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

A Thesis

by

SAMANTHA F. CUNNINGHAM

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

MASTER OF SCIENCE

August 2005

Major Subject: Animal Breeding

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Approved by:

Co-Chairs of Committee,	James O. Sanders
	Andy D. Herring
Committee Member,	James N. Derr
Head of Department,	Gary Acuff

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ABSTRACT

Evaluation of F_1 Cows Sired by Brahman, Boran, and Tuli for Reproductive and Maternal Performance and Cow Longevity. (August 2005)

Samantha F. Cunningham, B.S., Texas Tech University

Co-Chairs of Advisory Committee: Dr. J.O. Sanders
Dr. A.D. Herring

Birth (BW) (n = 1,107) and weaning weight (WW) (n = 1,024), pregnancy rate (PR) (n = 1,255), calf crop born (CCB) (n = 1,232), calf crop weaned (CCW) (n = 1,225), and cow's weight at palpation (CW) (n = 1,403) were evaluated from 1994 to 2004 in 143 F_1 females who were sired by Brahman (B), Boran (Bo), and Tuli (T) bulls and who were out of Angus and Hereford cows. In 2004, mouth scores (MS) (n = 71) were assigned to the remaining females. PR, CCB, CCW, CW, and BCS were evaluated using a model that consisted of sire of dam breed, dam of dam breed, and calf's birth year/age of dam as fixed effects. Sire of dam within sire breed of dam and dam within sire of dam within sire breed of dam were used as random effects. BW and WW were analyzed using the same model including calf's gender. Two-way interactions were tested for significance. Year/age was significant for all traits ($P < 0.05$). Adjusted means for BW for calves out of cows by B, Bo, and T sires were 35.66, 35.38, and 35.59 kg respectively, and were not different ($P > 0.05$). Adjusted means for WW for calves out of cows by B, Bo, and T sires were 233.4, 220.1, and 208.2 kg respectively, and were significantly different. For both BW and WW, male calves were heavier ($P < 0.05$)

than females. Adjusted means for PR for females sired by B, Bo, and T bulls were 0.914, 0.945, and 0.920, and were not different ($P > 0.05$). Adjusted means for CCB for females sired by B, Bo, and T bulls were 0.890, 0.943, and 0.910 respectfully, and Bo was higher ($P < 0.05$) than B. CCW showed the same ranking as CCB with adjusted means of 0.834, 0.887, and 0.857 for cows by B, Bo, and T bulls, with Bo being higher ($P < 0.05$) than B. CW adjusted means, in the fall of 2002, were 594.29, 519.38, and 517.3 kg. B-sired females were heavier ($P < 0.05$) than Bo- or T- sired cows. More Bo- ($P = 0.013$) and B-sired ($P = 0.003$) cows had solid mouths in 2004 than T-sired cows.

ACKNOWLEDGEMENTS

I first would like to thank my advisory committee: Dr. Jim Sanders, Dr. Andy Herring, and Dr. Jim Derr. Thanks especially to my co-chairs Dr. Sanders and Dr. Herring for all of your encouragement, support, teachings, and most importantly patience. I also need to thank Dr. Clare Gill and Dr. Jason Sawyer for all of their help and answers to my many questions, and also for their encouragement. Carla Dileo, thank you! Thanks for all of the little things that you do for us as graduate students; we probably don't tell you enough. Candice Moore, thank you for your help and support. And finally, Kleberg 114, thanks for everything!

I also extend many thanks to the other graduate students in the department who have made my time here so memorable. It's amazing what can happen when we explore the other floors! I've found friendship, encouragement, advice, perspective, and support. Thanks especially to the inhabitants of 434—we have had a great time.

Most importantly, I need to thank my friends and family who have never told me that something was out of my reach. You were always there to push me onward and you never stopped believing in me. Thank you, you know who you are. Mom and Dad, thank you does not say near enough to describe your love, your encouragement, and your enthusiasm. Regardless of the miles between us, you are there for me everyday and always.

