenues generated by selling calves, culled livestock, and hay and costs associated with livestock and hay production are used in the profit calculation. The objective assumed is to maximize the net present value of expected annual profits on a per acre basis as

$$(1)\quad \max_{S} NPV_t = \sum_{t=1}^{T} E\left(\frac{Revenues_t - Costs_t}{(1-d)^t}\right)|S;$$

$$S \in \{Stocking\ Rate, Normal\ \ Wean/Cull\ , Early\ Wean/Early\ Cull\ 10\ year\ olds,$$
$$Early\ Wean/Cull\ 9\ and\ 10\ year\ olds\ , Early\ Wean/Cull\ 8, 9, and\ 10\ year\ olds\}$$

where the objective function in equation (1) is the sum of discounted annual returns over time subject to resource and balance constraints, d is the discount factor of 5%, $Revenues_t$ are the annual revenues, and $Costs_t$ is the annual costs. Revenues and costs varied between years by employing joint empirical density of forage production, cattle prices, and feed prices. Producers choose stocking rate and cull strategy. Based on forage production and consumption, the quantity of hay purchased, net stockpiled, and sold is calculated. Ending stockpiled forage and herd inventory were carried forward into the next year.

Forage availability in year *t* for strategy *S* was constrained as:

$$(2)\quad ForageProd_t|S + Storedhay_{t-1}|S \times 0.875 + PurchasedHay|S\ \geq ForageFed_t|S +$$
$$StoredHay_t|S + SoldHay_t|S + StoredHay_t$$

where $ForageProd_t$ is the forage (including pasture and hay) raised on the farm in year *t*, $StoredHay_{t-1}$ is the stored hay in year $t-1$ net of decay (factor of 0.875), $PurchasedHay_t$ is the amount of hay purchased in year *t*, $ForageFed_t$ is the grazing forage plus hay consumed in year *t*, $StoredHay_t$ is the total hay stockpile in year *t*, and $SoldHay_t$ is the amount of hay sold in year *t*.

A baseline culling model, adapted from Azzam et al. (1990) and Bir et al. (2018), was used to represent culling when adequate forage was available through production and purchases (i.e., the baseline simulation). Culling probabilities of cows at a given age were

$$(3)\quad CR\ (\ CowAge_t) = Prob\ (Cull|Age_t)\ \times (1 -\ Cumulative\ CR\ Age_t)$$

where $CR\ (\ CowAge_t)$ is the culling rate probability of a cow at age *t*, if she was not culled in a previous year, $Prob\ (Cull|Age_t)$ is the culling probability of the cow given her age *t*, *Cumulative*

CR Age$_t$ is the culling rate probability the cow was culled from a previous age. The *Cumulative CR Age*$_t$ is

(4) $Cumulative\ CR\ Age_t = \sum_{i=1}^{t-1} CR\ (\ CowAge_{it})$.

When adequate forage is available or in the strategy where hay was purchased in deficit years, 17 heifers are retained annually. In other strategies, the cow herd fell below 100 mature cows in response to low forage availability. The number of heifers retained varied with strategy *S* and was determined dynamically to maintain a target of 100 mature cows subject to available forage under *S*. The number of cows is:

(5) $Cows_{jt} = Cows_{j-1.t-1} \times Prob(Cull\ at\ j-1\ ))|S\ \forall\ 1 < j \leq 10$.

Equation (5) accounts for the variation in the herd size subject to available forage under S. In (5), the number of *Cows* is indexed on age *j* and year *t*.

A baseline stocking rate[1] was established assuming the pastureland is flat, water sources are distributed throughout the property, and invasive species are managed (Bidwell et al. 2017). As adapted from Bidwell et al., stocking rate was determined as

(6) $Acres_t =$

$Dry\ Matter\ Needs\ per\ Day\ \times Grazing\ Period\ \div$

$Average\ Annual\ Forage\ Crop\ _t \times Forage\ Utilization\ Rate$.

In equation (6), $Acres_t$ is the acreage needed to meet the basic dry matter forage requirements for a 1300-pound cow in year *t*, *Dry Matter Needs per Day* is the dry matter per day each animal unit needs annually, the $Grazing\ Period$ is 365 days since it is assumed the producer continuously grazes the cow herd, $Average\ Annual\ Forage\ Crop$ was the average annual forage production on a dry matter basis[2], in year *t* and $Forage\ Utilization\ Rate_t$ is the

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[1] The stocking rate in this research is a grass stocking rate for continuously grazing cattle 365 days a year. Most rangeland in Oklahoma experiences some form of woody invasive species and to account for the tree factor the available herbaceous biomass would decrease by about 410 pounds per acre as tree canopy cover increases by 10% (Limb et al. 2010).

[2] The average annual yield on a dry matter basis is used because it was the most readily available resource for Payne County.

percentage of the average annual production assuming the cow herd will utilize 50% of forage produced for grazing (Ritten et al. 2010a). Hay production will utilize 80% of the forage produced for hay (Oklahoma Cooperative Extension Service 2015).

Annual revenues were calculated from the sales of weaned calves, culled livestock, and hay sales in a given year *t*. Bull weight was determined by assuming cow weight is 70% of the bull weight (Bir et al. 2018). Annual revenues modified from Bir et al. (2018) are calculated using the following equation:

$$(7)\ Revenues_t = \sum_{i=1}^{I_t} [CalfWeanWeight_{it} \times SalePriceSteers_{it} \times SteersSold_{it}|S \times \sum_{i=2}^{10} Cows_{it}\,|S + CalfWeanWeight_{it} \times SalePriceHeifers_{it} \times HeifersSold_{it}|S \times \sum_{i=2}^{10} Cows_{it}\,|S + CowWeight_{it}(CowAge_{it})|S \times CR(CowAge_{it}) \times CowCullPrice_{it} + \frac{CowWeight_t}{0.7} \times CullBullPrice_{it} \times \frac{8}{10} + HayPrice_t \times HayforSale_t|S].$$

In equation (7), variables are varied based on choice variable *S* for the different management strategies, $CalfWeanWeight_{it}$ is the individual calf's weaning weight in year *t*, $SalePriceSteers_{it}$ is the steer calves' sales price in year *t*, $SteersSold_{it}$ is the number of steers calves in year *t* $SalePriceHeifers_{it}$ is the heifer calves' sales price in year *t*, $HeifersSold_{it}$ is the number of heifer calves in year *t*, $Cows_{it}$ represents the number of cows at age *i* in year *t*, $CR(CowAge_{it})$ is the culling rate of a cow specified by her age, $CowWeight_{it}$ is the sales weight of the culled cow specified by her age ($CowAge_{it}$) at the time of culling in year *t*, $CowCullPrice_{it}$ is the sales price of cull cows in year *t*, $CullBullPrice_{it}$ is the sales price of cull bulls for the end of the breeding season in year *t*, $HayPrice_t$.is the price of hay in year *t*, and $HayForSale_t$ is the quantity of hay for sale in year *t*. It is assumed that on average the producer sells 8/10 of a bull each year.

Annual costs were calculated from the variable and fixed costs associated with cow-calf production in a given year *t.* One bull per 25 cows and heifers was assumed required with bull longevity of five years. Bull ownership costs are calculated as in Bir et al. (2018). Producer Price Index (PPI) (US Bureau of Labor Statistics 2019) was used to calculate the inflation adjustment of bull ownership costs between years. Other variable costs and fixed costs were sourced from Doye and Lalman (2011) as found in 2011 OSU Enterprise Budgeting for Beef Cattle on native pasture. The cost for grazing pasture at $13.39 per acre is found in Doye and Lalman (2011), but the cost for hay land at $13.95 per acre is the pasture rental rate for 2016 North Central Native Pasture is found in Doye and Sahs (2017). To inflate the fixed and variable costs for years prior to and since 2011, a general PPI (US Bureau of Labor Statistics 2019) was used. The same process was used to approximate the hay land costs from the 2016 calculation. Appendix table A1 lists the fixed and other variable costs. Costs were calculated using the following equation:

(8) $$Costs_t = FeedCost_{it}|CowWeight_{it} \times \sum_{i=2}^{10} Cows_{it}\,|S + OtherVarCost_t|CowWeight_{it} \times \sum_{i=2}^{10} Cows_{it}\,|S + FixedCost_t|CowWeight_{it} \times \sum_{i=2}^{10} Cows_{it}\,|S - BullCost\ \times \frac{1}{125}|S + HayPrice_t \times PurchasedHay_t \times HayTransportCost_t|S.$$

In equation (8) $FeedCost_{it}|CowWeight_{it}$ is the cost of feeding the cow-calf pair and 1/25 of a bull in year *t* per the cow's age and weight *(*$CowWeight_t$*)* at her age in year *t*, $FixedCost_t|CowWeight_{it}$ are the fixed costs for the cow-calf pair and 1/25 of a bull given the cow's age and weight ($CowWeight_t$) at her age in year *t*, $OtherVarCost_t|CowWeight_{it}$ are the other variable costs for the cow-calf pair and 1/25 of a bull given the cow's age and weight, $Cows_{it}$ is the number of cows of age *i* in year *t*, $HayPrice_t$ is the price of hay in year *t*, $HayPurchased_t$ is the quantity of hay purchased in year *t*, and $HayTransportCost_t$ is the price per ton costs associated with the quantity of hay purchased in year *t*. Variables are conditioned on the strategy *S* evaluated.

Calf weaning weights and birth weights were estimated similar to Bir et al. (2018). However our models included temperature and precipitation variables, allowing for the analysis of weather impacts on production.

Historical prices for weaned heifers and steers were from USDA-AMS (2019a). Prices for simulated weights were calculated using linear interpolation of reported prices. Feed rations were calculated using CowCulator (Lalman and Gill 2010) and annual price for hay, pasture, and 20% protein range cubes.

The number of steers sold was computed as

$$(9)\quad SteersSold_t = \left[\sum_{i=2}^{10} Cows_{it} \times CalvingRate_t/2 \times (1 - \frac{DeathRate}{2})\right] | S$$

where $SteerSold_t$ is equal to number of head of cows exposed in year *t* times one-half of the $CalvingRate_{it}$ of 0.873 (Sahs 2019) times one minus, $DeathRate_{it}$ of 0.042 (Sahs 2019) divided by two. The number of heifers sold is similarly computed, however heifers retained for breeding are subtracted.

Net forage is the grazing dry matter yield per acre from the forage model and a utilization rate of 50% (Ritten et al. 2010a). Dry matter loss due to baling was assumed to be 20%, the decay of hay due to exposed, ground storage was assumed to be 12.5%, forage dry matter content was assumed to be 90% all sourced from Oklahoma Cooperative Extension Service's *Beef Cattle Manual* (2015). Hay loss due to feeding was also assumed to be 20% as in Stotts (2011b).

Choice strategies

The producer chooses an initial stocking rate. Then, having observed annual forage availability and needs, the producer responds by varying culling strategies depending on the forage availability net of use. A flow chart for the model is shown in Figure 1. The following notation is used to denote choice variables:

$S^{stkrate}$ is the choice variable for stocking rate given a resource base;

S^{cull} is the choice variable for culling normally, culling the ten-year-olds early, deeply culling the nine- and ten- year olds; deeply culling the eight-, nine-, and ten- year olds; and S^{wean} is the choice variable for early or normally weaning the calves.

The maximization model was evaluated assuming producer behavior for varying net forage availability.

1. <u>Forage-surplus</u>

   In periods of surplus forage, the producer uses one or a combination of stockpile forage, winter graze forage, and/or sells hay. Calves are weaned in October in years of forage surplus.

   a. Winter graze forage

      At the baseline stocking rate, the net grazing forage available is simulated using equation (6). If the grazing forage available meets the grazing ration need for the number of cows (Cow_{it}) by their weight ($CowWeight_{it}$) then the excess forage was used for winter grazing. Each cow has a winter dry matter need assumed satisfied by feeding hay or winter grazing (when available) for a 90-day fall-winter period. If the excess amount meets the dry matter needs for the 90-day hay period, then the excess hay produced was stockpiled or sold. If the excess amount of grazing forage did not meet the full 90-day hay period, hay fed was adjusted from 15 – 90 days in fifteen-day intervals.

   b. Stockpile Hay

      If the net grazing forage did not meet the entirety of the 90-day hay feeding requirements, the cows were fed stockpiled forage first. Then, their net of hay need was met by utilizing the hay produced on the 120 acres dedicated to hay production. If the hay yields are in excess of the hay requirements, then hay is stockpiled until a maximum carry over rate of 25% of the 90-day hay requirement is obtained.

   c. Sell Hay

Hay in excess of 25% of 90-day requirements was sold.

2. Forage deficit

In periods of forage deficit, the producer's choices were to feed stockpiled hay, purchase hay, early wean, and/or early/deeply cull the herd.

a. Use Forage Stockpile

At the baseline stocking rate, the net forage available was simulated using equation (6). If the net forage available did not meet the forage requirements then the forage stockpile was used to fulfill the deficit when possible. If stockpiled did not meet 90-day haying needs, then annual hay produced was used.

b. Purchase Hay

If stockpiled and annual forage production did not meet needs, then hay is purchased. However, if the amount of purchased hay needed was above 10% of forage needs, then the producer chose an early wean and early/deep culling strategy.

c. Early Wean and Early/Deeply Cull the Herd

There were three early wean and early/deep cull strategies for the producer to choose. The first was to wean early and cull ten-year-old cows early (July). The second was to wean the calves early and deeply cull nine and ten-year-old cows. Third was to wean early and deeply cull eight, nine and ten year old cows. Each year, the producer was assumed to retain enough heifers to replace the cows culled in the herd with a maximum of 80% of mature (three-year-old and greater) cow's' heifer crop.[3]In years where the producer chooses one of the early wean and deep cull strategies, the cull cows and calves were sold in July. If the cow herd numbers fell below 80 producing cows, then one bull was culled as well.

[3] A maximum of 80% was assumed to assure only phenotypically sound heifers were retained.

