ASSESSING VARIABILITY IN HERD SIRE ECONOMIC VALUE FOR COMMERCIAL COW-CALF OPERATIONS UTILIZING MULTIPLE-SIRE MATING GROUPS

A Thesis

by

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ABSTRACT

Number of calves (n = 596) and weaning calf value (n = 574) from natural service, multi-sire breeding groups were evaluated in a crossbred research herd. Sires and dams that were F_1 crosses of Angus (A) and Nellore (N) were mated annually during 60- to 90-day breeding seasons to produce spring-born calves in 2009-2015. Numbers of sires used annually varied from 5 to 9; numbers of females exposed per bull ranged from 14 to 22 across years. Bulls were pastured together throughout the year as well as during breeding seasons. Sires were determined based on calf DNA genotyping. Calf number, birth date, birth weight, weaning weight, and economic value were determined annually per sire. Calf value was based on weaning weight and regional USDA-AMS reported prices for respective weaning dates. Calf prices were calculated separately for steers and heifers relative to 22.7 kg (50-lb) increments for corresponding weight class and year. Mixed model analyses were conducted that included fixed categorical effects of calf birth year, type of F_1 sire (A-sired vs. N-sired), sire nested within type, calf sex, and the interaction of F_1 sire type with calf sex. Covariates of Julian birth date and calf weaning age were included for birth weight and weaning weight analyses, respectively. Large differences in calf numbers and performance ($P < 0.05$) were observed. Weaned calves produced annually per sire ranged from 0 to 48. Average annual calf performance per sire ranged from 28.4 to 50.8 kg for birth weight and 146.5 to 249.0 kg for weaning weight. Annual economic value per sire ranged from $0 to $30,870 when considering half of each calf's value as attributed to the sire. Commercial cow-calf producers should consider potential sire variability for calf numbers, birth date distribution, and ratio of female-to-male calves in combination with traditional calf performance for improved economic assessments in their herds.

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INTRODUCTION

Many commercial cow-calf producers utilize multi-sire breeding groups for improved pregnancy rates; however, the lack of parentage identification creates uncertainty concerning the true value of the herd sires. Parentage testing can be used to determine the number of calves and performance of offspring produced, to which producers can make management decisions of bulls that are underperforming. Bull value varies greatly due to a number of different factors, all of which greatly influence the success of an operation. Breed, age, structural integrity, fertility, temperament, and manager use can all play a role in determining bull value and performance. Calf performance can greatly contribute to the productivity and profit of herd sires. Bulls producing calves that are born earlier in the calving season that are pounds heavier at weaning generate more profit when producing adequate amounts of offspring. Bull fertility and bull battery dynamics contributes to a sire's ability to produce offspring in multiple-sire mating groups. Dominant more experienced bulls tend to breed a higher percentage of females in a mating group; however, if the dominant sire is not fertile, the producer might see a decrease in pregnancy rates. Without knowing the productivity of each herd sire, producers make uninformed decisions regarding the use of each bull. Using DNA sire identification has the potential to identify several thousands of dollars worth of differences between sires within herds. The focus of this thesis is to use parentage testing in commercial cow-calf operations using multi-sire mating groups to assess variability in herd sire performance based on economic values.

LITERATURE REVIEW

Substantial financial and genetic risks and rewards can be associated with the purchase and use of commercial herd sires. Bull value can be an accumulation of many different factors that all contribute to the end goal of producing offspring. Factors like physical appearance, genetic prediction values, fertility traits, breed, age, etc. all play large roles in the value of herd bulls. Provided that bulls remain physically sound and fertile, many producers consider them a long-term investment. Bulls represent 50% of the genetic makeup of each year's calf crop, and up to 90% or more of the cowherd genetic makeup if the producer retains their own females over several generations (Dhuyvetter et al., 1996). The use of multi-sire mating groups in commercial operations can increase pregnancy rates (Lunstra and Laster., 1982, Molina et al., 2000). However, the increased number of sires that could potentially produce offspring does not allow producers to easily determine sire identification. Many commercial producers do not know the sires of their calves, and therefore do not know the true values of their bulls. Use of DNA sire identification has the potential to identify several thousands of dollars worth of differences between sires within herds; however, may producers may think the cost of sire determination is too expensive.

Simple Inheritance and Genetic Testing Concepts

Genetic testing is based on the principles of inheritance, and can best be explained through the use of "simply inherited" traits. Segers and Lourenco (2019) used black color status in Angus cattle to explain simple inherited traits. The black color status in many breeds of cattle is controlled by a single gene producing two possible outcomes: a black colored calf or a red colored calf. The color status is dependent upon which two alleles the offspring inherits from the sire and dam. Each individual offspring inherits one allele from the sire and one from the dam.

When considering coat color, the black allele is dominant; therefore red offspring must have two recessive alleles (Segers and Lourenco, 2019), but black animals may be homozygous dominant or heterozygous. In many cases, it is useful to know with certainty if black animals carry the red allele. If a producer's black herd sire is having red offspring, the bull is heterozygous.

Parentage Testing

Many commercial producers use multi-sire mating groups in order to increase pregnancy rates within their herd as compared to single-sire mating groups. In a 1982 study by Lunstra and Laster, pregnancy rates per estrus, of heifers mated to three sires (74.0%) was significantly higher than that of heifers that were mated to a single sire (62.9%). A disadvantage of multiple-sire mating groups is that producers have no simple way to determine the number of progeny produced by each sire, and, the subsequent performance of their offspring (Van Eenennaam et al,. 2007). Parentage testing not only allows one to determine the number of calves and performance of offspring but can be used by producers to make culling decisions of bulls that are not performing as desired (Van Eenennaam et al., 2007). Parentage testing is based around the idea that parents donate a copy of each allele to the offspring at every gene in the genome. Unlike that of simply inherited traits, many genes (or DNA markers) are used to compare calves to their potential parents (Segers and Lourenco, 2019). In the past, parentage verification was done through the usage of blood typing. However, in order to increase the accuracy of parentage tests, Single Nucleotide Polymorphisms (SNP) are used. Single nucleotide polymorphism can be defined as a single nucleotide change within a DNA Sequence (Spangler et al., 2014).

According to Heaton et al. (2002), SNP are fundamental units of genetic variation, which are attractive as markers due to their abundance throughout the genome, their genetic stability, and the fact that they are amenable to high-throughput automated analysis. A prerequisite for using cattle SNP in animal identification and paternity analysis is the description of a minimal set with sufficient power to uniquely identify individuals and their parents in a variety of popular breeds and crossbred populations (Heaton et al,. 2002). According to Anderson and Garza (2006), SNP genotypes can easily be standardized across many different laboratories, making them more universal for interpretation compared to previous techniques.

Heaton et al. (2002) conducted a study which found that 34 SNP would be sufficient to identify all 270,000 cattle registered by the American Angus Association in 2002 and similarly, 40 SNP were estimated to have enough power to individually identify all of the 100 million cattle and calves in the United States in 2002. According to Van Eenennaam (2016), DNA parentage testing can cost anywhere between $13-$20 per animal. Neogen, a genetic testing company for all species, has a genetic test (Igenity® Beef) that costs $29 that not only verifies parentage, but ranks females as replacements and scores commercial bulls. As new SNP genotyping platforms are continuously being developed, the cost to generate SNP genotypes will continue to go down and therefore, inexpensive genotyping assays using high-resolution SNP parentage panels will, without a doubt, become available in the future (Van Eenennaam et al., 2007). In fact, the cost of DNA sequencing an entire human genome in September 2001 was $96,263,072 and as of August 2020 the cost per human genome was $689 (NHGRI, 2020). Currently, cattle producers can utilize blood, hair and tissue samples to determine parentage identification. Zoetis, another genetic testing company, lists blood cards at $0.46 per card, hair cards at $0.10 per card and tissue collector tubes at $1.83. This does not account for any price charged to perform the actual DNA analysis conducted by the company.

Bull Value

Bull value within beef herds can be attributed to many different factors. Breed, age, structural integrity, fertility, temperament, and manager use all play roles in determining bull value. Dhuyvetter et al. (1996) found that bull prices are determined by bull characteristics of genetic, physical, and expected performance, and, by marketing techniques not necessarily related to the quality of the bull, but related to the producers' abilities and decisions. Dhuyvetter et al. (1996) determined that bull buyers were willing to pay premiums for black (versus red) Simmental, Gelbvieh, and Limousin bulls, polled (versus horned), and higher subjective ratings for conformation, muscling, and disposition. Price was found to be nonlinearly related to age, meaning that buyers paid a premium for older bulls, but at a decreasing rate (Dhuyvetter et al,. 1996). Younger bulls with lower serving capacities were more likely to have lower values, conversely older bulls, not sold previously, suggesting possible problems were also more likely to generate lower sale prices (Dhuyvetter et al., 1996). Dhuyvetter et al. (1996) interpretation of a U.S. Department of Agriculture study found bull's age and factors associated to age (size and number of offspring in herd) were ranked lower than physical factors (infertility, lameness, disease, and temperament) when making bull culling decisions whereas offspring performance was ranked between the two (Dhuyvetter et al,. 1996).

