THE EFFECTS OF CHRONOLOGICAL AGE, WEANING WEIGHT, AND AGE OF DAM ON ANGUS STAYABILITY AND LIFETIME EARNINGS

A Thesis

Presented to the

Faculty of the College of Graduate Studies and Research

Angelo State University

In Partial Fulfillment of the

Requirements for the Degree

MASTER OF SCIENCE

by

LANDON CODY WEBB

December 2019

Major: Animal Science

THE EFFECTS OF CHRONOLOGICAL AGE, WEANING WEIGHT, AND AGE OF DAM ON ANGUS STAYABILITY AND LIFETIME EARNINGS

by

LANDON CODY WEBB

APPROVED:

Dr. Chase Runyan

Dr. Micheal Salisbury

Dr. Loree Branham

Dr. Tia Agan

December 2019

APPROVED:

Dr. Micheal Salisbury
Dean, College of Graduate Studies and Research

ACKNOWLEDGEMENTS

I would like to extend my deepest gratitude to my committee members Dr. Chase Runyan, Dr. Micheal Salisbury, Dr. Loree Branham, and Dr. Tia Agan. It has been with their help this has all been possible. I would also like to thank my employer, Texas Scottish Rite Hospital/Rocker b Ranch for allowing me the time to pursue this endeavor. Last, but not least I would like to thank my family, especially my wife Sarah for continued encouragement and support. Many people have helped me along the way, and I will forever be indebted to them; what a long strange trip it has been.

ABSTRACT

The primary objective of this study was to examine whether chronological age or weaning weight status is a more important measure of a cow's lifetime productivity and profitability (LIFETIMEEARN). A secondary interest was investigating the stayability performance of heifers out of first calf heifers compared to heifers out of mature cows (HFC). Calving and weaning records of registered Angus cows (n = 224) from the Angelo State University ranch were compiled and sorted by varying effects (weaning weight, calving order, calving block, and age of dam). Only weaning weight (WWTBLOCK) was statistically significant ($P = 0.02$) for LIFETIMEEARN, with heavier calves at weaning earning more. Stayability in this study was defined as a female reaching four years of age and weaning three or more calves (3CALV). Terms that affect stayability were WWTBLOCK ($P = 0.025$) and CALVBLOCK ($P = 0.038$). The HFC variable had no effect on stayability ($P = 0.42$). In selecting replacement heifers these data showed it to be preferential to choose those heaviest at weaning and born early in the calving season; without regard to the age of the dam.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Heifer development is a vital part of the beef industry and is of high economic importance. The traditional ideas of developing to a particular target weight without respect to a minimum chronological age are likely out of date. Larger mature cow size, improved genetics, and changes in feedstuff availability have made lower target weights feasible, and in some production systems preferred. Cow longevity, or lifetime productivity, is economically vital but has low heritability and research is limited regarding the link between cow longevity and heifer development (Endecott et al., 2013). It can be difficult to observe and manage the changes in and effects on fertility on an annual basis. However, taking data from multiple years and pooling it to create a larger data set enables reproductive performance to be examined (Osoro and Wright, 1992). There is contention in the literature as to how one should gauge female fertility (Bormann and Wilson, 2010), as well recent ideas on how to develop heifers, such as what to weight they should be developed too (Endecott et al., 2013). Therefore, the objectives are to investigate whether chronological age or weight gain status is a more important measure of a cow's lifetime productivity. It is also worth investigating the stayability performance of heifers out of first calf heifers compared to heifers out of mature cows, due to a dearth of information regarding this comparison in the literature.

Journal of Animal Science

LITERATURE REVIEW

Cow longevity, or stayability, in a herd can be described as the ability of a female to produce a calf every 365 days for an extended period. Cow productivity begins with selecting a heifer development system. The two prevailing development intensive and extensive systems in the industry are high rates of gain in a dry lot setting and lower rates of gain in more grazing predominate system, respectively. Endecott et al. (2013) argued that genetics have changed in the general cattle population over the previous four decades, and managers need to understand that management practices will affect not just one reproduction cycle, but lifetime productivity. Research on heifer development systems and the associated impact on cow longevity are limited in the literature (Endecott et al., 2013). Most studies in the past focused on feeding heifers to a particular body weight (BW) percentage, often 60%-65% of the mature weight. This post-weaning feeding period was used to induce an earlier pubertal status (Arije and Wiltbank, 1971; Short and Bellows, 1971; Laster et al., 1972). Lancaster et al. (2017) stated that as post-weaning average daily gain (ADG) goes up, age at puberty comes down. As noted by Endecott (2013), recent studies in the last decade have shown the feasibility of developing heifers to a lighter BW (50-57%) without affecting reproductive performance. It is likely that feeding to attain a higher percentage of the mature body weight is not feasible due to reduced availability of traditionally used cheap feeds (Endecott et al., 2013) combined with the 30% increase in cow size over the last few decades (Beck et al., 2017).

