EVALUATION OF F_1 COWS SIRED BY BRAHMAN, BORAN, AND TULI BULLS FOR REPRODUCTIVE AND MATERNAL PERFORMANCE TRAITS AND COW LONGEVITY

A Thesis

by

CARL THOMAS MUNTEAN

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of requirements for the degree of

MASTER OF SCIENCE

May 2011

Major Subject: Animal Breeding

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Chair of Committee,	James O. Sanders
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ABSTRACT

Evaluation of F_1 Cows Sired by Brahman, Boran, and Tuli Bulls for Reproductive and Maternal Performance Traits and Cow Longevity. (May 2011)

Carl Thomas Muntean, B.S., Texas A&M University

Chair of Advisory Committee: Dr. James O. Sanders

Birth (BWT) (n = 1,335) and weaning weight (WWT) (n = 1,246), pregnancy rate (PR) (n = 1,513), calf crop born (CCB) (n = 1,504), calf crop weaned (CCW) (n = 1,500), cow weight at palpation (CW) (n = 1,662), and cow body condition score (BCS) (n = 1,666) were evaluated from 1994 to 2010 in 143 F_1 females sired by Brahman (B), Boran (Bo), and Tuli (T) bulls and out of Angus and Hereford cows. Mouth scores (MS) (n = 253) were assigned to the remaining cows from 2004 to 2009, excluding 2008. Pregnancy rate, CCB, CCW, CW, and BCS were evaluated using a model that consisted of sire of cow breed, dam of cow breed, and calf's birth year/age of cow as fixed effects. Cow within sire of cow within sire breed of cow and sire of cow within sire breed of cow were used as random effects. Birth weight and WWT were evaluated including sex of calf in the same model. Mouth scores were evaluated with two models. When broken and solid mouths were scored 1 and smooth 0, B- and Bo-sired cows (0.87 and 0.83) had higher scores ($P < 0.05$) than T-sired females (0.65). When solid mouths were scored 1 and smooth and broken scored 0, B-sired cows (0.40) were higher than T (0.07) ($P < 0.05$), and Bo (0.30) sired cows were not different from either ($P > 0.05$). The model for

MS only included sire of cow breed and calf's birth year/age of cow as fixed effects. Two-way interactions were tested for significance. Calf's birth year/age of cow was important for all traits ($P < 0.05$) except the first MS model. Adjusted means (LSM) for BWT for calves out of cows by B, Bo, and T sires were 34.1, 34.0, and 34.1 kg respectively, and were not different from one another ($P > 0.05$). Least squares means for WWT for calves out of cows by B, Bo, and T sires were 236.7, 217.5, and 197.2 kg, respectively, and were significantly different. For both BWT and WWT, male calves were heavier ($P < 0.05$) than females, by 2.13 kg and 10.39 kg, on average. Least squares means for PR for females sired by B, Bo, and T bulls were 0.900, 0.930, and 0.912, and were not different ($P > 0.05$). Adjusted means for CCB for females sired by B, Bo, and T sires were 0.872, 0.944, and 0.892 respectively, and Bo was higher ($P < 0.05$) than B and T. Calf crop weaned ranked the same as CCB with adjusted means of 0.805, 0.894, and 0.843 for cows by B, Bo, and T bulls, with Bo being higher ($P < 0.05$) than B. Cow weight adjusted means for cows by B, Bo and T sires were 537.1, 468.9, and 462.6 kg, respectively, with B-sired females being heavier ($P < 0.05$) than both Bo and T sired cows. Body condition scores for B, Bo, and T sired cows were 5.19, 5.43, and 5.15, respectively, with Bo-sired cows being the highest ($P < 0.05$). Higher reproductive rates were found for Bo-sired cows, but B-sired cows weaned heavier calves.

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TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

FIGURE Page

INTRODUCTION

Although the cattle inventory has been declining the past 4 years, beef production has remained the single largest sector of American agriculture (NCBA 2011). In 2007, 31 percent of all farms were classified as beef cattle operations, and, of these, 97 percent were family farms. In 2010, 26.3 billion pounds of beef were produced (NCBA 2011) and on January 1, 2011, there were 92.6 million cattle in the United States (Peña, 2011). With this industry being so vast, production efficiency is an important aspect that producers across the country should strive to increase. Chapman and ZoBell (2004) stated that the use of crossbreeding is one of the most powerful tools available to cattle producers to improve the efficiency of production in a herd. Beef cattle crossbreeding systems should focus on optimizing heterosis and breed differences to produce cattle that are best suited for different climatic environments and nutritional environments, as well as other traits important to specific markets (Gregory and Cundiff, 1980).

No single breed of cattle has proven to be superior in all environments across the United States. Highest productivity is in part due to appropriate matching of genotype and environment and utilizing non-additive genetic differences (heterosis) and complementarity to the fullest (Trail et al., 1985; Frisch and O'Neill, 1998; Cundiff et al., 2000). Complementarity in this case is used in the same manner as by Bourdon (2000) where it is described as the improvement in the performance of offspring resulting from crossing different breeds with complementary biological types. The added performance gained in numerous different production traits of crossbred

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animals compared to straightbreds is in part due to heterosis effects, or the advantage of the crossbred over the average performance of the 2 parental breeds (Lush, 1945). Three major traits controlling the performance and economics of a commercial beef herd, maternal ability, weaning rate, and growth potential of the calf, are greatly impacted by heterosis and its effects (Koger, 1980).

The "standard" crossbred female in the Southeastern United States today has at least some percentage of Brahman blood. One of the major concerns with the Brahman—*Bos taurus* F_1 female, however, is that she is unable to produce replacements that are equivalent to her level of production. With the production of the F_2 generation of the Brahman x *Bos taurus* cross, only one half of the heterosis seen in the F_1 is expected to be retained. Thus, this has led to interest in other tropically adapted breeds that could produce high levels of hybrid vigor when mated to both Brahman and *Bos taurus* breeds (Herring et al., 1996). There has been a great deal of interest in evaluating alternative breeds of African origin. The goal was to determine if the use of alternative germplasm of African origin such as the Boran and Tuli could be used to cross with Brahman x *Bos taurus* F_1 females to produce a second generation of females that can take advantage of more heterosis than is retained in the F_2 generation of the Brahman x *Bos taurus* cross (Vercoe and Frisch, 1992).

The objective of this study was to evaluate the reproductive and maternal performance and longevity traits of F_1 cows sired by Brahman, Boran, and Tuli bulls and out of Angus and Hereford cows. The results of the analyses were compared to previous reports on F_1 *Bos taurus-Bos indicus* cows for reproductive and maternal performance.

LITERATURE REVIEW

Crossbreeding in Beef Cattle

Systematic crossbreeding allows producers to take advantage of heterosis as well as the combination of desirable traits that are not available solely from one parent breed (Cundiff, 1970). Although these are potential advantages, the success of crossbreeding relies on the combinations of suitable parent breeds for specific production environments and management systems (Koger, 1980). There are three key reasons for the use of crossbreeding: breed combination, breed complementarity, and heterosis (Hammack, 1998) and the optimal genetic potential of the cattle to be mated depends on the environment, available feed resources, and market demands (Cundiff et al., 1993; Hammack, 1998).

Brahman

The Brahman (an American Zebu breed) has been important in the United States beef industry for many years, especially in the southeastern region where heat stress and parasites limit the productivity of *Bos taurus* breeds (Cartwright, 1980; Franke, 1980; Turner, 1980; Herring et al., 1996). The ability of the Brahman breed to tolerate heat and parasites led to the widespread interest to research their utility in crossbreeding programs. Cartwright (1980) stated that contributions that Zebu cattle can make to the U.S. beef production systems would be primarily through the utilization of Zebu hybrids. The greater difference between Brahman inheritance and that of the *Bos taurus* breeds offers heterotic (hybrid vigor) advantages when used in crossbreeding systems. This has resulted in the majority of commercial beef cattle herds in the southern United States being composed of crossbred cows with some degree of Brahman inheritance along with British, Continental, and possibly dairy breeding (Franke, 1980).

The American Brahman resulted from a series of upgrades occurring prior to and during the 1920's, 1930's, and 1940's, when various strains of Zebu males were mated to domestic cows present in the Gulf Coast region (Franke, 1980; Sanders, 1980). Zebu cattle, as found in the U.S. today, are made up of breeds originating in India and imported from both India and Brazil. The Gray Brahman is made up primarily of Guzerat and Nellore blood with some influence from other Zebu breeds (Sanders, 1980). Sanders (1980) also stated that the Guzerat was the most important breed involved in the formation of the Gray Brahman. The Guzerat originated in northern India and has been utilized as both a draft and milk breed there. They are a gray breed with short faces, lyre-shaped horns, and long broad ears. They have been maintained as a pure breed in Brazil as well as in India, where they are known as the Kankrej. The Nellore (Ongole) is also a native breed of India. Nellore cattle tend to have long narrow heads and small ears. In India they were used as a dual-purpose breed (milk and draft), but have been selected as a beef breed in Brazil (Sanders, 1980). According to Sanders (1980), until the mid 1920's, Nellore-type cattle made up the majority of the Zebu cattle in the U.S., and thus contributed greatly to the Brahman breed as their maternal base.

Along with being the most numerous Zebu breed in the United States, the Brahman is unique in that it was primarily maintained as a breed within the United States for creating crossbred replacements for commercial production rather than being used as a purebred breed of cattle for commercial production (Cartwright, 1980; Turner, 1980). Purebred Brahman females producing purebred Brahman calves tend to have a lower calving percentage, lower calf survival rates, and in turn lower calf crop weaned when compared to their straightbred *Bos taurus* contemporaries (Cundiff, 1970; Franke, 1980). In the review by Cundiff (1970), it was observed that purebred Brahman calves had somewhat higher weaning weights than those of Hereford and Shorthorn but similar to Angus. Several studies have also shown the inability of Brahman and Brahman derivative breeds to match the carcass quality and meat tenderness of other breeds of cattle available (Damon et al., 1960; Franke, 1980; De Rouen et al., 1992; Paschal et al., 1995; Wheeler et al., 2001). Also, in the review by Cartwright (1980) and study by Reynolds et al. (1980) the authors reported that high percentage Brahman cattle tend to have later onset of puberty and lower calf vigor. Riley et al. (2004) also found that straightbred Brahman calves had a 24.7% greater chance of poor vigor at birth than 2/3 Brahman calves did. Riley et al. (2001a) reported that as young cows and heifers, Brahman (both gray and red) cross dams had the lowest calf crop weaned of any of the *Bos indicus* that were evaluated, but from 4 to 9 years of age, these females did not have a lower calf crop weaned than other breeds in the study.

In addition to other differences, Brahman cross cattle are different from *Bos taurus* x *Bos taurus* crosses because of the additional performance attained from the higher levels of heterosis. Two to three times as much hybrid vigor is generally seen in *Bos indicus* x *Bos taurus* crosses when compared to crosses involving 2 *Bos taurus* breeds (Sanders, 1994). Sanders (1994) also wrote that the variations seen in Brahman crosses can be attributed to: hybrid vigor in the calf, hybrid vigor in the dam, the amount of Brahman in the calf, the amount of Brahman in the dam, and the amounts of other specific breeds in the calf and dam. Brahman cross calves offer numerous advantages when compared to many straightbred calves, including: increased survival rates (Franke, 1980), increased weaning weights (Gregory et al., 1979; Franke, 1980; Cundiff et al., 2000), and increased average daily gains (Paschal et al., 1991). Brahman cross cows have shown higher pregnancy rates (Riley et al., 2001a), higher calving rates (Peacock and Koger, 1980; McCarter et al., 1991), increased weaning rates (Peacock et al., 1971; Franke, 1980; McCarter et al., 1991), and a longer productive life (Bailey, 1991; Núñez-Dominguez et al., 1991) when compared to straightbreds and *Bos taurus*-cross dams. Although there are advantages to the Brahman—*Bos taurus* F_1 female, as stated earlier, her inability to produce a replacement with the same level of productivity as herself is a production concern that has led to interest in Boran and Tuli (Herring et al., 1996).

Boran

The Boran originated in the Kenya-Ethiopia region of Africa (Epstein, 1971; Porter, 1991) and is a shoulder-humped Zebu (*Bos indicus*) breed that has been used as the standard of comparison for beef production systems of East Africa (Trail and Gregory, 1981). They have long and wide, yet still well proportioned, heads and generally have short horns (Epstein, 1971). The Boran breed is also different from the Brahman in that they have small non-pendulous ears. They were originally developed for milk and meat production in the tropical conditions of Africa (Cundiff et al., 2000). Borans are highly fertile and mature earlier than most other *Bos indicus* breeds and are noted for their docility (DeSilva and Fitch, 1995).

The Boran is a possible alternative for the Brahman in some breeding operations due to the more conservative birth weights and mature cow sizes (Herring et al., 1996; Cundiff et al., 2000). Consequently, the Boran may produce a more moderate but still tropically adapted replacement. The U.S. Meat Animal Research Center (MARC) in Clay Center, Nebraska has evaluated the value of the Boran for beef cattle production and found that in comparison to cows sired by Brahman and Tuli, cows sired by Boran produced more favorable preliminary results. Boran-sired cows not only had a higher calf crop born, but also had a higher calf crop weaned (Cundiff et al., 2000). In another report from the same study, Freetly and Cundiff (1997) reported that Boran-sired heifers reached puberty at a younger age than heifers by Brahman bulls.

Tuli

The Tuli is a Sanga type of cattle that was developed in the 1940's from a research project that utilized what was thought to be the most productive type of the indigenous Tswana cattle in Zimbabwe (Cundiff et al., 1995). The origin of Sanga type cattle has been debated for numerous years. Many different ideas have come about in recent years as to how they evolved. Epstein (1971), Hetzel (1988), and Schoeman (1988) suggested that Sanga cattle evolved from crosses between Zebu and humpless longhorn cattle in central and eastern Africa, but a more recent study by Frisch et al. (1997) contradicts this as the frequencies of four DNA markers (RFLP) visualized as electrophoretic bands in the Tuli were vastly more similar to those of European breeds and dissimilar to Brahman and suggest that the Tuli originated from taurine ancestors. They further concluded that the separation of Tuli from European breeds occurred more recently than their separation from Indian breeds. Their findings led the authors to suggest that the Tuli be regarded as a *Bos taurus* breed. This conclusion is more in line with the findings by Meyer (1984) where he discussed that Tuli and other Sanga breeds were different from Zebu cattle in that they have a sub-metacentric Y-chromosome similar to *Bos taurus* rather than the acrocentric Y-chromosome of *Bos indicus* or Zebu. Anderung et al. (2007) evaluated 6 African cattle breeds (including 4 Sanga breeds) for 6 new X-chromosomal markers and found that there was a bias towards indicine types in the Y chromosome (63%), but not in the X chromosome (44%) (P = 0.037), however, the authors also reported that Nguni (a Sanga breed that is from Southern Africa and very similar to Tuli) has a Y chromosome that is exclusively taurine. For the X-chromosome, all breeds in the study had some level of indicine and taurine types (Anderung et al., 2007). Sanga type cattle have a cervico-thoracic hump that is situated in front of the withers and is well defined (also called "neck" hump) rather than the thoracic hump of Zebu types (Epstein, 1971).

The Tuli has been utilized in both production and research in Africa for many years and has recently become a breed of great interest in research studies in the United States. Tuli-sired calves were similar to the progeny of British sire breeds for preweaning performance in a study in Zimbabwe (Tawonezvi et al., 1988). Tuli cows have been noted as being extremely productive as well. In high performance environments, Hetzel (1988) noted that, when compared to Brahman, Boran, and other breeds of African origin, the Tuli was the most fertile breed as well as having the most productive females per unit of body weight. Tuli-sired females also reached puberty at a younger age than females by both Brahman and Boran (Freetly and Cundiff, 1997; Cundiff et al., 2000). Additionally, in a study by Trail et al. (1977), the Tuli exhibited a higher calving percentage and lower calf mortality rate than both Africander and Tswana. In a study in southeast Queensland, Australia, Tuli cattle have also shown evidence of heat tolerance similar to that of Brahman x Hereford crosses and better than Hereford (Gaughan et al., 1999). Moreover, Tuli appears to be an alternative to the Brahman in regards to their more moderate mature size (Browning et al., 1995; Herring et al., 1996; Cundiff et al., 2000) Although Tuli-sired calves are slower gaining when compared to Boran and Brahman-sired calves, they still offer advantages in carcass quality and are more similar, in this respect, to animals of the British beef breeds (Herring et al., 1996; Cundiff et al., 2000; Wheeler et al., 2001).

Growth Traits

Birth Weight

Birth weight is an extremely important trait that affects both the economics and productivity of an operation. Extreme birth weights are very detrimental to beef cattle operations due to their association with dystocia, which can cause calf mortality, cow loss, reduced calf performance, and decreased cow fertility (Roberson et al., 1986; Paschal et al., 1991; Cundiff et al., 1995). Cundiff et al. (1995) noted that calving ease is associated with birth weight and that there is a threshold point where increases in birth weight increase the incidence of dystocia, causing increases in calf mortality. Paschal et al. (1991) also stated that, because of the close association between birth weight and dystocia, breeds with large differences between sexes for birth weight can experience higher levels of dystocia when compared to the expected level determined by the average birth weight of the breed. The weight differences between sexes in *Bos indicus*-sired crossbred calves, are larger than that of *Bos taurus*-sired calves (Gregory et al., 1979; Bailey and Moore, 1980; Paschal et al., 1991). Large birth weights, and an increased incidence of dystocia, are more likely to occur when Brahman bulls are mated to *Bos taurus* heifers or small *Bos taurus* cows (Koger, 1980; Roberson et al., 1986). This is not the case with calves out of *Bos indicus*-sired cows. Jenkins and Ferrell (2004) noted that calves out of Brahman or Boran-sired females were lighter than calves out of cows sired by bulls of British descent. Brahman cows minimize differences in birth weight between sire breeds and restrict birth weights in calves when compared to *Bos taurus* cows (Comerford et al., 1987; Browning et al., 1995).

Many studies have evaluated birth weight in *Bos indicus*-*Bos taurus* cross calves, and Brahman has been the primary *Bos indicus* breed used in the United States. Notter et al. (1978), in a study of the performance of calves sired by Brahman, Hereford, Angus, Holstein, and Devon bulls and out of F_1 *Bos taurus* sired (numerous sire breeds) 2 year-old cows, reported that the Brahman-sired calves had the largest mean birth weight (35.3 kg). Bailey and Moore (1980) also noted that calves by Brahman bulls and out of Hereford cows were the heaviest at birth ($P < 0.01$) when compared to straightbred Herefords, Red Poll-Hereford, and Angus-Hereford crosses in Nevada. Comerford et al. (1987) also noted that Brahman-sired calves out of Limousin, Polled Hereford, Simmental and Brahman cows were heavier at birth ($P < 0.05$) than those by

Limousin, Polled Hereford, and Simmental bulls and out of the same types of cows, with the mean birth weight of Brahman-sired calves being 36.49 kg.

In a study evaluating direct and maternal breed effects of Brahman, Hereford, and Brahman-Hereford crossbreds on birth weight, Roberson et al. (1986) reported that the direct additive effect on birth weight was greater (4.6 kg) for Brahman when compared to Hereford, and that the maternal effect for Hereford was greater (7.5 kg) compared to Brahman. Elzo et al. (1990) found similar results when evaluating genetic effects using Brahman, Angus, and crossbred cattle. The authors noted that there was a negative additive maternal effect for Brahman dams (-2.71 kg), and positive additive direct effects (2.99 kg) of Brahman sires. This would support McCarter et al. (1991), who noted that the amount of calving ease increases as the amount of Brahman in the dam increases. Additionally, Riley et al. (2001a) noted that calves from Gir and Nellore cross females (34.81 kg and 36.68 kg, respectively) were lighter than those out of Angus, Gray, and Red Brahman, and Indu-Brazil sired cows (39.35 kg, 37.10 kg, 37.23 kg, and 37.16 kg, respectively) and that calves out of Angus-sired females had the highest birth weights when compared to those out of *Bos indicus*-sired cows.