According to a survey of 312 commercial cow calf producers, Simms et al. (1994) found that calving ease score was listed most commonly as the first criterion, and almost one-half of the producers that answered the survey had it in their first three criteria for herd sire selection. Simms et al. (1994) stated this as interesting, considering at that time only the Simmental and Gelbvieh breeds provided calving ease scores, and those breeds accounted for only around one-third of the bull purchases represented in the survey. Simms et al. (1994) also found birth weight ratio and birth weight expected progeny differences (EPD) to be the major performance items considered by producers. Based on responses, Charolais bull buyers emphasized birth weight much more than buyers of any other breed (Simms et al., 1994). This suggested that commercial producers associate high birth weights with Charolais herd sires. However, overall the relatively low level of emphasis on EPD indicated that producers were not using what Simms et al. (1994) considered the most important and influential selection criteria available (Simms et al., 1994). Garrett (2018) evaluated hedonic pricing models to estimate traits valuable to Beefmaster bull buyers using bull sale data collected from a purebred Beefmaster ranch in central Texas (n = 521, 19-27 month old bulls). Garrett (2018) found that commercial buyers placed more emphasis on physical traits of composition score on a 4-point scale, sire and maternal grandsire pedigree information, ribeye area ratio and weaning weight EPD. Whereas purebred breeders placed more emphasis on birth season, consignor or producer of the herd bull prospect, birth weight and yearling weight. Boyer et al. (2019) studied price determinants of performance-tested bulls and found some interesting differences in prices for EPDs. Calving ease EPD had the potential to add value to a sire, with each 1% change increasing the price of a bull by $36 in 2008 over the average and increasing the price by $119 in 2012 over the average (Boyer et al., 2019). Similarly, Brimlow and Doyle (2014) found that each 1-lb (each 0.45 kg) difference in birth to yearling gain EPD increased the average bull price by $18.58.

Irsik et al. (2008) studied the factors affecting the sale price of bulls consigned to a graded sale in middle Florida. All bulls consigned were graded by a 5-person committee of experienced cattle producers, who graded the bulls for all 13 years of sale data (Irsik et al., 2008). The committee graded herd sires based on eye appeal, conformation, frame size, weight on the day of sale and scrotal circumference on day of sale (Irsik et al., 2008). Grade A bulls sold for $593 more than grade C while grade B sires sold for $186 more than grade C (Irsik et al., 2008). This suggests that buyers valued the grading concepts and personnel. This could be contributed to the grades themselves or even the producers valuing the traits associated with many of the bulls that graded higher. Birth weight was also found to be a significant factor, where each 1-lb increase in the birth weight of the sire decreased its sale price by $4.86 (Irsik et al., 2008). Irsik et al. (2008) also found that breed played a significant factor in determining the price of herd sires in their study. When compared to Angus, all breeds except for Simmental and Brahman sold for significantly less (Irsik et al., 2008). Although the difference in sale prices of Brahman and Simmental when compared to Angus were not considered to be significant, economically speaking Brahman bulls sold for $682 less while Simmental bulls were discounted $409 (Irsik et al., 2008). However, these breeds could see significant differences in prices depending on the region that the herd sires are being marketed in. For instance, Brahman cattle and Brahman-influenced cattle are typically associated with the Gulf Coast of the southern United States. Therefore, their value is expected to decrease away from this region.

Calf Performance and Value

Calf value plays a large role in the productivity and usefulness of herd sires. Premium calves generate more profit per capita, thus sires more frequently producing these premium calves will generate more profit. Troxel and Barham (2007) studied factors affecting the selling price of feeder cattle sold at Arkansas livestock auctions. Factors such as grouping, sex, breed/breed type, color, horn status, frame scores, muscle scores, fill, body condition and health all played roles in differences in prices between calves (Troxel and Barham, 2007). Halfman et al., (2009) studied the factors that can effect Wisconsin feeder calf prices at local livestock markets and found that bull (-$5.15) and heifer (-$9.13) calves received discounts per hundredweight (per 45.45 kg) when compared to steer (base value) calves. Similarly, Lambert et al., (1989) found sex being an important fact in calf prices; finding steers to bring on average \$6.85 per hundredweight more than heifers. Troxel and Barham (2007) found that steers received a premium (\$6.48 vs. \$6.02) and muscle scores of 1 also received a premium (\$2.58 vs. \$0.02) when comparing the years 2000 and 2005 respectively. When comparing the years 2000 and 2005, both very different in terms of economy and rainfall, grouping, breed type, color, horn status, body condition and health all varied in sizes of premiums however there were increased values found within these factors (Troxel and Barham, 2007). Similarly, Halfman et al., (2009) found premiums associated with black hair coat (\$7.04, compared to red hair coat baseline). It was also discovered that significant discounts were given to horned cattle (-\$4.07) suggesting that cattle buyers preferred either dehorned or polled feeder calves (Halfman et al., 2009).

The concept of feeder calves having higher or lower price per unit weight across weight ranges is referred to as a price slide. Schroeder et al. (1988) found that weight had a nonlinear impact on feeder calf prices; in general, as weights went up prices per lb went down. Faminow and Gum (1986) also found weight to have a nonlinear impact on feeder cattle prices in Arizona. In the long run, Faminow and Gum (1986) found that price/weight lines for steers were generally convex and price/weight lines for heifers were usually slightly concaved. Schroeder et al., (1998) also concluded that cattle buyers at the time of the study would bid up heavier calves and bid down the prices of lighter, more thin cattle in the Fall then inversely bid up lighter calves and bid down heavier calves during the Spring. Lambert et al. (1989) also found a negative correlation between weight and price per hundredweight in feeder cattle. The price was found to decrease by \$1.26 per hundredweight for each additional hundredweight (Lambert et al., 1989). Even more, Lambert et al., (1989) found that prices for steers fell by $1.79 for each additional hundredweight while prices for heifers only fell by $0.72 for each additional hundredweight.

Bull Fertility due to Physiological Traits

Reproductive success can be considered one of if not the most important factor in beef cow herd profitability, and is important from both female and male aspects. Hopkins (2005) stated that the bull is the one individual most responsible for reproductive success or failure, and that it has been estimated that around 20% of bulls have some problem that can affect their reproductive success. This has historically been thought to result from differences in conception rates. However, paternal genetics can also play a large role in pregnancy maintenance/embryo loss, more specifically placenta formation (Franco et al., 2020). Sufficient placentation is necessary for proper exchange of nutrients between the fetus and the mother, and disruptions of these physiological processes could lead to pregnancy loss (Franco et al., 2020). If a cow does not produce a calf, it is important to understand if the cow, the bull, or the herd manager was at fault.

The term fertile, as applied to bulls, implies the ability to impregnate cows at a high enough rate that herd pregnancy rate is not limited by the bull (Hopkins, 2005). Infertility could be described as a bull that is incapable of impregnating cows now, but could improve with time or treatment. However, sterile bulls cannot impregnate cows at all and cannot conceivably regain fertility (Hopkins, 2005).

Herd sire age, as well as breed type plays a large role in the quality and volume of semen produced (Chenoweth et al., 1984, Fuerst-Waltl et al., 2006, Isnani et al., 2019). Fuerst-Waltl et al. (2006) evaluated the effects of age and environment on semen production and quality of Simmental bulls in Austria. Fuerst-Waltl et al. (2006) found that as bulls increased in age so did ejaculate volume, however, at 1 center in the study bulls >72 months decreased when compared to sires in the 48-72 months of age group. In general, as bulls increased in age there was a decrease in sperm concentration (Fuerst-Waltl et al., 2006). Isnaini et al. (2019) compared their native Bali breed with that of Simmental and Limousin breeds in Indonesia. Limousin bulls had the highest ejaculate volume (ml) and the greatest sperm concentration (billion/ml), and, total sperm number (billion/ejaculate) was found in Limousin and Simmental bulls as compared to their native Bali breed bulls. Anchieta et al. (2005) studied differences in semen quality of European and Zebu breeds in a Brazilian artificial insemination center. European breeds showed higher swirl, motility and concentrations of sperm than Zebu Breeds (Anchieta et al., 2005). However, a similar study by Koivisto et al. (2009) in the southeastern region of Brazil looked at gross sperm motility (graded from 0-5) in mature breeding bulls during winter, spring, summer and autumn. *Bos taurus* (Limousin and Simmental) bulls were observed to have lower gross sperm motility (2.5-3.2 vs. 3.3-3.4 respectively) than that of *Bos indicus* (Nellore) bulls with gross-motility being higher in *Bos indicus* bulls for each season (Koivisto et al., 2009).

In order to determine if a bull it fit for service, a Breeding Soundness Exam (BSE) should be conducted (Koziol and Armstrong, 2018). A BSE is intended to be a systematic and thorough examination of the bull that will lead to an estimation of the bull's fertility on the day examined (Hopkins, 2005). Hopkins (2005) stated scrotal circumference measurements and semen morphology relate best to bull fertility, and special care should be given to these parts of the exam. Ellis (2008) said testicular development, as measured by scrotal circumference, is a highly desirable selection indicator for fertility in both sires and daughters of those sires. Larger scrotal circumference has long been associated with increased sperm production and daughters that reach puberty an earlier age, therefore breeding and performing at an earlier age within the herd.