Whereas BW may be the most important factor influencing pubertal status in heifers, chronological age also plays a role (Lancaster et al., 2017). Before a heifer can become pubertal she must reach a target weight and a minimum age (Short et al., 1994). Lancaster et al. (2017) recommended a minimum age of 412 days. Lesmeister et al. (1973) noted that early calving heifers had a greater lifetime production and had a tendency to calve earlier for the entirety of their productive lifespan compared to the first calf heifers that calved later in the season. The same early calving cows will also produce more kilograms of calf weight during their productive lifespan, compared to the later calving heifers (Lesmeister et al., 1973). This difference in weight of calves was addressed by Funston and Deutscher (2004) who explained this was a result of the calf being older and having more nutrient availability prior to weaning.

It is important to note the difference between age at first calving (AFC) and calving day (CD). Age at first calving is the age of the female at the time of her first calving and involves puberty and, the ability to conceive, gestate, and deliver a calf (Bormann and Wilson, 2010). Adversely, CD assigns a number to each female based on the day she calves within the season compared to her contemporaries (first calf born= 1, next day=2, etc.). An earlier AFC was shown to result in an increased number of calvings (Nc) over a cow's lifetime (Lopez-Paredes et al., 2018). The same study showed no clear tendency in BW or carcass traits but did note that longevity, measured as Nc, was likely not accurately represented in the study due to the marketing of adults as slaughter animals. The proposed study would allow for a better analysis of Nc as a predictive measure.

Heritability estimates for traits in livestock are measured on a scale of 0.00 to 1.00 with the closer to 1.0 an estimate is, the more heritable it is. Heritability estimates for AFC range widely from 0.09 to 0.66 (Bormann and Wilson, 2010; Berry and Evans, 2014; Chiaia et al., 2015; Lopez-Paredes et al., 2018). There is a potential pitfall in selecting solely on AFC that comes as a result of inadvertently selecting the youngest born calves. These later born calves would be younger compared to their contemporaries at the time of breeding. Bormann and Wilson (2010) explained that later calving dams had heifers that were born later and thus had a better chance to be younger when they were bred. Furthermore, Bormann and Wilson (2010) argued that the use of CD was preferred as a selection tool over AFC. This was because of the aforementioned pitfall of selecting younger animals with a lower AFC. The earlier in the season a heifer can calve, the greater her potential longevity relative to heifers that calved later in the season. It is important to note that this metric is purely CD, not AFC (Endecott et al., 2013). It is possible that despite an intensive feeding program, a heifer is simply not old enough to conceive, carry, and deliver a calf.

In a study of heifers developed to the same target weight, but bred to calve at differing times, it was noted that the heifers that were older at the time of parturition had fewer dystocia issues (Funston and Deutscher, 2004). It was also noted that this difference in dystocia was not due to smaller calf birth weights and that the later calving cows had larger pre-breeding pelvic areas. Funston and Deutscher (2004) also noted that the later calving heifers were developed at both a decreased rate of gain and at a decreased cost. Cows with a later AFC showed greater calving ease, and cows with higher skeletal development at weaning tended to have earlier AFC (Lopez-Paredes et al., 2018). The case for using CD as a selection tool was made by Bormann and Wilson (2010) by stating that in spite of decreased heritability of CD, it does not have the associated downside of selecting younger heifers with respect to when they were born in the calving season. Bormann and Wilson (2010) also noted that calving day data is easy to collect, needing only the birth date of the calf as well as that of their contemporaries; they also pointed out an economic upside in that early calving cows have an additional opportunity to breed in a standard calving season and remain productive herd members. Heifers that become pregnant and calve at the immediate start of the breeding season show the greatest lifetime potential and reproductive efficiency (Lesmeister et al., 1973).

It is important to consider economic ramifications of heifer development systems, as well as their possible impact on cow longevity. The general theme of the research available indicates a preference toward early calving, allowing for more calves across a dam's productive lifetime. While reproductive traits typically have low heritability, carcass traits are typically much more heritable. Lopez-Parades et al. (2018) showed that the replacement rate expressed in number of replacements was 1.4% higher for late AFC cows. This study also showed no effect on carcass traits, regardless of AFC. It is important to note that the Lopez-Paredes et al. (2018) study promoted lowering the AFC in Spain from three years old to two years old, as practiced in the United States. A study in New Mexico revealed no reproductive performance difference in heifers developed to either 53% or 58% of their mature body weight, but there was additional cost in developing to 58% (Funston and Deustcher, 2004). A greater gross return was noted when developing heifers on a lower rate of gain or on a more extensive management plan (Endecott et al., 2013). Chiaia et al. (2015) stated that replacement heifers should be selected under the same management and environmental conditions that their progeny will be reared, giving credence to the idea of lower gain and target weight.