Lower birth weights for calves out of *Bos indicus* dams is not only true for calves out of their biological dam, it also appears to be true for embryo transfer calves out of *Bos indicus* surrogate dams. Baker (1989), in a study using embryos sired by Brahman and Hereford bulls and out of Brahman and Hereford cows transferred into Brahman and Hereford cows, found that there were interactions between the sire breed and donor breed and that, regardless of recipient breed, Brahman-sired F_1 calves had the heaviest birth weights, and the difference in the average of the reciprocal crosses was 9.5 kg. The authors also found that calves produced by Brahman recipients were lighter at birth than those of Hereford recipients. Thallman et al. (1992) reported that Brahman females generally produced small calves at birth, even in embryo transfer calves, no matter what bull breed was used. They concluded that calves out of *Bos taurus* cows and by Brahman bulls were approximately 6.8 kg heavier than that of their reciprocal cross.

The greater difference between males and females out of crossbred matings using *Bos indicus* sires rather than *Bos taurus* sires has been noted in numerous studies (Cartwright et al., 1964; Notter et al., 1978; Bailey and Moore, 1980; and Lemos et al., 1984). Lemos et al. (1984) found differences in birth weight of 4.7 kg between males and females of the 1/4 grade type, which were by Guzera bulls, when compared to only 0.8 kg difference between males and females for the other five grades in the study (all by predominantly Holstein-Friesian bulls). Amen et al. (2007) reported differences between embryo transfer males and females of F_1 *Bos indicus* (Brahman or Nellore)—Angus X Angus and *Bos indicus* x F_1 of 5.3 and 4.1 kg, respectively, whereas the reciprocal crosses of these matings (Angus x F_1 and F_1 x *Bos indicus*) had very small differences between males and females (1.5 and 1.1 kg, respectively). Trail et al. (1982) found a similar trend in results from a study involving Boran and Red Poll where Boran-sired calves were approximately 2.4 kg heavier than those sired by Red Poll bulls, and that crossbred calves out of Boran cows were 3.6 kg lighter than those out of Red Poll females.

Other studies have evaluated Brahman, Boran, and Tuli-sired calves together for birth weight. Cundiff et al. (1995, 2000) observed that birth weights of Brahman (46.6 kg), were heavier than Boran (43.4 kg), and both Brahman and Boran-sired calves were heavier than Angus and Tuli-sired calves (41 and 38.9 kg, respectively). Herring et al. (1996) observed that birth weights of F_1 calves sired by Brahman, Boran and Tuli were all significantly different (44.01, 40.25, and 36.36 kg, respectively).

In an earlier stage of the current study, Ducoing Watty (2002) found no differences for birth weight among calves out of Brahman, Boran, and Tuli-sired cows (35.53, 34.78, and 35.49, kg respectively). Cunningham (2005) and Maiga (2006), also in earlier phases of the current study, documented similar results, finding that there were no differences due to sire breed of cow.

Weaning Weight

Weaning weight is an extremely important character because, in many situations, it is a direct measure of the major product from the cow herd (Long, 1980). It is the combination of birth weight with preweaning gain. Preweaning gain is affected by both the animal's ability to grow and the maternal factors contributed by the dam. In today's beef cattle industry, weaning weight is of the utmost importance because it is a representation (in many cases) of the sale weight of an animal (Sanders, 1994). As with most things, though, too much emphasis on a single trait can be detrimental to a production system.

In a review, Franke (1980) documented advantages in weaning weight of F_1 Brahman-British calves from 7 kg to 26 kg over their parental averages. Backcross calves from F_1 Brahman-Hereford sires and straightbred Brahman and Hereford cows were 9.3% heavier at weaning than straightbred calves. Also, backcross calves out of F_1 Brahman-Hereford cows weighed 18.8% more than those of straight breeding at weaning. This advantage in weaning weight was attributed to the maternal heterosis of the F_1 dam. Similar average weaning weights for purebred Brahman (135.8 kg) and Hereford (133.6 kg) were reported by Roberson et al. (1986). In this study a 21 kg difference was observed between F_1 Brahman-Hereford calves (sire breed listed first) (144.2 kg) and F_1 Hereford-Brahman calves (165.2 kg).

McCarter et al. (1991) reported that weaning weights of calves increased from 226 to 237 kg, as the age of cow increased from 3 to 5 years old. They also noted that adjusted weaning weights increased as the proportion of Brahman increased. Due to linear and quadratic effects of increasing proportion of Brahman, weaning weight increases of 28.5 kg were observed for calves out of 1/2 Brahman cows when compared to calves out of cows with no Brahman (McCarter et al., 1991).

Additionally, Herring et al. (1996) reported that Brahman-sired calves (234.3 kg) were significantly heavier than Boran (217.1 kg) and Tuli-sired calves (209.1 kg), which were not significantly different from each other.

In Cycle V of the Germplasm Evaluation Program (**GPE)**, Brahman, Boran, and Tuli bulls (along with other breeds) were mated to Hereford, Angus, and MARC III (1/4 each Angus, Hereford, Red Poll, and Pinzgauer) cows (Cundiff et al. 2000). The authors observed that the second and subsequent calves by Charolais and F_1 Belgian Blue bulls and out of Brahman-sired cows had significantly heavier 200 d weights (234.5 kg) than those out of Boran-sired cows (221.8 kg), and Tuli-sired cows (214.1 kg).

In earlier phases of the current study, Ducoing Watty (2002) reported average weaning weights of 229.6, 214.6, and 200.4 kg for calves out of Brahman-, Boran-, and Tuli-sired F_1 cows. At a later phase, Cunningham (2005) saw slightly higher values (233.4, 220.1, and 208.2 kg), which were more similar to those found by Maiga (2006) (235.87, 221.10, and 208.35 kg).

Reproductive and Maternal Performance Traits

Cow Weight

Cow Weight is a very important trait that is a measure of mature size. It affects the nutritional requirements of an animal and in turn (because of the greater need for supplementation), the input costs of the animal as well. This is of great importance because the overall efficiency could potentially become closer to optimum if more moderately sized cattle that still offer profitable performance in their calf crops are utilized.

Typical live weights of mature females of indigenous breeds to Eastern and Southern Africa were reported by Maule (1973). He noted that straightbred Tuli cows generally ranged from 500 to 550 kg, and Boran cows commonly weighed between 350 to 450 kg in Africa (each in their native homes).

Hetzel (1988) reviewed 6 breed evaluations of cattle from a wide range of environments in East and Southern Africa (Botswana, Zambia, Zimbabwe, and Uganda) and classified them as high- and low-performance environments. He reported that in high production environments, Brahman straightbred cows (446 kg) were heavier than Tuli straightbred cows (400 kg) in Botswana, and both Brahman and Tuli cow weights in Botswana were heavier than Boran straightbred cows in Zambia (375 kg). In low production environments, Brahman cows evaluated in Zimbabwe (390 kg) were again heavier than both Tuli cows studied in Zimbabwe (369 kg) and Boran cows studied in both Zambia (371 kg) and Uganda (313 kg). The Tuli cows studied in Zimbabwe (369 kg) were heavier than Boran cows studied in Uganda (313 kg), but were not heavier than Boran cows studied in Zambia (371 kg).

In a study reported by Riley et al. (2001a), differences in cow weight of 6 different types of crossbred cows out of Hereford dams were attributed to sire breed of the cow ($P = 0.006$), lactation status ($P < 0.001$), pregnancy status ($P < 0.001$), year ($P < 0.001$), and the interaction of lactation status and sire breed of the cow. In this study the authors reported that 7 year old cows by Gray Brahman, Indu-Brazil, and Red Brahman bulls (585.57, 571.88, and 577.61 kg, respectively) were heavier ($P < 0.10$) than those by Angus sires (520.69 kg) but were not different ($P > 0.10$) from Gir- and Nellore-sired cows (538.43 and 549.54 kg). Neither Gir- nor Nellore-sired cows were different in weight (P > 0.10) from cows by Angus bulls.

In a study in Kenya, Trail and Gregory (1981) noted the differences between Boran and Sahiwal cattle. Although Boran heifers were 26 kg heavier than Sahiwal heifers at 660 days, their mature weights from 7 to 9 years old (414 and 418 kg respectively) were not different. The differences as heifers were attributed to the grading up of the Sahiwal and inconsistencies in their makeup (ranged from 7/8 to 31/32 as heifers and 3/4 to 15/16 as cows).

McCarter et al. (1991) compared 3-, 4-, and 5-year old cows consisting of different proportions of Brahman blood (0, 1/4, and 1/2 Brahman). These cows were all out of Angus or Hereford dams. Adjusted means of the F_1 Brahman-Angus and Brahman-Hereford cows were 478 and 482 kg, respectively. These weights were similar to those of the F_1 Angus-Hereford cows (467 kg), smaller than the Hereford-Angus cows (498 kg), and greater than cows having 1/4 Brahman blood (445 kg).

In Florida, Brahman-Angus, Senepol-Angus, and Tuli-Angus cows were evaluated for maternal and reproductive performance (Chase et al., 2004). The authors reported that as 2 year olds, the Brahman-sired cows were heavier (442.2 kg) than both Senepol-sired (411.4 kg) and Tuli-sired (401.2 kg) cows ($P < 0.01$). However, Tuli-sired cows were not different ($P > 0.01$) from Senepol-sired cows. As 7 year olds, the Brahman-sired cows again were the heaviest (561.5 kg; $P < 0.10$), but the Senepol sired cows were also heavier (538.1 kg; $P < 0.10$) than Tuli-sired cows (512.6 kg).

In an evaluation of the cows in the current study as yearlings, Herring et al. (1996) reported that the Brahman-sired yearling heifers were heavier ($P < 0.05$) (310.7 kg) than both Boran- (286.9 kg) and Tuli- sired heifers (279.7 kg) with Boran- and Tuli-sired heifers not being different ($P > 0.05$). In later phases of the current study, Ducoing Watty (2002), Cunningham (2005), and Maiga (2006) all reported that Brahman-sired cows were significantly heavier than Boran- and Tuli-sired cows.

Cow Body Condition Scores

Body condition scoring (**BCS**) is a system of assigning a number based on the relative fatness or body composition of a cow. The "standard" scale used in the industry ranges from 1 to 9, with a 1 being very thin body condition and a 9 representing extreme fatness (Herd and Sprott, 1994). Scoring body condition is a method that observers try to make objective, but it can have some slight variation between trained evaluators (usually no more than one score). The percentage of body fat at specific stages of a beef cow's production cycle plays an important role in the reproductive performance and overall productivity (Herd and Sprott, 1994). The changes in body condition of a cow are generally a very reliable method of assessing the nutritional status of a cow.

Herring et al. (1996), in the first evaluation of the cows in the present study, noted that Boran-sired heifers had the highest BCS as yearlings (5.53) but were not significantly different from Tuli-sired yearling heifers (5.33). Brahman-sired yearling heifers had significantly lower average BCS (5.09) than both the Boran- and Tuli-sired females.

Similarly, Freetly and Cundiff (1997) evaluated the growth and reproduction characteristics of Brahman-, Boran-, and Tuli-sired heifers out of Angus and Hereford dams under 2 different nutritional levels. They observed that at breeding, heifers by Boran bulls had higher BCS (7.6) than those by Brahman (7.0) and Tuli (7.0) bulls. In this same study, BCS was evaluated on the same females at palpation 65 d following breeding. The authors determined that there were significant differences between the

BCS of females from each of the 3 sire breeds with Boran-sired heifers the highest (6.6), followed by Brahman-sired (6.4), and then Tuli-sired heifers (6.0).

In a study in Florida, Chase et al. (2004) evaluated the maternal and reproductive performance of F_1 cows in the subtropics (including Brahman-Angus and Tuli-Angus females among others). Here the authors noted that as 2 year olds, there were no differences ($P > 0.01$) in BCS between the Brahman- and Tuli-sired females, but as 7 year olds, the Tuli-sired cows had a higher ($P < 0.01$) average BCS (6.2) than that of the Brahman-sired cows (5.7).

In earlier phases of the current study, Cunningham (2005) reported higher average BCS for Boran-sired cows (5.45) compared to both Brahman- (5.22) and Tuli-sired females (5.16). Significant differences were found among the sire breeds in the fall of 2002 when these F_1 cows were 9 and 10 years old with the same trend being seen overall: Boran-sired cows (5.5) being higher ($P < 0.05$) than Brahman- and Tuli-sired cows (5.3 and 5.1 respectively) (Cunningham, 2005). Maiga (2006) noted very similar results, with Boran-sired females having, again, the highest overall BCS (5.48), followed by Brahman-and Tuli-sired cows (5.23 and 5.18 respectively). The same trend was seen in 2000 when the cows were 7 and 8 (Boran- 6.19 > Brahman- 5.89 and Tuli-sired 5.63).

Pregnancy Rate

Freetly and Cundiff (1998), in their evaluation of first calf heifers (fed 2 different levels of nutrition) sired by 7 different breeds of sires and bred to Red Poll bulls, found that overall pregnancy rates for Boran-sired heifers (96%) and Tuli-sired females (95%)

were both higher than for Brahman-sired heifers (92%) but were not significantly different from one another.

Riley et al. (2001a) reported that Gray Brahman-sired cows out of Hereford dams had pregnancy rates of 96.4% when evaluated from 2 to 14 years of age with the highest (100.1) least squares means for pregnancy rate as 8 and 9 year olds and the lowest (87.4) as 11 year olds. The authors noted that pregnancy rates were on average lower or fluctuated more in cows over the age of 10, or both.

In Cycle V of the GPE at MARC, Cundiff et al. (2000) reported that Boran-sired heifers had the highest pregnancy rates (96.8%) followed by Tuli-sired heifers (90.2%) and Brahman-sired heifers (84.2%).

Ducoing Watty (2002) evaluated pregnancy rate in the cows in the current study from 1994 to 2001 using 3 different models. In the first model, the sire breed, dam breed and birth year / age of cow were included. The second model added the lactation status at weaning time of the cow to the first model. The third model consisted of the first model in addition to the cow condition at weaning time, as a covariate, nested within the sire breed of cow. The effect of sire breed of dam was marginally significant in models 1 and 3 where Boran-sired cows had the highest pregnancy rates followed by Tuli- and Brahman-sired cows. In model 2, there were no significant differences between sire breed of the cow, but there were differences between dam of cow breed with females out of Hereford dams having higher pregnancy rates than those out of Angus dams (95.5 and 90.5%, respectively). Birth year of calf / age of cow effects were significant in all 3 models.

Cunningham (2005) noted that sire breed of cow and dam breed of cow were not significant sources of variation for any of the 3 models (same as those used by Ducoing Watty (2002)). Birth year of calf / age of cow was, however, a significant source of variation in all 3 models.

Calf Crop Born

Calf crop born (**CCB)** is the percentage of cows calving compared to the number of cows that were exposed to a bull or artificially inseminated within a specific time frame and is, obviously, an economically important character (Long, 1980), and is a trait that is, obviously, closely associated with pregnancy rate. Riley et al. (2001a) noted that rankings for least square means by sire breed for calf crop born were similar to those of pregnancy rate, as determined by rectal palpation. In that study, Gray Brahman-sired cows had calving rates of 95.6%.

Hetzel (1988) reported differences in calving rate between straightbred cattle in East and Southern Africa, with Tuli cows being the highest (87%), followed by Boran (75%) and Brahman (72%). These numbers are similar to estimates reported by Maule (1973) in a review of literature of breeds in Southern Africa where he reported ranges in calving percentages for Tuli of 90 to 91% and for Boran of 69 to 82%.

Chase et al. (2004) found that Brahman-sired cows had lower calving percentages than Tuli-sired cows over a 6 year period (89.0 and 94.7%, respectively), although they were not significantly different. Cundiff et al. (2000) on the other hand, reported no differences in the calving rates of Brahman- (92.8%), Boran- (93.1%), and Tuli-sired cows (90.1%) in Cycle V of the GPE. Similarly, in a previous evaluation of the cows in the current study, Ducoing Watty (2002) documented no significant differences in CCB between Brahman-, Boran-, and Tuli-sired females (86.3, 92.7, and 89.0%, respectively).

Cunningham (2005) utilized 3 models to analyze CCB, but only used model 1 and model 3 in the final analyses. Model 1 included sire of cow breed, dam of cow breed, and birth year/age of cow, and model 3 used these same effects in combination with cow condition score within year/age. In model 1, Boran-sired cows ranked first followed by Tuli- and Brahman-sired cows (94.3, 91.0, and 89.0% respectively) with Boran-sired cows being different ($P<0.05$) than Brahman-sired cows. Model 3 showed similar calving rates for all three breeds. Maiga (2006) found slightly higher calving rates for all 3 breeds, but like Cunningham (2005), there were no significant differences between the breeds.

Calf Crop Weaned

Survival to weaning and calf crop born, of course, determine calf crop weaned (**CCW**) (Riley et al., 2001a). Hetzel (1988) noted that in straightbred cattle in East and Southern Africa, weaning rates of 82, 69, and 63% were observed in Tuli, Boran, and Brahman cows, respectively. Similarly, in an evaluation in Georgia of straightbred dams, producing both straightbred and crossbred calves, for reproductive rates as well as other traits, Comerford et al. (1987) found that Brahman cows had 62% calves weaned per cow exposed.

Riley et al. (2001a) found that although Gray Brahman-Hereford females had lower CCW as heifers (66.7%) and as 3 year olds, they had acceptable (> 89%) CCW from ages 4 to 9 and, at these later ages, were not significantly lower than Gir-, Indu-Brazil-, Red Brahman-, and Nellore-sired females. The authors reported CCW for Gray Brahman-sired females over all years of the study as 88.4%.

Chase et al. (2004), evaluating cows sired by Brahman, Senepol, and Tuli bulls, observed that both Brahman- and Tuli-sired cows weaned a higher ($P < 0.05$) percentage of calves than Senepol-sired cows (86.1, 86.5, and 70.2%, respectively) but Brahman- and Tuli-sired cows were not different ($P > 0.05$) from one another. Cundiff et al. (2000), in Cycle V of the GPE, also reported that there were no differences in Brahman- and Tuli-sired cows for weaning rate (84.3 and 84.1%, respectively). The authors also noted that Boran-sired cows were numerically higher for CCW but were not significantly different from Brahman- and Tuli-sired cows for this trait.

All 3 of the previous evaluations of the cows in the current study observed no significant differences in CCW due to sire breed of cow. In all 3 studies Boran-sired cows ranked first, followed by Tuli-sired cows, with Brahman-sired cows having the lowest weaning rates. Ducoing Watty (2002) found adjusted weaning rates for Boran-, Tuli-, and Brahman-sired cows of 87.4, 83.7, and 80.8%, respectively, Cunningham (2005) found slightly higher least squares means: Boran- (88.7%), Tuli- (85.7%), and Brahman-sired (83.4%), and Maiga's (2006) results were even higher: Boran- (89.8%), Tuli- (86.9%), and Brahman- (84.8%).

Mouth Score and Longevity

Longevity of beef cattle is defined as the reproductive lifespan of the cow (Tanida et al., 1988), or the ability of a cow to delay culling or death (Martinez et al., 2004). Rohrer et al. (1988) also defined productive longevity as the age when a cow dies or is culled because she presumably cannot wean another live calf due to subfertility or physical limitations. The reproductive lifespan of a cow impacts profitability of commercial beef operations (Tanida et al., 1988).