However, recent studies show lower sperm concentration (billion/ml) as bull's increase in age from young (2 years old) to middle (5 years old) to old (12 years old) Isnaini et al., 2019). Isnaini et al. (2019) stated that this could be explained by a degenerative change in the seminiferous tubule resulting in the lower sperm production as bulls age. However, BSE do not predict sub-fertile bulls or predict fertility potential of individual bulls (Bellin et al., 1998). Belli et al. (1998) studied a heparin-binding protein named fertility-associated antigen (FAA) located in sperm membranes in beef bulls. According to Bellin et al., (1998) bulls considered to have a high serving capacity and were positively ID to produce sperm with FAA impregnated more females (87%) then herd sires negative for FAA (78%).

Seminal traits such as semen sample volume, color, concentration, mass activity, and percentage of live spermatozoa have rarely been identified as having significant prediction value of reproductive performance (Hopkins and Spitzer, 1997). However, they can be an indication of sperm motility and morphology which are the most commonly measured seminal traits as well as a standard component of a BSE (Rathmann, 2005). Motility can be measured by either gross motility (the amount of swirling activity present in semen sample) or by measuring motility through the estimation of the percentage of individual sperm moving progressively forward (Rathmann, 2005). Evaluating spermatozoa morphology encompasses the detection of abnormalities or defects. Primary abnormalities are defects of the head and acrosome while secondary abnormalities are defects of the mid-piece (Rathmann, 2005). Decreased motility and severe morphology problems cannot only cause herd sires to fail a BSE but often affect the herd sire's ability to perform.

In summary, the BSE, when properly performed and interpreted provides a highly useful management tool and serves to reduce risk of potential sub-fertility in herd bulls (Ellis, 2008).

Hopkins (2002) also found that the BSE is cost effective since bulls that pass the examination on average will sire about 10% more calves during the breeding season, in turn grossing the producer a $20 to $25 return for each $1 spent on BSE. The yearly assessment of fertility-potential of bulls remains a key management tool to achieve higher reproductive performance (Ellis, 2008).

Herd Sire Fertility due to Behavior and Social Hierarchy

Chenoweth (1981) defined the term libido as the willingness and eagerness of a male to mount and to attempt service of a female. Chenoweth stated in a 2011 review that using sires with higher sex drive, or libido, have been reported to benefit pregnancy rate, time of conception, length of calving season, homogeneity of weaned calves and more efficient use of labor. However, Chenoweth (2011) also stated that other studies have shown poor or inconclusive relationships between bull libido/serving capacity assessments and herd fertility. Cattle breeding on pasture in a normal setting may not act or function in the same way as observed in an "artificial" setting.

Molina et al. (2000) looked at the sexual behavior of Zebu bulls in single-sire (SSM) and multiple-sire (MSM) mating groups in Costa Rica. The frequency, type and duration of sexual activities and courtship activities were observed for both SSM and MSM (Molina et al., 2000). SSM tended to more frequently show sexual activities when compared to MSM (267 vs. 124) (Molina et al., 2000). Even more, Molina et al. (2000) found a 9% difference in pregnancy rates between SSM and MSM in favor of multiple-sire mating groups.

Social behavior and herd bull dynamics play a large role in reproductive success. Under natural mating conditions, the social ranking of bulls within the herd hierarchy can influence sexual activity and reproductive performance (Ellis, 2008). The social relationships between herd sires appear to influence access to females within multi-sire breeding groups (Petherick, 2005). Petherick (2005) found that bulls of similar age that have been reared together are less likely to fight, which could decrease bull attrition through injuries. Fordyce et al. (2002) studied social behavior in high vs. low numbers of herd sires when exposed to a very similar number of females (300-350 cycling females). HIGH% and LOW% categories were determined by the number of bulls in each breeding group, with HIGH% consisting of 24 Brahman cross bulls and LOW% consisting of 10 Brahman cross bulls (Fordyce et al., 2002). Fordyce et al. (2002) observed that bull attrition occurred in the HIGH% breeding group, but not in the LOW% breeding group. Fordyce et al. (2002) found a 4-5% annual bull loss due to fractured legs of bulls in the HIGH% vs. no bull losses in the LOW% paddock. Dominance is expressed more strongly in older bulls (i.e. 3 to 4 years of age and older vs. 2 years or younger) and is more related to seniority than any other factor (Blockey, 1979). Makarechian and Farid (1985) stated that the usage of yearling bulls shortens the generation interval resulting in more genetic progress per year (given they produce offspring) when compared to continued use of older herd sires. Interestingly, mature bulls had a 6.4% larger calf crop and the oldest (3-year old) bull sired 40.9% of the calves in their study (Makarechian and Farid, 1985). Similarly, Chenoweth (1981) cited an unpublished study by Osterhoff where the oldest or second oldest bull in a multi-sire mating group sired 60% or more of the calves each year while the youngest bull sired 15% or fewer. Whitworth (2002) evaluated bulls of 3 different breeds (Bonsmara, Tuli and Waygu) of ages 13 to 19 mo. When comparing the sire age effect on number of offspring produced, it was found that the older Waygu sires (18-19 mo of age) produced the greatest number of calves (Whitworth, 2002). This difference in age may be considered to impact puberty more, as these bulls were closer or more similar in age then studies looking at bulls with multiple years of difference in age.

In older, more experienced herd sires, libido scores are often higher, the number of mounts decrease, and the number of services increase with age; suggesting that older bulls become more ‘efficient’ in serving capacity tests by decreasing time spent on detection and courtship (Petherick, 2005). Dominant bulls may impregnate more cows and limit the reproductive performance and calf outputs from subordinate bulls (Ellis, 2008). Conversely, dominant bulls may hinder the estrus-detection and mating of subordinate bulls without impregnating a higher proportion of cows (Ellis, 2008). This could decrease the female:bull ratio required for maximum production. Dominant herd bulls with lower semen quality may compromise herd fertility (McCosker et al., 1989). Additionally, dominant herd bulls with lower calf value could decrease overall profits through inferior offspring.

Social dynamics can alter performance of bulls with differing serving capacities. For instance, Godfrey and Lunstra (1989) found that high and low serving capacity bulls could achieve similar amounts of mating activity in single-sire scenarios on 15 intact estrual heifers. However, it was determined that bulls categorized as high serving capacity bulls served more females than low serving capacity bulls when placed in multi-sire breeding groups with 30 estrus-induced, ovariectomized heifers (Godfrey and Lunstra, 1989). Still, in this test each bull had 15 heifers available and only served 25-30% of the heifers, however, each heifer that was served was served twice (Godfrey and Lunstra, 1989). Godfrey and Lunstra (1989) hypothesized this to be due to the relative inexperience of the young bulls used in the study.

Herd sire performance relies heavily on the bull’s ability to successfully identify females in estrus, impregnate them, and produce viable offspring that can later be weaned and sold. Abell et al. (2017) studied the calving distributions of individual bulls used in a multiple-sire breeding program over a 7-year period. Each breeding group ranged from 23 to 243 cows with an average female:bull ratio of 16 (Abell et al., 2017). Herd sires and females evaluated consisted of purebred and composites of approximately 16 breeds ranging from 100% to 6.25% of any given breed (Abell et al., 2017). Bulls were evaluated using a ranking system based on the individual sires calving rate per pasture over the breeding season, with Rank 1 = the bull with the greatest calving rate, Rank 3 = given to the sire with the lowest calving rate and all others bulls being given Rank of 2 (Abell et al., 2017). The average observed percentage of calves sired per pasture per rank were found as such: Rank 1 – 34%, Rank 2 – 15% and Rank 3- 3% (Abell et al., 2017). Rank 1 sires produced 113% more calves then the expected pasture average, Rank 2 sires produced 6% less than expected and Rank 3 herd bulls sired 81% less than expected (Abell et al., 2017). Abell et al. 2017 compared the bulls during three 21-day intervals, which showed each rank decreasing in calving percent per bull from interval 1 to interval 2 and from interval 2 to interval 3.

In Queensland Australia, Fordyce et al. (2002) found that when anywhere from 300-350 females were exposed to a HIGH% (24) and LOW% (10) of Brahman cross bulls in different paddocks. Up to 90% of the 230-380 calves resulting from each mating had been sired by between 6 and 8 herd sires; reducing the bull:female ratio from 3.7% to 2.8% (from 27.0 to 35.7 females per sire, respectively) showed no difference in conception rates (Fordyce et al., 2002). From this project Holroyd et al. (2002) compared calf output of 235 bulls in various multiple-sire mating groups among 92 Santa Gertrudis, 25 5/8 Brahman and 119 Brahman herd sires. Holroyd et al. (2002) found that 58% of the 235 sires produced 10% or less calves in each of their respective mating groups, with 6% not siring any calves at all. However, 14% of the sires produced over 30% of the calves in each of their respective mating groups (Holroyd et al., 2002). Multi-sire groups of 8-24 bulls showed a maximum percent of calves sired per individual bull of 26% while groups of 2-7 bulls showed a maximum percent of calves sired per individual bull of 59% (Holroyd et al., 2002). The range in calf percentage from individual sires was 11-36% in the large sire groups of 8 to 24 bulls compared to range of 24-94% in the smaller sire groups of 2 to 7 bulls (Holroyd et al., 2002).