Empirical Models

Birth weight model

The MIXED procedure in SAS Enterprise Guide 9.4 (SAS Institute Inc. 2012) was used to calculate the calf birth weight model. The calf birth weight model was a modified from Bir et al. (2018) to include weather variability.

Calf birth weight (*CalfBirthWeight$_{it}$*) was estimated as

(10) $$CalfBirthWeight_{it} = \beta_1 + \beta_2 CowAge_{it} + \beta_3 CowAge_{it}^2 + \beta_4 Lag(Forage_{it}) + \beta_5 Lag(Forage_{it}^2) + \beta_6 DamBreed_{it} + \beta_7 SireBreed_{it} + \beta_8 Ln(CowWeight_{it}) + \beta_9 Location \times Season_{it} + \beta_{10} Sex_{it} + u_{it} + w_t + c_t \ .$$

In equation (10), $CalfBirthWeight_{it}$ is animal *i's* calf birth weight in pounds in year *t*; $CowAge_{it}$ is the cow's age for animal *i* in year *t*; $Lag(Forage_{it})$ is a lag on the amount of forage available in tons to represent the amount of forage available per acre consumption for spring calving cows during gestation and the growing season; $DamBreed_{it}$ is dam breed; $SireBreed_{it}$ is sire breed; $Ln(CowWeight_{it})$ is the natural log of the weight of the cow; $Location \times Season_{it}$ ε{El Reno Spring, North Range Fall, North Range Spring} is the location and calving season interaction; and Sex_{it} ε{Heifer, Steer} is calf sex. The error term u_{it}, the random effect for year w_t, and the random effect for cow c_t were assumed to be independent and normally distributed.

Weaning weight model

The calf weaning weight model was also estimated using the MIXED procedure in SAS Enterprise Guide 9.4 (SAS Institute Inc. 2012) and was similarly modified from Bir et al. (2018). Calf weaning weight (*CalfWeanWeight$_{it}$*) was estimated as

(11) $$CalfWeanWeight_{it} = \alpha_1 + \alpha_2 CowAge_{it} + \alpha_3 CowAge_{it}^2 + \alpha_4 Forage_{it} + \alpha_5 Forage_{it}^2 + \alpha_6\ DamBreed_{it} + \alpha_7 SireBreed_{it} + \alpha_8 Ln(CowWeight_{it}) +$$

$\alpha_9 Location \times Season_{it} + \alpha_{10} Sex_{it} + \alpha_{11} AgeWean_{it} + \alpha_{12} CalfBirthWeight_{it} +$

$z_{it} + r_t + h_t$.

In equation (11), $CalfWeanWeight_{it}$ is animal *i*'s calf weaning weight in pounds in year *t*. Forage $(Forage_{it})$ is a lead on the amount of forage available in tons to represent the amount of forage available per acre consumption for the fall calving cows during gestation and the growing season. Age at weaning $(AgeWean_{it})$ is the age of the calf in days at weaning for animal *i* in year *t*. Other variables are the same as in (10). The error term z_{it} and the year random effect r_t and the random effect for cow h_t were assumed to be independent and normally distributed.

As with Bir et al. (2018) the error term indicated the presence of heteroscedasticity due to cow age $(CowAge)$. So, the SAS *repeated/local* command was used to correct variance estimates with White's heteroscedasticity procedure (White 1990; SAS Institute Inc. 2012).

Rations

Mature cow rations for each month of the cow's life (based on weight, age, and stage of gestation/lactation) were developed using CowCulator to find the yearly total needed (Lalman and Gill, 2010). Cows were assumed to be 65% of their mature weight by age one, at 85% mature weight by age two, and gain 4% each year at ages three through five before reaching their mature weight at age six (Bir et al. 2018). Cows were assumed to be Angus, grazing native range, and calving March 15. Body condition score targets were set as in Bir et al. (2018).

Sensitivity Analysis

Stocking rate

The stocking rate is varied from 6 – 14 acres per cow-calf pair in one-half acre intervals. First, the net present value for the 30-years of returns (1987 – 2016) is observed for each strategy at the baseline rate of 8.5 acres per cow-calf pair assuming 50% forage utilization (Ritten et al.

2010a). Then, as the stocking rate for the 100-cow herd is varied, a grid search for an optimal stocking rate was conducted.

Forage utilization

Since the average county hay yields per acre were used in the forage simulation model, some producer's may experience below or above average yields per acre. To observe how above or below average yields affects forage availability and profit, the grazing baseline forage yields per acre and hay yield per acre are varied from 50% to 140% of the baseline yield in intervals of 10% for the time period. The net present value at the baseline stocking rate for the different grazing utilizations was calculated at various stocking rates to find the profit-maximizing stocking rates.

Data

Data for forage production were taken from the USDA National Agriculture Statistics Service (NASS 2019). Payne and Canadian County hay yields (excluding Alfalfa) for the years of 1960 – 2017[4] measured in tons/acre were downloaded from NASS Quickstats (2019a). Cattle related data were collected from Oklahoma State University North Range and El Reno research stations in Oklahoma from 2002 – 2017 and include 3,020 observations. The year, cow weight, dam breed, sire breed, calf birth weight, calf weaning weight, cow age, calf age at weaning measured in days, and the calving season data summary are reported in Table 1 and 2.

Cattle rations were comprised of native forage grazing, 20% protein range cubes, and prairie (native) hay. Grazing pasture costs and hay land costs were from Doye and Lalman (2011) and Doye and Sahs (2016), respectively. Historical average prairie hay price data from 1987 – 2016 were used in the hay purchase costs and hay sale value (NASS 2019b). Calculations for 20% protein range cubes from Bir et al. (2018) were used since historical cube price data was not available. Veterinary costs, marketing, labor, fuel and fixed costs were sourced from Doye and Lalman (2011). Calving and weaning rates were sourced from Sahs (2019).

[4] Payne and Canadian County hay yields for 2008 are hay yields.

Livestock Marketing Information Center (2019) auction data for calf prices, cull cow prices, and cull bull prices were used. Historical calf prices from 1987 – 2016 from Oklahoma City were used. The calf weaning age was assumed to be 205 days on October 15 unless early weaned, plus or minus seven days. In early weaning years, calves were assumed to be weaned at 122 days on July 15, plus or minus seven days. Open cows are assumed to be sold at the end of the breeding season July 15 plus or minus seven days. Early/deeply culled cows were assumed to be sold on July 15, plus or minus seven days.

Historical Oklahoma City cull cow prices for 1992 – 2016 for the month of July were used in the model (USDA-NASS 2019b). Since the years of 1987 – 1991 were not reported in the USDA data, missing prices were imputed using the relationship between 700- 800-pound steer prices and cull cow prices. Historical Oklahoma City cull bull prices from 2013 to 2016 were available. Cull bulls are assumed to be sold at the end of the breeding season on July 15, plus or minus seven days. The relationship between cull cow prices and cull bull prices is positively correlated, so the cull cow prices were used to approximate the cull bull prices for the years of 1987 – 2012. The prices for cull cows and cull bulls are provided in in Appendix table A2.

Historical prices for calves weighing less than 200 pounds were not available from Oklahoma City. The weaning weights in the year of an early weaning and deep cull are smaller than or between the weight range of 200 and 300 pounds. Therefore, linear interpolation was used to approximate calf prices for the predicted calf weaning weights. If the calf weighed less than 200 pounds, the 200-pound price was used as the sale price.

Table 1. Summary statistics of cattle characteristics

Item	Mean	SD	Minimum	Maximum
Observations	3020	--	--	--
Cow Age	5.0	2.4	1	15
Cow Weight (lbs.)	1226.4	198.4	704	1922
Calf Birth Weight (lbs.)	86.3	16.67	31	200
Weaning Weight (lbs.)	523.4	114.4	77	952
Year Born	2008.5	4.0	2002	2016
Age at Weaning in Days	215.8	38.7	101	340

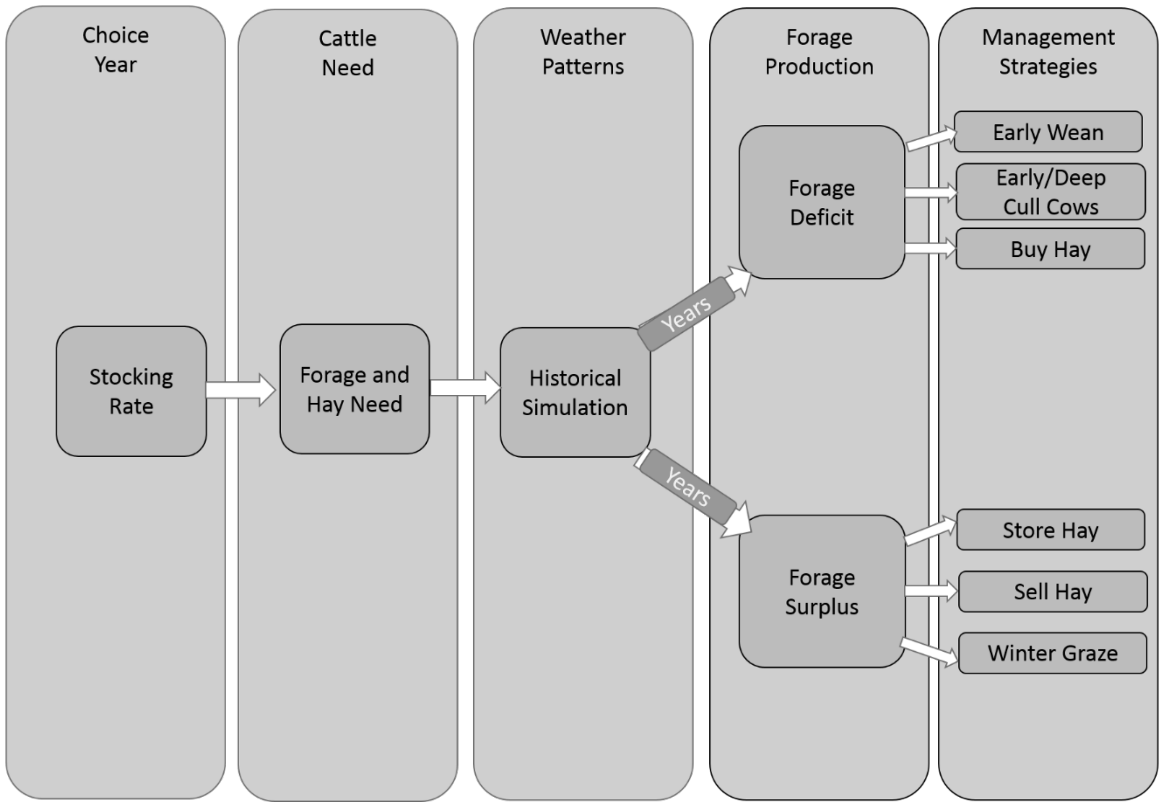

Figure 1. Decision flow chart for the model

Table 2. Summary statistics of cattle characteristics

Category	Frequency	Percent
Season		
Fall	455	15.1
Spring	2565	84.9
Breed of Sire		
Angus	1346	44.6
Brangus	209	6.9
Bonsmara	110	3.6
Charolais	276	9.1
Gelbvieh	67	2.2
Hereford	337	11.2
Maine	323	10.7
Red Poll	90	3.0
Romosinuano	59	2.0
SimAngus	126	4.2
Unknown	77	2.5
Breed of Dam		
Angus	1619	53.6
Brangus	715	23.7
Bonsmara x Brangus	73	2.4
Charolais x Angus	65	2.2
Charolais x Brangus	11	0.4
Gelbvieh	85	2.8
Hereford x Angus	119	3.9
Hereford x Brangus	88	2.9
Maine x Brangus	1	0.0
Romosinuano	68	2.3
South Devon	46	1.5
SimAngus x Angus	112	3.7
Unknown	18	0.6
Calf Sex		
Bull	60	2.0
Heifer	1492	49.4
Steer	1468	48.6
Location		
El Reno, OK	1095	36.3
OSU North Range, OK	1925	63.7

CHAPTER IV

RESULTS

Regression Diagnostics

The previous chapter explained $CalfBirthWeight_{it}$ and $CalfWeanWeight_{it}$ models were estimated using SAS Enterprise Guide 9.4's MIXED procedure (SAS Institute Inc. 2012). White's heteroscedasticity consistent variance-covariance matrix was estimated for the both models (White 1990) since heteroscedasticity was detected.

Empirical Regression Results

Birth weight variables

The *CalfBirthWeight* model coefficient estimates are shown in Table 3. Of the 31 variables in the model, 18 are significant at $p \leq 0.10$ or smaller with nine of the 31 significant at $p \leq 0.0001$.The cow age (*CowAge*) coefficient is positive and statistically significant as found in Bir et al. (2018). The cow age squared ($CowAge^2$) coefficient is negative and statistically significant. The cow age coefficients imply birth weight increases at a diminishing rate as the cow ages, with a maximum birth weight at age eight. The dummy variable for an Angus cow (*DamBreed*) is statistically significant with unknown breed as the base showing calf birth weight increases by 4.7 pounds for an Angus cow compared to the unknown breed. The natural log of cow weight (*Ln(CowWeight)*) coefficient is positive and statistically significant indicating that calf birth weight increases at a decreasing weight as cow weight increases. The dummy variable for an Angus bull (*SireBreed*) is statistically significant. Birth weight increases by 0.90 pounds for an Angus bull compared to the base breed of unknown breed. The dummy variable calf sex (*Sex*) is statistically significant with heifer calves weighing 3.3 pounds less than the steer calves base at birth. The interaction term (*Location*×*Season*) is not statistically significant. The coefficients for a lag of forage *Lag*(*Forage*) and *Lag*($Forage^2$) are not statistically significant.