The ability of a cow to have a long and productive lifespan is important for commercial cattlemen because a longer productive life means: a lower number of cows for producing replacements, reduced costs for producing replacements, fewer young cows, and in turn, a larger calf crop and proportion of calves for sale, as well as a higher number of cows surviving to sell as culls (Núñez-Dominguez et al., 1991). Greater longevity in females also allows producers to be more selective when retaining replacements even though it increases the generation interval (Rohrer et al., 1988).

Riley et al. (2001b) noted that a cow's productive life is limited by physical soundness as she ages. As cows age, the deterioration of their teeth affects their ability to harvest forage to meet their nutritional requirements for maintenance and other physiological functions such as reproduction and lactation (Riley et al., 2001b; Thrift et al., 2003). Núñez-Dominguez et al. (1991) stated that cows with unsound mouths, especially in range settings, may require more time to forage, and even then, may not meet their full nutritional requirements for optimum body condition and resistance to disease or injuries.

Bailey (1991) evaluated 3 different reproductive life span traits that included number of mating seasons per dam, lifetime total number of full-term calves born dead or alive and lifetime total number of calves weaned per dam. In this study, breed composition of the female played a major role in her reproductive life span. They found that Brahman cross cows had more mating seasons, gave birth to more calves, and weaned more progeny than Hereford, Red Poll, F_1 Hereford-Red Poll, F_1 Angus-Hereford, F_1 Angus-Charolais, and F_1 Red Poll-Hereford females.

Núñez-Dominguez et al. (1991), in a study evaluating Hereford, Angus, and Shorthorn purebreds as well as all possible reciprocal crosses, discussed the advantage of crossbred over straightbred cows for survival and incisor condition. The cumulative survival of crossbreds was greater than that of straightbreds at any age, meaning that crossbreds had a lower probability of being culled than straightbreds at younger ages. When cows were 12 years old, more crossbred than straightbred cows were still in the herd regardless of which culling policies were used (actual: 42 vs 25%; imposed: 23 vs 14%) (Actual culling practices included disposing of any cow that had 2 consecutive breeding seasons without being pregnant. Imposed culling was "removing" cattle that failed to breed in any given breeding season.). Crossbred cows lived longer by 1.36 years under actual culling and 0.99 years under imposed culling than straightbred cows. Also, more straightbred (7.1%) than crossbred (1.7%) cows were culled for emaciation and this was attributed to crossbred cows having less tooth wear and fewer missing teeth than straightbreds.

Riley et al. (2001b) discussed lifetime productivity in F_1 *Bos indicus* females and found Nellore cross cows to have the highest percentage (60%) of the original cows remaining at 14 years of age compared to Gir- (40%), Red Brahman- (23.8%), Gray Brahman- (19.1%), Angus- (13.3%), and Indu-Brazil-sired (5.3%) cows. The authors also analyzed mouth soundness of 14 year old females by using 2 different methods. In both methods, mouth soundness was analyzed as a binary trait. In the first method, smooth mouths were assigned scores of 0 and broken or solid mouths were assigned a value of 1. Broken mouths were those having one or more teeth loose or missing and smooth mouths were those having no incisors remaining. Although no differences were seen between the *Bos indicus* crossbreds, Angus-sired females had a higher incidence of smooth mouths than any other in the study. In the second method, smooth or broken mouths were assigned a value of 0 and solid mouths a value of 1. With this method, no differences were found among any of the sire breed groups.

Cunningham (2005), using similar methods to Riley et al. (2001b), found that in the first model Boran-sired females averaged 1.0, meaning that no Boran-sired cows were scored as smooth, followed by Brahman-sired (0.96) cows, which were significantly higher than Tuli-sired (0.76) cows. With the second model, the sire breeds ranked in the same manner with least squares means of 0.67, 0.55, and 0.28 for Boran-, Brahman-, and Tuli-sired cows, respectively, with Boran- and Brahman- sired cows having significantly higher values. The percentage of females remaining in the herd in 2004 was also evaluated, with more Boran-sired cows remaining than either Brahman- or Tuli-sired cows (69, 51, and 50%, respectively).

Maiga (2006) evaluated these same cows using similar models and found that in model 1, Boran- and Brahman-sired cows had higher mouth scores than Tuli-sired cows (0.95, 0.94, 0.78, respectively). In model 2, Brahman crosses had significantly higher mouth scores (0.53) than Tuli crosses (0.24) with Boran crosses being intermediate (0.34).

Brahman x British F_1 cows have repeatedly been proven to be highly productive. However, as mentioned previously, to this point the Brahman x British F_1 cow has been unable to produce a replacement as productive as herself. Two African breeds, Tuli and Boran, will be evaluated in this study to determine their value as crossbreds in commercial beef production in Central Texas. Tuli and Boran have consistently been shown to be productive breeds in African evaluations.

MATERIALS AND METHODS

Data from 143 F_1 Brahman x Hereford, Brahman x Angus, Tuli x Hereford, Tuli x Angus, Boran x Hereford, and Boran x Angus cows born in 1992 (66) and 1993 (77) at the Texas A&M Agrilife Research Center at McGregor were evaluated for reproductive and maternal performance and longevity traits. The semen of 9 Tuli, 7 Boran, and 16 Brahman bulls was used to breed mature Angus and Hereford cows by artificial insemination. Boran and Tuli semen was imported from Australia, and semen from Brahman bulls considered representative of the breed in the early 1990's was obtained from purebred breeders and commercial breeding services. Herring et al. (1996) reported birth, weaning, and post weaning performance of the animals in this study as well as carcass characteristics of the steer mates from the same matings. Ducoing Watty (2002), Cunningham (2005), and Maiga (2006) have analyzed the data on the same cows and their calves through the respective years of their studies. The updated data through the 2009 calves were analyzed in the current study.

The females in this evaluation were bred to Angus bulls in 1993 and 1994 as yearling heifers. In 1994, the 1992-born cows (2-year olds) were bred to Brangus bulls. All of the cows were bred to Brangus bulls in 1995, F_1 Hereford-Brahman bulls in 1996, F_1 Brahman-Angus bulls in 1997, F_1 Angus-Brahman bulls in 1998, 3/8 Nellore-5/8 Angus bulls in 1999, F_1 Nellore-Angus bulls in 2000, 3/8 Nellore-5/8 Angus bulls in 2001 and 2002, and Angus bulls from 2003 to 2009. Cows were bred to different breeds of bulls in different years throughout the study, but all females were bred to the same breed of sire each year. Calves were born from approximately February 15 to May 5 each year and were weaned in October or November at approximately 7 months of age. Calves born to these F_1 heifers and cows from 1994 to 2009 were also evaluated. Each calf was weighed and tagged within 48 h of birth. Male calves were castrated when birth measures were recorded. At weaning, calves were weighed and assigned body condition scores (BCS), and heifers were vaccinated against brucellosis. Pregnancy rate, calving rate and weaning rate were evaluated in the F_1 cows as binary (0 or 1) traits using least squares analyses.

Cows were palpated at weaning each year to determine their pregnancy status. Also, at this time, weights were recorded and body condition scores assigned. A set culling criteria was utilized that allowed a cow to have 2 failures to have or wean a calf before she was sold. After cows were 14 years of age, they were culled for any failure to have or wean a calf, regardless of their previous record. Other reasons for culling included severe injuries, poor health, and poor udders (large or pendulous udder/teats that would hinder the ability of future calves to nurse). From 2004 to 2009 (excluding 2008) at palpation, cows were also evaluated for incisor condition and assessed a score. Initially, 5 scores were assigned (solid, short and solid, weak, broken, and smooth), but these were condensed into 3 scores for analysis (solid, broken, and smooth). Females with no teeth loose or missing were designated as solid mouths, females with one or more teeth loose or missing were designated as broken mouths, and if the female had small and very deteriorated incisors, or none at all, she was designated as a smooth mouth. Mouth score was analyzed as a binary of trait of all females remaining in the study.

The average high and low temperatures for each year of the study for McGregor, Texas are presented in Table 1. These measures of climate were utilized as a tool to help understand variations in performance of the cows that could potentially be attributed to climate conditions at the research station.

Table 1. Average high and low temperatures and annual precipitation for McGregor, Tx

Year	Maximum[a]	Avg. Low[b], °F	Avg. High[c], °F
1992	97	No Data	89
1993	99	41	92
1994	100	41	93
1995	102	42	91
1996	100	38	91
1997	No Data	43	No Data
1998	105	43	97
1999	104	45	95
2000	105	42	94
2001	102	41	94
2002	100	38	92
2003	105	40	93
2004	98	44	91
2005	102	45	94
2006	105	44	97
2007	102	43	91
2008	105	41	96
2009	105	44	97

[a] The highest recorded temperature from June 1 to August 31 of the year specified
[b] The average low temperature from January 1 to March 31 of the year specified
[c] The average high temperature from June 1 to August 31 of the year specified
(Weather Underground, 2011)

Statistical Analysis

The variables considered in this study were analyzed using the mixed model procedure of SAS (2002). Calf's BWT (n = 1,335) and WWT (n = 1,246) were evaluated using a model that included the effects of sire breed of cow, dam breed of cow, calf's birth year/age of cow, and calf's sex as fixed effects. Dam's sire within sire breed of cow, and dam within dam's sire within sire breed of cow were used as random effects. A second model for birth weight included birth date because of the tendency of spring born calves in Central Texas to be heavier later in the calving season, but this covariate was not included in the final models used to compare the breeds. In the weaning weight model, weaning age within year was included as a covariate. Cow condition score at palpation (n = 1,666), cow's weight at palpation (n = 1,662), pregnancy rate (n = 1,513), calf crop born (n = 1,504), and calf crop weaned (n = 1,500) were evaluated using a model that included sire breed of cow, dam breed of cow, and calf birth year/age of cow as fixed effects. Cow's sire within sire breed and cow within cow's sire within sire breed were used as random effects. Models that included body condition of the cows were tested to evaluate their effects on these variables, but were not included in the final models used to compare the breeds.

Mouth scores (n = 253) were analyzed using 2 different models. In model one, a value of zero was assigned to smooth mouthed cows and a value of one to both broken and solid mouthed females. In the second model, a value of zero was assigned to all smooth and broken mouthed cows and a value of one was assigned to solid mouths. Fixed effects included were sire breed of cow, dam breed of cow, and calf's birth year/age of cow, and random effects included cow's sire within sire breed of cow, and cow within cow's sire within cow's sire breed. All possible 2-way interactions between main effects were tested for significance. Interactions with a $P \leq 0.25$ were included in final models.

RESULTS AND DISCUSSION

Pregnancy Rate

The least squares means and standard errors for pregnancy rates for the calving years 1994 to 2010 in the Brahman-, Boran-, and Tuli-sired F_1 cows by sire breed are presented in Table 2.

Sire of cow breed and dam of cow breed were not sources of variation for pregnancy rate (P = 0.221 and 0.991, respectively); even so, Boran-sired females had the highest least squares mean (0.930) followed by Tuli-sired females (0.912) and Brahman-sired females (0.900). Ducoing Watty (2002), Cunningham (2005), and Maiga (2006) observed the same trend in previous evaluations of these same F_1 females.

Birth year of calf/age of cow, however, was significant in explaining variation in pregnancy rate. Although differences were not evaluated statistically among individual means, there were obvious differences among the means for birth year of calf/age of cow. In Figure 1, note that cows born in 1992 showed a significant decrease in pregnancy rate as 3 year olds after their second breeding season (0.593) as compared to their first breeding season (0.939). The 1993-born cows had adjusted values of 0.898 and 0.948 respectively as 2 and 3 year olds and showed a decrease as 4 year olds (0.763). These results are consistent with Ducoing Watty (2002), Cunningham (2005), and Maiga (2006). Ducoing Watty (2002) attributed these differences in pregnancy rates between the 2 groups of cows in their first 3 breeding seasons to differences in environment, nutrition, and management of the 2 groups as heifers. In 1998, the pregnancy rates for the 1992 and 1993-born cows became closer together and remained that way until 2004. In 2005, the pregnancy rates of the 1992-born cows began to decline (0.964) and reached an even lower pregnancy rate in 2006 (0.888). This can apparently be attributed to environmental effects such as weather and forage conditions since the pregnancy rates for both of these groups increased tremendously from 2007 to 2008. This increase in pregnancy rate could be, at least partly, attributed to the high number of less productive cows being culled in 2005 and 2007, leaving the more productive cows in the herd for future matings, but almost certainly also reflects environmental differences between the years. After 2007, the pregnancy rates increased in 2008, recorded new lifetime lows in 2009, and increased in 2010. Although the effects of culling larger quantities of cows that have failed to breed twice in their lifetime, as well as increased age of the cows, may have played a role in the up and down trends evaluated in the later years of this study, true environmental effects, such as rainfall and other weather conditions, almost certainly had effects on the cows and/or the bulls to which they were exposed in the different years.

Table 2. Least squares means (LSM) and standard errors (SE) for pregnancy rate by sire breed of dam

	LSM ± SE	n
Sire breed of dam		
Brahman	0.900 ± 0.012	568
Boran	0.930 ± 0.013	430
Tuli	0.912 ± 0.013	522

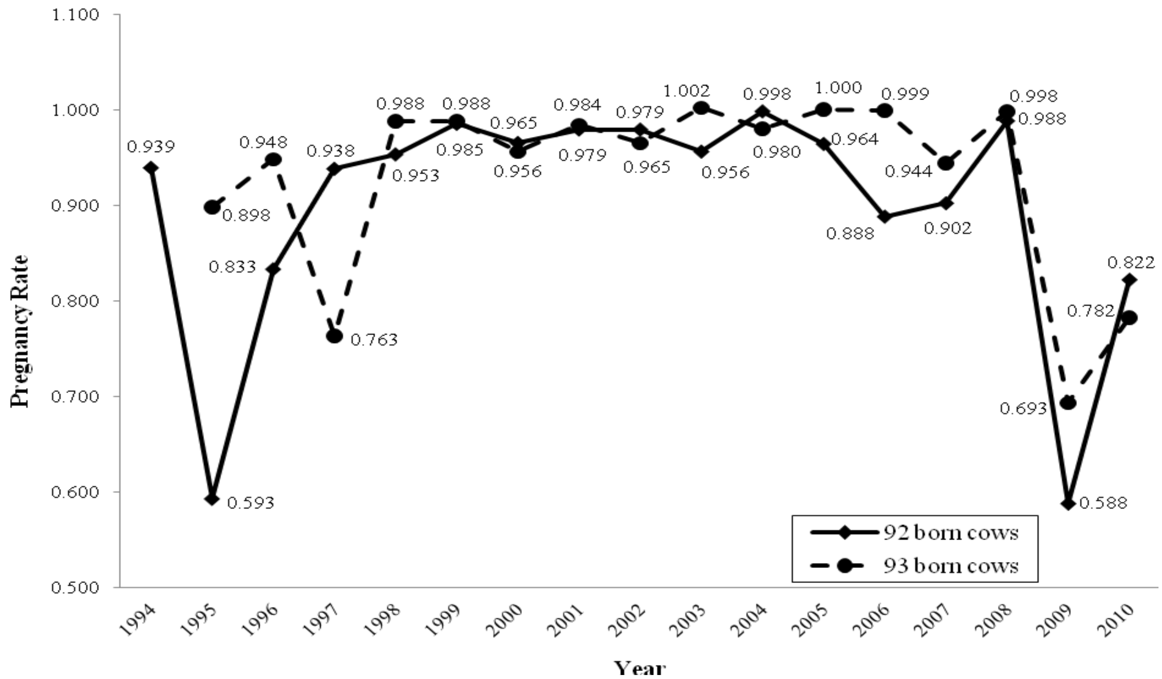

Figure 1. Least squares means for pregnancy rate by year for both 1992 and 1993-born cows

Calf Crop Born

Calf crop born was analyzed with all of the fixed effects used in pregnancy rate with the addition of the interaction of dam breed of cow x calf's birth year/age of cow. Least squares means and standard errors for calf crop born by sire breed of dam are presented in Table 3. Differences due to sire of cow breed were found for calf crop born (P = 0.004). As would be expected, the same trend found for pregnancy rate was also seen in calf crop born. Boran-sired females had the highest adjusted mean (0.944) followed by Tuli-sired females (0.892) and Brahman-sired females (0.872). The Boran-sired cows were different from Brahman- and Tuli-sired cows (P < 0.05), but Brahman- and Tuli-sired cows were not different from one another (P > 0.05). The same trends were found by Ducoing Watty (2002), Cunningham (2005), and Maiga (2006), and all of them found differences due to sire of cow (*P* = 0.064, 0.061, and 0.071 respectively). Freetly and Cundiff (1998) did not find differences due to sire of cow breed (*P* > 0.05) in their study of heifers sired by Brahman, Boran, and Tuli bulls out of Angus and Hereford dams. In that study, females were evaluated under 2 different nutritional levels, and no significant differences in calf crop born were attributed to sire breed, dam breed, or nutritional level, although the same trend as in the current study was reported (0.92, 0.89, and 0.80 respectively for Boran-, Tuli- and Brahman-sired heifers). Similarly, Cundiff et al. (2000) found no differences (*P* > 0.05) between F_1 females by Boran, Brahman, and Tuli bulls (0.931, 0.928, and 0.901, respectively).

Table 3. Least squares means (LSM) and standard errors (SE) for calf crop born by sire breed of dam

	LSM ± SE	n
Sire breed of dam		
Brahman	$0.872^{a} \pm 0.014$	566
Boran	$0.944^{b} \pm 0.016$	421
Tuli	$0.892^{a} \pm 0.014$	523

[a,b]Least squares means in the same column without common superscripts differ (*P* < 0.05).

Birth year of calf/age of cow was also important (*P* < 0.001) in affecting calf crop born, but differences among the individual means were not evaluated statistically. As expected, calf crop born by birth year of calf/age of cow followed a similar trend to pregnancy rate (Figure 2). Cows born in 1992 showed a drastic decrease in calf crop born as 3 year-olds (from 0.949 in 1994 to 0.610 in 1995), increased slightly as 4 year-olds to 0.735, and reached a similar calving rate in 1997 (0.946) as recorded as 2 year-olds. Cows born in 1993 did not show the same trend as they increased from 2 to 3 years old (0.876 to 0.912), and decreased as 4 year-olds (0.732). Although slight fluctuations were seen, both 1992 and 1993-born cows remained above their 2 year old calf crop born averages until 2005. Calf crop born for both groups of cows decreased in 2006 (0.837 and 0.838 respectively for 1992 and 1993-born cows) and both groups fluctuated widely but followed nearly the same pattern through 2009.