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INTRODUCTION

The beef industry within the United States is the largest, and perhaps, most complex sector of American agriculture. Due to the nature of its size and intricacy, beef producers should be seeking optimal herd performance for their environment and market.

No single breed of cattle can have maximum levels of production in all environments. Instead of searching for one perfect breed that can excel in all production environments, producers should strive to match an animals' genotypes with the given production environment and the available marketing options. One way to do this is to utilize crossbreeding. A crossbreeding system should be able to optimize heterosis and breed differences (Gregory and Cundiff, 1980).

The concept of crossbreeding in order to take advantage of any available heterosis or breed complementarity is important, and it has been witnessed in the temperate regions of the United States. It is most evident in the Southern more sub-tropical type climates of the U.S. where Zebu breeds are utilized in crossbreeding schemes to provide a level of heat tolerance that is intermediate to that of pure *Bos taurus* and pure *Bos indicus* strains (Turner, 1980; Cartwright, 1980). Unfortunately, the F_1 Brahman – *Bos taurus* female is incapable of producing replacements that equal her level of production (Herring et al., 1996); thus investigation of alternative forms of tropically adapted germplasm has gained interest. The Tuli, a Sanga breed, and the

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This thesis follows the style of Journal of Animal Science.

Boran, a Zebu breed, are both breeds that are African in origin, and both could prove to be a supplement or a complement to Brahman within crossbreeding systems desiring tropical adaptation.

The objective of this study was to evaluate F_1 cows sired by Brahman, Boran, and Tuli bulls to compare these three tropically adapted breeds for the traits that represent reproductive and maternal performance. The results of the analyses are compared to previous reports of maternal and reproductive performance of F_1 *Bos taurus-Bos indicus* females.

LITERATURE REVIEW

As the single largest segment of American agriculture (National Agriculture Statistic Service, 2002), the beef industry should aim to capitalize on improved herd performance. One way to enhance the performance of a beef cow herd is to utilize crossbreeding. Gregory and Cundiff (1980) reported that beef cattle crossbreeding systems should have the objective to optimize heterosis and breed differences, and, that proper utilization of major differences among or between breeds will contribute to the overall production efficiency. The best measure of production efficiency within the beef industry is the economic status of the operation. This characterization of economic characters will allow for identification of the breeds to utilize to achieve heterosis and exploit genetic differences (Trail and Gregory, 1981).

Heterosis greatly affects nearly all economically important traits concerning beef production (Gregory et al., 1965; Gregory et al., 1966; Long and Gregory, 1974; Gregory et al. 1978); for example, the three most influential traits on beef herd performance and economics are weaning rate, maternal ability, and growth potential of calf (Koger, 1980). Heterosis and breed complementarity can be achieved through crossing diverse breeds to create the genetic potential needed to match markets, environments, and available feed resources (Cundiff et al., 1993). Added performance can be attributed to heterosis effects or the superiority of crossbred animals over the average of the parents in individual performance (Lush, 1945). The greatest effects of heterosis are seen in lowly heritable traits when two completely divergent lines are crossed (Comerford et al., 1987), for instance *Bos indicus* X *Bos taurus*.

The beef industry is one of the most diverse sectors of American agriculture. Perhaps the driving force of this diversification is the geographical demands placed on cattle to perform in a particular environment. The Zebu and/or Zebu influenced breeds are propagated and marketed primarily in the South, just as the European-type cattle are located across the country, but bred mainly as purebreds in more temperate climates. This geographic segregation of breeds is largely due to the differences between the two primary cattle types: Zebu and European. The two differ not only anatomically and physically with differing sub-species designation, but the production traits of each also differ as a result (Cartwright, 1980). Cartwright (1980) listed the differences between the two types to be heat adaptation vs. cold tolerance; reproduction, parturition, and lactation (maternal characters); growth and maturation rates; temperament; and complementarity and combining ability. These are all qualities of beef breeds that should be considered when formulating crossbreeding schemes. These two sub-species also differ at the level of molecular genetics. Genetic research has yielded discoveries within the cyto- and molecular genetic fields (Herring, 1994).