Another concern in heifer development is the performance of a heifer's calf, especially if it is a female (HFC). Conventional management practices have encouraged the producer to sell this progeny as it is thought that it will never perform as well as its contemporaries. In a review of the literature, there is little research to reflect this.

MATERIALS AND METHODS

The cow herd at Angelo State University consists of registered Black Angus (*Bos taurus*) animals. These animals are produced both for research purposes, as well as sale to the general public. The ranch the cow herd is located on is located in Tom Green County, which is a mostly flat and semi-arid area of Texas. The cattle split their time grazing native rangelands and improved pastures, while being supplemented with custom rations.

Calving data and weaning weight data from 2005 – 2018 were compiled into a multi-year analysis to evaluate the probabilities and impacts of interest in this study. These data were derived from records obtained from the Angelo State University Angus herd. Only data from registered Angus animals was examined. These data were originally collected on site by student research assistants over multiple years.

Multiple models were incorporated to determine the most suitable analysis based on data completeness. Proc Mixed models of SAS 9.4 (SAS Inst., Inc., Cary, NC) was used to detect differences in lifetime earning potential using a model that included, actual weaning weight blocks (WWGTBLOCK), age of dam (AOD), calving order (CD), calving block within year (CALVBLOCK), and interactions as model terms. The CALVBLOCK effect consisted of splitting the calving season into three blocks. These blocks were each 21 days long and were defined as such: Early (days 1-21), Intermediate (days 22-42), and Late (day 42+). The CD effect took each calf and assigned it a sequential number, starting with 1 for the first calf born that season. This numbering system continued throughout the season with each additional calf receiving a larger number, reflecting birth later into the calving season. Additional analysis included the Proc Logistic regression procedure to analyze binary data of cow longevity (cows that have achieved 4 years of age or older and 3 calves or more yes=1, no=0). Terms included body weight blocks (WWGTBLOCK), calving order within season (CALVEORDER), and age of dam within year (AOD) to detect differences in physiological growth vs chronological age effects on cow longevity. In these data the standard deviation for actual weaning weight of all females in all years was 38.74 kgs and the Heavy WWGTBLOCK only includes those females whose actual weaning weights were one (1) standard deviation or greater above the true mean and the Light WWGTBLOCK included females whose actual weaning weights were one (1) standard deviation or lower than the true mean of the data. The Intermediate weight block included females +/- < 1 standard deviation from the mean. Calving block was determined within each year by separating the calving season into 21-day increments. In the Proc Logistics analysis, probability plots of predicted estimates were evaluated. Differences between groups were evaluated using a pre-determined α of 0.05 or less.

Initially, multiple model effects and interactions were included in the preliminary analysis. Then, a backward stepwise model selection procedure was used to sequentially remove terms that resulted in $P \geq 0.50$ until the appropriate term and interactions of interest in this study were remaining. Model terms that were removed included actual weaning weight (WWT) as a covariate, WWGTBLOCK × CALVEORDER, WWGTBLOCK × AOD, CALVEBLOCK × AOD.