Summary of Literature Review and Research Objectives

Bull value can be affected by a variety of different factors. Bull fertility, genetics, and social dominance all play a role in the herd sire's ability to produce productive calves. Commercial producers should understand the value of their herd sires as well as the potential loses that can be associated with inferior production from their herd sires. Utilizing parentage verification to determine herd sire and his associated production can help describe an operation's variation for production and profit potential. The objectives of this thesis were to evaluate the use of parentage testing in commercial cow-calf operations using multi-sire mating groups to assess variability in herd sire performance based on economic values.

MATERIALS AND METHODS

General Animal and Background Information

Data for this thesis were previously collected through approved Institutional Animal Care and Use Committee (IACUC) protocols at the Texas A&M AgriLife Research Center at McGregor. The Center is located at approximately 31^{o} North, -97^{o} East in McLennan County Texas. This region has elevation of approximately 290 – 300 m above sea level, annual rainfall of approximately 915 mm, and typically 210 - 220 frost-free days annually from April to November.

All animals in this project (sires, dams, calves) were born on the McGregor Research Center. Animals are kept on predominantly warm-season, improved, perennial pastures with supplemental feeding typical during winter months of November through January. Herds are managed for Spring-calving with typical breeding seasons occurring in May through July annually. Calves have birth date and birth weight recorded within 24 h of birth. Calves were vaccinated for clostridial diseases at 2 to 4 mo of age annually, and weaned at approximately 7 mo of age. Approximately 1 mo prior to weaning, calves are administered a bovine respiratory disease (BRD) vaccine. At calf weaning, calves are weighed and receive booster clostridial and BRD vaccinations. At this time (or at pre-weaning) cows are pregnancy checked, weighed and have body condition score assigned. In general, cows are managed to have body condition score of 5 to 6 (on 1-to-9 scale).

Sires of calves were determined based on SNP genotyping of DNA isolated from blood samples collected prior to calf weaning. The calves were second-generation crosses (F_2) of Nellore (N) and Angus (A) where both Angus-sired (A x N) and Nellore-sired (N x A) F_1 parents were used as both sires and dams to yield four reciprocal F_2 calf types.

Cows were exposed to bulls for natural service matings annually during 60 to 90 day breeding seasons. All herd sires passed a BSE prior to the breeding season. The number of sires used annually varied from 5 to 9, with the number of females exposed per bull ranging from 14 to 22 per season. Female reproduction is a major research focus in this herd, so lower female:bull ratios were used so that conception rate potential might not be reduced. Herd sires of the same age were reared together post-weaning. All sires pastured together throughout the year including during the breeding season; herd sires were pastured with other bulls when they were not used for breeding. All dams were managed together as a single contemporary group annually.

Data and Associated Statistical Analyses

There were 596 birth records and 574 weaning records for calf birth years of 2009 to 2015. Available calf records included birth weight, birth date, weaning weight, and weaning date in addition to sire and dam pedigree information. The 2008 records were deleted (n = 67) due to a lack of sire identification on a majority of the calves born. Calves born from 2009-2015 with undetermined sire identification were removed automatically during analysis. Calf market prices reported through the USDA Agricultural Marketing Service for Texas auctions in 22.7 kg (50 lb) increments were utilized that were relative the week the calves were weaned to calculate calf value ($/animal) based on the animal weight and market price; separate prices and slides were used for steers vs. heifers. Calf value divided by 2, to account for 50% genetic makeup attributed to its sire.

Calf birth weight, weaning weight and weaning value were analyzed through mixed model analysis of variance that included fixed effects of calf birth year, sire breed type (AN vs. NA), sire nested within breed type, calf sex, and the potential interaction of calf sex with sire breed type. The potential 3-way interaction of sire breed type-dam breed type-calf sex was also investigated. Calf Julian birth date was used as covariate for birth weight; calf weaning age was used as a covariate for weaning weight and calf weaning value. Model effects were considered as important trends with $P < 0.10$ based on F-tests.

Annual calf value per sire was calculated by taking the average calf value for each sire that year then multiplying it by the number of calves born to that sire. Additionally, bulls were assigned a net return value calculated as a cumulative value from all calves weaned and sold minus an assumed annual input cost of $700 for developing, housing and caring for the bulls prior to the seasons the herd sires were used in. For sires that were not used in consecutive years, bulls were considered to not have any overhead cost for years not in use, and therefore did not receive the same deduction as bulls used in that year. No initial purchase cost of herd sires was accounted for.

RESULTS AND DISCUSSION

The overall summary of the calf trait continuous variables is provided in Table 1. Because the analyses are reflections of economic values and U.S. beef industry standards for price reporting, the values in many places are reported in imperial units rather than metric. The mean prices and associated equations used to calculate individual calf prices each year are provided in Table 2. Figures 1 and 2 illustrate the relationships between the price slide equations and the observed prices for steer and heifer calves, respectively.

Table 1. Summary of means for birth weight, weaning weight, Julian birth date, weaning age and calf weaning value of 2009 – 2015 birth years.

Variable	N	Mean	SD	CV	Minimum	Maximum
Birth weight, lb	596	77.7	15.50	20.0	42.00	130.00
Weaning weight, lb	575	492.9	76.34	15.5	236.00	670.00
Julian date, d	597	71.4	16.45	23.0	17.00	138.00
Weaning age, d	581	204.6	26.78	13.1	86.00	275.00
Calf value, $	574	729.2	269.61	37.0	309.71	1540.14

Interestingly, the coefficient of variation (CV) in performance traits, calf values, input trait costs, and net return (profit) show increasing values in this order in beef cow herds (Southwest SPA Summary). Although these values are not tested statistically, it is interesting to note that the CV is 37% for calf value, but 15.5% for weaning weight. The southwest SPA summary from 2012-2016 showed a similar CV for average weaning weight (22%), but CV of 70% for grazing cost per cow and 441% for annual net return (profit) per cow.

Table 2. Average weekly Texas auction prices[1] price slide equations by weight class and sex used to calculate calf-weaning price.

	300-350	350-400	400-450	450-500	500-550	550-600	600-650	Equation	R-square
2008 Steer[2]	128.83	121.24	110.87	106.78	96.66	95.40	88.09	y = -6.7182x + 133.71	0.977
2008 Heifer[2]	103.60	105.00	92.12	92.76	86.02	84.02	82.58	y = -3.9686x + 108.17	0.897
2009 Steer	115.20	107.03	99.12	100.59	93.61	89.15	91.14	y =-4.0518x + 115.61	0.891
2009 Heifer	100.94	87.00	87.28	83.95	86.78	85.21	85.12	y =-1.8407x + 95.403	0.468
2010 Steer	127.59	122.59	112.44	112.94	106.01	103.17	103.86	y =-4.1593x + 129.29	0.908
2010 Heifer	99.02	116.71	100.00	93.69	102.28	98.49	94.97	y =-1.6534x + 107.35	0.219
2011 Steer-1[3]	159.15	152.51	142.32	145.17	136.14	135.52	126.84	y =-4.8961x + 162.11	0.934
2011 Steer-2[3]	162.19	156.29	136.42	142.01	142.23	135.02	133.65	y =-4.3696x + 161.45	0.728
2011 Heifer-1[3]	136.83	136.76	128.76	129.33	125.08	123.73	123.75	y =-2.4636x + 139.03	0.884
2011 Heifer-2[3]	138.48	134.07	125.43	122.66	117.43	121.71	116.44	y =-3.5300x + 139.29	0.849
2012 Steer	183.95	176.47	174.00	165.44	154.06	150.88	136.12	y =-7.6646x + 193.65	0.970
2012 Heifer	164.17	162.37	141.92	144.36	133.34	134.90	135.32	y =-5.3596x + 166.64	0.796
2013 Steer	197.74	197.65	183.50	173.04	161.17	160.94	147.37	y =-8.8159x + 209.75	0.964
2013 Heifer	170.00	165.28	150.83	158.37	148.27	146.48	137.57	y =-4.9089x + 173.46	0.875
2014 Steer	319.47	282.46	304.68	261.53	249.15	229.69	239.13	y =-14.36x + 326.89	0.838
2014 Heifer	273.61	267.94	275.99	243.51	217.66	217.44	213.57	y =-12.123x + 292.74	0.858
2015 Steer	218.00	271.76	245.19	203.80	179.79	176.51	163.25	y =-15.005x + 268.35	0.674
2015 Heifer	209.05	206.66	188.05	176.49	163.24	160.56	161.62	y =-9.2607x + 217.85	0.915