Weaning weight variables

The *CalfWeanWeight* model coefficient estimates are reported in Table 4. Of the model's 33 variables, 13 are significant at the $p \leq 0.10$ or less, with eight significant at $p \leq 0.0001$.In agreement with Bir et al. (2018), the cow age (*CowAge*) coefficient is positive and statistically significant. The cow age squared ($CowAge^2$) coefficient is negative and statistically significant. The cow age coefficients imply weaning weight increases at a diminishing rate as the cow ages with a maximum weaning weight at age eight. The dummy variable for an Angus bull (*SireBreed*) is statistically significant with a base of unknown breed. Angus sired calves at weaning weighed about 12 pounds less than the unknown base breed. The dummy variable for and Angus cow (*DamBreed*) is statistically significant related to the base breed of unknown. Thus, an Angus dam's calf's weaning weight decreases by about 26 pounds compared to the unknown breed. The natural log of cow weight (*Ln(CowWeight)*) coefficient is positive and statistically significant suggesting calf weaning weight increases at a decreasing rate as cow weight increases. The dummy variable calf sex (*Sex*) is statistically significant with heifer calves weighing nearly 17 pounds less than steer calves at weaning. The interaction term (*Location*×*Season*) is negative and statistically significant compared to the base location and season of North Range, spring born calves indicating fall born calves wean at nearly 33 pounds lighter than spring born calves. The coefficient for forage (*Forage*) and ($Forage^2$) are not statistically significant.

Baseline Scenario

The expected net present value (NPV) per head was computed under various stocking rates under the baseline scenario for spring-calving Angus cows with a mature weight of 1,300 pounds. The stocking rate was varied from six acres per cow-calf unit to fourteen acres per cow-calf unit in 0.5 acre increments. Table 5 provides Expected NPV amount in dollars per acre in the baseline herd, where 100 mature females are maintained throughout the simulation period. As stocking rates in cow-calf pair per acre decreased, the net present value increased per acre. Average grazing surplus (deficit) dry matter yields in (lbs./acre) for the baseline herd at various stocking rates are reported in Table 6. These results suggest lower stocking rates (cows/acre) are more profitable over the 30 years analyzed due to lower purchased feed costs.

If a forage deficit occurs and remains after feeding stockpiled hay, then produced hay is fed. If a forage deficit remains after feeding available hay, available stockpile, and available grazing forage, then hay is purchased. If a forage surplus occurs, then the net amounts are utilized by stockpiling for future years or selling. If an excess of grazing forage occurs the forage can be used to winter graze the herd for a portion or entirety of the 90 day hay feeding period. If an excess of hay occurs, then the amount above 25% of the herd's 90-day hay need the model sells it. The pounds of forage allocated or purchased under each scenario are reported in Table 7. Some caution is warranted in interpreting and extrapolating on these results. The data used to estimate production functions and used for forage production did not include extremely low or high stocking rates. Few producers in central Oklahoma with native pastures would stock at six acres per cow or as light as 14 acres per cow.

Early Weaning and Deep Culling

Since feed costs are typically one of the largest variable expenses for cow-calf enterprises, feed cost is reduced by utilizing range forage to meet the majority of cow-calf herd nutritional requirements (Ramsey et al. 2005). The producer was assumed to purchase 20%

protein cubes to supplement the protein requirements. Rations are reported in Appendix table 13A. So, the herd depends on native forage and native hay to meet its forage requirements.

If a forage deficit was apparent and the model predicting hay deficit 10% or more, an early/deep culling decision was modeled in the baseline grazing utilization rate as summarized in Table 8. Three herd reduction scenarios were modeled: early cull ten-year-old cows, early cull nine- and ten-year-old cows, and early cull eight-, nine-, and ten-year-old cows. Note, the culling strategies were adaptive. In the latter two strategies, culling of nine-year-old cows or eight-, and nine-year-old cows was only deep enough to mitigate forage deficits, if possible. Any remaining forage deficits after deep culling were offset by purchasing hay. Under these strategies, calves were assumed weaned and sold in July. Early/deeply culling cows also occurred in July. Forage needs were recomputed given the early weaning and early/deep cull. Herd inventories by year per the baseline stocking rate are reported in Appendix table 17A.

The three early/deep-culling strategies removed the oldest cows first while utilizing normal culling percentages (see Appendix table 15A). Ten-year-old cows were culled each year regardless of the culling strategy, but when early weaning occurs the entire calf crop was sold in July. In deficit years with the early/deep-culling strategies, heifers were not retained. Therefore, building the herd back to 100 cows takes longer with the deepest culls. The herd was assumed to be closed, so female numbers decreased, there were fewer heifers calved from mature cows (three-year-old and older). Details on heifer retention percentages are in Appendix table 16A.

Expected NPVs per acre by strategy across various stocking rates while selling hay are shown in Table 8. Expected NPV's increased as acres per cow increased, i.e. stocking rate decreased. The average grazing surplus (deficit) dry matter yields in pounds per acre per culling and weaning strategy per the baseline utilization rate are reported in Table 9. The average grazing surplus (deficit) yields increased as acres per cow increased as in Torell et al. (2010) Ritten et al. (2010) and Hamilton et al. (2016). As stocking rate per acre decreased, the cows met most nutritional requirements through grazing because of the high nutritional values of native grass

(Bir et al. 2018). Since cattle met more of their nutritional requirements and maintained body condition score, the need for deep culling and early weaning decreased as stocking rate decreased, i.e., acres per cow increased. On average, at 10.5 acres/cow-calf unit and higher with a 50% forage utilization reduced the need to deeply cull and early wean only to years of severe drought (2006, 2011, and 2013). At 13 acres/cow-calf pair deep culling was unnecessary even in severe years. Expected NPV of each strategy continued increased until it plateaued at 17 acres/cow- calf pair[5] due to the severity of the 2011 drought. If the 2011 drought had not occurred, the stocking rate could have been increased and expected NPV plateauing earlier. However, higher stocking rates, i.e., fewer acres per pair, required more drastic culling with longer-term economic implications. A deep cull and lack of heifer retention in 2011 equated to few weaned calves in 2012 and 2013 and a higher percentage of weaned heifers retained in those years to rebuild to 100 cows by 2014. So, the results demonstrated the economic advantages of flexibility provided by lower stocking rates in the drought-prone Southern Plains.

There is a wide range of differences between the returns per culling decision. An example of the variation per stocking rate per culling strategy is displayed in Figure 2. Another example is the nominal per acre returns for stocking at 11 acres per cow calf pair in Figure 3. An overall trend for when the deep cull and early weaning years occur due to the years of severe drought in the observation period. However, there is a variation as to which years the culls occur based on how close the drought years are to each other and how many cattle are in the herd at the time. While Culling Strategy 3, culling eight-, nine- and ten-year olds, provides the highest expected NPVs due to lower forage needs of the smaller herd and more forage and cull animals to sell, it requires the longest time to rebuild the herd. This result is similar to those found in Bastian et al. (2009). Since the herd is closed, only replacements were taken from the operation’s calf crops. Few breeding females provided fewer replacements and since a maximum retention of 80% of the heifer crop was assumed, three years are required to build back to 100 cows.

[5] As noted earlier, caution is warranted in interpreting results for extreme, high or low, stocking rates.

Sensitivity Analysis

One potential concern with culling more cows and selling hay was hay sells obscuring the profitability of various stocking rates. So, sensitivity analyses were performed on the culling strategies without selling hay. Expected NPVs per acre by strategy across various stocking rates by not selling hay are shown in Table 10. After eliminating hay sales, stocking at 12.5 acres per cow-calf pair provided the highest returns. Returns per acre from stocking at 11.5 acres per cow-calf pair or higher were reasonably flat.

Sensitivity analyses were performed on the impact of forage yields. Since the data used for the forage model are average hay yields for Payne County, Oklahoma consideration needs to take place for pastures which produce above-average and below-average yields. So, the baseline forage yields were varied from 50% to 140% of the baseline grazing yields at a 50% utilization rate and the baseline hay yields at an 80% utilization rate. Expected NPV per acre for the baseline grazing utilization rate and various percentages of the baseline forage yields are reported in Table 11. Average yields in dry matter pounds per acre for baseline grazing utilization rate and various grazing percentages are reported in Table 12.

Expected NPVs for the cow herd were increasing at a decreasing rate as the percentage of the baseline yields increase. Producers with pasture yields above the baseline yields earned positive returns on the average while producers with pasture yields below the baseline yields earned negative returns on the average. As expected, producers with higher forage yields were better able to withstand drought at a comparable stocking rate.

Table 3. Parameter estimates for calf birth weight (lb.) model (n=3,020)

Variable	Estimate	Standard Error	t Value	Pr > |t|
Intercept	21.11	11.97	1.76	0.0998
CowAge	5.42	0.61	8.95	<0.0001
$CowAge^2$	-0.41	0.05	-8.44	<0.0001
SireBreed (Unknown Base)				
Angus	0.90	1.89	0.48	0.6344
Brangus	2.74	2.43	1.13	0.2586
Bonsmara	4.55	2.57	1.77	0.0765
Charolais	6.62	2.10	3.15	0.0016
Gelbvieh	8.65	2.77	3.12	0.0018
Hereford	5.92	2.01	2.94	0.0033
Maine	8.40	2.49	3.37	0.0008
Red Poll	8.91	2.71	3.28	0.0010
Romosinuano	2.46	2.84	0.87	0.3858
SimAngus	0.79	2.30	0.34	0.7328
DamBreed (Unknown Base)				
Angus	4.67	3.54	1.32	0.1868
Brangus	15.62	3.77	4.14	<0.0001
Bonsmara x Brangus	16.02	4.07	3.93	<0.0001
Charolais x Angus	3.97	5.76	0.69	0.4909
Charolais x Brangus	17.89	4.15	4.31	<0.0001
Gelbvieh	17.91	4.09	4.38	<0.0001
Hereford x Angus	-2.26	3.84	-0.59	0.5559
Hereford x Brangus	17.51	4.06	4.31	<0.0001
Maine x Brangus	7.27	13.10	0.55	0.5791
Romosinuano	11.00	4.13	2.67	0.0078
South Devon	5.13	4.17	1.23	0.2200
SimAngus x Angus	8.23	3.86	2.13	0.0331
Sex (Steer Base)				
Bull	2.13	2.38	0.90	0.3701
Heifer	-3.26	0.51	-6.34	<0.0001
Ln(CowWeight)	16.89	2.50	6.76	<0.0001
Season (Spring Base)				
Fall	1.01	1.07	0.95	0.3431
Lag(Forage)	-1.06	10.13	-0.10	0.9169
Lag($Forage^2$)	-0.07	2.41	-0.03	0.9775

Table 4. Parameter estimates for calf wean weight (lb.) model (n=3,020)

Variable	Estimate	Standard Error	t Value	Pr > |t|
Intercept	-276.92	40.33	-6.87	<0.0001
BirthWeight_lb	1.44	0.09	16.82	<0.0001
CowAge	21.30	2.81	7.56	<0.0001
CowAge^2	-1.69	0.22	-7.54	<0.0001
SireBreed (Unknown Base)				
Angus	-11.56	8.48	-1.36	0.1729
Brangus	-16.84	10.77	-1.56	0.1180
Bonsmara	-1.06	11.35	-0.09	0.9257
Charolais	-1.22	9.36	-0.13	0.8967
Gelbvieh	12.89	12.26	1.05	0.2932
Hereford	-7.52	9.07	-0.83	0.4072
Maine	-3.32	11.05	-0.30	0.7636
Red Poll	-32.07	12.01	-2.67	0.0077
Romosinuano	-22.05	12.54	-1.76	0.0787
SimAngus	9.23	10.24	0.90	0.3674
DamBreed (Unknown Base)				
Angus	-26.20	19.89	-1.32	0.1879
Brangus	-1.50	20.99	-0.07	0.9431
Bonsmara x Brangus	12.92	22.62	0.57	0.5678
Charolais x Angus	-76.09	31.27	-2.43	0.0150
Charolais x Brangus	17.84	23.11	0.77	0.4401
Gelbvieh	7.64	22.78	0.34	0.7373
Hereford x Angus	-37.00	21.45	-1.73	0.0846
Hereford x Brangus	1.74	22.63	0.08	0.9389
Maine x Brangus	-49.84	64.01	-0.78	0.4363
Romosinuano	-17.18	22.98	-0.75	0.4546
South Devon	-34.07	23.29	-1.46	0.1416
SimAngus x Angus	0.07	21.93	0.00	0.9976
Sex (Steer Base)				
Bull	-2.14	11.22	-0.19	0.8485
Heifer	-16.87	2.24	-7.54	<0.0001
AgeWean_days	1.92	0.04	47.82	<0.0001
LN(CowWeight)	98.18	12.72	7.72	<0.0001
Season (Spring Base)				
Fall	-31.12	4.96	-6.26	<0.0001
Forage	32.60	22.07	1.48	0.1400
Forage^2	-17.76	7.02	-2.53	0.0115

Table 5. Expected net present value per acre ($/acre) for the baseline herd and various stocking rates

Stocking Rate	NPV/acre
ac/cow	($/acre)
6	$(535)
6.5	$(437)
7	$(354)
7.5	$(281)
8	$(219)
8.5	$(166)
9	$(118)
9.5	$(78)
10	$(44)
10.5	$(8)
11	$25
11.5	$50
12	$73
12.5	$93
13	$101
13.5	$108
14	$113

Note: The baseline herd maintains 100 mature females each year for the simulation period. This strategy normally culls cows and sells calves in October. In forage deficit years, the producer purchases hay to meet herd nutritional requirements.

Table 6. Average surplus (deficit) grazing yield (lbs./acre) for the baseline herd and various stocking rates

Stocking Rate Ac/Cow	Average Net Grazing Yield DM lbs/ac
6	(1027.02)
6.5	(847.17)
7	(693.02)
7.5	(559.42)
8	(442.52)
8.5	(339.37)
9	(247.68)
9.5	(165.64)
10	(91.81)
10.5	(25.01)
11	35.72
11.5	91.16
12	141.99
12.5	188.75
13	231.91
13.5	271.88
14	308.99

Note: The baseline herd maintains 100 mature females each year for the simulation period. This strategy normally culls cows and sells calves in October. In forage deficit years, the producer purchases hay to meet herd nutritional requirements.