A large fraction of crossbred animals in the Southern tier of the United States contain some percentage of *Bos indicus* blood. Turner (1980) stated that the ultimate use of Zebu and other tropically adapted breeds of cattle, like the Sanga breeds from Africa, are in well-defined crossbreeding programs. Crossbreeding is a particularly important part of the beef industry, especially in the Gulf Coast region of the U.S. In this region of the country, the majority of all beef cows are of *Bos taurus* X *Bos indicus* breeding because the production level of the *Bos taurus* female is restricted in the warmer sub-tropical climates of the Southern United States (Turner, 1980).

Zebu cattle, when propagated as straight bred animals, display an increased age of puberty, lowered calf survival rates, lessened weaning rates, slowed rates of gain, and lowered carcass quality when compared to *Bos taurus* type cattle (Franke, 1980). Zebu cattle are also better suited for hot climates than *Bos taurus*, and this advantage in adaptation makes them valuable to crossbreeding in Southern U.S. regions (Turner, 1980). Additionally, calves of *Bos taurus* X *Bos indicus* breeding often gain faster than the average of the two parent types, and reproductive performance and maternal effects of females are greatly improved when compared to straight *Bos indicus* females (Turner, 1980). The most valuable gain resulting from crossing *Bos taurus* and *Bos indicus* is the crossbred cow. This F_1 female is fertile, she has tremendous calving ease, and she will wean heavy calves (Sanders, 1994). Most importantly, the crossbred cow possesses an advantage in heterosis that can be measured by the performance of her offspring (Turner and McDonald, 1969).

Within the U.S., there are few breeds available to choose from when tropical adaptation is desired—Brahman is the most common by far. There are other breeds, but their numbers are few and availability limited: the Criollo type cattle (non-humped cattle tracing to the Iberian peninsula), Senepol (non-humped cattle originating in the US Virgin Islands through a cross of Red Poll and N'Dama), and Asian Zebu (humped cattle that were used in the formulation of the American Brahman) (Herring, 1994). This has led to the search and discovery of other sources of tropically adapted germplasm, like the

Boran and the Tuli, due to the inability of the F_1 *Bos indicus* X *Bos taurus* female to produce a replacement capable of the same level and quality of production as herself (Herring et al., 1996).

The Boran originated in Africa, in the Kenya-Ethiopia region (Rouse, 1970; Epstein, 1971; Porter, 1991) and is a shoulder-humped Zebu, like the Brahman. Boran cattle can be of any color from gray to red to very near black and they can be horned or polled.

Tuli cattle are a Sanga (neck humped) breed, also from Africa. The Tuli originated in the region of Africa that is now Zimbabwe. These individuals can be white or any shade of red, and they can be horned or polled (Epstein, 1971). Sanga males have a Y chromosome like that of the *Bos taurus* rather than the *Bos indicus*. The Sanga had previously been thought to be the result of crossing the *Bos indicus* and *Bos taurus* in Africa hundreds of years ago (Epstein and Mason, 1984). A more recent study by Hanotte et al. (2000) used a Y specific chromosome marker to explore the amount of Zebu influence on the African continent. They found that the number of the indicine Y allele as compared to the taurine Y allele varied greatly by geographic region. In fact, in the South African region, where Tuli are found in Zimbabwe, 93% of all Y alleles sampled from 14 breeds, were taurine. Also, of the Sanga breeds sampled across Africa, only 29% possessed the indicine Y chromosome, and the vast majority were found in Ethiopia and its neighboring Eritrea, far north of Zimbabwe. Therefore, according to Hanotte et al. (2000), the penetration of Zebu influence in African cattle populations is dependent upon adaptation to disease, farmer preference, and geographic isolation, with the later pertaining to the main Sanga populations. The authors concluded that the Sanga in Southern Africa has some Zebu background, and that it is of predominantly female origin. This agrees with the findings of Frisch et al. (1997) who reported the banding pattern of the Sanga Y chromosome to be not unlike that of European breeds and quite different from Brahman. This is also concurrent with Manwell and Baker (1980) who reported that the Sanga is nearer to *Bos taurus* on a phylogenetic tree than to Zebu. Also, Hanoette et al. (2000) were surprised to find that the Sanga population sampled in the Lake Victoria region and Southern Africa were dominated by the taurine Y allele.