RESULTS

Life Time Earning Analysis

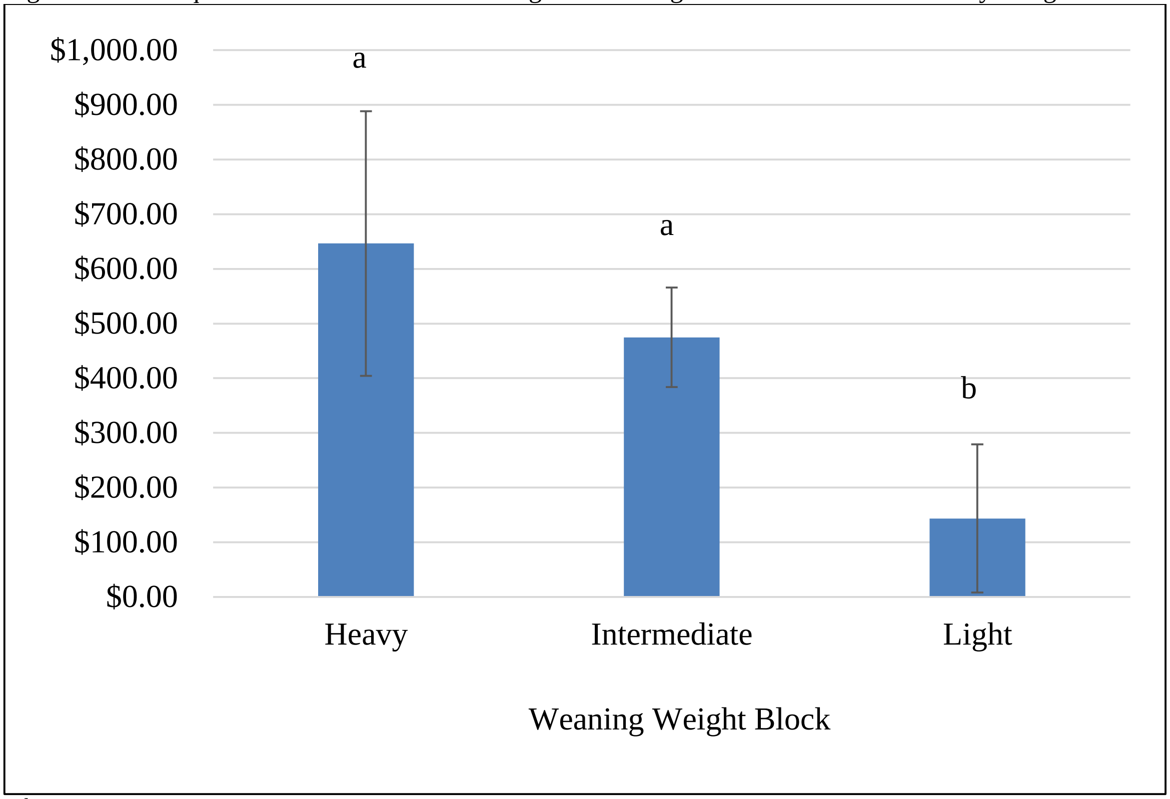
In these data, Life Time Earning (LIFETIMEEARN) is a dependent variable that was tabulated by multiplying the number of weaned calves a cow has produced by a profit per cow per year estimate ($195.00). The profit per cow estimate is reflective of all U.S. cattle herds from 2005 – 2019 and is compiled by economic research data available by CattleFax (CattleFax Outlook and Trends, 2019), Sterling Marketing Economic Research and Advisory (Nalivka, 2019), and Drover's Profit Tracker (Henderson, 2019). The LIFETIMEEARN variable was analyzed with a mixed model procedure and included Wean Weight Block (WWTBLOCK), calving block within year (CALVEBLOCK), calving order within year (CALVEORDER), Age of Dam (AOD), and the WWGTBLOCK × CALVEBLOCK interaction. Significance levels of the main effects and the interaction term of the mixed model analysis are presented in Table 1. While this model resulted in WWTBLOCK as the single *P* – value of less than 0.05, AOD, as a main effect, approached significance, but no other model term or interaction was a source of significant variation.

Table 1. Significance levels (*P*-values) for effects in the Life Time Earning model of ASU Angus cattle from 2005-2018

Effect	*P*-values
Weaning Weight Block within year (WWGTBLOCK)	0.02
Calving Block within year (CALVEBLOCK)	0.97
Calving Order within year (CALVEORDER)	0.42
Age of Dam (AOD)	0.17
WWGTBLOCK × CALVEBLOCK	0.99

The least squares mean of LIFETIMEEARN for the WWGTBLOCK analysis is presented in figure 1.

Figure 1. Least Squares Mean of Lifetime Earning of ASU Angus Cattle from 2005-2018 by Weight Block



[a, b] superscripts designate differences ($P \leq 0.05$)

In these data, females in the Light WWGTBLOCK were significantly lower than the Heavy and Intermediate WWGTBLOCK for LIFETIMEEARN, which confirms Carpenter and Hogan. (2018). Although it was not in the scope of this analysis, the Pearson's Correlation Coefficient between the WWGTBLOCK and the CALVEBLOCK variables was 0.39. This was somewhat lower than expected because it is reasonable to extrapolate that females that are born earlier in the calving season should be older and therefore heavier at weaning; which would imply that more of the early born females should be in the Heavy WWGTBLOCK designation. A reason why these data may deviate from this assumption could be due to the blocking system used for analysis. In these data the standard deviation for actual weaning weight of all females in all years is 38.74 kgs and the Heavy WWGTBLOCK only includes those females whose actual weaning weights are one (1) standard deviation or greater above the true mean. Also, the actual age in days of the females at the time of weaning would be a preferred variable to consider in these data, but specific information on weaning dates from 2005 – 2018 was unavailable and therefore actual age in days from birth to weaning was unavailable at the time of this analysis.

Three or More Calves Weaned

Brigham et al. (2007) claimed that cow longevity and overall lifetime profit potential is greater for females that achieve 4 years of age and have weaned 3 or more calves. The Proc Freq model statements of SAS were used to examine the Chi Square (χ^2) analysis of the distribution tables of Three or More Calves (yes or no) by WWGTBLOCK and results are presented in Table 2.