Table 7. Forage allocation dry matter lbs. (lbs./100 cows) for the baseline stocking rate of 8.5 acre and 50% forage utilization rate

Year	Grass Avail.[1]	Grass[2] Need	Net Graze[3]	Winter[4] Graze	Hay[5] Avail.	90 Day[6] Need	Net Hay[7]	Max[8] Carry	Forward[9] Avail.	Hay Fed[10]	Surplus[11] (Deficit)	Hay for Sale[12]	Purchase Hay[13]	Cull[14] Decision
1987	1101600	1402812	(301212)	0	311040	336960	(25920)	0	72305	638172	(327132)	0	327132	YES
1988	765000	1402812	(637812)	0	216000	336960	(120960)	0	71245	974772	(758772)	0	758772	YES
1989	1377000	1402812	(25812)	0	388800	336960	51840	51840	75143	362772	26028	0	0	NO
1990	1201050	1402812	(201762)	0	339120	336960	2160	2160	109436	538722	(154242)	0	154242	NO
1991	1254600	1402812	(148212)	0	354240	336960	17280	17280	22593	485172	(129042)	0	129042	NO
1992	1147500	1402812	(255312)	0	324000	336960	(12960)	0	14248	592272	(253152)	0	253152	YES
1993	1201050	1402812	(201762)	0	339120	336960	2160	2160	56516	538722	(199602)	0	199602	YES
1994	1285200	1402812	(117612)	0	362880	336960	25920	25920	44700	454572	(89802)	0	89802	NO
1995	1055700	1402812	(347112)	0	298080	336960	(38880)	0	65492	684072	(363312)	0	363312	YES
1996	1109250	1402812	(293562)	0	313200	336960	(23760)	0	35395	630522	(317322)	0	317322	YES
1997	1086300	1402812	(316512)	0	306720	336960	(30240)	0	6520	653472	(346752)	0	346752	YES
1998	933300	1402812	(469512)	0	263520	336960	(73440)	0	(26238)	806472	(542952)	0	542952	YES
1999	1262250	1402812	(140562)	0	356400	336960	19440	19440	50179	477522	(121122)	0	121122	NO
2000	1269900	1402812	(132912)	0	358560	336960	21600	21600	60195	469872	(94302)	0	94302	NO
2001	1025100	1402812	(377712)	0	289440	336960	(47520)	0	7572	714672	(406332)	0	406332	YES
2002	1116900	1402812	(285912)	0	315360	336960	(21600)	0	20236	622872	(307512)	0	307512	YES
2003	1269900	1402812	(132912)	0	358560	336960	21600	21600	(1000)	469872	(111312)	0	111312	NO
2004	1185750	1402812	(217062)	0	334800	336960	(2160)	0	21951	554022	(200322)	0	200322	YES
2005	1224000	1402812	(178812)	0	345600	336960	8640	8640	39524	515772	(170172)	0	170172	NO
2006	673200	1402812	(729612)	0	190080	336960	(146880)	0	(6512)	1066572	(868932)	0	868932	YES
2007	1453500	1402812	50688	50688	410400	336960	73440	73440	221599	336960	73440	0	0	NO
2008	1246950	1402812	(155862)	0	352080	336960	15120	15120	74153	492822	(76482)	0	76482	NO
2009	1185750	1402812	(217062)	0	334800	336960	(2160)	0	38618	554022	(205992)	0	205992	YES
2010	1185750	1402812	(217062)	0	334800	336960	(2160)	0	30203	554022	(219222)	0	219222	YES

Table 7. Forage allocation dry matter lbs. (lbs./100 cows) for the baseline stocking rate of 8.5 acre and 50% forage utilization rate *continued*

Year	Grass Avail.[1]	Grass[2] Need	Net Graze[3]	Winter[4] Graze	Hay[5] Avail.	90 Day[6] Need	Net Hay[7]	Max[8] Carry	Forward[9] Avail.	Hay Fed[10]	Surplus[11] (Deficit)	Hay for Sale[12]	Purchase Hay[13]	Cull[14] Decision
2011	612000	1402812	(790812)	0	172800	336960	(164160)	0	(59215)	1127772	(954972)	0	954972	YES
2012	841500	1402812	(561312)	0	237600	336960	(99360)	0	(29344)	898272	(660672)	0	660672	YES
2013	918000	1402812	(484812)	0	259200	336960	(77760)	0	13716	821772	(562572)	0	562572	YES
2014	1071000	1402812	(331812)	0	302400	336960	(34560)	0	10568	668772	(366372)	0	366372	YES
2015	1224000	1402812	(178812)	0	345600	336960	8640	8640	(5331)	515772	(170172)	0	170172	NO
2016	1147500	1402812	(255312)	0	324000	336960	(12960)	0	(1504)	592272	(260712)	0	260712	YES

[1]Grass Avail. is the total amount of grass available on a dry matter basis in the given year.
[2]Grass need is the total amount of grass needed on a dry matter basis by the herd in a given year.
[3]Net Graze is the net amount surplus (deficit) of grass available on a dry matter basis in a given year.
[4]Winter Graze is the amount of surplus forage available to graze in part or entirety of the 90-day hay period in a given year.
[5]Hay Avail. is the total amount of hay available from production in a given year.
[6]90 Day Need is the amount of hay needed by the herd for the 90-day hay feeding period in a given year.
[7]Net Hay is the net amount, surplus (deficit) of hay available on a dry matte basis in a given year.
[8]Max Carry is the amount of hay available up to the maximum amount of 25% of the herd's grass plus hay need in a given year.
[9]Forward Avail. is the amount of forward available to either fill deficit needs to supply to the forage surplus in a given year.
[10]Hay Fed is the total amount of hay the herd needs from the 90 day hay period and the deficit net graze amounts in a given year.
[11]Surplus (Deficit) is the total forage, grass and hay, surplus (deficit) in a given year.
[12]Hay for Sale is the amount excess hay available in a given year.
[13]Purchase Hay is the additional amount of hay needed to be purchased to meet the herd's ration needs in a given year.
[14]Cull Decision is the decision to implement an early weaning and early/deep culling strategy if hay needs are in excess of 10% of the herd's total grass plus total hay need in a given year.

Table 8. Expected net present value ($/acre) by culling strategy for various stocking rates by selling hay

	Buy/Sell Hay Normally Cull Cows	Early Wean Strategy 1 Early Cull 10 yr. old cows	Early Wean Strategy 2 Deep Cull 9 & 10 yr. old cows	Early Wean Strategy 3 Deep Cull 8, 9 & 10 yr. old cows
Stocking rate of 6.0 acres/cow				
NPV/period	($535)	($87)	($48)	$43
Stocking rate of 6.5 acres/cow				
NPV/period	($437)	($57)	($34)	$53
Stocking rate of 7.0 acres/cow				
NPV/period	($354)	($28)	($7)	$63
Stocking rate of 7.5 acres/cow				
NPV/period	($281)	($22)	($2)	$73
Stocking rate of 8.0 acres/cow				
NPV/period	($219)	($17)	$11	$80
Stocking rate of 8.5 acres/cow				
NPV/period	($166)	($12)	$36	$87
Stocking rate of 9.0 acres/cow				
NPV/period	($118)	($7)	$47	$94
Stocking rate of 9.5 acres/cow				
NPV/period	($78)	($1)	$58	$100
Stocking rate of 10.0 acres/cow				
NPV/period	($44)	$4	$70	$105
Stocking rate of 10.5 acres/cow				
NPV/period	($8)	$34	$85	$109
Stocking rate of 11.0 acres/cow				
NPV/period	$25	$60	$100	$113
Stocking rate of 11.5 acres/cow				
NPV/period	$50	$79	$113	$115
Stocking rate of 12.0 acres/cow				
NPV/period	$73	$100	$120	$124
Stocking rate of 12.5 acres/cow				
NPV/period	$93	$114	$125	$135
Stocking rate of 13.0 acres/cow				
NPV/period	$101	$122	$129	$145
Stocking rate of 13.5 acres/cow				
NPV/period	$108	$129	$132	$149
Stocking rate of 14.0 acres/cow				
NPV/period	$113	$133	$135	$151

Table 9. Average grazing surplus (deficit) yield (lbs./acre) per culling and culling strategy during years of deficit forage yields for various stocking rates

	Normally Cull Cows	Early Cull 10 yr. old cows	Deeply Cull 9 & 10 yr. old cows	Deeply Cull 8, 9 & 10 yr. old cows
Stocking rate of 6.0 acres/cow				
DM lbs./ac	-1027.0	-346.7	-299.2	-267.8
Stocking rate of 6.5 acres/cow				
DM lbs./ac	-847.2	-284.3	-263.7	-213.3
Stocking rate of 7.0 acres/cow				
DM lbs./ac	-693.0	-192.1	-198.6	-152.5
Stocking rate of 7.5 acres/cow				
DM lbs./ac	-559.4	-164.5	-134.6	-102.6
Stocking rate of 8.0 acres/cow				
DM lbs./ac	-442.5	-131.1	-89.9	-51.9
Stocking rate of 8.5 acres/cow				
DM lbs./ac	-339.4	-102.2	-33.7	-1.7
Stocking rate of 9.0 acres/cow				
DM lbs./ac	-247.7	-73.2	6.5	44.1
Stocking rate of 9.5 acres/cow				
DM lbs./ac	-165.6	-48.4	61.9	83.4
Stocking rate of 10.0 acres/cow				
DM lbs./ac	-91.8	-28.0	101.2	127.3
Stocking rate of 10.5 acres/cow				
DM lbs./ac	-25.0	35.8	153.8	153.5
Stocking rate of 11.0 acres/cow				
DM lbs./ac	35.7	93.8	174.8	178.1
Stocking rate of 11.5 acres/cow				
DM lbs./ac	91.2	121.1	200.4	188.1
Stocking rate of 12.0 acres/cow				
DM lbs./ac	142.0	170.7	215.9	206.6
Stocking rate of 12.5 acres/cow				
DM lbs./ac	188.8	216.3	227.2	244.3
Stocking rate of 13.0 acres/cow				
DM lbs./ac	231.9	258.4	268.9	287.5
Stocking rate of 13.5 acres/cow				
DM lbs./ac	271.9	297.4	302.9	317.6
Stocking rate of 14.0 acres/cow				
DM lbs./ac	309.0	333.6	338.9	354.7

Table 10. Expected net present value ($/acre) by culling strategy for various stocking rates by not selling hay

	Buy Hay Normally Cull Cows	Early Wean Strategy 1 Early Cull 10 yr. old cows	Early Wean Strategy 2 Deep Cull 9 & 10 yr. old cows	Early Wean Strategy 3 Deep Cull 8, 9 & 10 yr. old cows
Stocking rate of 6.0 acres/cow				
NPV/period	($535)	($118)	($74)	($4)
Stocking rate of 6.5 acres/cow				
NPV/period	($437)	($99)	($66)	($1)
Stocking rate of 7.0 acres/cow				
NPV/period	($354)	($85)	($57)	$1
Stocking rate of 7.5 acres/cow				
NPV/period	($281)	($78)	($51)	$4
Stocking rate of 8.0 acres/cow				
NPV/period	($219)	($75)	($44)	$9
Stocking rate of 8.5 acres/cow				
NPV/period	($166)	($60)	($33)	$14
Stocking rate of 9.0 acres/cow				
NPV/period	($120)	($46)	($23)	$17
Stocking rate of 9.5 acres/cow				
NPV/period	($84)	($33)	($15)	$21
Stocking rate of 10.0 acres/cow				
NPV/period	($56)	($28)	($7)	$25
Stocking rate of 10.5 acres/cow				
NPV/period	($37)	($13)	$3	$29
Stocking rate of 11.0 acres/cow				
NPV/period	($24)	($2)	$13	$34
Stocking rate of 11.5 acres/cow				
NPV/period	($14)	$8	$20	$38
Stocking rate of 12.0 acres/cow				
NPV/period	($6)	$17	$24	$42
Stocking rate of 12.5 acres/cow				
NPV/period	($2)	$20	$27	$41
Stocking rate of 13.0 acres/cow				
NPV/period	$2	$23	$28	$40
Stocking rate of 13.5 acres/cow				
NPV/period	$5	$24	$28	$40
Stocking rate of 14.0 acres/cow				
NPV/period	$8	$25	$27	$40

Table 11. Expected net present value ($/acre) for the baseline grazing utilization rate (50% utilization) and baseline hay utilization rate (80% utilization) and various percentages of the baseline forage yields

50% Utilization Yield (% of Baseline)	NPV ($/acre)
50% of the Baseline Utilization Rate	($637)
60% of the Baseline Stocking Rate	($543)
70% of the Baseline Stocking Rate	($449)
80% of the Baseline Stocking Rate	($355)
90% of the Baseline Stocking Rate	($260)
100% of the Baseline Stocking Rate	($166)
110% of the Baseline Stocking Rate	($76)
120% of the Baseline Stocking Rate	$7
130% of the Baseline Stocking Rate	$88
140% of the Baseline Stocking Rate	$171

Table 12. Average yield (DM lbs./ac) for the baseline grazing utilization rate (50% utilization) and baseline hay utilization rate (80% utilization) and various percentages of the baseline forage yields

50% Utilization Yield (% of Baseline)	Average Grazing Yield DM lbs./ac	Average Hay Yield DM lbs./ac
50% of the Baseline Utilization Rate	655.50	185.08
60% of the Baseline Utilization Rate	786.60	222.10
70% of the Baseline Utilization Rate	917.70	259.12
80% of the Baseline Utilization Rate	1048.80	296.13
90% of the Baseline Utilization Rate	1179.90	333.15
100% of the Baseline Utilization Rate	1311.00	370.16
110% of the Baseline Utilization Rate	1442.10	407.18
120% of the Baseline Utilization Rate	1573.20	444.20
130% of the Baseline Utilization Rate	1704.30	481.21
140% of the Baseline Utilization Rate	1835.40	518.23