[1]Prices were obtained from weekly USDA-AMS market reports and are kept in industry-standardized units of $ per 100 lb ($/cwt).
[2]2008 steer and heifer records (n= 67) were excluded due to a large number of offspring lacking sire verification
[3]Some calves were weaned earlier than typical in 2011 due to drought.
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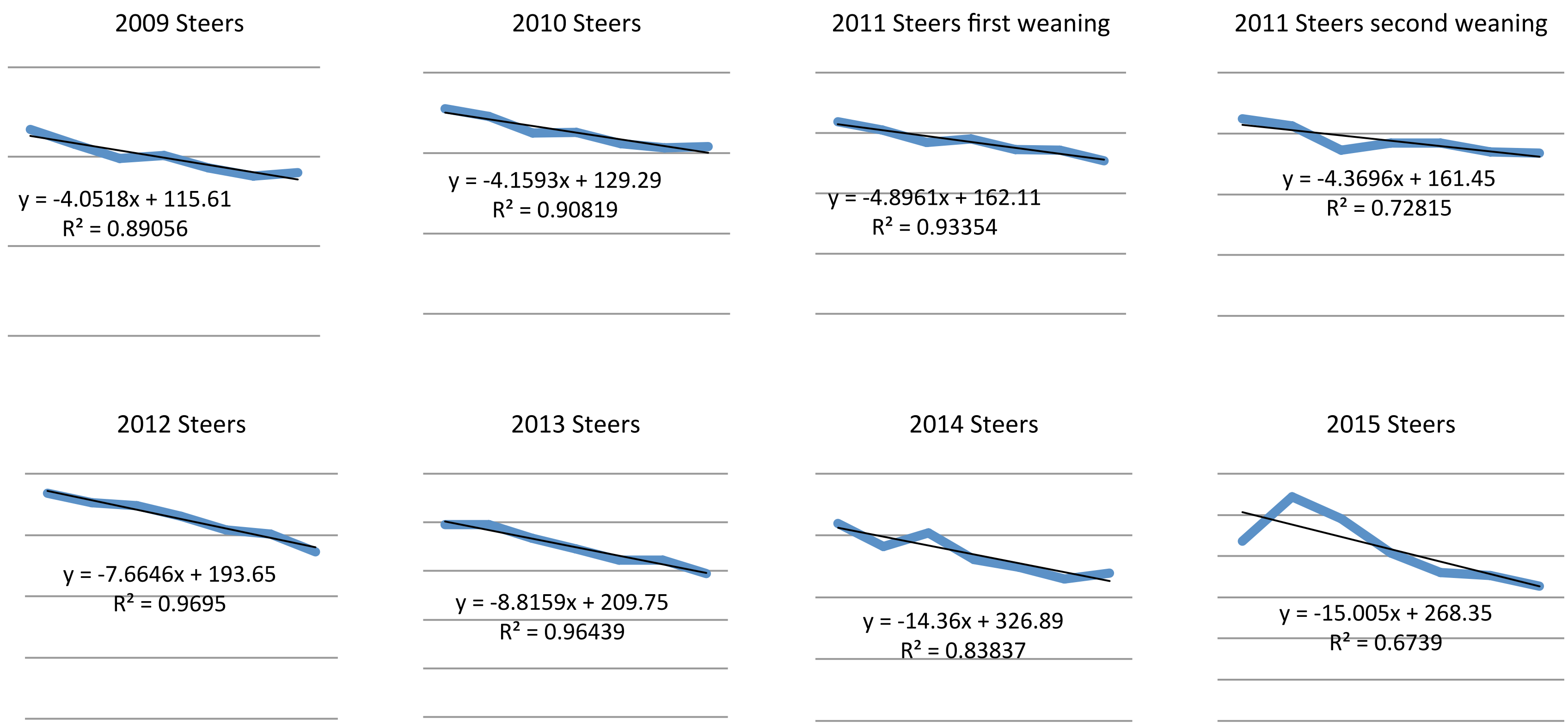

Figure 1. Weaning price slide equations for steer calves in 2009 to 2015 birth years. Graphs depicted show linear equations derived with x-axis being weaning weight in 50-lb increments across weight ranges of 300 to 650 lb, and y-axis of dollars per hundred weight. The blue line shows the actual price line for steers in the given year.

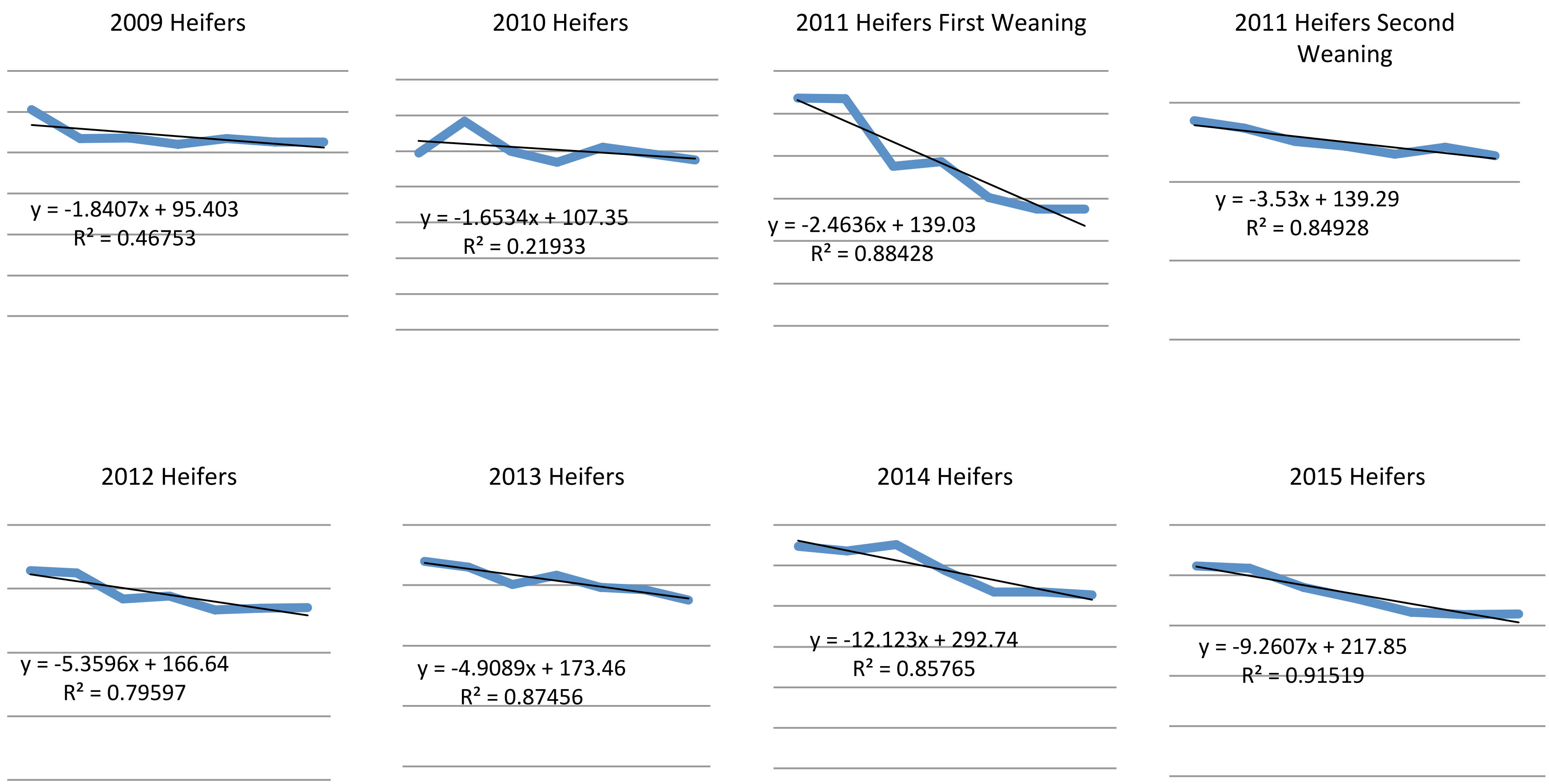

Figure 2. Weaning price slide equations for heifers calves from 2009 to 2015. Graphs depicted show linear equations derived with x-axis being weaning weight in 50lb increments across weight ranges of 300 to 650 lb, and y-axis of dollars per hundred weight. The blue line shows the actual price line for heifers in the given year.

Table 3 shows the significance levels from the calf trait statistical models. Year differences were not as important for birth weight (*P* = 0.069) as they were for weaning weight (*P* < 0.001), and therefore calf value. Sire effect, with sire breed nested, influenced birth weight (*P* = 0.013), weaning weight (*P* = 0.041) and calf value (*P* = 0.049). Sire breed approached importance for birth weight (*P* = 0.089) and was not important for weaning weight and calf value. Calf sex effects were important for birth weight (*P* < 0.001), weaning weight (*P* < 0.001) and value at weaning (*P* < 0.001). Sire breed by sex affected both birth weight (*P* = 0.016) and weaning weight (*P* = 0.049), but did not affect calf value. The three-way interaction sire breed type-dam breed type-calf sex approached importance for weaning weight (*P* = 0.10) and calf value (*P* = 0.089). Julian date effect was found to be important for birth weight (*P* = (0.032). Weaning date effect influenced both weaning weight (*P* < 0.001) and calf value (*P* < 0.001) at weaning. The least squares means for these calf traits across years are shown in Table 4.