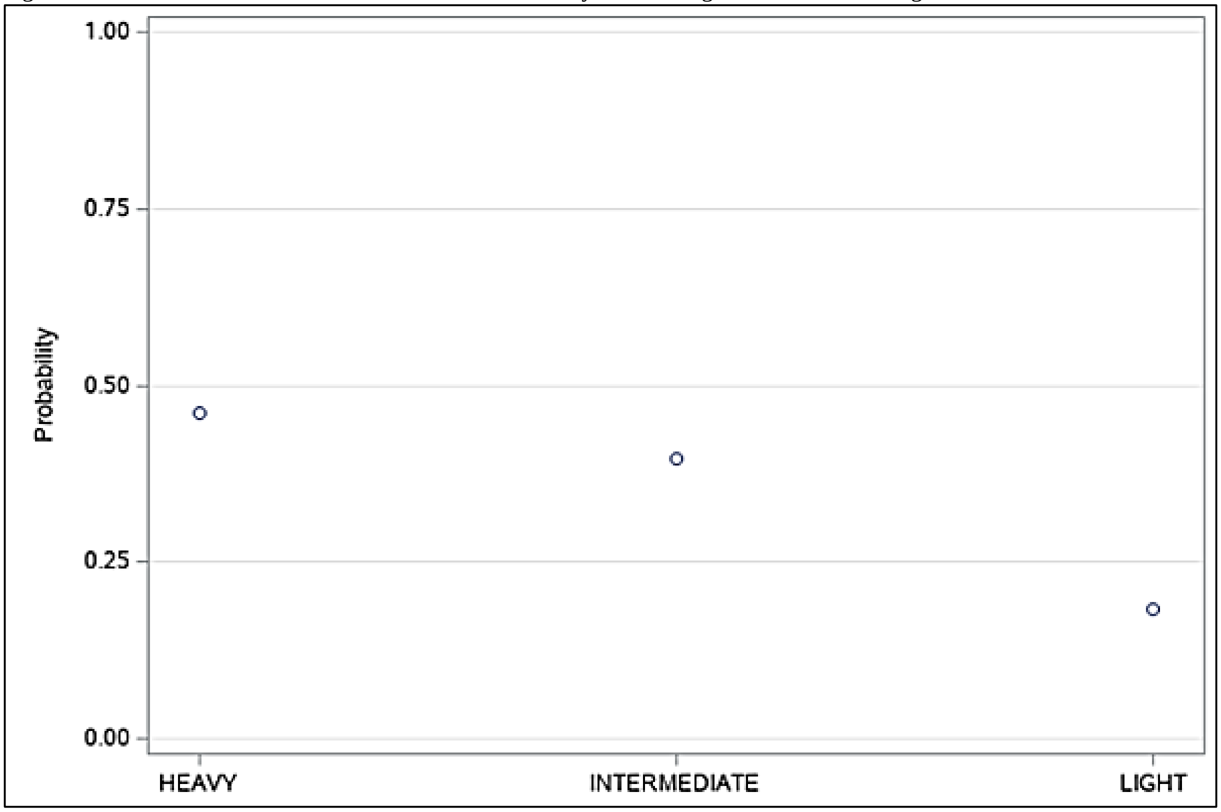
Table 2. Distribution of Wean Weight Block (WWTBLOCK) by Three or More Calves of ASU Angus Cattle from 2005-2018

	Three or More Calves		
WWGTBLOCK[a]	No	Yes	Total
Heavy	21 53.9% of HEAVY row 14.9% of NO column	18 46.1% of HEAVY row 21.7% of YES column	39
Intermediate	89 60.5% of Intermediate row 63.1% of NO column	58 39.5% of Intermediate row 69.9% of YES column	147
Light	31 81.6% of LIGHT row 22.0% of NO column	7 18.4% of LIGHT row 8.4% of YES column	38
Total	141	83	224

a Weight blocks defined as Heavy (+ 1 SD above mean), Intermediate (+/- < 1 SD from mean), Light (+1 SD below mean); SD= 38.74kgs

The distribution of females that were able to produce, raise, and wean 3 calves or more was the lowest for the females that are categorized in the Light weight block (8.4%) as compared to the Heavy and Middle weight blocks (21.7% and 69.9% respectively). While the χ^2 of the Proc Freq procedure yielded a $P = 0.025$, the use of the probabilities associated with the Three or More Calves variable was warranted to better understand the impact of weight characterization and its ability to predict profitability success. Therefore, Proc Logistics models to define binary data of Three or More Calves (yes or no) into probabilities was used and is presented in Figure 2.

Figure 2. Predicted Probabilities for Three or More Calves by Wean Weight Block of ASU Angus Cattle from 2005-2018



The probability plots of three or more calves as described by the WWGTBLOCK illustrates a distinct pattern of declining likelihood from the Heavy WWGTBLOCK through the Light WWGTBLOCK. These data suggest that efforts to select for and retain females that are one standard deviation above the true mean for actual weaning weight have the greatest likelihood of weaning 3 or more calves at the ASU MIR Center. While parentage and genomic data for pre-weaning growth were not in the scope of this study, it is not unreasonable to conclude that a potential unintended benefit of selection pressure for high weaning weight expected progeny differences (EPD) should also contribute to a greater number of females that will be productive through their 3rd calving cycle.