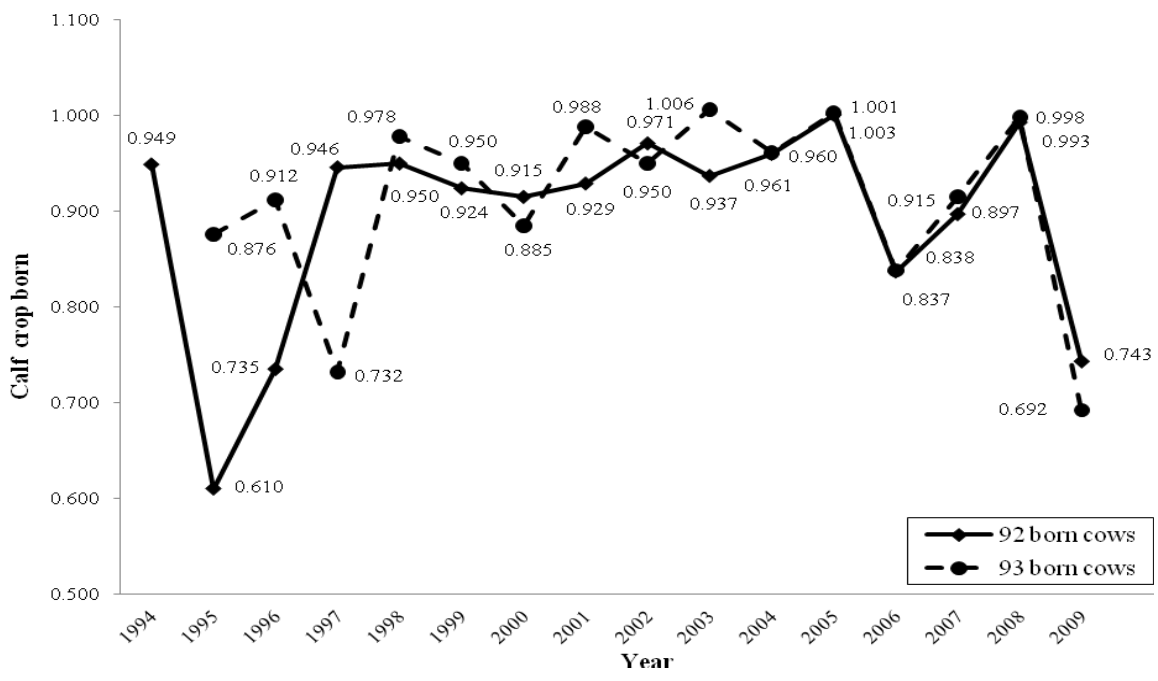

Figure 2. Least squares means for calf crop born by year for both 1992 and 1993-born cows

There were differences due to dam of cow breed x birth year of calf/age of cow interaction for calf crop born (*P* = 0.059). Figures 3 and 4 illustrate the least squares means observed for the interaction in 1992 and 1993-born females. In the 1992-born females, cows out of Angus dams had a less extreme decrease from their calf crop born in 1994 to 1995 than did cows out of Hereford dams (decrease of 0.250 vs. 0.429 respectively). Cows out of Angus dams had higher means until 1997, but from 1997 to 2009, the adjusted means alternate in highs and lows between cows out of Angus and Hereford dams. Females out of Hereford cows had the most extreme decreases at later ages within the study when compared to cows out of Angus dams. The largest and smallest differences between the 2 maternal breeds were in 2009 (0.555) and 1999 (0.004). In the 1993-born females, cows out of Hereford dams had higher adjusted means than cows out of Angus dams in all but 2007 where half-blood Angus females had a higher mean by 0.045. Ducoing Watty (2002) noted a similar trend in a previous phase of this same study. The means in the 1993-born cows were, on average, more similar between cows out of Angus and Hereford dams than in 1992-born cows with the largest and smallest differences being in 2000 (0.193) and 1999 (0.010).

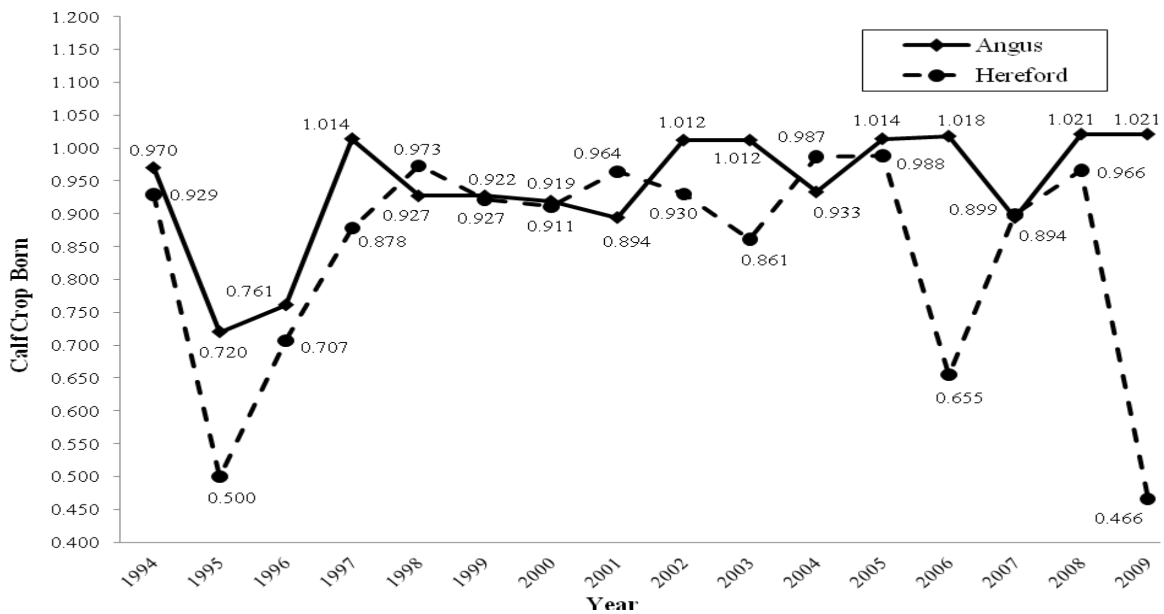

Figure 3. Least squares means for calf crop born by dam breed of dam x birth year of calf/age of cow interaction for cows born in 1992

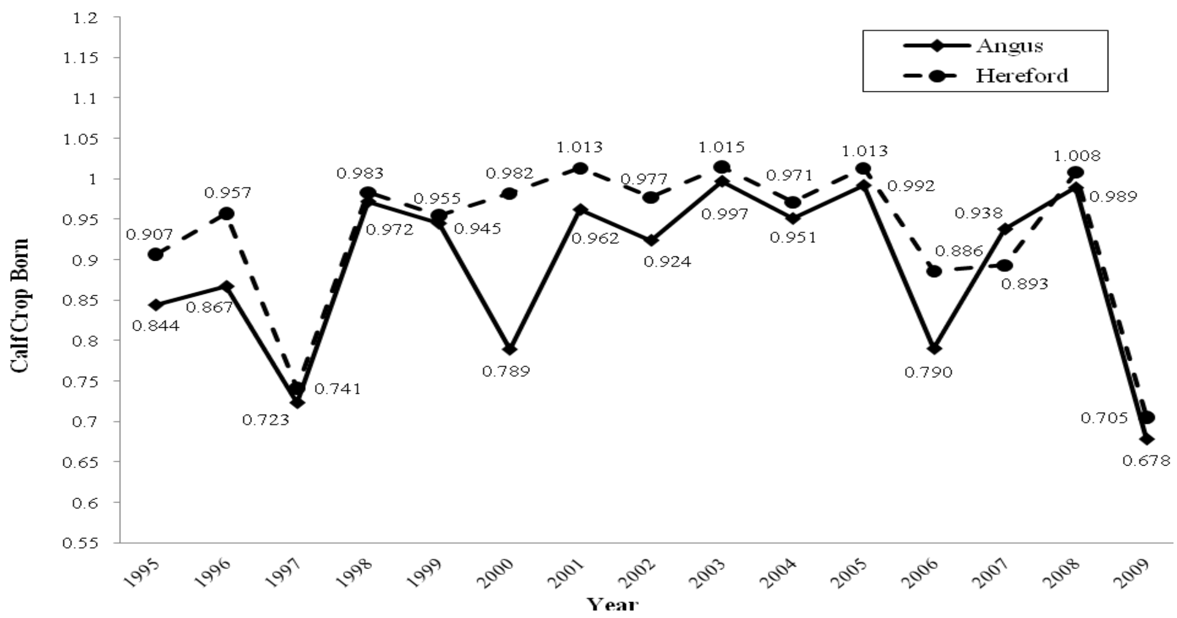

Figure 4. Least squares means for calf crop born by dam breed of dam x birth year of calf/age of cow interaction for cows born in 1993

Birth Weight

Birth weight was analyzed using the fixed effects of sire of cow breed, dam of cow breed, birth year of the calf/age of cow, sex of calf, dam of cow breed x sex of calf, and dam of cow breed x birth year of the calf/age of cow. Least squares means and standard errors by sire of cow breed are presented in Table 4. Sire of cow breed and dam of cow breed were not sources of variation in birth weight (P = 0.973 and 0.146). The adjusted means for the effect of sire of cow breed in calves out of Brahman-, Boran- and Tuli-sired females were similar (34.1, 34.0, and 34.1 kg respectively). In previous phases of the current study, Ducoing Watty (2002), Cunningham (2005), and Maiga (2006) found similar results to the current phase. In all 3 of their analyses, sire of cow breed was not a significant source of variation and the authors noted similar adjusted means. Cundiff et al. (2000) found average birth weights slightly higher than in the current study, but still with no differences (P > 0.05), for calves out of Brahman-, Boran- and Tuli-sired females (37.3, 37.0, and 38.4 kg respectively). Adjusted means for calves out of cows with Angus dams were slightly lighter than those out of females with Hereford dams (33.8 vs. 34.4).

Birth year of calf/age of cow was important (P < 0.001) for birth weight, and least squares means by year for 1992 and 1993-born cows are presented in Figure 5. Birth weights increased as cows matured and aged to 8 and 9 year-old cows in 2001 (38.3 and 38.5 kg in calves out of 1992 and 1993-born cows, respectively). Least squares means for birth weight began to decrease in 2004 for both ages of cows and reached lifetime lows in 2007 when cows were 14 and 15 year-olds (25.3 and 28.7 kg for

1992 and 1993-born cows' calves respectively). These lower birth weights are most likely due to the use of Angus bulls after 2004, rather than crossbred bulls containing some percentage of *Bos indicus* blood previously. After 2007, adjusted means for birth weight increased to 2008 for both ages of cows, but while the 1992-born cows' adjusted means increased to 2009, the 1993-born cows' decreased. This increase in birth weights in 2008 parallels the increase in calf crop born in the same year meaning that environmental conditions could have been favorable that year causing the increases. McCarter et al. (1991) noted that in cows out of Angus and Hereford dams with various levels of Brahman breeding, as age increased from 3 to 5 years old, birth weights increased significantly. Similarly, Roberson et al. (1986) noted that birth weights of calves increased with age until cows reached 7 years old and then declined in Brahman, Hereford, and Brahman x Hereford crosses.

Table 4. Least squares means (LSM) and standard errors (SE) for birth weight by sire breed of dam

	LSM ± SE, kg	n
Sire breed of dam		
Brahman	34.1 ± 0.41	494
Boran	34.0 ± 0.55	386
Tuli	34.1 ± 0.48	461

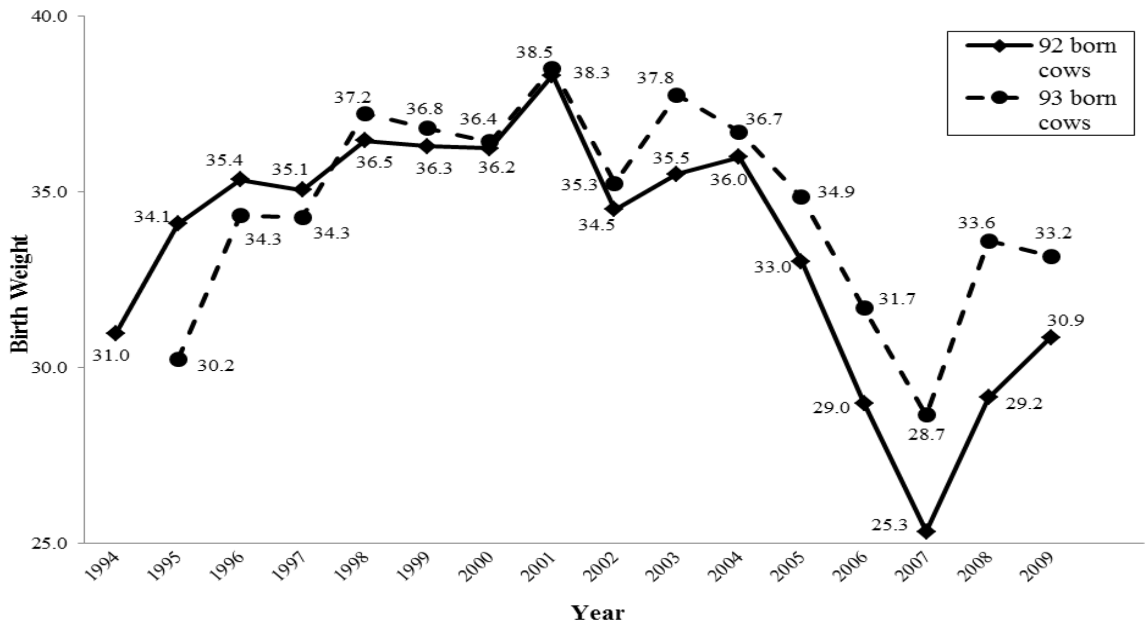

Figure 5. Least squares means for birth weight by year in cows born in 1992 and 1993

Least squares means and standard errors for birth weight by sex of calf and dam of cow breed x sex of calf interaction are presented in Table 5. Sex of calf affected birth weight ($P < 0.001$) with female calves being 2.1 kg lighter, on average, than their male contemporaries. This is similar to results of previous phases of the study by Ducoing Watty (2002) (2.15 kg), Cunningham (2005) (2.43 kg) and Maiga (2006) (2.28 kg). The interaction of dam breed of cow and sex of the calf was also important ($P < 0.001$). In calves out of cows with Angus dams, males were 3.0 kg heavier than females (35.3 vs. 32.2 kg respectively) (Figure 6). Male calves out of cows with Hereford dams were 1.2 kg heavier than the females (35.0 vs. 33.8 respectively). There were no differences ($P >$ 0.05) between male calves out of the 2 types of cows, but female calves out of cows with

Hereford dams were heavier (P < 0.05) than those out of cows with Angus dams by 1.52 kg (33.8 vs. 32.2 kg respectively).

Table 5. Least squares means (LSM) and standard errors (SE) for birth weight by sex of calf and dam of cow breed x sex of calf interaction

	LSM ± SE, kg	n
Sex of calf		
Female	$33.0^{a} \pm 0.31$	668
Male	$35.1^{b} \pm 0.31$	673
Dam of cow breed x sex of calf		
Female x Angus	$32.2^{a} \pm 0.42$	303
Male x Angus	$35.3^{b} \pm 0.42$	288
Female x Hereford	$33.8^{c} \pm 0.37$	365
Male x Hereford	$35.0^{b} \pm 0.37$	385

[a, b,c] Least squares means in the same column without a common superscript differ (P < 0.05).

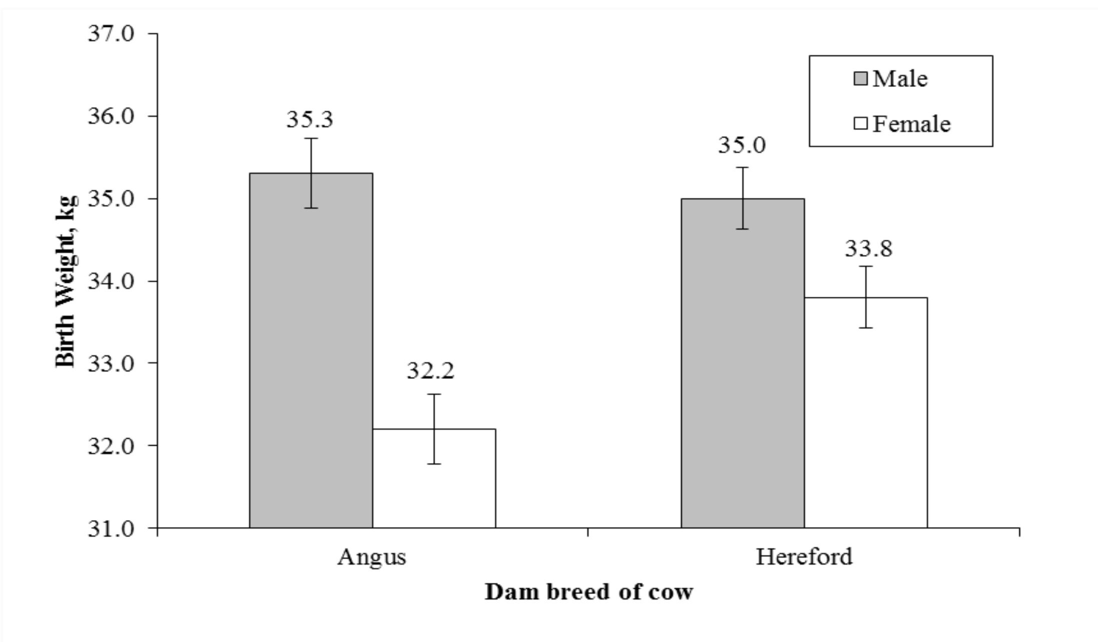

Figure 6. Least square means for birth weight by dam breed of cow x sex of calf interaction

The interaction between dam of cow breed and birth year of calf/age of cow, was also important (P = 0.003) for birth weight. The trends associated with this interaction for cows born in 1992 and 1993 are presented in Figures 7 and 8. In the 1992-born cows, adjusted means tended to increase, for both females out of Angus and Hereford dams, to the highest of the cows' lives in 2001 when they were 9 year-old cows (38.3 and 38.3 kg, respectively). After 2004 when the 1992-born cows were 12 year-olds, there was a steady decrease in the adjusted means for birth weight to 2007 when the cows were 15 years old. In 2007, these 1992-born cows had the lowest least squares means for birth weight of their lifetime (25.5 and 25.1 kg respectively for cows out of Angus and Hereford dams), but in both maternal breeds, adjusted means increased again until 2009. In the 1993-born cows, similar trends to the 1992-born cows were seen. For cows out of Angus and Hereford dams, the highest (2001: 39.4 and 37.7 kg) and lowest (2007: 28.5 and 28.8 kg) means for birth weight were recorded in the same years as the 1992-born females, but here, the cows were 8 and 14 years old, respectively in the 2 years. In 2001 calves were sired by F_1 Nellore-Angus bulls and in 2007, calves were by Angus sires. This means that increases or decreases in birth weight cannot be solely attributed to a constant age, but management differences, environmental changes across years, and sire breed of calf were also associated with birth weight changes across years. These differences in cow age have led to age of dam adjustment factors provided in the BIF guidelines.