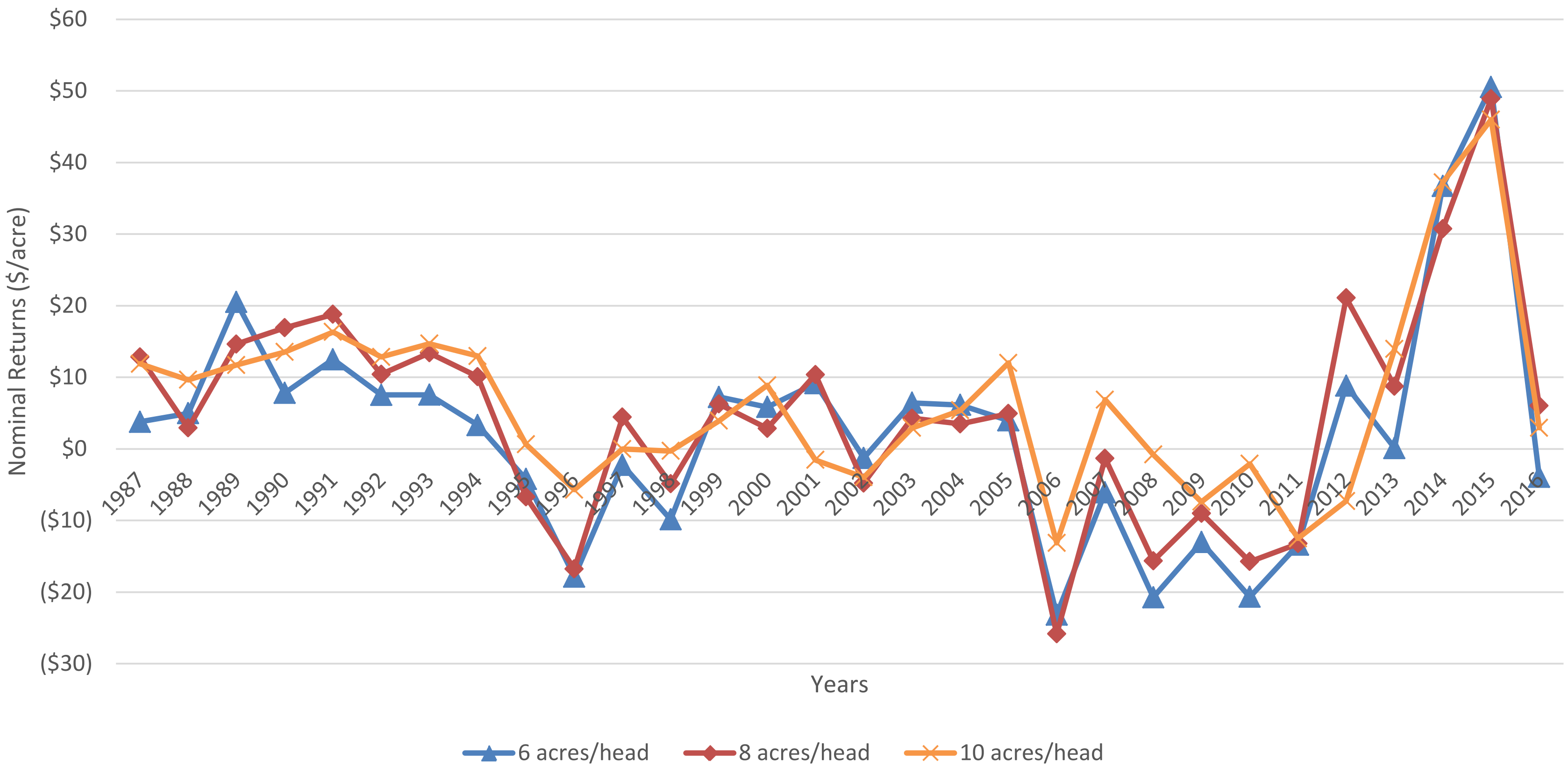

Figure 2. Graph of nominal returns per acre by year for culling 8, 9, and 10 year olds during forage deficit years.

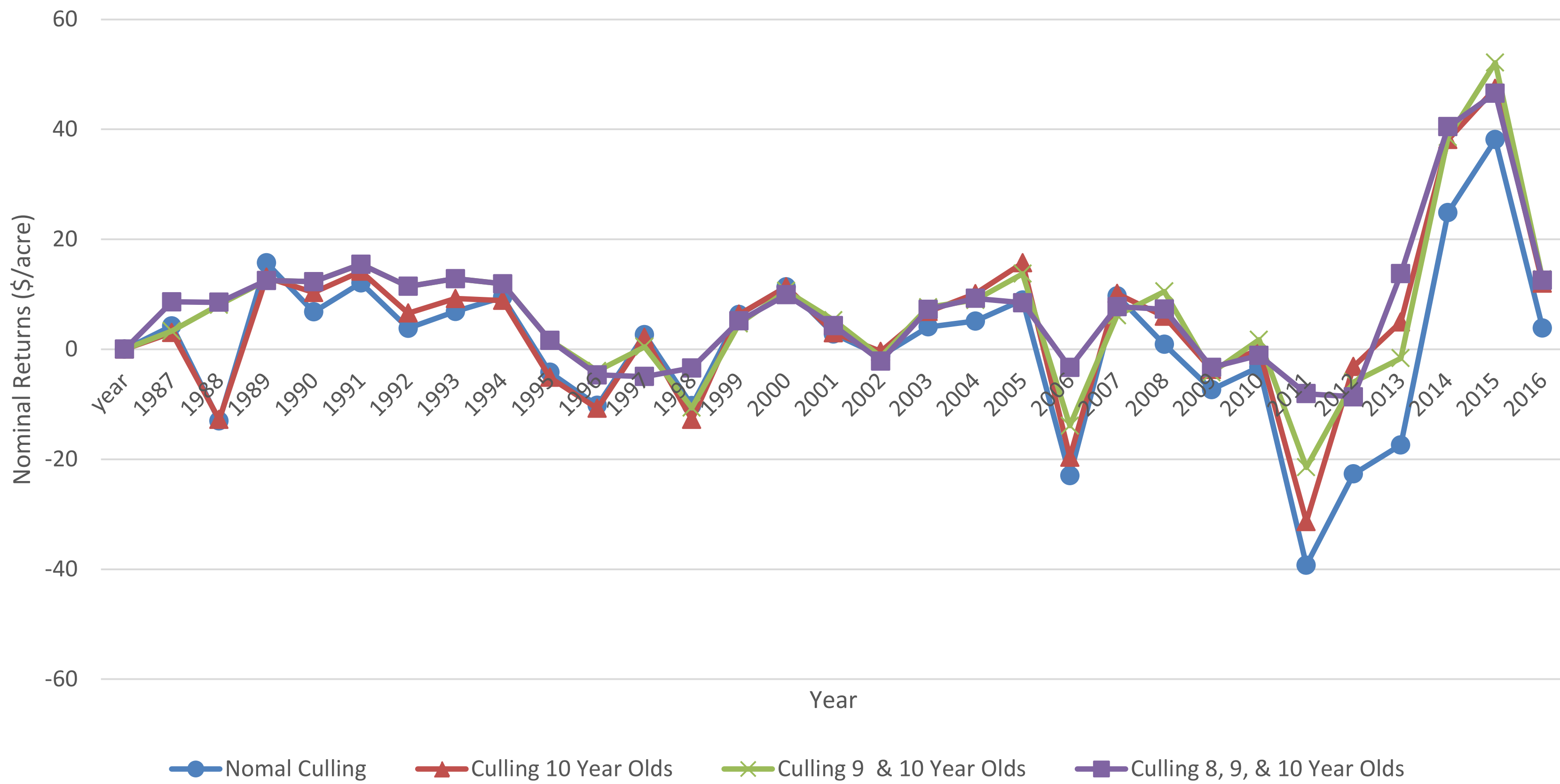

Figure 3. Graph of nominal returns by year for various culling strategies stocking at 11 acres/cow-calf pair.

CHAPTER V

CONCLUSIONS

Conclusion

Few studies have assessed economically-optimal stocking rates for cow-calf enterprises in the presence of drought. Since on cow-calf production practices are numerous due to the dynamics of environmental, biological, and market price relationships, deliberation of study assumptions and methodologies vary. This research builds on previous research considering dynamic relationship between weather and cow-calf production. The nonlinear relationship of forage yields, cow weights, calf birth weights, calf weaning weights, and herd management in this research provide a novel insight into the impacts of drought on profitability. Drought management scenarios common to U.S. Southern Plains beef cow-calf enterprises are assessed, including variations of early weaning calves, early/deep culling cows, purchasing hay by culling strategy in forage deficit years. An Angus spring calving herd consuming native range forage and hay was simulated for this study. Expected net present values for each drought management scenario in the model were computed with a 100-head herd of 1300-pound mature-weight cows.

The relationships of cow weight, calf birth weight and calf weaning weight were estimated using data from two Oklahoma research stations. Historical county hay yields for Payne County, Oklahoma were used to simulate the impacts of drought on cow-calf profitability under alternative management strategies. Data for cow-calf production from 2002 to 2016 included 3,020 observations and data for hay yields from 2016 – 2017 included 115 observations. Lalman and Gill's (2010) Cowculator software tool was used to calculate rations. Historical calf prices, cull cow prices, cull bull prices, and feed prices were utilized for the 30-year period simulated.

Results indicate expected NPVs are sensitive to forage yields per acre. Sensitivity analyses suggest producers with above average pasture yields are better able to withstand drought. Early weaning has negligible effects on ration needs, therefore early/deep culling is necessary to substantially reduce forage requirements. In years where a forage deficit occurs, it is more economically beneficial to deeply cull older cows rather than purchase hay.

Net present values per acre of each strategy were computed for a 30-year time frame. Results reveal stocking rates of 10 acres per cow or higher reduce the need for mitigating the effects of moderate drought years and reserve deeply culling the herd to only those years of severe drought. Herd reduction has higher economic returns than hay purchases, however deep culls reduce herd numbers for two to three years.

In years of forage surplus, the producer benefits from stockpiling hay and selling excess hay. Throughout the observation period, the producer is assumed to stockpile a maximum of 25% of the herd's grazing and 90-day hay period needs. In some years with yield surpluses, the producer also has the opportunity to winter graze cows for a portion or entirety of the 90-day feeding period, which allows surplus hay to be sold. The producer is assumed to feed stock-pile hay before feeding the current year's hay crop.

Results imply that expected NPV's are sensitive to hay sales. While stocking rates at 10 acres per cow or higher reduce the need for mitigating the effects of moderate drought, the highest expected returns occurred at 12.5 acres. Returns per acre at 11.5 acres per cow or higher were reasonably flat when the producer did not sell hay.

Implications

Results here and elsewhere (Gillard and Monypenny 1990; Torell et al. 2010; Ritten et al. 2010b) suggest stocking rates may be too high in drought-prone areas. All producers are acreage constrained in a given production year. If a producer chooses to stock heavily in years of surplus forage yields, then it is economically beneficial to reduce herd size by deeply culling and weaning early in years of forage deficit rather than purchasing feed to meet the herd's needs.

Actual forage yield data for both North Range and El Reno were not available. Concerns may arise with generalizing these results as average hay yields on the county level were used for two locations. These concerns were addressed with sensitivity analyses and similar conclusions reached. One additional concern is that the intertemporal impacts of overgrazing were not considered. Published research quantifying these impacts was not found. However, anecdotal evidence suggests that overgrazed pastures require more time, measured in years, to recover from drought. If that is the case, then the results here are conservative and reduced stocker rates are still recommended. The data used here come from moderately stocked pastures, so it was not possible to evaluate long-term impacts of overgrazing.

Study Limitations

Forage assumptions in terms of quality were assumed from research station publications, so the rations vary across Southern Plains producers. Further, cow breed and mature weight vary across producers. So, optimal stocking rates vary across producers in the region.

Data used in this research was from OSU North Range and El Reno. Both locations moderately stock cattle, therefore, caution should be used when interpreting findings of extreme stocking rates, both high and low. Range recovery was not considered in this study, however, anecdotal evidence suggests overstocking may require years of recovery post severe drought periods while lighter stocked pastures may recover quicker.

Finally, a risk-averse producer will not favor the wide range of returns that result from the deep cull strategies, specifically the deeper the age groups culled. It is likely risk -averse producers will stock at lower rates compared to risk-neutral producers to mitigate return variability caused by drought. However, this research did not explore risk aversion. A flexible stocking approach to stock heavier in surplus forage years and partially liquidate in forage deficit years may be an option for less risk-averse producers.

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APPENDICES

Table A1. Variable and fixed costs per cow by year

Year	Variable Costs[1]	Fixed Costs
1987	$153.14	$66.90
1988	$160.19	$69.98
1989	$166.07	$72.55
1990	$174.45	$76.20
1991	$170.33	$74.41
1992	$172.83	$75.50
1993	$174.30	$76.14
1994	$179.15	$78.26
1995	$184.74	$80.70
1996	$189.73	$82.88
1997	$186.35	$81.40
1998	$180.47	$78.84
1999	$187.82	$82.05
2000	$200.17	$87.44
2001	$188.26	$82.24
2002	$195.32	$85.32
2003	$205.02	$89.56
2004	$220.74	$96.43
2005	$239.55	$104.64
2006	$243.38	$106.31
2007	$262.48	$114.66
2008	$251.17	$109.72
2009	$261.75	$114.34
2010	$278.79	$121.79
2011	$293.64	$128.27
2012	$296.14	$129.36
2013	$296.87	$129.68
2014	$289.52	$126.47
2015	$269.68	$117.81
2016	$276.59	$120.82

Note: Adapted from Doye and Lalman (2011).
[1]Variable costs include pasture rental rates sourced from Doye and Sahs (2017) multiplied by the hay pasture available divided by the head in the baseline herd.