The frequency distribution of calving block (CALVEBLOCK) by three or more calves is presented in Table 3. Calving block was determined within each year by separating the calving season into 21-day increments. This blocking system is not set on a defined calendar range of dates because of the varying dates that calving seasons began and ended from 2005 – 2018.

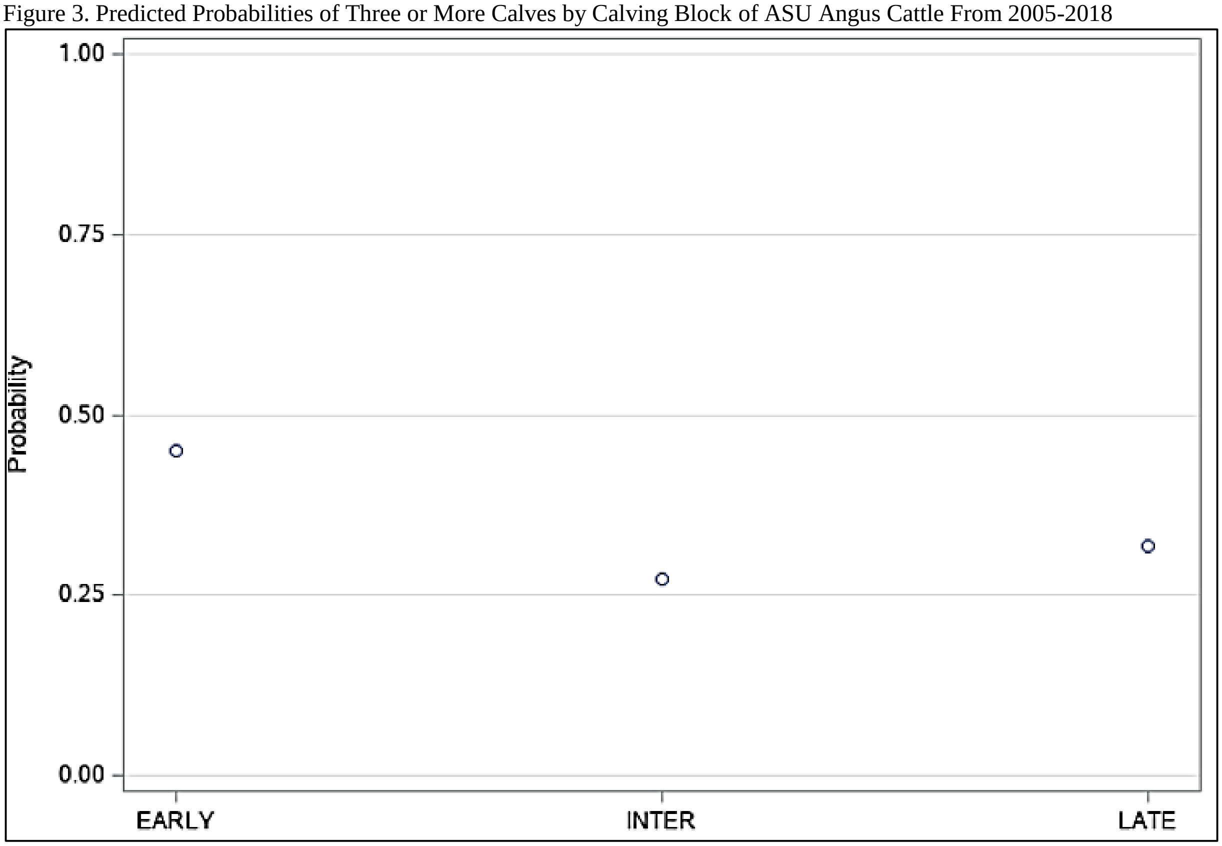
Table 3. Distribution of Calving Block (CALVEBLOCK) by Three or More Calves of ASU Angus Cattle from 2008-2018

	Three or More Calves		
CALVEBLOCK[a]	No	Yes	Total (n=244)
Early	62 54.9% of Early row 44.0% of NO column	51 45.1% of Early row 61.5% of YES column	113
Intermediate	48 72.7% of Inter. row 34.0% of NO column	18 27.3% of Inter. row 21.7% of YES column	66
Late	31 68.9% of Late row 22.0% of NO column	14 31.1% of Late row 16.9% of YES column	45
Total	141	83	224

a- Calving blocks defined as Heavy (day 1-21), Intermediate (day 22-42), and Late (day 42+) of calving season

Because efforts to artificially inseminate (AI) were used in most years, 50.4% of all females were born in the first 21-day block from 2005 – 2018. Even so, 45.1% of females born in the first 21-days of a calving season produced, raised, and weaned three or more calves as compared to calving block 2 (heifers born days 22 – 42 of a calving season) at 27.3% and calving block 3 (heifers born days 42 or later of a calving season) at 31.1%. Although percentage distributions are beneficial analysis, estimates presented as probabilities that can be used in management and decision-making schemes are helpful from a practical production perspective. So, the Predicted Probabilities of Three of more calves by Calving Block designation are presented in Figure 3.