Table 3. Significance levels for calf birth weight, weaning weight and weaning value.

Effect	Birth weight	Weaning weight	Calf value
Year	0.069	< 0.001	< .0001
Sire (sire breed)	0.013	0.041	0.049
Sire breed	0.089	--	--
Calf sex	< 0.001	< 0.001	< 0.001
Sire breed × sex	0.016	0.049	--
Sire breed × Dam breed × sex	--	0.100	0.089
Julian date, d	0.032	--	--
Weaning age, d	--	<.0001	<.0001

Table 4. Least squares means for birth weight, weaning weight and calf value by year

	Birth weight, kg			Weaning weight, kg			Calf value, $	
YEAR	N	Estimate	Standard Error	N	Estimate	Standard error	Estimate	Standard error
2009	63	34.5	1.21	63	214.9	4.24	430.99	12.198
2010	87	34.2	1.02	87	223.7	3.79	493.33	10.898
2011	109	34.5	0.83	108	214.3	3.92	625.54	11.267
2012	99	37.0	0.95	100	224.1	3.13	724.57	9.020
2013	91	36.3	0.97	91	226.2	3.32	780.44	9.547
2014	88	35.6	1.03	82	216.0	3.53	1195.14	10.156
2015	19	32.8	1.70	19	208.7	5.99	847.79	17.231

Year was significant for weaning weight and value at weaning. Birth weight averages by year ranged from 32.8 ± 1.70 kg in 2015 to 37.0 ± 0.95 kg in 2012. Weaning weight averages for year effect ranged from 208.7 ± 5.99 kg in 2015 to 226.2 ± 3.32 kg in 2013. Although weaning weight largely influences calf value, yearly changes in prices created a range in calf value from $430.99 ± $12.198 in 2009 to $1195.14 ± $10.156 in 2014. Differences in rainfall, supplementation as well as general variations in weather conditions could all contribute to the year-to-year differences in weaning weight and calf value.

Table 5 shows the birth weight and weaning weight means for the sire type x calf sex interaction. It is important to understand sire type interactions with birth weight as it has been found on numerous occasions that *Bos indicus*-sired calves from *Bos taurus* dams results in larger birth weights than both purebred calves and *Bos taurus*-sired calves from *Bos indicus* females. Ellis et al., (1965) studied both purebred Brahman and Hereford calf birth weights as well as Brahman x Hereford cross birth weights. Purebred Hereford calf birth weights were found to be near the mean while purebred Brahman calves were more then 8 lb. below the mean (Ellis et al., 1965). Brahman x Hereford and Hereford x Brahman cross birth weights were 12.75 lb. above average and 6.46 lb. below average respectively. Ellis et al., (1965) equated the 19 lb. difference in birth weight between the two reciprocal crosses the different maternal effects, or sex-linked effects, or both. Several more recent studies have documented this phenomenon (Brown et al., 1993; Amen et al., 2007; Dillon et al., 2015).

The two-way interaction between sire breed and calf sex displayed a range in birth weight from 32.1 ± 0.97 kg in the F_2 AN sired female calves to 36.5 ± 0.85 kg in the F_2 NA sired male calves. Weaning weight within the two-way interaction between sire breed and calf sex ranged from 206.6 ± 3.53 kg in F_2 female calves sired by NA bulls to 228.6 ± 3.63 kg in F_2 male calves sired by AN herd sires.

Table 5. Birth weight and weaning weight for the sire breed by calf sex interaction.

		Birth weight, kg			Weaning weight, kg		
Sire Breed[1]	Sex	N	Estimate	SE	N	Estimate	SE
F_1 AN	F	134	32.1	0.97	133	206.6	3.53
F_1 AN	M	123	35.8	1.02	122	228.6	3.63
F_1 NA	F	120	35.5	0.96	118	212.1	3.33
F_1 NA	M	179	36.5	0.85	177	225.8	2.95

[1]AN = Angus × Nellore, NA = Nellore × Angus

When comparing the three-way interaction sire breed-dam breed-calf sex, both weaning weight and calf value approached significance. The least square means for these combinations are provided in Table 6. Among all different sire breed x dam breed x sex combinations, the average weaning weight ranged from 202.3 ± 4.77 kg in the F_2 AN x AN female calves to 229.5 ± 3.70 kg in the F_2 AN x NA male calves. The range in average calf value for the three-way interaction varied from \$643.08 ± 13.727 in the F_2 AN x AN female calves to \$798.18 ± 10.653 in the F_2 NA x AN male calves. When comparing the differences between male and female calves of the same sire breed x dam breed combination, the largest difference in weaning weights was found between F_2 AN x AN calves with male calves weaning 25.5 kg heavier then the female calves. The lowest difference in weaning weights among male and female calves of the same sire and dam breed combinations was found in the F_2 NA x AN calves with the males weaning 10.6 kg heavier than the female calves. When looking at calf value, not surprisingly the largest difference between male and female calves of the same sire/dam breed combination was found in the F_2 AN x AN calves with the male calves on average bringing \$152.21 more then females of the same breed combination. Surprisingly, the lowest difference between male and female calves was found in the F_2 AN x NA calves with the males calves bringing \$113.34 more on average than female calves.

Table 6. Three-way interaction comparing weaning weight and calf value for sire breed, dam breed and calf sex.

Sire Breed	Dam Breed	Sex	N	Weaning weight, kg		Calf value, $	
				Estimate	SEM	Estimate	SEM
F1 AN	F1 AN	F	35	202.3	4.77	643.08	13.727
F1 AN	F1 AN	M	34	227.8	4.78	795.29	13.743
F1 AN	F1 NA	F	98	210.8	3.51	674.48	10.097
F1 AN	F1 NA	M	88	229.5	3.7	787.82	10.647
F1 NA	F1 AN	F	38	216.3	4.36	678.02	12.551
F1 NA	F1 AN	M	65	226.9	3.7	798.18	10.653
F1 NA	F1 NA	F	80	207.8	3.62	664.86	10.42
F1 NA	F1 NA	M	112	224.7	3.09	784.31	8.884

[1]AN = Angus × Nellore; NA = Nellore × Angus

Table 7 shows the number of calves and the mean calf performance for individual sires, across all years. Large differences were seen due to sire ID for birth weight ($P = 0.069$), weaning weight ($P < 0.001$) and calf value ($P < .0001$). Birth weight varied amongst sires with the range of birth weights falling between 30.5 ± 0.95 kg (Sire ID 032T) and 42.1 ± 3.86 kg (Sire ID 262S). Weaning weights varied from 195.5 ± 12.82 kg (Sire ID 441W) and 233.5 ± 5.78 kg (Sire ID 174U). Prices used for average calf value varied depending on the year thus creating better opportunities for some bull's calves to make more money given the year the herd bull sired the calves. Therefore, average calf value ranged from \$669.47 ± 36.055 (Sire ID 441W) to \$771.68 ± 16.622 (Sire ID 174U) amongst individual bulls over the 7-year period.

Because weaning weight played such a large role in determining calf value, sires that consistently produced offspring with increased weaning weights proved to be more beneficial in this production scheme. Although feeder calf grades were not available in the current study, Troxel and Barham (2007) found that steers received a premium as well as muscle scores of 1, therefore sires that produced an increased number of steers or increased number of calves with muscle scores of 1 could potentially result in more income. All traits in feeder calves are influenced by herd sires.

Table 7. Average birth weight, weaning weight and calf value for each sire

			Birth weight			Weaning weight			Calf value	
Sire ID	Sire Breed[1]	Years used	N	Estimate	SE	N	Estimate	SE	Estimate	SE
032T	F_1 AN	4	60	30.5	0.95	59	215.6	3.30	724.04	9.501
061U	F_1 AN	1	8	34.3	2.38	8	225.4	8.09	751.88	23.286
127S	F_1 AN	1	3	35.4	3.86	3	225.4	13.19	742.49	37.942
128S	F_1 AN	6	120	34.3	0.66	120	218.7	2.43	728.86	6.991
158U	F_1 AN	2	9	36.2	2.22	9	218.2	7.59	732.38	21.834
206S	F_1 AN	1	12	34.9	2.18	12	213.4	7.51	721.58	21.600
262S	F_1 AN	1	3	42.1	3.86	3	232.8	13.19	754.77	37.944
324T	F_1 AN	4	15	32.4	1.70	14	218.5	6.00	726.80	17.256
414S	F_1 AN	1	5	34.1	3.09	5	211.4	10.60	697.82	30.495
437U	F_1 AN	1	1	31.4	6.41	1	206.4	21.91	697.86	63.055
441W[2]	F_1 AN	0	3	31.8	3.74	3	195.5	12.82	669.47	36.895
461T	F_1 AN	3	7	32.6	2.47	7	217.1	8.57	730.33	24.655
487T	F_1 AN	3	11	31.7	2.05	11	230.3	7.04	748.92	20.256
174U	F_1 NA	5	16	37.0	1.68	16	233.5	5.78	771.68	16.622
229T	F_1 NA	5	53	33.9	0.94	52	217.5	3.28	727.56	9.434
230T	F_1 NA	1	25	36.5	1.59	25	219.3	5.47	719.56	15.741
297J	F_1 NA	2	37	36.0	1.30	37	220.6	4.61	732.60	13.264
422T	F_1 NA	1	5	32.1	3.00	5	208.6	10.25	707.51	29.489
437J	F_1 NA	3	3	38.7	3.80	3	203.5	12.92	697.02	37.164
482T	F_1 NA	5	160	37.7	0.59	157	229.5	2.08	763.47	5.985

[1] AN = Angus × Nellore; NA = Nellore × Angus.
[2]This bull was not intended for use and entered the breeding herd from a nearby pasture.