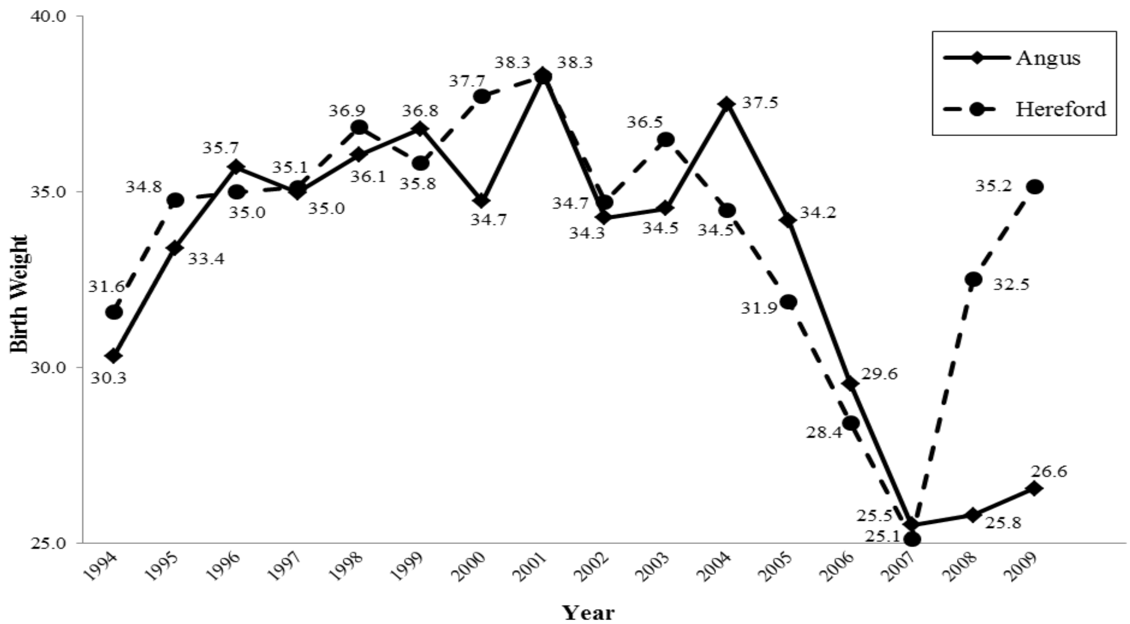

Figure 7. Least squares means for birth weight by dam breed of dam x birth year of calf/age of cow interaction in cows born in 1992

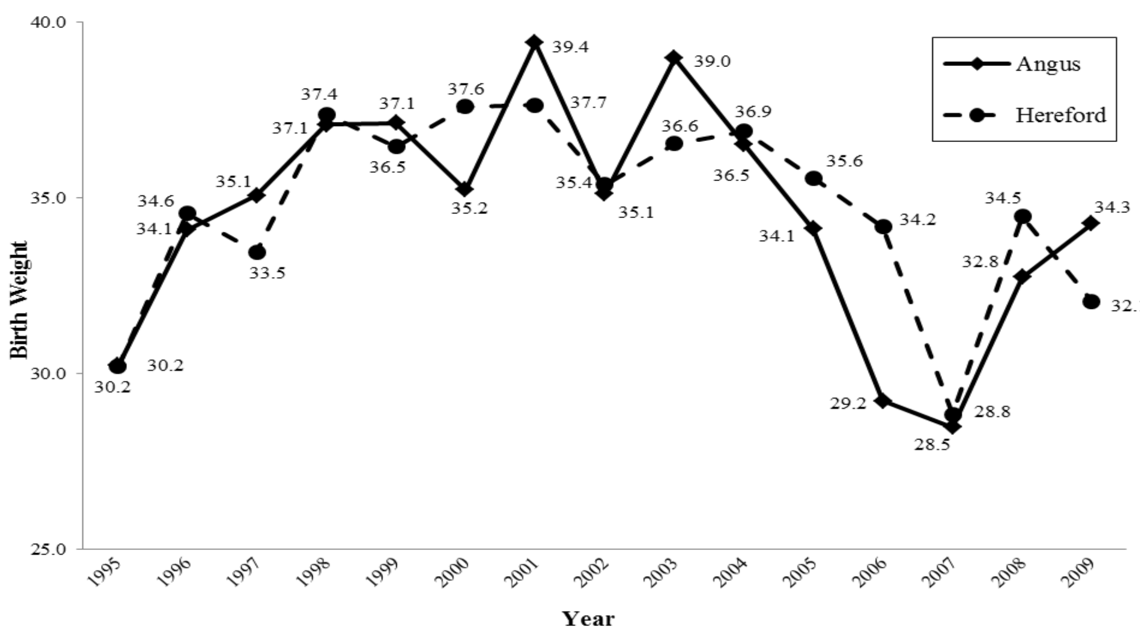

Figure 8. Least squares means for birth weight by dam breed of dam x birth year of calf/age of cow interaction in cows born in 1993

Calf Crop Weaned

Calf crop weaned was analyzed using the same model as calf crop born. Least squares means and standard errors for calf crop weaned by sire breed of cow are presented in Table 6. The effect of sire of cow breed was an important source of variation for calf crop weaned (P = 0.006) with adjusted means for Brahman-, Boran-, and Tuli-sired cows being 0.810, 0.894, and 0.843, respectively. Least squares means for Boran-sired cows were higher (P < 0.05) than Brahman-sired cows, but neither Boran- or Brahman-sired females were different (P > 0.05) from Tuli-sired cows. Dam breed of cow did not affect calf crop weaned (P = 0.180) Ducoing Watty (2002) ran 3 models for calf crop weaned in a previous phase of the current study, one of which included all of the same fixed effects as in the current phase. In this model, the author noted that sire of cow breed was not significant, but the adjusted means were very similar to those found in the current phase (0.808, 0.874, and 0.837 for Brahman-, Boran-, and Tuli- sired females, respectively). Likewise, Cunningham (2005) and Maiga (2006) reported that sire breeds of dam did not differ (P = 0.130 and 0.131) in their earlier evaluations of these same cows and presented means of 0.834, 0.887, and 0.857 and 0.848, 0.898, and 0.869, respectively, for Brahman-, Boran-, and Tuli-sired females. Cundiff et al. (2000) reported similar results to the previous phases of the current study. The authors noted that sire of cow breed was not a significant source of variation and observed adjusted means of 0.843, 0.862, and 0.841 for Brahman-, Boran-, and Tuli-sired cows raising their second and subsequent calves starting as 3 year-olds and ending as 7 year-olds. Chase et al. (2004) found breed type to be important (P < 0.01) in an evaluation of Brahman x Angus, Senepol x Angus, and Tuli x Angus cows having their second and subsequent calves by Charolais bulls and reported means for Brahman- and Tuli-sired cows that were not different from one another ($P > 0.05$) of (0.861 and 0.865 respectively).

Table 6. Least squares means (LSM) and standard errors (SE) for calf crop weaned by sire breed of dam

	LSM ± SE	n
Sire breed of dam		
Brahman	$0.810^{a} \pm 0.018$	566
Boran	$0.894^{b} \pm 0.020$	421
Tuli	$0.843^{a,b} \pm 0.018$	523

[a, b] Least squares means in the same column without a common superscript differ ($P < 0.05$).

Calf's birth year/age of cow was also important ($P < 0.001$). Differences among specific calf's birth year/age of cow combinations were not estimated. The trend of calf crop weaned, as expected, is similar to pregnancy rate and calf crop born (Figure 9). The lowest adjusted mean for 1992-born cows was recorded in 1995 as 3 year old cows raising their second calves (0.591) and the 1993-born cows did not reach their lifetime low for calf crop born until they were 16 year-olds in 2009 (0.661). For both the 1992 and 1993-born cows, there was a large decrease in calf crop weaned from 2008 to 2009.

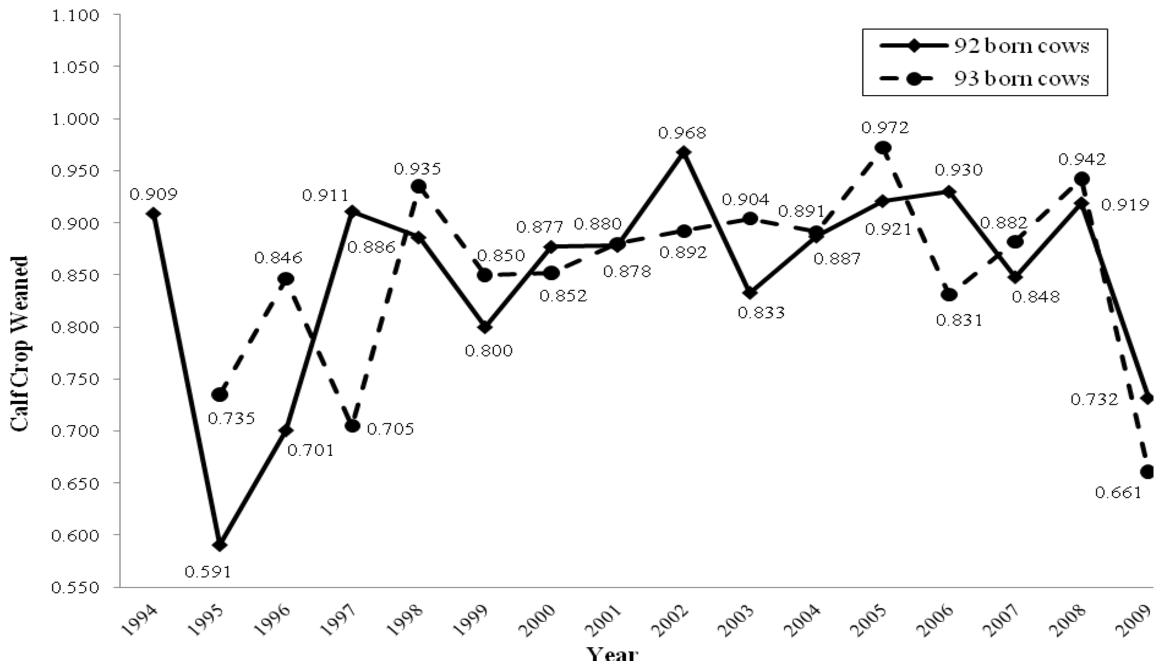

Figure 9. Least squares means for calf crop weaned by year in cows born in 1992 and 1993

There were differences (P = 0.225) due to the interaction of dam of cow breed with calf's birth year/age of cow. The least squares means associated with this interaction for the 1992 and 1993-born cows are presented in Figures 10 and 11, respectively. The adjusted means in the 1992-born cows are similar to those found in pregnancy rate and calf crop born. Cows out of Angus and Hereford cows had higher adjusted means in different years in these 1992-born cows, with the lowest adjusted means for females out of Angus dams in 1995 (0.682) and for those out of Hereford dams in 2009 (0.450). In the 1993-born cows, females out of Hereford cows had higher means for calf crop born in every year of the study except 2007, but for calf crop weaned, there were five years where cows out of Angus females had higher adjusted means (1995, 2001, 2003, 2004, and 2008). Also, in these 1993-born cows, there were no years where the weaning rate was below 60% regardless of maternal breed.

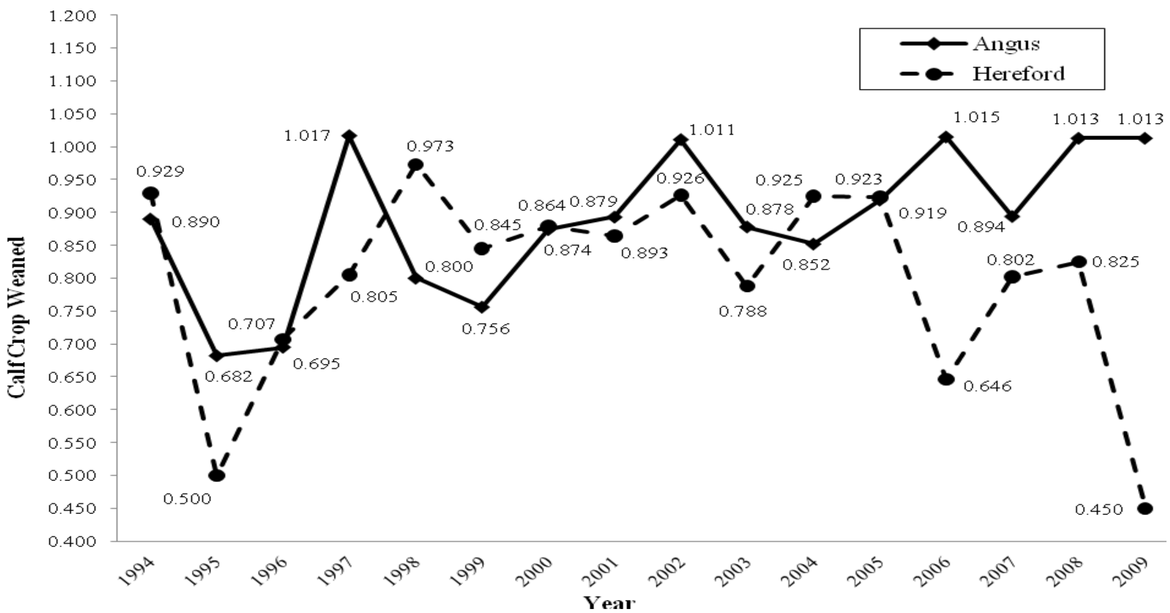

Figure 10. Least squares means for calf crop weaned by dam breed of dam x birth year of calf/age of cow interaction in cows born in 1992

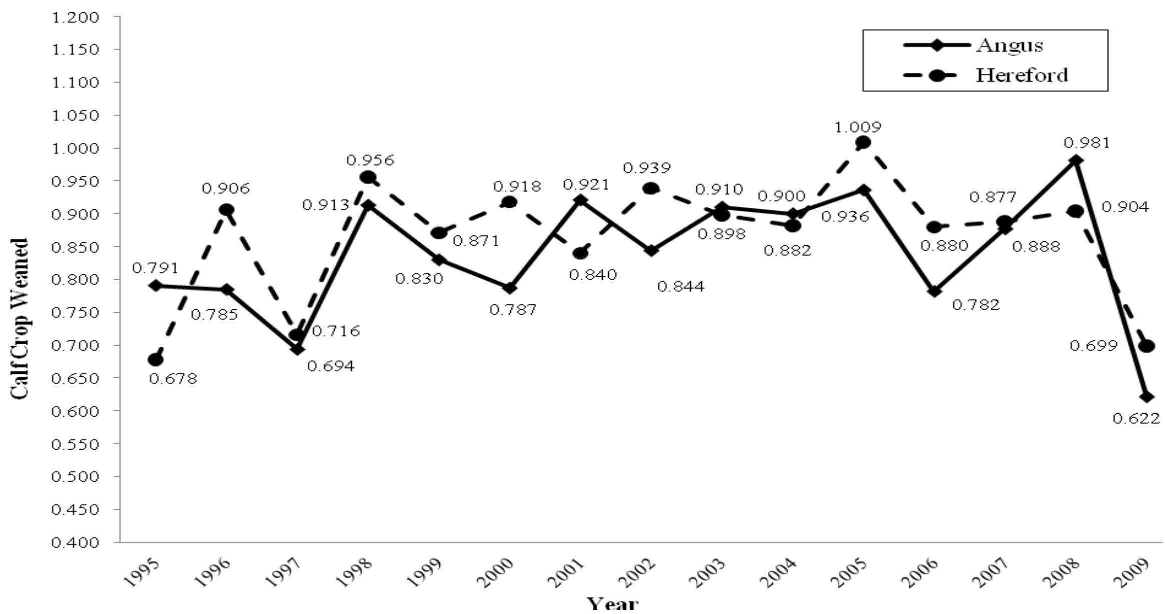

Figure 11. Least squares means for calf crop weaned by dam breed of dam x birth year of calf/age of cow interaction in cows born in 1993

Weaning Weight

The weaning weight analysis included sire of cow breed, dam of cow breed, calf's birth year/age of cow, sex of calf, sire of cow breed x calf's birth year/age of cow, sire of cow breed x sex of calf, and calf's birth year/age of cow x sex of calf as fixed effects. Least squares means and standard errors for weaning weight by sire of cow breed, sex of calf, and sire breed of dam x sex of calf are presented in Table 7. In 1994, 11 cows that were open at the end of the breeding season were bred by Simmental bulls from a neighboring pasture. These cows calved in the fall of 1995 with calves by these Simmental bulls. These fall calves were removed from the weaning weight analysis.

Sire of cow breed was a source of variation ($P < 0.001$) for weaning weight, but dam of cow breed was not ($P = 0.798$). Sire breed of the cow means were all different from one another (P < 0.05), with Brahman-sired cows weaning the heaviest calves (236.7 kg), Tuli-sired cows weaning the lightest (197.2 kg), and Boran-sired cows being intermediate for weaning weight (217.5 kg). These adjusted means rank the same as in previous phases of the current study. For calves out of Brahman-, Boran-, and Tuli-sired cows, Ducoing Watty (2002) reported adjusted means of 229.6, 214.6, and 200.4, which were slightly lower than those found by Cunningham (2005) and Maiga (2006) (233.4, 220.1, and 208.2 and 235.9, 221.1, and 208.4, respectively). In the current study, there is a larger spread, from weaning weights of calves out of Brahman- and Tuli-sired cows, than in previous phases. This is in part due to Brahman-sired cows weaning heavier calves in every year since the most recent previous phase (2006), and the Tuli-sired cows having a more extreme decline in weaning weights than Brahman- and Boran-sired cows in the later years of the study (2006 and later).

The effect of sex of calf was also important (P < 0.001) for weaning weight. Male calves averaged 10.4 kg heavier at weaning than the heifer calves. This difference is similar to that found for these same cows through 2001 where Ducoing Watty (2002) found males to be 10.8 kg heavier than females but slightly lower than the differences reported by Cunningham (2005) and Maiga (2006) (13.1 and 13.4 kg, respectively). Herring et al. (2006) found a difference of 14.7 kg between males and females when the cows in the current study and their male contemporaries were weaned calves.

Table 7. Least squares means (LSM) and standard errors (SE) for weaning weight by sire breed of dam, sex of calf, and sire breed of dam x sex of calf

	LSM ± SE, kg	n
Sex of calf		
Female	$211.9^{a} \pm 2.1$	622
Male	$222.3^{b} \pm 2.0$	630
Sire breed of dam		
Brahman	$236.7^{a} \pm 2.8$	453
Boran	$217.5^{b} \pm 3.5$	368
Tuli	$197.2^{c} \pm 3.2$	431
Sire breed of dam x sex of calf[d]		
Female x Brahman	$229.2^{a} \pm 3.1$	231
Male x Brahman	$244.3^{b} \pm 3.1$	222
Female x Boran	$213.1^{a} \pm 3.7$	170
Male x Boran	$222.0^{b} \pm 3.6$	198
Female x Tuli	$193.6^{a} \pm 3.5$	221
Male x Tuli	$200.8^{b} \pm 3.4$	210

[a, b,c] Least squares means in the same column without a common superscript differ (P < 0.05).
[d] Least squares means for the sire breed of cow x sex of calf interaction were only compared within sire breed of cow.

The interaction of sire breed of dam and sex of the calf was also an important source of variation (P = 0.026) for weaning weight. Figure 12 shows the adjusted means of this interaction. Although males and females are significantly different from one another for all 3 types of cows, the difference between male and female calves out of Brahman-sired calves is 15.1 kg and the difference between sexes of calves out of Boran- and Tuli-sired cows is 8.9 and 7.2 kg. This is similar to observations by Riley et al. (2001a), where calves out of Gray Brahman-Hereford cows differed 20.2 kg between males and females, whereas male calves out of Angus x Hereford cows were only 8.2 kg heavier than females at weaning. Ducoing Watty (2002) also found similar results with male calves out of Boran- and Tuli- sired cows being around 8 kg heavier than females and those out of Brahman-sired cows being 14.8 kg heavier.

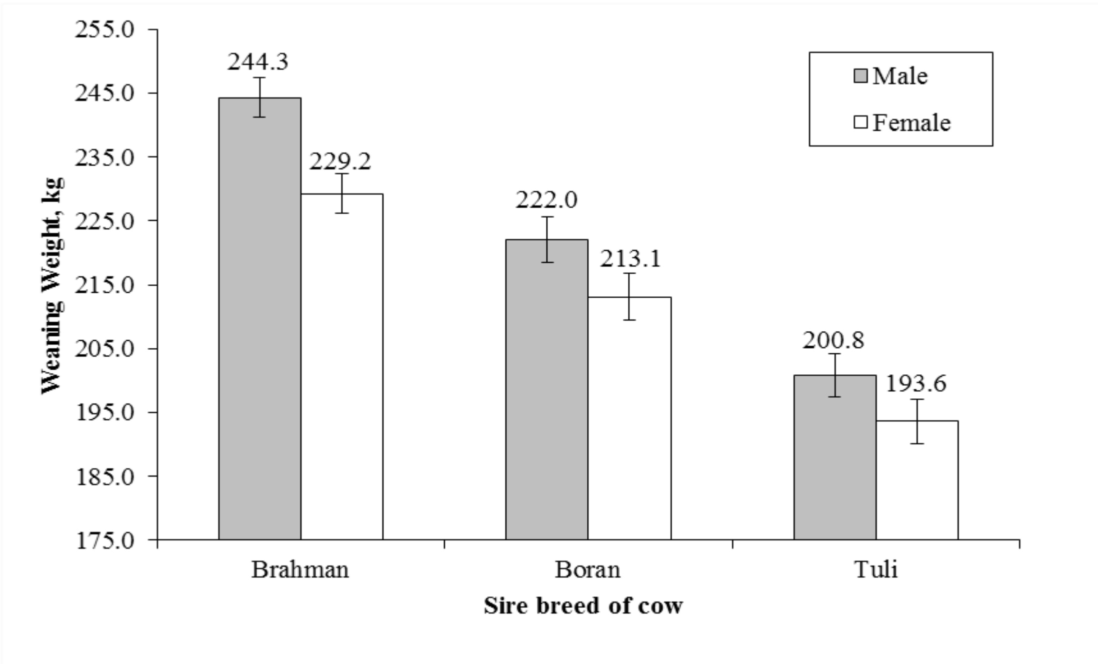

Figure 12. Least squares means for weaning weight by sire breed of dam x gender of calf interaction

As in birth weight, there were differences due to birth year of calf/age of cow (*P* < 0.001). As for previous traits, differences among calf's birth year/age of cow were not analyzed. Figure 13 illustrates the adjusted means for calf's birth year/age of cow for 1992 and 1993-born cows. Calves out of first calf heifers born in 1992 (183.7 kg) were lighter than calves out of first calf heifers born in 1993 (202.3 kg). Adjusted means for the first calves raised by 1992-born cows were the lightest of their lifetime (183.7 kg), although after 2005, weaning weights of these cows' calves decreased substantially (40 kg lighter in 2006 than 2005). The lightest adjusted means for weaning weight in the 1993-born calves came as 3 year-olds in 1996 (181.7 kg). The greatest decrease in weaning weights of calves out of the 1993-born cows also came from 2005 to 2006 (41.6 kg).