Figure 3. Predicted Probabilities of Three or More Calves by Calving Block of ASU Angus Cattle From 2005-2018



Even though a higher proportion of females are born in the Early calving block, the probability that those females wean three or more calves is more suitable therefore, additional preference should be given to heifers born early in the calving season as candidates as replacements in the ASU cow herd.

The χ^2 of the distribution of heifer calves that were produced by first calf heifers (HFC) that were able to wean three or more calves had a *P*-value of 0.42. No statistical differences were detected in this analysis and these results are presented in Table 4.

Table 4. Distribution of Heifer out of Heifer (HFC) by Three Calves or More of ASU Angus Cattle From 2005-2018

	Three Calves or More		
HCF	No	Yes	Total
No	108.0	60.0	168.0
	64.3% of No row	35.7% of No row	
	77.1% of No column	72.3% of Yes column	
Yes	32.0	23.0	55.0
	58.2% of Yes row	41.8% of Yes row	
	22.9% of No column	27.7% of Yes column	
Total	140.0	83.0	223.0

Interestingly, these data suggest that from 2005 – 2018, 41.8% of the heifers produced by first calf heifers will go on to produce, raise, and wean three or more calves.Which is not different from heifer progeny produced by cows that have weaned 2 or more calves (35.7%). At the present time, this was the first reported evaluation of daughters from first calf heifers compared to daughters of multi-parous cows from a herd longevity perspective.

DISCUSSION

Whereas the only effect that was statistically significant for LIFETIMEEARN was WWGTBLOCK ($P = 0.02$), in the Lifetime Earning analysis, it is important to note the influence of AOD ($P = 0.17$), which approached statistical significance. It is possible that AOD could become more significant were this study repeated with a larger sample size.

The three or more calves (3CALV) variable was used as a measure of cow longevity and stayability. The traditional stayability measure is a cow in production until 6 years of age, or producing 5 calves (Brigham et al., 2007; Roberts et al., 2015). Snelling et al. (1995) noted that since production environments can produce significant variability in longevity, two to eight calves were required for a cow to break even, after salvage value. While stayability heritability estimates were low (0.18) at 6 years of age, the estimate for 4 year – old females was similar at 0.17 (Brigham et al., 2007). Brigham et al. (2007) also noted an anecdotal association that females calving at 4 years of age will likely remain until 6, and then be culled for non-reproductive related issues.

When looking at the impact of WWGTBLOCK × 3CALV ($P = 0.025$) the calves in the Heavy weight block were more likely to produce three or more calves at 46.1% as compared to the Intermediate and Light blocks. This is important to note because Carpenter and Hogan (2018) reported that selecting the biggest heifers can lead to increasing the average size of the cow in the herd. This increased size means those larger females will have higher nutritional requirements, and this could be problematic in semi-arid areas such as Tom Green County.

The impact of CALVBLOCK × 3CALV ($P = 0.038$) revealed a higher likelihood (45.1%) of a female born in the Early calf block to remain in the herd and produce three or more calves. This supports data demonstrated by Cushman et al. (2013) that stated early calving heifers were more likely to have increased longevity. Each female was given a CD number and then broken up into three groups that reflected their order of calving. These blocks were defined as 21 – day calving blocks. Females with the earlier CALVBLOCK expressed the highest likelihood to remain in the herd longer.

The impact of HFC × 3CALV (P = 0.42) revealed no differences between stayability in a female produced by a first calf heifer and a female not produced by a first calf heifer. It was not in the scope of this study to look at HFC terminal traits such as marbling, average daily gain (ADG), or ribeye area. Further research should be conducted to examine these relationships more in depth.

IMPLICATIONS

Results of these data imply that heavier heifers at weaning will have more lifetime earnings than lighter heifers at weaning and should be selected for when seeking replacements. Heifers born in the first 21 days of the breeding season also have the most projected stayability in these data. Finally, these data suggest that heifers out of first calf heifers are just as likely to produce three or more calves as heifers out of an older cow.