Table A2. Cull cow and bull prices

Year	July Cull Cow Prices ($/cwt)	July Cull Bull Prices ($/cwt)	October Cull Cow Prices ($/cwt)
1987	$39.13	$44.88	$36.40
1988	$40.34	$46.27	$39.01
1989	$43.41	$49.80	$39.12
1990	$45.85	$52.59	$42.99
1991	$47.03	$53.95	$40.15
1992	$50.33	$57.73	$49.54
1993	$49.54	$56.83	$45.81
1994	$45.69	$52.41	$39.00
1995	$41.00	$47.03	$34.13
1996	$33.63	$38.58	$33.00
1997	$40.75	$46.74	$34.50
1998	$31.25	$35.85	$27.75
1999	$38.50	$44.16	$35.25
2000	$43.00	$49.32	$37.50
2001	$44.75	$51.33	$39.50
2002	$36.75	$42.15	$35.50
2003	$45.54	$52.24	$49.75
2004	$58.25	$66.82	$51.25
2005	$56.13	$64.38	$50.25
2006	$47.75	$54.77	$49.00
2007	$59.50	$68.25	$49.50
2008	$60.00	$68.82	$48.00
2009	$45.00	$51.62	$44.25
2010	$55.25	$63.37	$56.00
2011	$69.25	$79.43	$61.50
2012	$81.75	$93.77	$75.25
2013	$80.25	$92.05	$82.50
2014	$120.50	$138.22	$117.00
2015	$113.75	$130.48	$80.75
2016	$76.75	$88.04	$58.75

USDA-AMS (2019b).

Table A3. October weaned heifer prices ($/head) by cow age distribution

	Dam Age								
Year	2 Yr. Old	3 Yr. Old	4 Yr. Old	5 Yr. Old	6 Yr. Old	7 Yr. Old	8 Yr. Old	9 Yr. Old	10 Yr. Old
1987	$247.12	$264.80	$278.41	$287.95	$293.68	$293.19	$288.63	$280.00	$267.29
1988	$266.24	$285.00	$299.45	$309.58	$315.66	$315.15	$310.31	$301.14	$287.64
1989	$292.39	$313.40	$329.59	$340.93	$347.74	$347.16	$341.74	$331.47	$316.36
1990	$291.66	$312.57	$328.68	$339.96	$346.73	$346.16	$340.77	$330.55	$315.52
1991	$338.79	$362.40	$380.57	$393.31	$400.96	$400.31	$394.22	$382.69	$365.72
1992	$297.97	$318.97	$335.13	$346.46	$353.26	$352.68	$347.27	$337.01	$321.92
1993	$303.89	$325.56	$342.24	$353.93	$360.95	$360.36	$354.77	$344.18	$328.60
1994	$270.39	$289.39	$304.02	$314.27	$320.42	$319.90	$315.00	$305.72	$292.06
1995	$214.53	$229.95	$241.82	$250.14	$255.13	$254.70	$250.73	$243.20	$232.12
1996	$167.14	$178.81	$187.80	$194.10	$197.87	$197.56	$194.55	$188.85	$180.45
1997	$284.84	$304.85	$320.27	$331.07	$337.55	$337.00	$331.84	$322.06	$307.67
1998	$225.52	$241.21	$253.30	$261.77	$266.85	$266.42	$262.37	$254.71	$243.42
1999	$268.81	$288.03	$302.82	$313.20	$319.42	$318.89	$313.94	$304.55	$290.73
2000	$348.58	$373.16	$392.08	$405.34	$413.30	$412.63	$406.29	$394.28	$376.61
2001	$313.88	$335.85	$352.77	$364.63	$371.75	$371.14	$365.48	$354.74	$338.94
2002	$283.97	$304.01	$319.45	$330.27	$336.76	$336.22	$331.04	$321.25	$306.83
2003	$312.70	$334.52	$351.33	$363.10	$370.17	$369.57	$363.95	$353.28	$337.59
2004	$387.23	$414.59	$435.65	$450.42	$459.27	$458.53	$451.47	$438.11	$418.43
2005	$445.73	$477.20	$501.43	$518.42	$528.61	$527.75	$519.63	$504.26	$481.63
2006	$430.27	$460.26	$483.35	$499.54	$509.25	$508.43	$500.69	$486.04	$464.48
2007	$393.31	$422.15	$444.35	$459.92	$469.26	$468.47	$461.03	$446.94	$426.20
2008	$339.86	$363.84	$382.31	$395.25	$403.02	$402.36	$396.18	$384.46	$367.21
2009	$309.56	$331.44	$348.27	$360.08	$367.16	$366.56	$360.92	$350.24	$334.51
2010	$373.31	$399.58	$419.80	$433.98	$442.49	$441.77	$435.00	$422.16	$403.27
2011	$441.30	$471.88	$495.43	$511.93	$521.83	$521.00	$513.11	$498.17	$476.18
2012	$565.63	$605.02	$635.34	$656.60	$669.36	$668.28	$658.12	$638.88	$610.56
2013	$519.83	$556.45	$584.64	$604.40	$616.26	$615.26	$605.82	$587.93	$561.60
2014	$847.01	$906.39	$952.11	$984.16	$1,003.38	$1,001.76	$986.44	$957.44	$914.74
2015	$847.94	$907.32	$953.04	$985.09	$1,004.31	$1,002.69	$987.38	$958.37	$915.67
2016	$487.26	$521.42	$547.72	$566.16	$577.22	$576.28	$567.47	$550.79	$526.23

Source: USDA-AMS (2019a).

Table A4. October weaned steer prices ($/head) by cow age distribution

	Dam Age								
Year	2 Yr. Old	3 Yr. Old	4 Yr. Old	5 Yr. Old	6 Yr. Old	7 Yr. Old	8 Yr. Old	9 Yr. Old	10 Yr. Old
1987	$324.93	$346.49	$363.09	$374.73	$381.71	$381.12	$360.27	$365.03	$349.52
1988	$349.32	$372.19	$389.80	$402.14	$409.55	$408.92	$403.02	$391.85	$375.41
1989	$371.62	$396.40	$415.47	$428.84	$436.87	$436.19	$429.80	$417.70	$399.88
1990	$370.16	$394.77	$413.72	$427.01	$434.98	$434.31	$427.96	$415.93	$398.23
1991	$407.08	$433.44	$453.74	$467.97	$476.51	$475.78	$468.99	$456.11	$437.15
1992	$350.32	$373.25	$390.89	$403.27	$410.69	$410.06	$404.15	$392.95	$376.47
1993	$373.69	$398.42	$417.45	$430.79	$438.80	$438.12	$431.75	$419.67	$401.89
1994	$333.35	$355.11	$371.86	$383.60	$390.65	$390.05	$384.44	$373.81	$358.17
1995	$270.12	$288.12	$301.98	$311.69	$317.52	$317.03	$312.39	$303.59	$290.65
1996	$204.40	$217.67	$227.88	$235.03	$239.33	$238.97	$235.55	$229.07	$219.53
1997	$376.30	$400.86	$419.77	$433.03	$440.98	$440.31	$433.98	$421.98	$404.31
1998	$269.70	$287.14	$300.58	$310.00	$315.65	$315.17	$310.67	$302.14	$289.60
1999	$328.81	$350.62	$367.42	$379.19	$386.25	$385.65	$380.03	$369.37	$353.69
2000	$417.20	$444.52	$465.55	$480.29	$489.14	$488.39	$481.34	$468.00	$448.36
2001	$419.96	$447.27	$468.30	$483.05	$491.89	$491.14	$484.10	$470.76	$451.11
2002	$351.54	$374.59	$392.33	$404.77	$412.23	$411.60	$405.66	$394.40	$377.83
2003	$377.22	$401.68	$420.52	$433.73	$441.65	$440.98	$434.67	$422.72	$405.12
2004	$477.74	$509.08	$533.21	$550.12	$560.27	$559.41	$551.33	$536.02	$513.49
2005	$540.40	$575.83	$603.11	$622.23	$633.70	$632.73	$623.60	$606.29	$580.81
2006	$547.18	$582.63	$609.92	$629.05	$640.53	$639.56	$630.42	$613.10	$587.61
2007	$460.28	$491.53	$515.60	$532.47	$542.59	$541.73	$533.67	$518.40	$495.93
2008	$414.45	$441.61	$462.52	$477.18	$485.98	$485.23	$478.23	$464.96	$445.43
2009	$368.09	$392.24	$410.83	$423.86	$431.68	$431.02	$424.80	$413.00	$395.64
2010	$476.98	$508.16	$532.16	$548.99	$559.08	$558.23	$550.19	$534.96	$512.54
2011	$547.34	$582.60	$609.75	$628.79	$640.21	$639.24	$630.15	$612.92	$587.56
2012	$688.79	$733.37	$767.70	$791.76	$806.19	$804.98	$793.48	$771.70	$739.64
2013	$584.30	$622.52	$651.95	$672.58	$684.96	$683.91	$674.06	$655.38	$627.90
2014	$1,063.66	$1,132.94	$1,186.28	$1,223.66	$1,246.10	$1,244.20	$1,226.33	$1,192.49	$1,142.68
2015	$1,125.59	$1,198.83	$1,255.21	$1,294.74	$1,318.45	$1,316.45	$1,297.56	$1,261.78	$1,209.12
2016	$607.99	$647.58	$678.07	$699.44	$712.27	$711.18	$700.97	$681.63	$653.15

Source: USDA-AMS (2019a).

Table A5. July weaned heifer prices ($/head) by cow age distribution

	Dam Age								
Year	2 Yr. Old	3 Yr. Old	4 Yr. Old	5 Yr. Old	6 Yr. Old	7 Yr. Old	8 Yr. Old	9 Yr. Old	10 Yr. Old
1987	$105.00	$122.67	$136.28	$145.82	$151.55	$151.06	$146.51	$137.87	$125.16
1988	$115.34	$123.82	$148.56	$158.69	$164.76	$164.25	$159.41	$150.24	$136.75
1989	$123.39	$138.22	$160.60	$171.94	$178.75	$178.17	$172.75	$162.48	$147.37
1990	$123.54	$137.56	$160.55	$171.84	$178.61	$178.03	$172.64	$162.43	$147.39
1991	$149.00	$156.21	$190.78	$203.52	$211.16	$210.52	$204.43	$192.90	$175.92
1992	$129.19	$138.52	$166.34	$177.67	$184.47	$183.90	$178.48	$168.23	$153.13
1993	$129.70	$142.65	$168.05	$179.74	$186.76	$186.16	$180.58	$169.99	$154.41
1994	$117.64	$125.43	$151.26	$161.52	$167.67	$167.15	$162.25	$152.97	$139.31
1995	$90.61	$101.37	$117.89	$126.21	$131.20	$130.78	$126.80	$119.27	$108.19
1996	$73.32	$77.17	$93.98	$100.27	$104.05	$103.73	$100.72	$95.02	$86.63
1997	$123.91	$132.15	$159.33	$170.14	$176.62	$176.07	$170.91	$161.13	$146.74
1998	$99.32	$103.91	$127.10	$135.57	$140.65	$140.22	$136.18	$128.51	$117.22
1999	$114.29	$126.48	$148.30	$158.68	$164.90	$164.37	$159.42	$150.03	$136.21
2000	$150.99	$162.14	$194.49	$207.75	$215.71	$215.04	$208.70	$196.69	$179.02
2001	$137.23	$145.20	$176.12	$187.97	$195.09	$194.49	$188.82	$178.09	$162.29
2002	$122.77	$132.23	$158.26	$169.08	$175.57	$175.02	$169.85	$160.06	$145.64
2003	$137.24	$144.34	$175.86	$187.64	$194.71	$194.11	$188.48	$177.82	$162.13
2004	$167.28	$180.41	$215.70	$230.47	$239.32	$238.58	$231.52	$218.16	$198.48
2005	$192.70	$207.56	$248.41	$265.39	$275.58	$274.72	$266.60	$251.23	$228.60
2006	$189.13	$198.44	$242.21	$258.40	$268.11	$267.29	$259.56	$244.90	$223.34
2007	$161.43	$189.17	$212.48	$228.04	$237.38	$236.59	$229.15	$215.06	$194.33
2008	$147.03	$158.20	$189.48	$202.43	$210.19	$209.54	$203.35	$191.64	$174.39
2009	$133.72	$144.23	$172.43	$184.23	$191.32	$190.72	$185.08	$174.39	$158.67
2010	$162.09	$173.38	$208.59	$222.77	$231.27	$230.56	$223.78	$210.95	$192.06
2011	$195.44	$202.95	$249.56	$266.07	$275.97	$275.13	$267.25	$252.31	$230.32
2012	$248.95	$260.70	$318.66	$339.92	$352.68	$351.60	$341.44	$322.20	$293.88
2013	$225.43	$241.62	$290.24	$310.00	$321.86	$320.86	$311.41	$293.53	$267.20
2014	$369.60	$392.24	$474.70	$506.75	$525.97	$524.35	$509.04	$480.03	$437.33
2015	$370.54	$392.35	$475.63	$507.68	$526.91	$525.28	$509.97	$480.96	$438.26
2016	$212.63	$225.64	$273.09	$291.52	$302.58	$301.65	$292.84	$276.15	$251.59

Source: USDA-AMS (2019a).