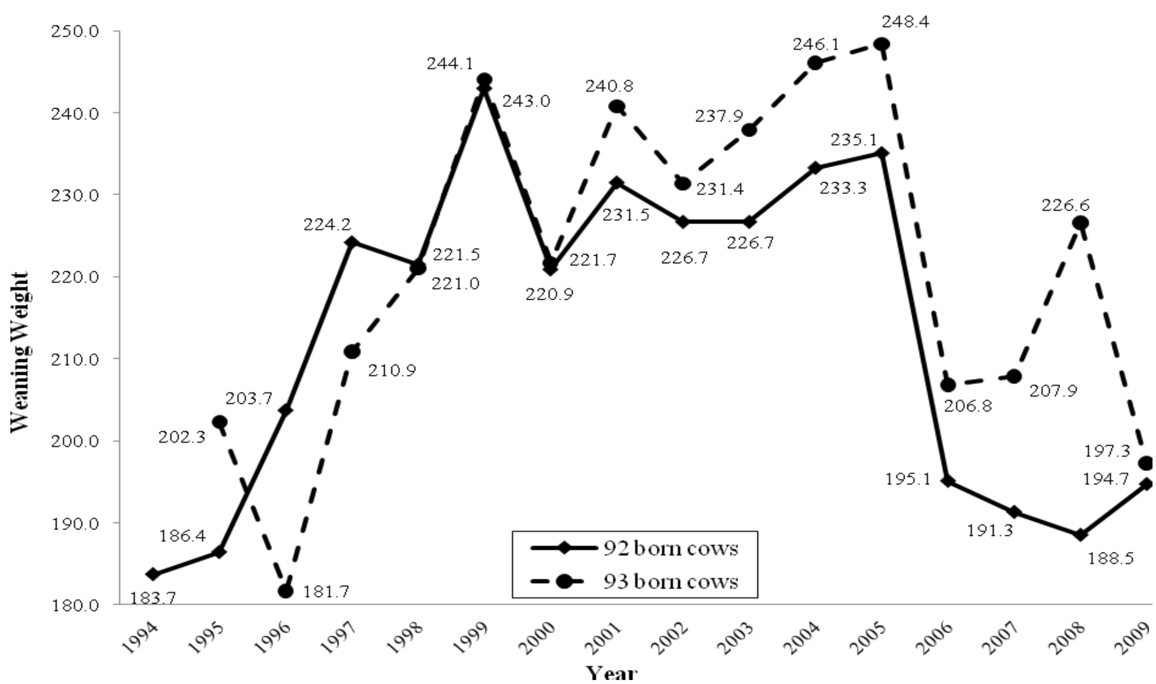

Figure 13. Least squares means for weaning weight by year in cows born in 1992 and 1993

The interaction of sire of cow breed with calf's birth year/age of calf was also important (P = 0.001) and the adjusted means are illustrated in Figures 14 and 15. As for previous traits, the specific differences associated with this interaction were not evaluated. For the 1992-born females, in all years of the study, calves out of the

Brahman-sired cows were heavier than calves out of Boran-sired cows, which were also heavier than calves out of Tuli-sired cows. The year with the smallest difference in adjusted means for weaning weight by sire of cow breed was 2003 (217.7 to 232.5 kg) and the largest range was in 2009 when calves out of Brahman-sired cows averaged 254.8 kg, and those out of Tuli-sired cows averaged 147.8 kg. In the 1993-born cows, calves out of Brahman-sired cows had higher adjusted means than those out of Boran- and Tuli-sired cows for all years except 2003 when calves out of Boran-sired cows were heavier, on average, than those out of Brahman-sired cows (246.3 vs. 238.5 kg). As for the 1992-born cows, calves out of Boran-sired cows were heavier than those from Tuli-sired cows for the 1993-born cows in all years of the study. The smallest difference between the sire of cow breed for the 1993-born cows was in 1997 (11.2 kg) and the largest difference was in 2006 (68.5 kg).

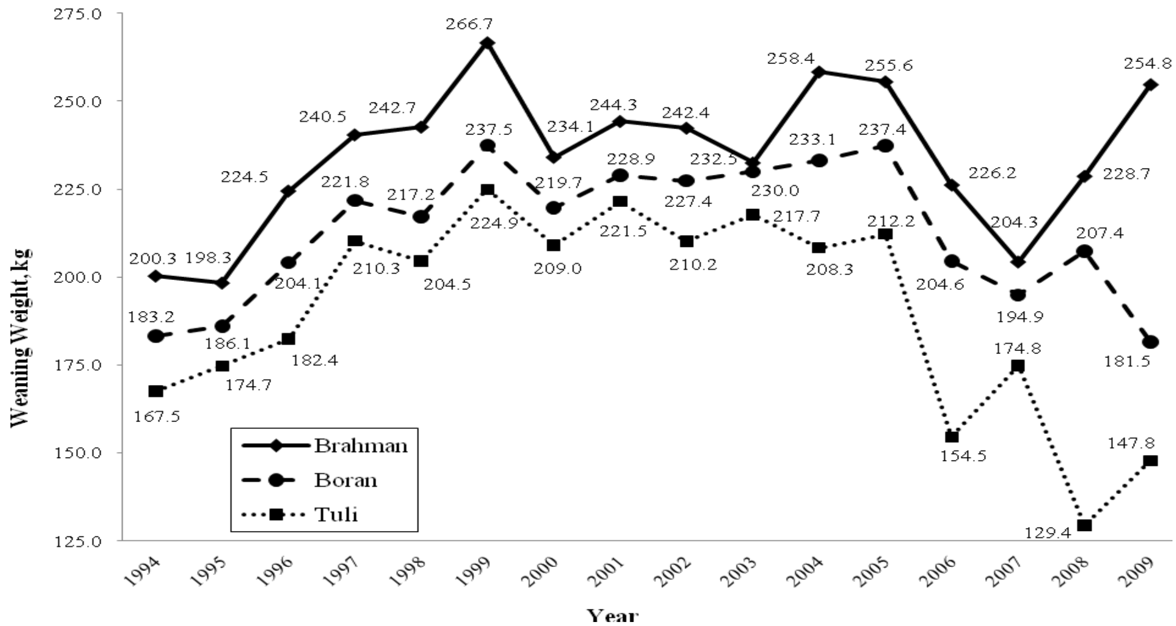

Figure 14. Least squares means for weaning weight by sire breed of cow x calf's birth year/age of cow for cows born in 1992

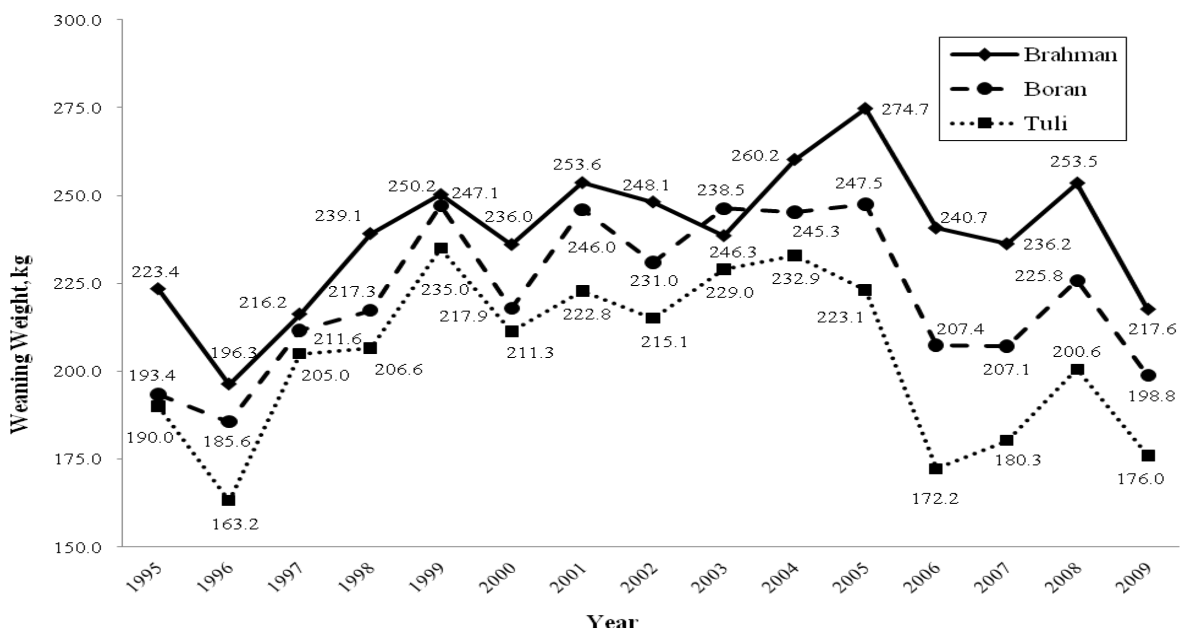

Figure 15. Least squares means for weaning weight by sire breed of cow x calf's birth year/age of cow for cows born in 1993

The calf's birth year/age of cow x sex of calf interaction was also important (*P* = 0.013) for weaning weight, and the adjusted means are illustrated in Figures 16 and 17. For every year of the study, weaning weight means for males born to the 1992-born cows were heavier than females, except for the first year (1994) and last year (2009) of this evaluation. In 1994, females averaged 186.3 kg and males averaged 181.1 kg, and in 2009 females weaned, on average, 198.4 kg and males 191.0 kg. There were 8 years within this evaluation of the 1992-born cows, where male calves were more than 10.4 kg (the average weight difference between male and female calves) heavier at weaning than females (1996, 2000, 2001, 2002, 2003, 2004, 2006, and 2007). In the 1993-born cows, male calves were heavier at weaning than females for the majority of the years of the study; the exceptions were 1996 and 2009 (182.9 vs. 180.5 and 206.5 vs. 188.2 kg, respectively, for females versus males). There were again 8 years where males were more than 10.4 kg heavier than females (1997, 1998, 1999, 2000, 2002, 2003, 2006 and 2009).

An alternative model was also utilized to determine the effect of age at weaning on weaning weight. The regression coefficient of weaning weight on weaning age of the calf was 0.79 ± 0.03 kg/d.

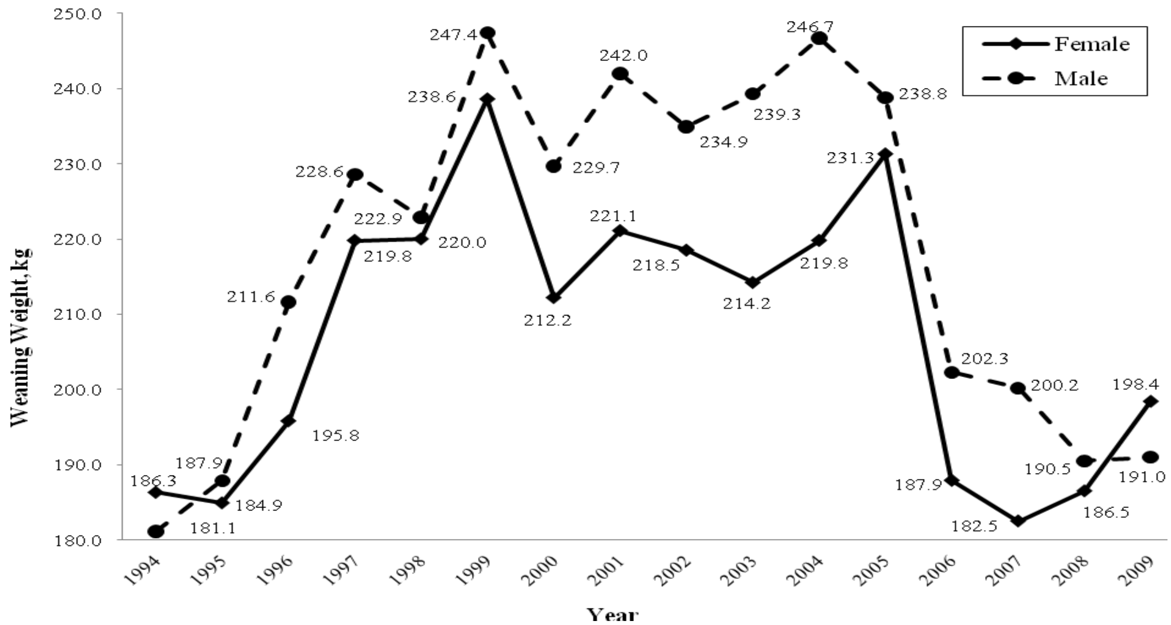

Figure 16. Least squares means for weaning weight by calf’s birth year/age of cow x sex of calf for cows born in 1992

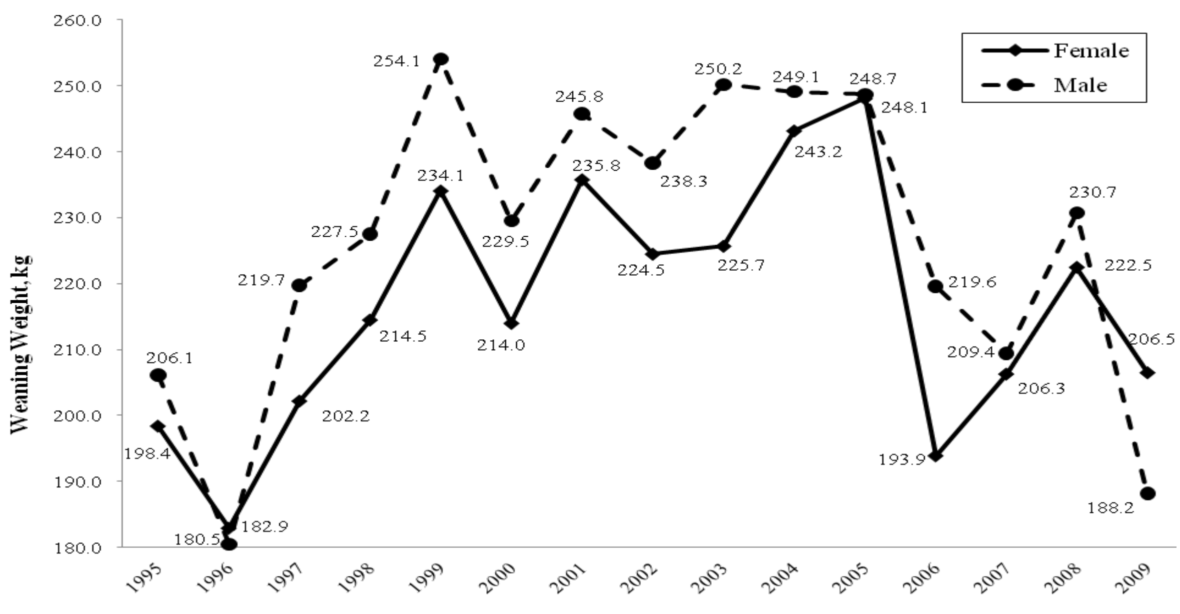

Figure 17. Least squares means for weaning weight by calf’s birth year/age of cow x sex of calf for cows born in 1993

Cow Weight

Cow weight (including weights of females as yearling heifers) was analyzed using a model that included sire of cow breed, dam of cow breed, calf's birth year/age of cow, sire of cow breed x dam of cow breed, sire of cow breed x calf's birth year/age of cow, and dam of cow breed x calf's birth year/age of cow as fixed effects. Least squares means and standard errors for cow weight by sire of cow breed are presented in Table 8.

Sire of cow breed was important ($P < 0.001$), with Brahman-sired cows being heavier than both Boran- and Tuli-sired cows, which were not different from one another (537.1 vs. 468.9 and 462.6 kg, respectively). Although the means were higher in the current analysis, the same trend was seen in results reported by Herring et al. (1996) on these females as yearlings, Ducoing Watty (2002) on these females through 2001 when they were 8 and 9 year-olds, Cunningham (2005) on these females through 2004 as 11 and 12 year-olds, and Maiga (2006) as 12 and 13 year olds. Hetzel (1988) noted that in 2 different production environments in Africa, Brahman cow weights were heavier than both Tuli and Boran straightbred cow weights. In high production environments, Tuli females studied in Botswana (400 kg) were heavier than Boran females studied in Zambia (375 kg). In low production environments, however, Boran females studied in Zambia (371 kg) were heavier than Tuli cows studied in Zimbabwe (369 kg), but Boran cows studied in Uganda (313 kg), were not.

There were differences ($P < 0.001$) due to birth year of calf/age of cow. Least squares means for cow weight by year for 1992 and 1993-born cows are presented in Figure 18. Yearling heifers born in 1993 (305.3 kg) were heavier than yearling heifers born in 1992 (279.8 kg). As 2 year-old females, 1992- and 1993-born females had very similar weights (389.4 and 386.8 kg respectively). After 1997, the least squares means for cow weights for 1992- and 1993-born cows followed the same trend by year, even though the 1993-born cows were a year younger. The 1992-born cows reached the highest average weight of their lifetime (up to the fall of 2009) in 2005 when they were 13 (556.2 kg). The 1993-born cows reached their highest average weight in 2004 when they were 11 (571.2 kg). Since 2008, cow weights declined in both the 1992- and 1993-born cows.

Table 8. Least squares means (LSM) and standard errors (SE) for cow weight (kg) by sire breed of dam

	LSM ± SE, kg	n
Sire breed of dam		
Brahman	$537.1^{a} \pm 6.1$	628
Boran	$468.9^{b} \pm 8.2$	465
Tuli	$462.6^{b} \pm 7.0$	580

[a, b] Least squares means in the same column without common superscript differ ($P < 0.05$).