LITERATURE CITED

Arije, G.F., and J. N. Wiltbank. 1971. Age and Weight at Puberty in Hereford Heifers. J. Anim. Sci. 33: 401-406. doi:10.2527/jas1971.332401

Beck, P. A., M. S. Gadberry, S. A. Gunter, E. B. Kegley, and J. A. Jennings. 2017. Invited Review: Matching forage systems with cow size and environment for sustainable cow-calf production in the southern region of the United States. Prof. Anim. Scien. 33:289–296. doi:10.15232/pas.2016-01557

Berry, D. P., and R. D. Evans. 2014. Genetics of reproductive performance in seasonal calving beef cows and its association with performance traits. J. Anim. Sci. 92:1412–1422. doi:10.2527/jas.2013-6723

Bormann, J., and D. E. Wilson. 2010. Calving day and age at first calving in Angus heifers. J. Anim. Sci. 88:1947–1956. doi:10.2527/jas.2009-2249

Brigham, B.W., S.E. Speidel, R.M. Enns, and D.J. Garrick. 2007. Stayability to alternate ages Proceedings, Western Section, American Society of Animal Science. Vol. 58

Carpenter, B.B., and R.J. Hogan. 2018. Rangeland heifer development strategies. Applied Reproductive Strategies in Beef Cattle Proceedings. Ruidoso, NM

Cattlefax Research Data. 2019. Cow-Calf Trends. Retrieved from URL: https://www.cattlefax.com/#!/about/cattlefax-trends-cow-calf-webinar

Chiaia, H. L. J., M. V. A. de Lemos, G. C. Venturini, C. Aboujaoude, M. P. Berton, F. B. Feitosa, R. Carvalheiro, L. G. Albuquerque, H. N. de Oliveira, and F. Baldi. 2015. Genotype × environment interaction for age at first calving, scrotal circumference, and yearling weight in Nellore cattle using reaction norms in multitrait random regression models. J. Anim. Sci. 93:1503–1510. doi:10.2527/jas.2014-8217

Cushman, R.A., L.K. Kill, R.N. Funston, E.M. Mousel, and G.A. Perry. 2013. Heifer calving date positively influences calf weaning weights through six parturitions. J. Anim. Sci 91:4486-4491 doi.10.2527/jas2013-6465

Endecott, R.L., R. N. Funston, J. T. Mulliniks, and A. J. Roberts. 2013. JOINT ALPHARMA BEEF SPECIES SYMPOSIUM: Implications of beef heifer development systems and lifetime productivity. J. Anim. Sci. 91: 1329–1335. doi:10.2527/jas.2012-5704

Funston, R. N., and G. H. Deutscher. 2004. Comparison of target breeding weight and breeding date for replacement beef heifers and effects on subsequent reproduction and calf performance. J. Anim. Sci. 82:3094–3099. doi:10.2527/2004.82103094

Henderson, G. 2019. Beef Profit Tracker. Retrieved from URL: https://www.drovers.com/article/profit-tracker

Lancaster, P., J. Arthington, and P. Moriel. 2017. Targeting ADG of Developing Replacement Heifers Using Age and Body Weight. AN305. Gainesville: University of Florida Institute of food and Agricultural Sciences. Published 2014, revised 2017.

Laster, D. B., H. A. Glimp, and K. E. Gregory. 1972. Age and Weight at Puberty and Conception in Different Breeds and Breed-Crosses of Beef Heifers. J. Anim. Sci. 34:1031–1036. doi:10.2527/jas1972.3461031x

Lesmeister, J. L., P. J. Burfening, and R. L. Blackwell. 1973. Date of First Calving in Beef Cows and Subsequent Calf Production. J. Anim. Sci. 36:1–6. doi:10.2527/jas1973.3611

López-Paredes, J., M. A. Pérez-Cabal, J. A. Jiménez-Montero, and R. Alenda. 2018. Influence of age at first calving in a continuous calving season on productive, functional, and economic performance in a Blonde d'Aquitaine beef population, J. Anim. Sci. 96: 4015–4027. doi:10.1093/jas/sky271

Nalivka, J. 2019. Sterling Beef Profit Tracker. Retrieved from URL: https://cdn.farmjournal.com/s3fs-public/inline-files/Beef%20Tracker%20102219.pdf.

Osoro, K., and I. A. Wright. 1992. The effect of body condition, live weight, breed, age, calf performance, and calving date on reproductive performance of spring-calving beef cows. J. Anim. Sci. 70:1661–1666. doi:10.2527/1992.7061661

Short, R. E., and R. A. Bellows. 1971. Relationships among Weight Gains, Age at Puberty and Reproductive Performance in Heifers. Journal of Animal Science 32:127–131. doi:10.2527/jas1971.321127

Short, R. E., R. B. Staigmiller, R. A. Bellows, and R. C. Greer. 1994. Breeding heifers at one year of age: Biological and economic considerations. In: M. J. Fields and R. S. Sands, editors, Factors affecting calf crop. CRC Press, Boca Raton, FL. p. 55–68.

Snelling, W.M., B.L. Golden, and R.M. Bourdon. 1995. Within-herd genetics analyses of stayability of beef females. J. Anim. Sci. 73:993-1001