Table A6. July weaned steer prices ($/head) by cow age distribution

	Dam Age								
Year	2 Yr. Old	3 Yr. Old	4 Yr. Old	5 Yr. Old	6 Yr. Old	7 Yr. Old	8 Yr. Old	9 Yr. Old	10 Yr. Old
1987	$151.56	$173.13	$189.73	$201.37	$208.35	$207.76	$202.20	$191.66	$176.16
1988	$165.46	$188.32	$205.93	$218.28	$225.68	$225.06	$219.16	$207.99	$191.54
1989	$172.44	$197.21	$216.29	$229.66	$237.68	$237.00	$230.61	$218.51	$200.69
1990	$172.25	$196.86	$215.81	$229.10	$237.07	$236.40	$230.05	$218.02	$200.32
1991	$195.12	$221.49	$241.78	$256.01	$264.55	$263.83	$257.03	$244.15	$225.19
1992	$166.03	$188.95	$206.60	$218.97	$226.40	$225.77	$219.86	$208.66	$192.18
1993	$174.93	$199.65	$218.69	$232.03	$240.03	$239.36	$232.98	$220.91	$203.13
1994	$158.42	$180.18	$196.93	$208.67	$215.72	$215.12	$209.51	$198.88	$183.24
1995	$125.41	$143.41	$157.27	$166.98	$172.81	$172.32	$167.68	$158.88	$145.94
1996	$97.78	$111.04	$121.25	$128.41	$132.70	$132.34	$128.92	$122.44	$112.91
1997	$178.81	$203.37	$222.29	$235.54	$243.50	$242.83	$236.49	$224.49	$206.83
1998	$129.41	$146.86	$160.30	$169.71	$175.36	$174.88	$170.38	$161.86	$149.31
1999	$153.46	$175.27	$192.06	$203.83	$210.90	$210.30	$204.68	$194.02	$178.34
2000	$197.58	$224.90	$245.93	$260.67	$269.52	$268.77	$261.73	$248.38	$228.74
2001	$200.35	$227.67	$248.70	$263.44	$272.28	$271.54	$264.49	$251.15	$231.51
2002	$166.24	$189.29	$207.03	$219.47	$226.94	$226.31	$220.36	$209.10	$192.53
2003	$180.51	$204.98	$223.81	$237.02	$244.94	$244.27	$237.96	$226.01	$208.42
2004	$225.78	$257.11	$281.24	$298.16	$308.30	$307.45	$299.37	$284.06	$261.52
2005	$255.55	$290.98	$318.26	$337.38	$348.85	$347.88	$338.74	$321.44	$295.96
2006	$262.16	$297.61	$324.91	$344.04	$355.52	$354.55	$345.41	$328.09	$302.60
2007	$209.00	$240.25	$264.32	$281.18	$291.30	$290.45	$282.39	$267.12	$244.65
2008	$196.10	$223.25	$244.17	$258.82	$267.62	$266.88	$259.87	$246.60	$227.07
2009	$173.95	$198.09	$216.69	$229.72	$237.54	$236.88	$230.65	$218.85	$201.49
2010	$226.33	$257.50	$281.51	$298.33	$308.43	$307.58	$299.53	$284.30	$261.89
2011	$263.80	$299.07	$326.22	$345.25	$356.67	$355.71	$346.61	$329.39	$304.03
2012	$330.35	$374.93	$409.26	$433.32	$447.76	$446.54	$435.04	$413.26	$381.20
2013	$276.97	$315.20	$344.63	$365.26	$377.64	$376.59	$366.73	$348.06	$320.57
2014	$506.69	$575.96	$629.30	$666.69	$689.12	$687.23	$669.36	$635.52	$585.70
2015	$536.79	$610.02	$666.41	$705.93	$729.65	$727.65	$708.76	$672.98	$620.32
2016	$289.63	$329.22	$359.71	$381.08	$393.90	$392.82	$382.61	$363.27	$334.79

Source: USDA-AMS (2019a).

Table A7. Simulated Angus heifer birthweights (lbs.) by cow age distribution

	Dam Age								
Year	2 Yr. Old	3 Yr. Old	4 Yr. Old	5 Yr. Old	6 Yr. Old	7 Yr. Old	8 Yr. Old	9 Yr. Old	10 Yr. Old
1987	48.41	52.08	54.94	56.98	58.24	58.37	57.67	56.16	53.84
1988	48.64	52.31	55.17	57.21	58.48	58.60	57.90	56.39	54.07
1989	48.34	52.01	54.87	56.91	58.18	58.30	57.60	56.10	53.77
1990	48.38	52.05	54.91	56.95	58.21	58.33	57.64	56.13	53.80
1991	48.91	52.58	55.44	57.48	58.75	58.87	58.17	56.66	54.34
1992	48.65	52.32	55.18	57.22	58.49	58.61	57.91	56.40	54.08
1993	48.46	52.13	54.98	57.03	58.29	58.41	57.72	56.21	53.88
1994	48.71	52.38	55.23	57.27	58.54	58.66	57.97	56.46	54.13
1995	48.35	52.02	54.88	56.92	58.19	58.31	57.61	56.10	53.78
1996	48.86	52.53	55.38	57.42	58.69	58.81	58.12	56.61	54.28
1997	48.70	52.37	55.23	57.27	58.54	58.66	57.96	56.45	54.13
1998	48.95	52.62	55.47	57.52	58.78	58.90	58.21	56.70	54.37
1999	48.42	52.09	54.94	56.99	58.25	58.37	57.68	56.17	53.84
2000	48.64	52.31	55.17	57.21	58.47	58.59	57.90	56.39	54.06
2001	48.79	52.46	55.31	57.36	58.62	58.74	58.05	56.54	54.21
2002	48.61	52.28	55.14	57.18	58.45	58.57	57.87	56.36	54.04
2003	48.86	52.53	55.39	57.43	58.70	58.82	58.13	56.62	54.29
2004	48.60	52.27	55.13	57.17	58.44	58.56	57.86	56.35	54.03
2005	48.61	52.28	55.14	57.18	58.45	58.57	57.87	56.36	54.04
2006	48.90	52.57	55.43	57.47	58.73	58.85	58.16	56.65	54.33
2007	48.12	51.79	54.64	56.68	57.95	58.07	57.38	55.87	53.54
2008	48.62	52.29	55.15	57.19	58.46	58.58	57.88	56.37	54.05
2009	48.60	52.27	55.13	57.17	58.44	58.56	57.86	56.35	54.03
2010	48.67	52.35	55.20	57.24	58.51	58.63	57.94	56.43	54.10
2011	49.18	52.85	55.70	57.75	59.01	59.13	58.44	56.93	54.60
2012	48.93	52.60	55.46	57.50	58.77	58.89	58.19	56.68	54.36
2013	48.66	52.33	55.18	57.22	58.49	58.61	57.92	56.41	54.08
2014	48.75	52.42	55.28	57.32	58.59	58.71	58.01	56.50	54.18
2015	48.78	52.45	55.31	57.35	58.61	58.73	58.04	56.53	54.20
2016	48.75	52.42	55.28	57.32	58.59	58.71	58.02	56.51	54.18

Table A8. Simulated Angus steer birthweights (lbs.) by cow age distribution

	Dam Age								
Year	2 Yr. Old	3 Yr. Old	4 Yr. Old	5 Yr. Old	6 Yr. Old	7 Yr. Old	8 Yr. Old	9 Yr. Old	10 Yr. Old
1987	51.67	55.34	58.20	60.24	61.50	61.62	60.93	59.42	57.09
1988	51.90	55.57	58.43	60.47	61.73	61.86	61.16	59.65	57.33
1989	51.60	55.27	58.13	60.17	61.44	61.56	60.86	59.35	57.03
1990	51.64	55.31	58.16	60.21	61.47	61.59	60.90	59.39	57.06
1991	52.17	55.84	58.70	60.74	62.01	62.13	61.43	59.92	57.60
1992	51.91	55.58	58.44	60.48	61.75	61.87	61.17	59.66	57.34
1993	51.72	55.39	58.24	60.28	61.55	61.67	60.98	59.47	57.14
1994	51.96	55.63	58.49	60.53	61.80	61.92	61.22	59.71	57.39
1995	51.61	55.28	58.14	60.18	61.44	61.57	60.87	59.36	57.04
1996	52.11	55.78	58.64	60.68	61.95	62.07	61.37	59.86	57.54
1997	51.96	55.63	58.49	60.53	61.80	61.92	61.22	59.71	57.39
1998	52.21	55.88	58.73	60.78	62.04	62.16	61.47	59.96	57.63
1999	51.68	55.35	58.20	60.24	61.51	61.63	60.94	59.43	57.10
2000	51.90	55.57	58.43	60.47	61.73	61.85	61.16	59.65	57.32
2001	52.05	55.72	58.57	60.61	61.88	62.00	61.31	59.80	57.47
2002	51.87	55.54	58.40	60.44	61.71	61.83	61.13	59.62	57.30
2003	52.12	55.79	58.65	60.69	61.96	62.08	61.38	59.87	57.55
2004	51.86	55.53	58.39	60.43	61.70	61.82	61.12	59.61	57.29
2005	51.87	55.54	58.40	60.44	61.71	61.83	61.13	59.62	57.30
2006	52.16	55.83	58.69	60.73	61.99	62.11	61.42	59.91	57.58
2007	51.37	55.04	57.90	59.94	61.21	61.33	60.64	59.13	56.80
2008	51.88	55.55	58.41	60.45	61.72	61.84	61.14	59.63	57.31
2009	51.86	55.53	58.39	60.43	61.69	61.82	61.12	59.61	57.29
2010	51.93	55.60	58.46	60.50	61.77	61.89	61.19	59.68	57.36
2011	52.44	56.11	58.96	61.01	62.27	62.39	61.70	60.19	57.86
2012	52.19	55.86	58.72	60.76	62.02	62.15	61.45	59.94	57.62
2013	51.92	55.59	58.44	60.48	61.75	61.87	61.18	59.67	57.34
2014	52.01	55.68	58.54	60.58	61.85	61.97	61.27	59.76	57.44
2015	52.04	55.71	58.56	60.61	61.87	61.99	61.30	59.79	57.46
2016	52.01	55.68	58.54	60.58	61.85	61.97	61.27	59.76	57.44

Table A9. Simulated Angus heifer October weaning weights (lbs.) by cow age distribution

	Dam Age								
Year	2 Yr. Old	3 Yr. Old	4 Yr. Old	5 Yr. Old	6 Yr. Old	7 Yr. Old	8 Yr. Old	9 Yr. Old	10 Yr. Old
1987	276.70	296.49	311.73	322.41	328.82	328.28	323.17	313.50	299.27
1988	280.77	300.56	315.80	326.49	332.90	332.35	327.25	317.58	303.35
1989	275.33	295.12	310.36	321.05	327.46	326.91	321.81	312.14	297.91
1990	276.07	295.86	311.10	321.78	328.19	327.65	322.55	312.88	298.64
1991	284.07	303.86	319.10	329.78	336.19	335.65	330.54	320.88	306.64
1992	280.94	300.73	315.97	326.65	333.06	332.52	327.42	317.75	303.51
1993	277.63	297.42	312.66	323.34	329.75	329.21	324.10	314.43	300.20
1994	281.69	301.48	316.72	327.40	333.81	333.27	328.17	318.50	304.27
1995	275.48	295.28	310.52	321.20	327.61	327.07	321.96	312.29	298.06
1996	283.50	303.29	318.53	329.22	335.63	335.09	329.98	320.31	306.08
1997	281.66	301.45	316.69	327.37	333.78	333.24	328.14	318.47	304.23
1998	284.37	304.17	319.41	330.09	336.50	335.96	330.85	321.18	306.95
1999	276.84	296.63	311.87	322.55	328.96	328.42	323.31	313.65	299.41
2000	280.74	300.53	315.77	326.45	332.86	332.32	327.22	317.55	303.32
2001	282.75	302.54	317.78	328.47	334.88	334.33	329.23	319.56	305.33
2002	280.34	300.13	315.37	326.06	332.47	331.92	326.82	317.15	302.92
2003	283.60	303.39	318.63	329.32	335.73	335.18	330.08	320.41	306.18
2004	280.16	299.96	315.20	325.88	332.29	331.75	326.64	316.97	302.74
2005	280.33	300.13	315.37	326.05	332.46	331.92	326.81	317.14	302.91
2006	283.95	303.74	318.98	329.66	336.07	335.53	330.43	320.76	306.52
2007	269.93	289.72	304.96	315.64	322.05	321.51	316.40	306.73	292.50
2008	280.48	300.27	315.51	326.20	332.60	332.06	326.96	317.29	303.06
2009	280.15	299.94	315.18	325.86	332.27	331.73	326.63	316.96	302.72
2010	281.26	301.05	316.29	326.98	333.38	332.84	327.74	318.07	303.84
2011	285.63	305.43	320.66	331.35	337.76	337.22	332.11	322.44	308.21
2012	284.24	304.03	319.27	329.95	336.36	335.82	330.71	321.04	306.81
2013	280.99	300.78	316.02	326.70	333.11	332.57	327.47	317.80	303.57
2014	282.34	302.13	317.37	328.05	334.46	333.92	328.81	319.15	304.91
2015	282.65	302.44	317.68	328.36	334.77	334.23	329.13	319.46	305.22
2016	282.34	302.14	317.37	328.06	334.47	333.93	328.82	319.15	304.92

Table A10. Simulated Angus steer October weaning weights (lbs.) by cow age distribution

	Dam Age								
Year	2 Yr. Old	3 Yr. Old	4 Yr. Old	5 Yr. Old	6 Yr. Old	7 Yr. Old	8 Yr. Old	9 Yr. Old	10 Yr. Old
1987	298.26	318.06	333.30	343.98	350.39	349.85	330.71	335.07	320.84
1988	302.34	322.13	337.37	348.05	354.46	353.92	348.82	339.15	324.91
1989	296.90	316.69	331.93	342.61	349.02	348.48	343.38	333.71	319.47
1990	297.63	317.43	332.67	343.35	349.76	349.22	344.11	334.44	320.21
1991	305.63	325.43	340.67	351.35	357.76	357.22	352.11	342.44	328.21
1992	302.51	322.30	337.54	348.22	354.63	354.09	348.98	339.31	325.08
1993	299.19	318.98	334.22	344.91	351.32	350.77	345.67	336.00	321.77
1994	303.26	323.05	338.29	348.97	355.38	354.84	349.73	340.07	325.83
1995	297.05	316.84	332.08	342.77	349.17	348.63	343.53	333.86	319.63
1996	305.07	324.86	340.10	350.78	357.19	356.65	351.55	341.88	327.64
1997	303.22	323.02	338.26	348.94	355.35	354.81	349.70	340.03	325.80
1998	305.94	325.73	340.97	351.66	358.07	357.52	352.42	342.75	328.52
1999	298.40	318.20	333.44	344.12	350.53	349.99	344.88	335.21	320.98
2000	302.31	322.10	337.34	348.02	354.43	353.89	348.78	339.11	324.88
2001	304.32	324.11	339.35	350.03	356.44	355.90	350.80	341.13	326.89
2002	301.91	321.70	336.94	347.62	354.03	353.49	348.39	338.72	324.48
2003	305.17	324.96	340.20	350.88	357.29	356.75	351.65	341.98	327.74
2004	301.73	321.52	336.76	347.45	353.86	353.31	348.21	338.54	324.31
2005	301.90	321.69	336.93	347.62	354.02	353.48	348.38	338.71	324.48
2006	305.51	325.31	340.55	351.23	357.64	357.10	351.99	342.32	328.09
2007	291.49	311.28	326.52	337.21	343.62	343.08	337.97	328.30	314.07
2008	302.05	321.84	337.08	347.76	354.17	353.63	348.53	338.86	324.62
2009	301.72	321.51	336.75	347.43	353.84	353.30	348.19	338.52	324.29
2010	302.83	322.62	337.86	348.54	354.95	354.41	349.31	339.64	325.40
2011	307.20	326.99	342.23	352.91	359.32	358.78	353.68	344.01	329.78
2012	305.80	325.60	340.84	351.52	357.93	357.39	352.28	342.61	328.38
2013	302.56	322.35	337.59	348.27	354.68	354.14	349.03	339.37	325.13
2014	303.90	323.70	338.94	349.62	356.03	355.49	350.38	340.71	326.48
2015	304.21	324.01	339.25	349.93	356.34	355.80	350.69	341.02	326.79
2016	303.91	323.70	338.94	349.62	356.03	355.49	350.39	340.72	326.49