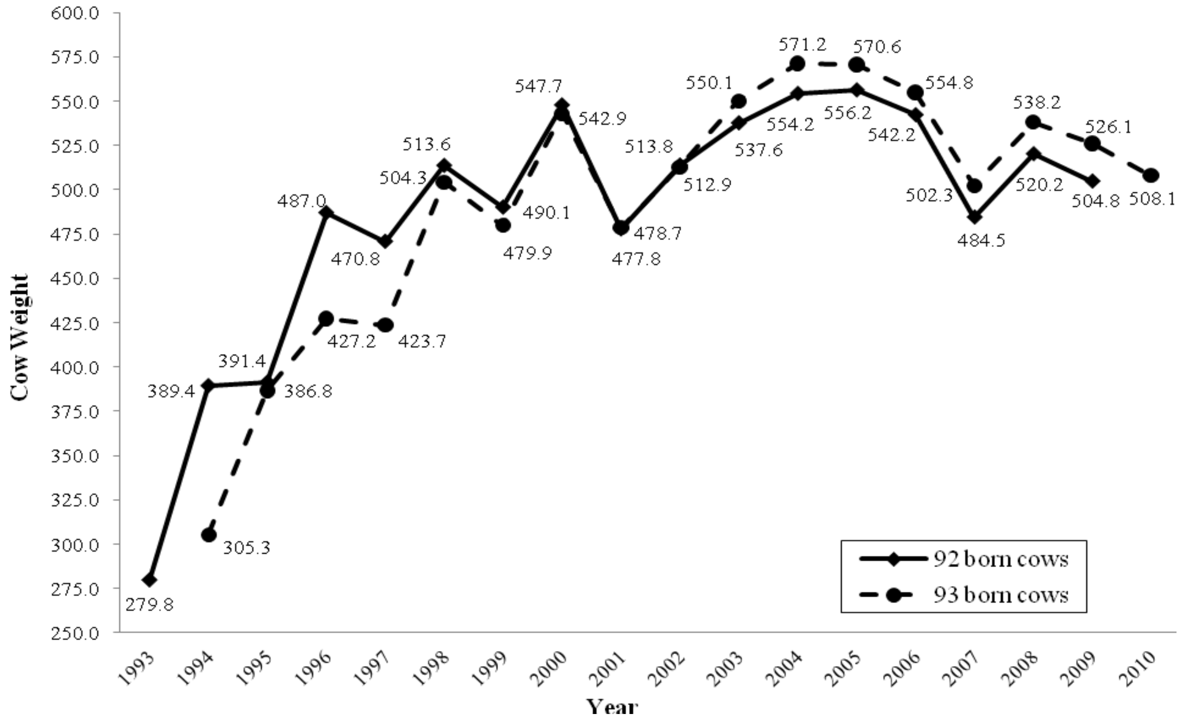

Figure 18. Least squares means for cow weight by year in cows born in 1992 and 1993

The interaction of sire of cow breed with dam of cow breed was also important (P = 0.083) for cow weight, and the least squares means are presented in Table 9 and Figure 19. Again, regardless of dam breed, Brahman-sired females were heavier than Boran- and Tuli-sired females. Unlike previous phases of the current study by Ducoing Watty (2002), Cunningham (2005) and Maiga (2006), there were no significant differences between cows out of Angus and Hereford dams and by the same sire breed. Note however, in Brahman- and Boran-sired females, those out of Angus dams were slightly heavier than those out of Hereford dams, but in Tuli-sired cows, those out of Hereford dams were slightly heavier. This could be attributed to the dilution gene in Tuli cattle. There were Tuli x Angus females that were smokey colored and had rat tails (similar to some Simmental-cross cattle) that had lower performance and longevity within the current study.

Table 9. Least squares means (LSM) and standard errors (SE) for cow weight (kg) for sire of cow breed x dam of cow breed interaction

	Sire of cow breed		
	Brahman	Boran	Tuli
Dam of cow breed			
Angus	$545.1^{a} \pm 8.1$	$473.1^{b} \pm 11.3$	$455.4^{b} \pm 9.1$
Hereford	$529.0^{a} \pm 7.7$	$464.8^{b} \pm 9.8$	$469.8^{b} \pm 8.2$

[a,b] Least squares means in the same row without common superscript differ ($P < 0.05$).

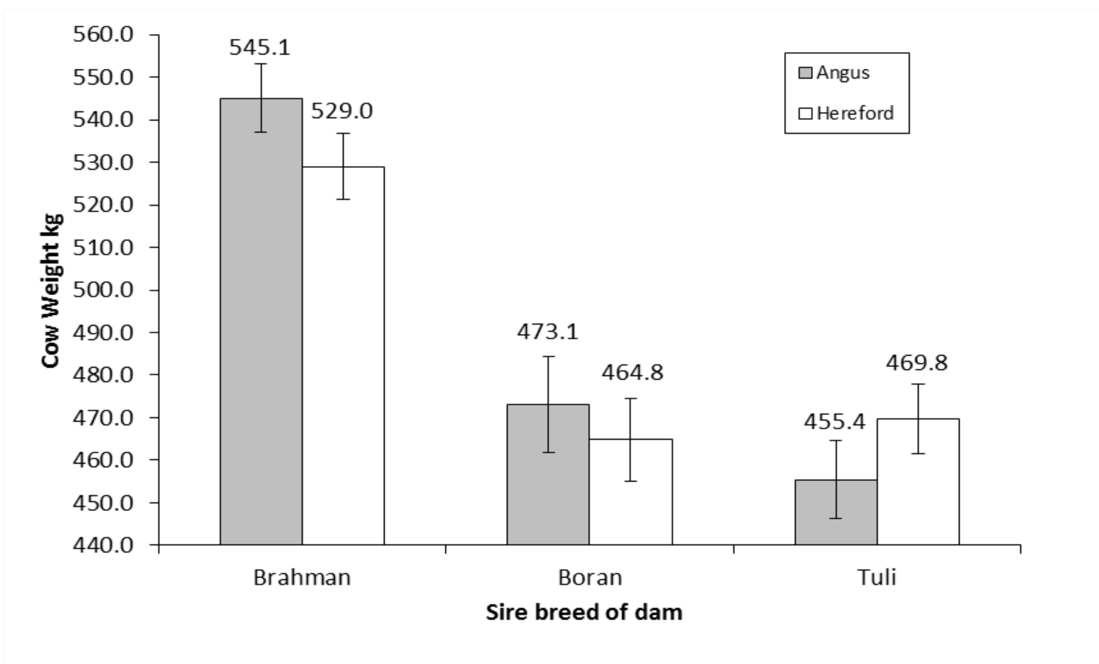

Figure 19. Least squares means for cow weight by sire breed of dam x dam breed of dam

Sire breed of cow x calf's birth year/age of the cow interaction was also an important source of variation for cow weight (*P* < 0.001). The adjusted means for this interaction for cows born in 1992 and 1993 are presented in Figures 20 and 21, respectively. Brahman-sired cows had higher adjusted means than Boran- and Tuli-sired cows in all years of the study for both groups. Boran- and Tuli-sired cows had similar adjusted means in both groups. In the 1992-born cows, Boran-sired cows were only heavier than Tuli-sired females in 1993-1995, 2004-2007, and 2009, whereas in the 1993-born cows, Boran-sired females were heavier in every year of the study except 1998. Unlike previous evaluations of the current study, there was not one year or age where all breeds of females reached their maximum weight. Brahman- and Boran-sired females born in 1992 and 1993-born Tuli-sired females reached their highest adjusted means for cow weight in 2004 (612.5, 531.8, and 538.3 kg, respectively), whereas 1992-born Tuli-sired females and 1993-born Brahman- and Boran-sired females reached their highest means in 2005 (528.5, 618.5, and 558.8 kg, respectively). Cows born in 1992 had lighter yearling heifer weights than those born in 1993 as well as a smaller difference between the lightest breed (Tuli-sired) and the heaviest breed (Brahman-sired) as yearling heifers (38.8 vs. 21.7 kg, respectively). Cundiff et al. (2000) reported similar means for yearling heifers to those in the current study for Brahman-, Boran-, and Tuli-sired females (329.1, 303.2, and 302.3 kg respectively).

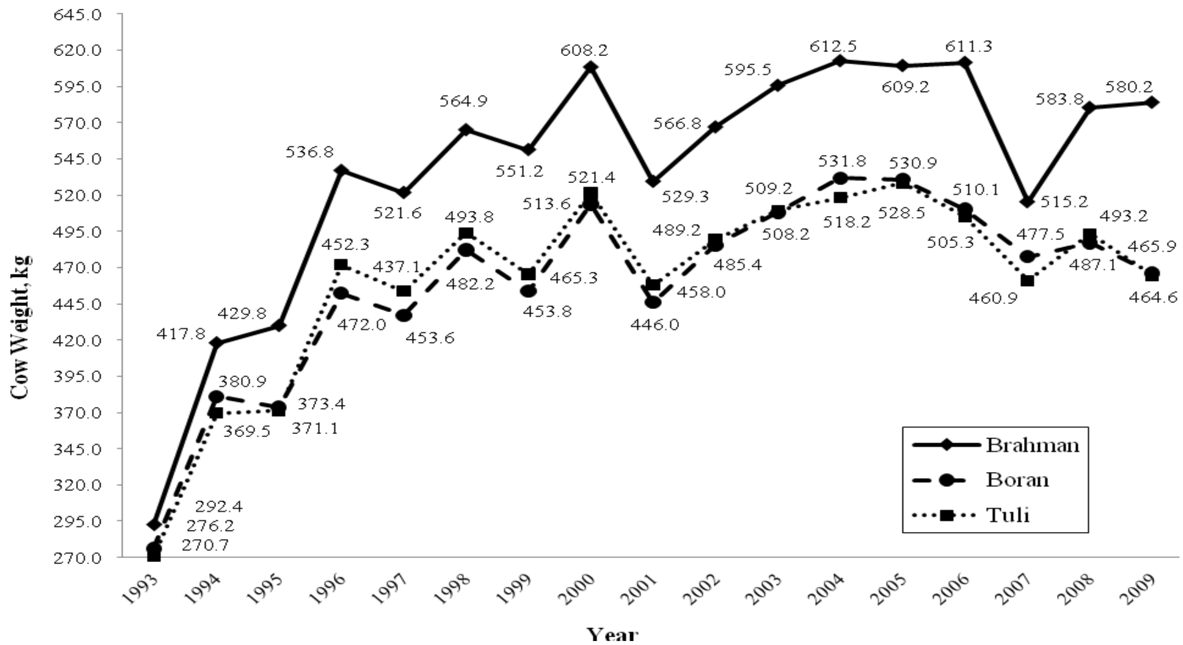

Figure 20. Least squares means for cow weight by sire breed of cow x calf's birth year/age of cow for cows born in 1992

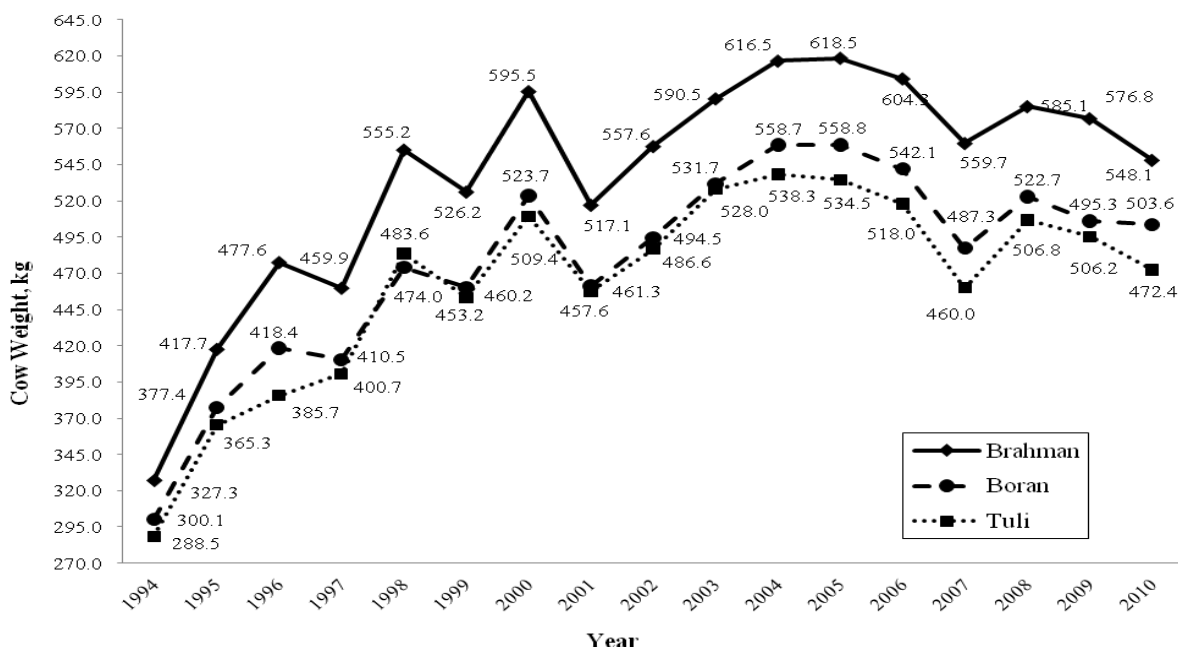

Figure 21. Least squares means for cow weight by sire breed of cow x calf's birth year/age of cow for cows born in 1993

The interaction of dam of cow breed with calf's birth year/age of cow was also a source of variation for cow weight (*P* = 0.087) and the adjusted means are presented in Figures 22 and 23 for cows born in 1992 and 1993, respectively. Adjusted means for both maternal types were very similar in both groups of cows with those out of Hereford dams having higher means in a greater number of years in the 1992-born cows and those out of Angus dams having higher means in all but 2 of the years (2004 and 2005) in the 1993-born cows.

An alternative model including cow condition score at palpation was also utilized to determine the effect of BCS on cow weight. The regression coefficient of cow weight on cow condition score was 29.02 ± 1.01 kg/unit of condition score. This is slightly lower than Hammack and Gill (2003), who noted that mature cow weight varies from 7 to 8 percent for each unit change in BCS and even up to 10 percent when extremes in muscling are present.

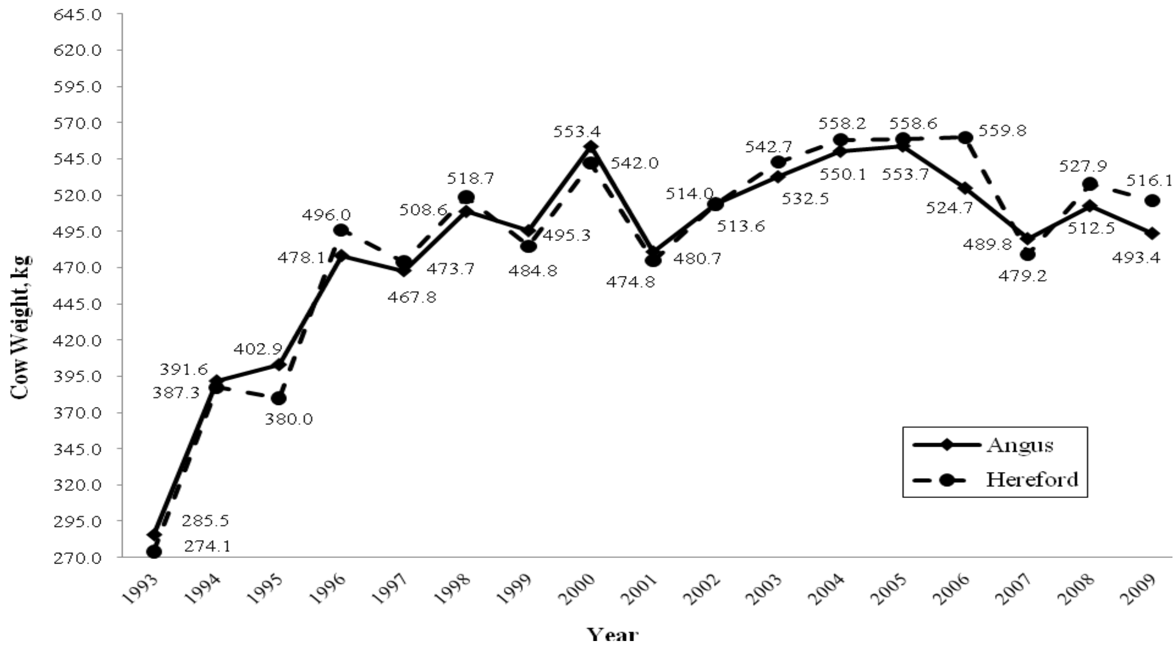

Figure 22. Least squares means for cow weight by dam breed of cow x calf's birth year/age of cow for cows born in 1992

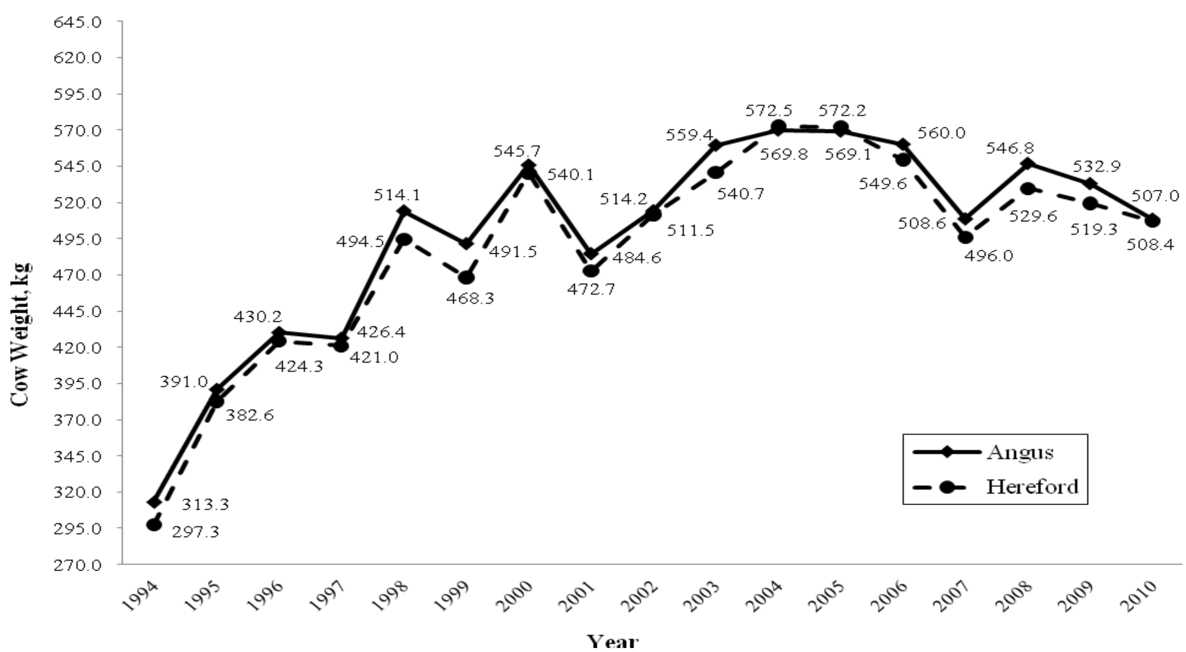

Figure 23. Least squares means for cow weight by dam breed of cow x calf's birth year/age of cow for cows born in 1993

Cow Body Condition Score

Cow body condition score (including condition scores taken on yearling heifers) was analyzed using a model that included sire of cow breed, dam of cow breed, and calf's birth year/age of cow as fixed effects. Adjusted means and standard errors for cow body condition score by sire breed of dam are presented in Table 10.

Sire of cow breed was important (P < 0.001), with Boran-sired females having higher adjusted means than both Brahman- and Tuli-sired females, which were not significantly different from one another (5.43, 5.19, and 5.15, respectively). These results are consistent with previous reports on these same cows by Cunningham (2005) and Maiga (2006). Dam of cow breed was not important (P = 0.302).

Birth year of calf/age of cow was also an important source of variation in cow condition score (P < 0.001), and the adjusted means are presented in Figure 24. Females born in 1993 had higher values for condition score as yearling heifers than did females born in 1992 (5.40 vs. 5.19, respectively). Cows born in 1992 reached the highest average condition score of the study to date in 2000 (6.05), whereas the 1993-born cows reached their highest scores in 1996 and 2008 (5.79 for both), followed closely by 1998 and 2000 (5.76 and 5.77). The two age groups of cows also reached their lowest condition scores in different years, with 1992-born cows having an adjusted mean of 4.52 in 1997 and 1993-born cows having adjusted means of 4.73 in 2010 and 4.75 in 2007.