Table 8 illustrates the individual herd sire traits on an annual basis. No statistical analysis was run on the economic values reported in Table 8. Because this information is a reflection of economic value and U.S. beef industry standards, the values from these considerations are kept in imperial units rather than metric. Variability within each year is discussed because large differences in average prices occurred across these project years.

In the 2008 breeding season, 7 bulls were exposed to 99 females with a 14.1 female:bull ratio, however some of the females exposed belonged to another genetic group. There were 66 calf birth records recorded but only 63 calves had sires determined after DNA verification with 6 bulls having sired calves. There were 33 female calves (52.38%) and 30 male calves (47.62%), staying relatively close to the probable 50:50 ratio of male:female calves born any given year. Whitworth (2002) found no difference in the percentages of bull and heifer calves when compared to the expected 50:50 ratio during experiment 1 or experiment 2. Bull 032T was the herd bull that did not sire any calves, however 032T was used as a yearling and therefore would not be considered to be of breeding age yet and therefore not considered in the yearly income or net cumulative value for this year. It is assumed that social hierarchy played a role in the lack of production of herd sire 032T, as the other herd bulls were between 2 and 9 years of age. It is known that the older bulls may influence access to females within multi-sire mating groups (Petherick, 2005). The number of calves born and weaned for an individual sire ranged from 0 to 22. The yearly profit per sire ranged from $666.69 to $4,854.47. The net cumulative value for sires ranged from -$1,783.31 to $2,404.47.

Table 8. Bull performance per year of sires that produced offspring.

Year	Bull ID	Percentage of calves born in 1st 21 days	Calves weaned	Avg. calf value	Yearly income
2009	127S	66.7%	3	$444.46	$666.69
2009	128S	55.6%	18	$435.18	$3,916.58
2009	206S	66.7%	12	$425.23	$2,551.36
2009	262S	66.7%	3	$457.47	$686.20
2009	297J	77.3%	22	$441.32	$4,854.47
2009	414S	80.0%	5	$461.99	$1,154.97
2010	032T	0.0%	24	$547.95	$6,575.43
2010	229T	0.0%	2	$495.75	$495.75
2010	230T	12.0%	25	$571.80	$7,147.47
2010	324T	0.0%	4	$556.76	$1,113.53
2010	422T	0.0%	5	$537.40	$1,343.49
2010	461T	0.0%	3	$553.64	$830.46
2010	482T	0.0%	17	$559.69	$4,757.35
2010	487T	0.0%	7	$575.26	$2,013.41
2011	032T	39.1%	22	$527.79	$5,805.69
2011	061U	12.5%	8	$514.76	$2,059.05
2011	128S	60.6%	33	$561.78	$9,269.31
2011	174U	0.0%	1	$575.89	$287.94
2011	229T	38.1%	21	$556.25	$5,840.60
2011	297J	33.3%	15	$518.47	$3,888.49
2011	437J	0.0%	3	$458.44	$687.66
2011	437U	0.0%	1	$456.83	$228.42
2011	461T	25.0%	4	$570.02	$1,140.04
2012	032T	69.2%	13	$794.51	$5,164.30
2012	128S	54.2%	24	$721.95	$8,663.43
2012	158U	25.0%	8	$775.56	$3,102.25

Table 8. (Continued).

Year	Bull ID	Percentage of calves born in 1st 21 days	Calves weaned	Avg. calf value	Yearly income
2012	174U	50.0%	2	$813.77	$813.77
2012	229T	33.3%	12	$727.82	$4,366.93
2012	441W	0.0%	3	$669.72	$1,004.58
2012	482T	29.0%	38	$775.61	$14,736.54
2013	128S	52.8%	36	$770.11	$13,862.06
2013	158U	100.0%	1	$886.94	$443.47
2013	174U	30.0%	10	$817.47	$4,087.34
2013	229T	20.0%	5	$793.25	$1,983.12
2013	324T	0.0%	2	$721.83	$721.83
2013	482T	43.2%	37	$821.33	$15,194.59
2014	128S	44.4%	8	$1,187.17	$4,748.68
2014	174U	0.0%	3	$1,293.93	$1,940.90
2014	229T	46.2%	12	$1,230.72	$7,384.32
2014	324T	62.5%	7	$1,225.16	$4,288.06
2014	482T	54.9%	48	$1,286.24	$30,869.76
2014	487T	100.0%	4	$1,177.04	$2,354.08
2015	128S	100.0%	1	$1,008.93	$504.47
2015	324T	0.0%	1	$810.12	$405.06
2015	482T	29.4%	17	$952.05	$8,092.45

[1]Bulls that did not sire any offspring were not included in table.

Feeder calf prices in 2009 could be considered to be lower when compared to other years. For instance, the average steer price for 500-550 lb. steers in 2009 was $93.61($/cwt) and the average steer price for 500-550 lb. steers in 2014 was $249.15 ($/cwt). Therefore, calves from the 2008-breeding season that sold in 2009 sold for less on average then other years in the study. There were 3 bulls that sired 82.54% of the calves that had sires identified and were the only bulls that turned a profit for the year. Abell et al. (2017) also found similar results in multiple-sire pastures, as bulls ranked as more prolific sires over a 7-year period sired 113% greater calves then the expected pasture average. Similarly, Makarechian and Farid (1985) studied bull fertility under group mating conditions and found that in a group of five mature herd sires (one 3-year old and four 2-year olds) the 3 year old bull sired 40.9% of the calves. Likewise, Chenoweth (1981) cited an unpublished study by Osterhoff where the oldest or second oldest bull in a multi-sire mating group sired 60% or more of the calves each year while the youngest bull sired 15% or fewer. Sire 297J producing the most offspring may not have been due to being the dominant bull, but being the oldest sire (9 years old) may have contributed more to his experience and efficiency in terms of number of mounts and the number of actual services (Petherick, 2005). Interestingly, sire 297J's calves on average weighed 2.8 lb heavier than calves sired by 414S, however, calves sired by 414S on average weaned 8.94 lb heavier than calves sired by 297J. This difference in weaning weights among the calves led to a $20.67 difference per head in favor of sire 414S. However, sire 414S only weaned 5 calves while 297J weaned 22 calves meaning 297J produced more total pounds and thus more profit. Moreover, 297J was 9 years old at the beginning of breeding season and 414S was 2 years old, leaving one to expect a certain level of dominance asserted by 297J leading him to sire the largest number of calves.

In the 2009 breeding season, 8 bulls were exposed to 108 females with a 13.5 female:bull ratio. There were 95 birth weight records recorded with 87 of these calves having sires identified through DNA analysis and all 8 bulls were found to have sired calves. However, the number of calves born and weaned per sire ranged from 2 to 25, and just 3 bulls sired 75.86% of the calves that had sires determined. All herd sires used during the 2009-breeding season were the same age and raised together. Pretherick (2005) found that bulls from similar age groups that have been reared together are less likely to fight, decreasing the instances of injured bulls during the breeding season. According to Blockey (1979), dominance is expressed more strongly in older bulls (i.e. 3 to 4 years of age and older). Since the entire group of herd sires used were 2 years of age going into the 2009-breeding season, dominance among the bulls should have been less of a factor. The yearly income per sire ranged from $830.46 to $7,147.47. The net cumulative value for individual sires ranged from -$1,954.25 to $4,697.47, of which only the 3 bulls that sired the bulk majority of the calves made any profits. When comparing some of the sires, it was found that 032T's calves on average out weighed sire 487T's calves at birth by 4.29 lb. However, 487T's calves on average weaned 46.29lb heavier than calves sired by 032T, which led to a difference in calf value of $27.31 per head in favor of sire 487T. Interestingly, 20 of the 25 calves sired by 230T were bull calves and 230T sired the most calves in the first 21days of calving season. This may have attributed to 230T's ability to generate the largest yearly income for the 2010 calf crop as male calves on average receive premiums when compared to heifer calves (Lambert et al., 1989; Troxel and Barham., 2007; Halfman et al., 2009).