Table A11. Simulated Angus heifer July weaning weights (lbs.) by cow age distribution

	Dam Age								
Year	2 Yr. Old	3 Yr. Old	4 Yr. Old	5 Yr. Old	6 Yr. Old	7 Yr. Old	8 Yr. Old	9 Yr. Old	10 Yr. Old
1987	117.56	137.35	152.59	163.28	169.68	169.14	164.04	154.37	140.14
1988	121.64	130.58	156.67	167.35	173.76	173.22	168.11	158.44	144.21
1989	116.20	130.16	151.23	161.91	168.32	167.78	162.67	153.00	138.77
1990	116.93	130.21	151.96	162.65	169.06	168.51	163.41	153.74	139.51
1991	124.93	130.98	159.96	170.65	177.06	176.51	171.41	161.74	147.51
1992	121.80	130.60	156.84	167.52	173.93	173.39	168.28	158.61	144.38
1993	118.49	130.32	153.52	164.20	170.61	170.07	164.97	155.30	141.07
1994	122.55	130.68	157.59	168.27	174.68	174.14	169.03	159.36	145.13
1995	116.35	130.17	151.38	162.06	168.47	167.93	162.83	153.16	138.92
1996	124.37	130.89	159.40	170.08	176.49	175.95	170.84	161.18	146.94
1997	122.52	130.67	157.55	168.24	174.65	174.10	169.00	159.33	145.10
1998	125.24	131.03	160.27	170.95	177.36	176.82	171.72	162.05	147.81
1999	117.70	130.26	152.73	163.42	169.82	169.28	164.18	154.51	140.28
2000	121.60	130.58	156.64	167.32	173.73	173.19	168.08	158.41	144.18
2001	123.62	130.79	158.65	169.33	175.74	175.20	170.09	160.42	146.19
2002	121.21	130.54	156.24	166.92	173.33	172.79	167.68	158.01	143.78
2003	124.47	130.91	159.50	170.18	176.59	176.05	170.94	161.27	147.04
2004	121.03	130.53	156.06	166.74	173.15	172.61	167.51	157.84	143.60
2005	121.20	130.54	156.23	166.91	173.32	172.78	167.68	158.01	143.77
2006	124.81	130.96	159.84	170.53	176.94	176.39	171.29	161.62	147.39
2007	110.79	129.82	145.82	156.50	162.91	162.37	157.27	147.60	133.37
2008	121.35	130.56	156.38	167.06	173.47	172.93	167.82	158.15	143.92
2009	121.01	130.53	156.04	166.73	173.14	172.60	167.49	157.82	143.59
2010	122.13	130.63	157.16	167.84	174.25	173.71	168.60	158.93	144.70
2011	126.50	131.36	161.53	172.21	178.62	178.08	172.97	163.31	149.07
2012	125.10	131.00	160.13	170.82	177.22	176.68	171.58	161.91	147.68
2013	121.85	130.60	156.89	167.57	173.98	173.44	168.33	158.66	144.43
2014	123.20	130.75	158.23	168.92	175.32	174.78	169.68	160.01	145.78
2015	123.51	130.78	158.54	169.23	175.64	175.09	169.99	160.32	146.09
2016	123.21	130.75	158.24	168.92	175.33	174.79	169.68	160.02	145.78

Table A12. Simulated Angus steer July weaning weights (lbs.) by cow age distribution

	Dam Age								
Year	2 Yr. Old	3 Yr. Old	4 Yr. Old	5 Yr. Old	6 Yr. Old	7 Yr. Old	8 Yr. Old	9 Yr. Old	10 Yr. Old
1987	139.13	158.92	174.16	184.84	191.25	190.71	185.60	175.94	161.70
1988	143.20	162.99	178.23	188.92	195.33	194.78	189.68	180.01	165.78
1989	137.76	157.56	172.79	183.48	189.89	189.35	184.24	174.57	160.34
1990	138.50	158.29	173.53	184.21	190.62	190.08	184.98	175.31	161.07
1991	146.50	166.29	181.53	192.21	198.62	198.08	192.98	183.31	169.07
1992	143.37	163.16	178.40	189.08	195.49	194.95	189.85	180.18	165.95
1993	140.06	159.85	175.09	185.77	192.18	191.64	186.53	176.86	162.63
1994	144.12	163.91	179.15	189.84	196.24	195.70	190.60	180.93	166.70
1995	137.91	157.71	172.95	183.63	190.04	189.50	184.39	174.72	160.49
1996	145.93	165.73	180.97	191.65	198.06	197.52	192.41	182.74	168.51
1997	144.09	163.88	179.12	189.80	196.21	195.67	190.57	180.90	166.66
1998	146.81	166.60	181.84	192.52	198.93	198.39	193.28	183.61	169.38
1999	139.27	159.06	174.30	184.98	191.39	190.85	185.75	176.08	161.84
2000	143.17	162.96	178.20	188.89	195.29	194.75	189.65	179.98	165.75
2001	145.18	164.97	180.21	190.90	197.31	196.77	191.66	181.99	167.76
2002	142.77	162.57	177.81	188.49	194.90	194.36	189.25	179.58	165.35
2003	146.03	165.82	181.06	191.75	198.16	197.61	192.51	182.84	168.61
2004	142.60	162.39	177.63	188.31	194.72	194.18	189.07	179.40	165.17
2005	142.76	162.56	177.80	188.48	194.89	194.35	189.24	179.57	165.34
2006	146.38	166.17	181.41	192.09	198.50	197.96	192.86	183.19	168.95
2007	132.36	152.15	167.39	178.07	184.48	183.94	178.83	169.17	154.93
2008	142.91	162.70	177.94	188.63	195.04	194.49	189.39	179.72	165.49
2009	142.58	162.37	177.61	188.29	194.70	194.16	189.06	179.39	165.16
2010	143.69	163.48	178.72	189.41	195.82	195.27	190.17	180.50	166.27
2011	148.06	167.86	183.10	193.78	200.19	199.65	194.54	184.87	170.64
2012	146.67	166.46	181.70	192.38	198.79	198.25	193.14	183.48	169.24
2013	143.42	163.21	178.45	189.14	195.54	195.00	189.90	180.23	166.00
2014	144.77	164.56	179.80	190.48	196.89	196.35	191.25	181.58	167.34
2015	145.08	164.87	180.11	190.79	197.20	196.66	191.56	181.89	167.65
2016	144.77	164.57	179.81	190.49	196.90	196.36	191.25	181.58	167.35

Table 13A. Annual cow feed requirements by culling and weaning strategy in pounds per cow

	Strategy	Normally Wean Normally Cull	Early Wean Cull 10 yr. olds	Early Wean Cull 9 & 10 yr. olds	Early Wean Cull 8, 9 & 10 yr. olds
Age	Feed				
1	Native forage	9509	9509	9509	9509
	Cubes	32	32	32	32
	Hay	0	0	0	0
2	Native forage	11496	11496	11496	11496
	Cubes	331	331	331	331
	Hay	0	0	0	0
3	Native forage	11825	11825	11825	11825
	Cubes	354	354	354	354
	Hay	0	0	0	0
4	Native forage	12176	12176	12176	12176
	Cubes	372	372	372	372
	Hay	0	0	0	0
5	Native forage	12543	12543	12543	12543
	Cubes	384	384	384	384
	Hay	0	0	0	0
6	Native forage	13013	13013	13013	13013
	Cubes	392	392	392	392
	Hay	0	0	0	0
7	Native forage	13013	13013	13013	13013
	Cubes	392	392	392	392
	Hay	0	0	0	0
8	Native forage	13013	13013	13013	6907
	Cubes	392	392	392	392
	Hay	0	0	0	0
9	Native forage	13013	13013	6907	6907
	Cubes	392	392	392	392
	Hay	0	0	0	0
10	Native forage	13013	6907	6907	6907
	Cubes	392	392	392	392
	Hay	0	0	0	0

Table 14A. Feed prices

Year	Native Hay[1] ($/ton)	Wheat Mids[2] ($/ton)	Cotton Seed[3] ($/ton)	Molasses[4] ($/ton)	20% Range Cube ($/ton)[5]
1987	$51.75	$53.54	$178.85	$75.62	$92.58
1988	$62.50	$71.38	$228.35	$92.81	$120.09
1989	$62.75	$85.85	$172.46	$82.49	$112.26
1990	$58.17	$64.80	$173.42	$79.74	$98.51
1991	$53.33	$60.53	$170.86	$87.65	$95.13
1992	$46.67	$74.83	$169.27	$77.34	$103.82
1993	$52.50	$67.26	$199.61	$99.68	$108.76
1994	$61.17	$74.11	$164.48	$87.65	$102.19
1995	$57.08	$90.60	$212.38	$127.18	$129.00
1996	$59.67	$108.29	$218.77	$99.68	$141.85
1997	$57.83	$80.11	$204.40	$91.43	$118.50
1998	$59.08	$60.47	$153.30	$72.18	$89.25
1999	$53.50	$51.05	$138.93	$67.03	$78.44
2000	$52.33	$53.74	$135.73	$72.18	$79.41
2001	$59.00	$61.06	$137.33	$72.18	$84.75
2002	$59.58	$73.58	$175.65	$84.21	$105.15
2003	$54.42	$72.13	$236.33	$89.37	$122.93
2004	$48.75	$76.70	$182.04	$86.96	$109.26
2005	$52.17	$72.26	$174.06	$82.15	$103.73
2006	$80.00	$98.23	$202.80	$108.96	$130.57
2007	$78.42	$130.77	$319.37	$139.90	$188.79
2008	$86.08	$165.26	$290.63	$153.30	$203.27
2009	$76.67	$109.59	$300.21	$127.52	$168.49
2010	$75.33	$111.68	$364.08	$160.18	$190.43
2011	$96.67	$162.92	$380.05	$213.80	$230.94
2012	$122.92	$164.91	$459.89	$241.98	$257.57
2013	$105.08	$158.22	$411.99	$174.96	$236.42
2014	$90.25	$143.97	$316.18	$141.27	$196.61
2015	$78.00	$111.65	$281.05	$135.08	$164.22
2016	$78.00	$79.30	$300.21	$116.52	$148.07

Sourced: Wheat mids, cotton seed, and molasses data from Bir et al. (2018) was used for the calibration figures to create the range cube.
Corresponding Prices were sourced from: [1]Oklahoma Native Hay Prices from USDA-NASS (2019b); [2]Oklahoma Wheat Prices from USDA-NASS (2019c); [3]Oklahoma Soybean Prices from USDA-NASS (2019d); [4]Oklahoma Corn Prices from USDA-NASS (2019e).
[5]20% range cubes are a composite of wheat mids, cotton seed, and molasses prices.

Table 15A. Normal cull rate

Cow Age	Probability of being culled
1	0.000
2	0.049
3	0.123
4	0.072
5	0.141
6	0.121
7	0.086
8	0.114
9	0.168
10	0.125

Note: Adapted from Azzam et al. (1990)

Table 16A. Normal heifer retention

Cows Age	2 yr. old	3 yr. old	4 yr. old	5 yr. old	6 yr. old	7 yr. old	8 yr. old	9 yr. old	10 yr. old
Number of cows	17	15	13	12	11	9	9	8	6
Weaning Rate	0.4155	0.4155	0.4155	0.4155	0.4155	0.4155	0.4155	0.4155	0.4155
Heifers Weaned	7	6	5	5	5	4	4	3	2
Heifers Retained	0	2	2	2	2	2	2	3	2
Heifers for Sale	7	4	3	3	3	2	2	0	0

Table 17A. Cows herd number in the baseline scenario based on the forage deficit culling decision by culling and weaning strategy

Year	Normal Wean Normal Cull	Early Wean Cull 10 yr. olds	Early Wean Cull 9 & 10 yr. olds	Early Wean Cull 8, 9 & 10 yr. olds
1987	100	100	100	100
1988	100	100	100	86
1989	100	83	77	77
1990	100	68	68	68
1991	100	82	76	76
1992	100	87	85	82
1993	100	88	85	83
1994	100	94	91	90
1995	100	100	99	96
1996	100	100	97	93
1997	100	83	86	83
1998	100	98	98	95
1999	100	86	80	95
2000	100	67	70	84
2001	100	81	79	85
2002	100	86	89	86
2003	100	85	86	67
2004	100	90	91	75
2005	100	97	98	84
2006	100	98	100	91
2007	100	96	97	87
2008	100	86	88	80
2009	100	100	100	89
2010	100	100	100	97
2011	100	82	81	100
2012	100	92	83	79
2013	100	76	74	71
2014	100	59	57	56
2015	100	68	66	65
2016	100	74	73	70

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