Table 10. Least squares means (LSM) and standard errors (SE) for cow body condition score[a] (BCS) by sire breed of dam

	LSM ± SE	n
Sire breed of dam		
Brahman	$5.19^{b} \pm 0.04$	629
Boran	$5.43^{c} \pm 0.04$	469
Tuli	$5.15^{b} \pm 0.04$	579

[a] Body condition scores were assigned at palpation in the fall of each previous year.
[b,c] Least squares means in the same column without common superscript differ (*P* < 0.05).

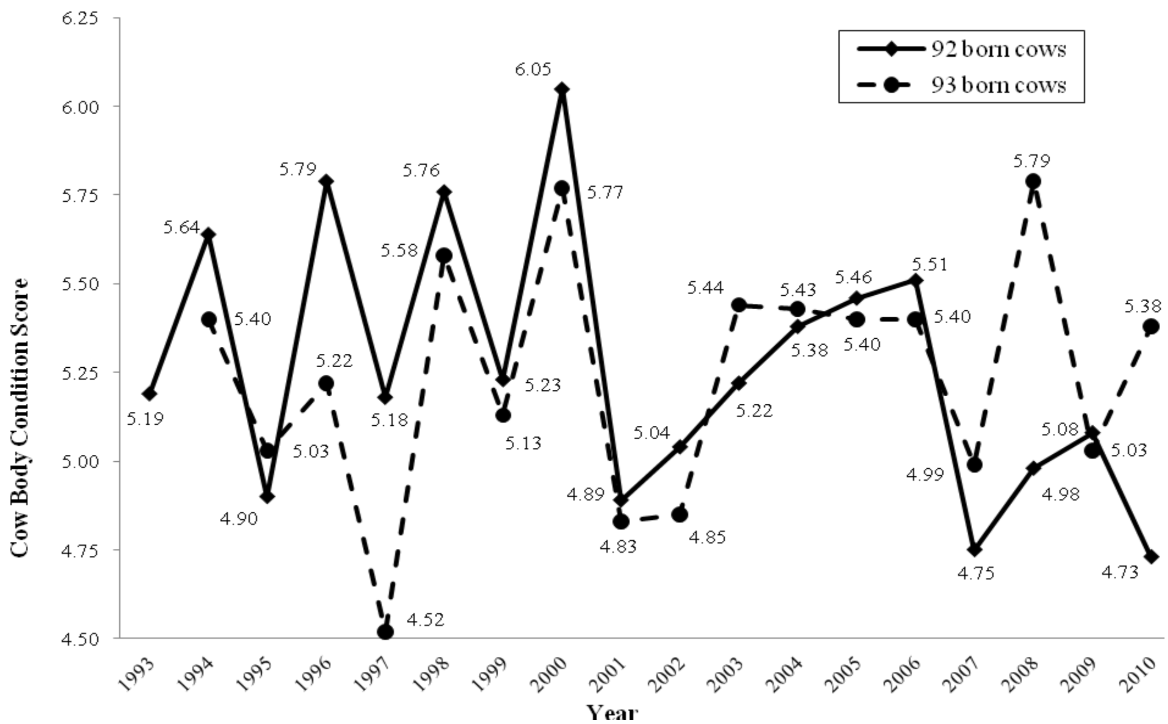

Figure 24. Least squares means for cow body condition score by year in cows born in 1992 and 1993

Another model including the interaction of sire of cow breed and calf's birth year/age of cow was run to see if there was any trend that could be identified. The interaction was not important (P = 0.625); however, in the 1993-born cows, Boran-sired females had higher condition score means than Brahman- and Tuli-sired females in all years of the study. For cows born in 1992, this was not true, with Brahman-, Boran-, and Tuli-sired females interchanging with the highest condition scores. The highest condition scores for all paternal breeds in the study were in 2000 for cows born in 1992 with Brahman-, Boran- and Tuli-sired females having adjusted means of 6.04, 6.30, and 5.80, respectively. For 1993-born cows, Boran-sired cows were the only ones assigned the highest scores in 2000 (6.15). The highest condition scores for 1993-born Brahman- and Tuli-sired females were in 2008 and 1998, respectively (5.78 and 5.54).

Mouth Score

Mouth score was analyzed using 2 different models, and least squares means, and standard errors for these scores by sire of cow breed are presented in Table 11.

In model 1, smooth mouths (no incisors present) were assigned a value of 0 and broken (at least 1, but not all, incisor loose or missing) or solid mouth cows were assigned a 1. Sire of cow breed was important (P = 0.007); Brahman- and Boran-sired females (0.874 and 0.833) had higher mouth scores than Tuli-sired females (0.659), but were not different from each other. Calf's birth year/age of cow was not important (P = 0.131); note that only cows that were 11 years and older were evaluated for mouth score.

In model 2, cows with broken or smooth mouths were assigned a value of 0, and a 1 was assigned to cows with solid mouths. Sire of cow breed was again important (P =

0.017) in explaining the variation of mouth scores. In this model, Brahman-sired females had an adjusted mean of 0.403, being higher than Tuli-sired females (0.070). Boran-sired females (0.295) were intermediate to cows by Brahman and Tuli bulls, but were not significantly different from either.

As cows get older, their mouth scores are expected to either remain the same, or have degraded more from the previous year or assessment. In Figure 25 (model 1), the mouth scores appear to increase from 2004 where they were 0.913 to 2005 where they were 0.919 in cows born in 1992. In Figure 26 (model 2), there is an increase in mouth score mean for cows born in 1992 from 2005 (0.293) to 2006 (0.327). This would mean that the mouth was actually in better shape than it was the year before, which is obviously not what is happening, especially in 11, 12, and 13 year-old cows. This unexpected trend can be attributed to inconsistencies in the determination of mouth scores across the years of the study. There were occurrences where cows were designated one mouth score in one year and a better mouth score the next, resulting in unexpected outcomes. Also, some of the cows in the earlier years were gone in the later years.

Cunningham (2005), in a previous phase of this study, evaluated mouth score in the same way as in the current phase. In that earlier analysis, in the first model, although not different from one another, Boran- and Brahman-sired cows had higher mouth scores than cows sired by Tuli bulls (1.0, 0.96, and 0.76, respectively). The second model ranked the paternal breeds the same as in the first model (0.67, 0.55, and 0.28, respectively). Maiga (2006) found the exact same rankings as in the current study, but with slightly higher values for both models. Brahman-, Boran-, and Tuli-sired females had means of 0.94, 0.95, and 0.78 for model 1 and 0.53, 0.39, and 0.24 for model 2, respectively. Riley et al. (2001b) evaluated 14 year-old cows for mouth scores using two different models equivalent to those in the current study. The authors reported means slightly higher than those found in the current study for both model equivalents. For *Bos indicus* F_1 cows evaluated with a model similar to model 1, means ranged from 0.92 to 1.01, while those evaluated in a similar manner as in model 2 ranged from 0.32 to 0.57.

Table 11. Least squares means (LSM) and standard errors (SE) for mouth scores by sire breed of dam

	Model 1[b] LSM ± SE	Model 2[c] LSM ± SE	n
Sire breed of dam			
Brahman	$0.874^{d} \pm 0.05$	$0.403^{d} \pm 0.08$	86
Boran	$0.833^{d} \pm 0.05$	$0.295^{d,e} \pm 0.08$	
Tuli	$0.659^{e} \pm 0.05$	$0.070^{e} \pm 0.08$	75

[a] Mouths were not scored in 2008 when 1992-born cows were 15 and 1993-born cows were 16.
[b] Analyzed as a binary trait, where smooth = 0 and broken or solid =1.
[c] Analyzed as a binary trait, where smooth or broken = 0 and solid = 1.
[d,e] Means in the same column without common superscript differ ($P < 0.05$).

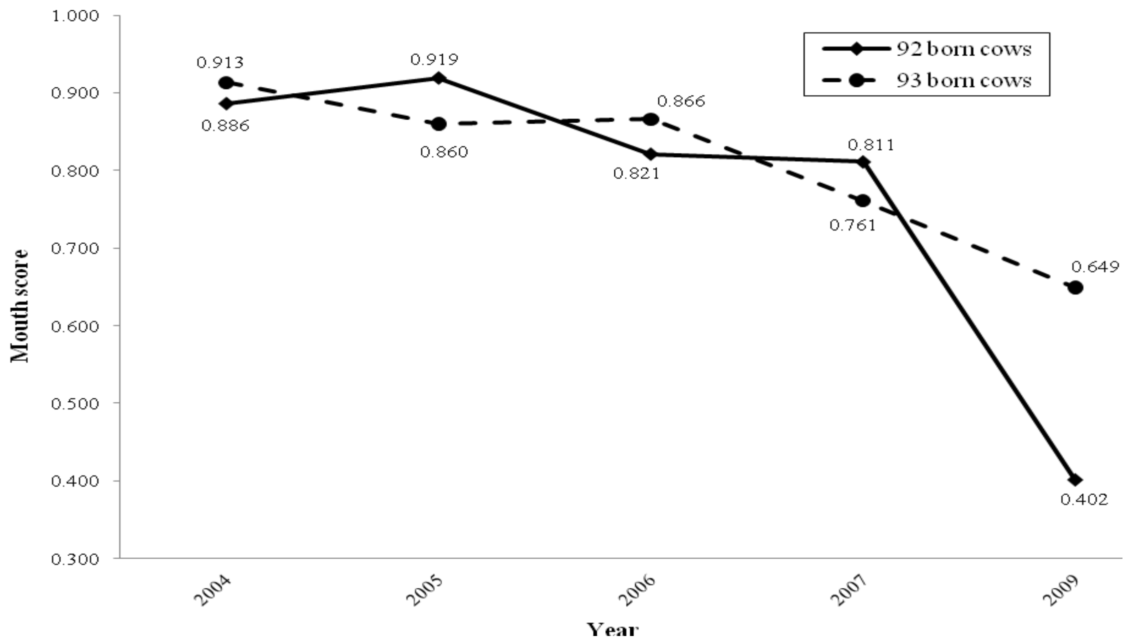

Figure 25. Least squares means for mouth score by year for model 1 including smooth = 0 and broken and solid = 1

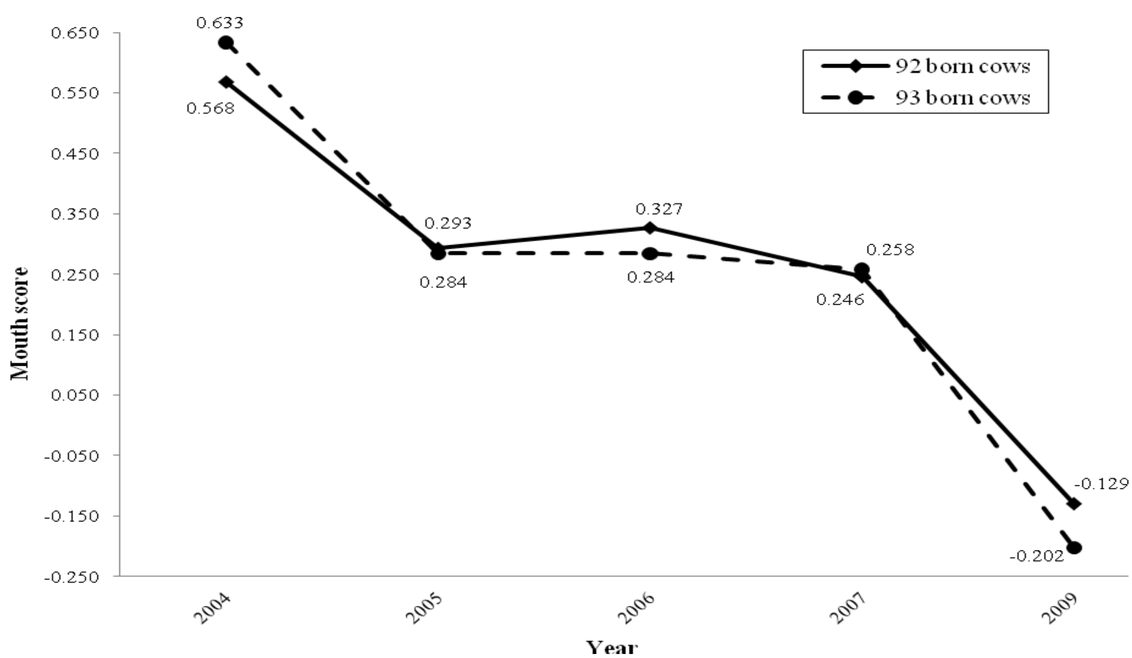

Figure 26. Least squares means for mouth score by year for model 2 including smooth and broken = 0 and solid = 1

SUMMARY

F_1 cows sired by Brahman, Boran, and Tuli bulls were evaluated for reproductive and maternal performance and cow longevity traits. Pregnancy rate, calf crop born, calf crop weaned, birth weight and weaning weight of their calves, cow weight, cow body condition score at palpation, and mouth scores were assessed to determine differences between the 3 sire types.

Pregnancy rate did not differ due to sire of cow breed or dam of cow breed (P = 0.221 and 0.991 respectively), but calf's birth year/age of cow was important (P < 0.001). In the 1992-born cows, pregnancy rate decreased as females aged from 2- to 3-year olds . This trend was not seen in the 1993-born cows, as pregnancy rates increased between these ages and decreased as they were four-year olds. After cows were 4-year olds, pregnancy rates fluctuated slightly until 2009 where cows in both groups reached the lowest pregnancy rates of their lifetimes. Pregnancy rates increased from 2009 to 2010 in both groups. Boran-sired females had the highest average pregnancy rate (0.930) over the years of the study, followed by Tuli-sired females (0.912) and Brahman-sired females (0.900).

Sire of cow breed did have an effect (P = 0.004) on calf crop born. The rank of sire breeds was the same for calf crop born as pregnancy rate. Boran-sired cows ranked the highest followed by Tuli- and Brahman-sired cows (0.944, 0.892, and 0.872, respectively). The effect of calf's birth year/age of cow was also a source of variation for calf crop born (P < 0.001). Similar trends to those found for pregnancy rate were

found for calf crop born for this effect. The interaction of dam of cow breed with calf's birth year/age of cow was also important (P = 0.059).

Differences due to sire of cow breed and dam of cow breed were not found for birth weight of calf (P = 0.973 and P = 0.146, respectively). Birth weights were similar between calves out of Brahman-, Boran-, and Tuli-sired cows (34.1, 34.0, and 34.1 kg, respectively). Sex of calf was an important source of variation for birth weight (P < 0.001); males were 2.1 kg heavier, on average, than females. Calf's birth year/age of cow also affected birth weight (P < 0.001). The heaviest birth weights were found in 2001 when cows were 8 and 9 year-olds and the calves were sired by F_1 Nellore-Angus bulls (38.5 and 38.3 kg, respectively) and the lightest in 2007 when the cows were 14 and 15 and the calves were sired by Angus bulls (28.7 and 25.3 kg, respectively). Differences due to the interactions of dam of cow breed with sex of calf and dam of cow breed with calf's birth year/age of cow were also found (P < 0.001 and P = 0.003, respectively).

Sire of cow breed affected calf crop weaned (P = 0.006); Boran-sired cows had a higher adjusted mean (0.894) than Brahman-sired cows (0.810), with Tuli-sired females not different from either (0.843). Calf's birth year/age of cow was also a source of variation (P < 0.001). Calf crop weaned means for calf's birth year/age of cow were, as expected, similar to pregnancy rate and calf crop born. The dam of cow breed by calf's birth year/age of cow interaction was also important (P = 0.225).

Sire of cow breed also had an effect on weaning weight (P < 0.001) with calves out of Brahman-sired cows being the heaviest (236.7 kg) followed by those out of

Boran-sired cows (217.5 kg), and Tuli-sired cows (197.2 kg). Differences due to sex of calf were found for weaning weight ($P < 0.001$) with males averaging 10.4 kg heavier than females. The interaction of sire of cow breed with sex of calf also affected weaning weight ($P = 0.026$). In calves out of Brahman-, Boran-, and Tuli-sired cows, males outweighed females by 15.1, 8.9, and 7.2 kg, respectively. Calf's birth year/age of cow was another effect that was important for weaning weight ($P < 0.001$). The lowest adjusted mean for weaning weights were found in first calf heifers born in 1992 (183.7 kg), but in the 1993-born cows, the lowest weaning weight was in 1996 when most females had their second calves (181.7 kg). The largest decline in weaning weights was seen from 2005 to 2006 for both groups of females. After 2006, there were no distinct trends in calf weaning weights for either groups of cows. The interaction of calf's birth year/age of cow with sex of calf was also important. The regression of weaning weight on weaning age of the calf was 0.79 kg/d.

There was an effect of sire of cow breed ($P < 0.001$) on cow weight at palpation. Brahman-sired females (537.1 kg) had heavier average cow weights than Boran- and Tuli-sired cows (468.9 and 462.6 kg, respectively), which were not different from one another. Calf's birth year/age of cow was also important ($P < 0.001$). The heaviest cow weights were reached by 1992-born cows in 2004 (571.2 kg) and by 1993-born cows in 2005 (556.2 kg). The lightest weights, as expected, were taken on both groups of cows as yearlings in 1993 and 1994 (279.8 and 305.3 kg, respectively). Differences due to the interaction of sire of cow breed with dam of cow breed were found ($P = 0.0831$). Although not significantly different, Brahman- and Boran-sired cows out of Angus dams had heavier cow weights at palpation across all years of the study (545.1 and 473.1 kg, respectively) than those by the same sire breed and out of Hereford dams (529.0 and 464.8 kg, respectively). Conversely, Tuli-sired cows out of Hereford dams were heavier than those out of Angus dams (469.8 vs. 455.4 kg, respectively). There were also interactions of sire of cow breed x calf's birth year/age of cow and dam of cow breed x calf's birth year/age of cow ($P < 0.001$ and $P = 0.087$, respectively). In an alternative model including cow condition score at palpation, the regression coefficient for cow weight on cow condition score was 29.02 kg/unit of condition score.

Sire of cow breed affected cow body condition score at palpation ($P < 0.001$). Cows by Boran bulls (5.43) had higher condition scores than those by Brahman and Tuli bulls (5.19 and 5.15, respectively), which were not different from each other. The effect of calf's birth year x dam of cow interaction was also important ($P < 0.001$). No specific trend across years was seen in either group of cows. These changes in condition score were obviously affected by environmental factors such as rainfall, forage quality and availability, and temperature.

Sire of cow breed was important for mouth score ($P = 0.007$ and $P = 0.017$, respectively) in two distinct analyses. In the first, smooth mouth cows were given a value of 0 and broken and solid mouths a 1, and Brahman- and Boran-sired females (0.874 and 0.833) had higher mouth scores than Tuli-sired females (0.659) but were not different from each other. In the second analysis a value of 0 was assigned to cows with broken or smooth mouths and a 1 was assigned to cows with a solid mouth. In that analysis Brahman-sired females had a mouth score mean of 0.403, which was greater than Tuli-sired females (0.070). Boran-sired females (0.295) had mouth scores intermediate to those of cows by Brahman and Tuli bulls, and did not differ significantly from either. Calf's birth year/age of cow was important in the second analysis ($P <$ 0.001), but was not in the first ($P = 0.131$). In some cases, mouth scores increased from one year to the next due, at least partly, to changes in evaluators and their criteria for assessing scores.

In this study, Boran-sired cows had an advantage in reproductive rates when compared to Brahman- and Tuli-sired females. Brahman-sired females weaned heavier calves in every year of the study except one. This advantage in weaning weight of calves out of Brahman-sired cows might partially offset lower reproductive rates and higher maintenance requirements. Boran- and Tuli-sired cows were moderate in size and weighed less than Brahman-sired cows, throughout the study. Tuli-sired cows weaned the lightest calves and had the most tooth wear and deterioration as they aged, which could lead to shorter productive lives. Based on these results, there appears to be potential for Boran-British crossbred cows to be suitable for beef producers in the South.

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