In the 2010 breeding season, 139 females were exposed to 9 bulls having a 15.4 female:bull ratio during the breeding season. There were 120 birth weight records taken however 109 calves had sires identified using DNA analysis and all 9 herd sires exposed produced offspring. The number of calves born and weaned for individual sires ranged from 1 to 33. The yearly income per sire ranged from $228.42 to $9,269.31. Net cumulative value varied greatly as some of the bulls were on their second breeding season and therefore had more total calves born. Net cumulative value for bulls siring calves during the 2011 calf crop ranged from -$2,137.58 to $10,119.89. There were 4 bulls that sired 15 or more calves; 3 of which turned a net profit the previous year and 1 that after its second season made a net profit. Interestingly, 3 of the sires that produced the most offspring were either 3 or 4 years of age; however, one of the herd bulls was 11 years old at the beginning of the breeding season. When comparing 2 of the 4 bulls that sired

15 or more calves, it was noted that calves sired by 229T weighed on average 4.15 lb less at birth then calves sired by 297J. Those calves sired by 229T then weaned 23.63 lb greater than calves sired by 297J; leading to a $38.00 difference in calf value with calves sired by 229T on average bringing a higher price.

In the 2011 breeding season, 122 females were exposed to 7 breeding age bulls with a female:bull ratio of 17.4. There was 106 calf birth records assigned, however there was 100 calves with sires identified through DNA analysis of which 6 herd sires used produced offspring as well as one bull that was not in the breeding group (441W). The number of calves born and weaned for a single sire ranged from 0 to 38. Of the calves born, 2 sires produced 62.00% of the calves with sire ID determined. In a similar study about calf output in multiple-sire herds, Holroyd et al. (2002) found that of the 235 bulls used during the study 58% sired 10% or less calves in each of their respective groups with 6% not siring any calves. Even more, only 14% of the 235 herd sires produced over 30% of the calves in each of the respective multi-sire mating groups (Holroyd et al., (2002). The yearly income per sire ranged from $0 to $14,736.54. The net cumulative value per sire ranged from -$2,048.29 to $17,999.32. When comparing two of the herd sires used during the 2011 breeding season, calves sired by 032T on average weighed 3.46lb lighter than calves sired by 128S. Even more, when evaluating weaning weights and calf value, calves sired by 032T out-weighed calves sired by 128S at weaning by 39.20 lb and on average brought $72.56 per head more when sold. However, 128S sired 11 more calves than 032T, which enabled his calves to accumulate a yearly income of $8,663.43, $3,499.13 more then sire 032T. This shows that the number of calves produced is the most economically significant factor for determining bull value.

In the 2012 breeding season, 117 females were exposed to 6 breeding age bulls with a female:bull ratio of 19.5. There were 98 calf birth weight records determined, however only 91 calves had sires determined through DNA analysis of which 6 bulls were accounted for. The number of calves born and weaned for individual sires ranged from 1 to 37 with 2 sires producing 80.22% of the offspring with sire ID determined. The yearly income per sire ranged from $443.47 to $15,194.59. The net cumulative value per sire ranged from -$1,314.64 to $31,161.38.

In the 2013 breeding season, 111 females were exposed to 6 bulls with a female:bull ratio of 18.5. There were 95 calf birth weight records taken however, after DNA analysis only 88 calves had sires determined of which all 6 bulls were found to have produced offspring. The number of calves born for individual sires ranged from 3 to 51 and the number of calves weaned ranged from 3 to 48 with one sire producing 57.95% of the calves with sire ID determined. The yearly income per sire ranged from $1,940.90 to $30,869.76. The net cumulative value per sire accumulated after the 2013 breeding season ranged from $1,212.49 to $60,308.24. Feeder calf prices for calves born and sold in 2014 were the highest during the study. Steer calves weighing 500-550 lb. sold for $249.15 ($/cwt) and heifers weighing 500-550 lb. sold for $217.66 ($/cwt). Interestingly, sire 482T sired 51 of the calves born and 48 of the calves weaned in the 2014 calf crop, the most of any sire during that breeding season. Of those calves born, 33 were bull calves (64.71%) and given the large number of calves born, 54.90% were born in the first 21 days of calving season. Even more, 20 of the 28 calves born in the first 21 days of calving season were male offspring. The earlier births combined with producing more steer calves may have attributed to 482T's calves weaning 16.58 lb heavier than the next closest sire. The increased number of steer calves contributes to more yearly income due to the fact that steers bring more on average per hundredweight (Lambert et al., 1989; Troxel and Barham., 2007; Halfman et al., 2009).

In the 2014 breeding season, 108 cows were exposed to 5 bulls with a female:bull ratio of 21.6, however not all of the females exposed belonged to this genetic group. There were 24 calf birth weight records taken with only 19 calves having sires determined through DNA verification. Of the 5 herd bulls turned out, only 3 herd sires produced F_2 calves that could be used for this project. The number of calves born and weaned per sire ranged from 0 to 17 with 1 herd sire producing 89.47% of the offspring with sire ID determined. The yearly income per sire ranged from $0.00 to $8,092.45 and the net cumulative value per sire post 2015 calf crop ranged from $2,678.48 to $67,700.69.

Table 9. Sires used during each breeding season and the number of calves weaned per sire.

Bull	Bull Birth Year	Sire Breed[1]	2008/2009	2009/2010	2010/2011	2011/2012	2012/2013	2013/2014	2014/2015
127S	2006	AN	3						
206S	2006	AN	12						
262S	2006	AN	3						
414S	2006	AN	5						
128S	2006	AN	18		33	24	36	8	1
032T	2007	AN	0	24	22	13			
324T	2007	AN		4			2	7	1
461T	2007	AN		3	4	0			
487T	2007	AN		7				4	0
061U	2008	AN			8				
158U	2008	AN				8	1		
437U	2008	AN			1				
297J	1999	NA	22		15				
432H	1998	NA							
437J	1999	NA			3				
229T	2007	NA		2	21	12	5	12	
230T	2007	NA		25					
422T	2007	NA		5					
482T	2007	NA		17		38	37	48	17
174U	2008	NA			1	2	10	3	0

[1]AN = Angus × Nellore; NA = Nellore × Angus

Impressively, during sire 482T's 5 years of service he sired 157 weaned calves with a net cumulative profit of $67,700.69 averaging $13,540.14 per year in service. Sire 229T was also used for 5 years throughout the project, siring 52 calves worth a net cumulative profit of $14,820.72 averaging out to $2,964.14 per year in service. 482T's calves on average across the 5 years he sired calves weaned at 229.5 kg while 229T's calves on average weaned at 217.5 kg. The 2013 calf crop reared offspring from both sires, of the 5 calves born to 229T only 20.00% were born in the first 21d of calving season while 482T sired 37 calves and 43.24% of those calves were born in the first 21d of calving season. Typically calves born earlier in the breeding season weigh more at weaning and this was no exception, as calves sired by 482T weaned on average 21.96 lb heavier than calves sired by 229T.

SUMMARY AND CONCLUSIONS

DNA parentage testing can be beneficial to the commercial cow-calf producer. Understanding individual herd sire production and profitability allows producers to better manage and evaluate their bull battery in multi-sire mating groups. This study evaluated sire variability for traditional calf performance traits and relative annual income using F_1 NA or F_1 AN sires on F_1 NA or F_1 AN dams to produce F_2 calves from 2009-2015 at Texas A&M AgriLife Research Center at McGregor. Differences in yearly income of the highest producing sire and the lowest producing sire in this study ranged from $4,187.78 to $28,928.87 depending on the given year. Across all years, income per sire ranged from $0 to $30,869.76. The number of calves born to individual sires ranged from 0 to 51, and the number of calves weaned for individual sires ranged from 0 to 48. Although weaning weight plays such a large role in determining calf value, the number of calves weaned per sire should be considered the most important factor driving economic performance per sire. Sires that had the highest average calf value in a given year did not necessarily generate the most profit if other sires produced a larger number of offspring. Of the 7 years of calf crops produced, one sire generated the most profit (Sire 482T) in four consecutive years. Male:Female ratio of calves born to individual sires more than often stayed relatively close to 50:50. However, when sires did produce more male offspring, this generated more income.

Additional studies should be conducted that account for individual calf characteristics to more precisely evaluate individual sires such as: muscle score, frame score, horned vs. polled, hide color, etc. relative to the herds' region as this would determine appropriate premiums and discounts given on each calf over the weight class average value. Also, further studies should be conducted to look at economic values for increasing female:bull ratios for breeding herds. This study had a relatively low female:bull ratio (ranging from 108 females to 8 bulls to 108 females to 5 bulls) to help ensure female reproduction was not limited, which leads one to question how different the number of calves produced per sire might change when given more females to breed. This may decrease dominance as bulls would be more focused on servicing females then fighting of less dominant sires. Commercial cow calf producers should consider using DNA parentage verification to formulate data to better understand and manage herd sires within their operation.

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