Both of these breeds (Tuli and Boran) have been considered as potential supplements or alternatives to Brahman when heat adaptation is a desired trait to be injected into the cow herd. These females have shown to be very maternally and reproductively productive in their native lands (Trail and Gregory, 1981; Hetzel, 1988). Unfortunately, there are limited data regarding production traits pertaining to cow productivity.

Beef Production in the United States

The complexity of the American beef industry is primarily due to the various climatic conditions across the continent. This vast array of production environments has created a need to match the cattle to the environment in which they are asked to produce; there is also a need for cattle to complement regional market conditions. Research has yielded results indicating that no one breed of cattle is capable of maximum production in all environments, creating the need for crossbreeding systems that capitalize on any potential heterosis and breed complementarity. This concept is important across the nation and has been witnessed in the temperate regions of the United States; however, it is most noticeable in the Southern more sub-tropical type climates where Zebu breeds are utilized in crossbreeding schemes to add heat tolerance that is intermediate to that of pure *Bos taurus* and pure *Bos indicus* strains (Turner, 1980; Cartwright, 1980).

There are two primary strains of cattle in existence: humped and non-humped. Humped cattle are those having some form of hump located either over the shoulder (thoracic humped) or the neck (cervico-thoracic hump). Those classed as Zebu are shoulder-humped (Mason, 1984), whereas the Sanga-type cattle are neck humped. However, Sanga cattle are not the only cattle having neck humps. There are those cattle derived from crosses of Zebu and non-humped cattle (*Bos taurus*) that possess a cervico-thoracic hump such as Beefmaster, Santa Gertrudis, Brangus, and the like (Mason, 1984).

Brahman

The Brahman is the first breed thought of and the most numerous when considering *Bos indicus* types in the United States. The Brahman is unique in that it is maintained as a breed within the United States for creating crossbred replacements for commercial production rather than using purebred cattle in the commercial setting (Turner, 1980; Sanders, 1994). Purebred Brahman females are said to have lower calving rates, calf survival rates, and thus weaning rates than other straight bred cattle (Franke, 1980). The birth weights of calves sired by Brahman bulls and out of *Bos taurus* females tend to be larger; therefore, the level of calving difficulty is increased when Brahman bulls are bred to *Bos taurus* females, particularly heifers (Gregory et al., 1979; Reynolds et al., 1980; Roberson et al., 1986; Paschal et al., 1991). Brahman, Brahman derivative, and other Zebu influenced cattle have measured less desirable in carcass quality and meat tenderness than other breeds available (Franke 1980; Paschal et al., 1995; Hilton et al., 2004). In a study by Paschal et al. (1995), Zebu crosses had post weaning gains greater than Angus crosses, and these same cattle had yield grades similar to their Angus contemporaries.

Brahman cross cattle differ from other types of crossbreds (*Bos taurus* X *Bos taurus*) due to heightened levels of hybrid vigor. Variation in performance of Brahman-cross cattle is dependent upon the level of hybrid vigor in the calf, the level of hybrid vigor in the dam, the amount of Brahman in the calf, the percentage of Brahman in the dam, and the amount of any other breed or breeds in the calf and/or dam (Sanders, 1994). In a review of the utility of Brahman crosses, Franke (1980) stated that Brahman-cross calves have been shown to have increased survival rates, slight increases in weaning rates, and larger birth weights if the calves are sired by Brahman bulls and out of *Bos taurus* females, and significantly larger weaning weights than many straight bred calves. Preweaning performance of crossbred calves can largely be attributed to the genetic value of the dam (Sanders, 1994). As part of a crossbreeding scheme, Brahman influence is appealing due to the increased longevity and maternal calving ease of the *Bos indicus* X *Bos taurus* crossbred (Turner, 1980) in addition to heterosis for reproductive traits such as fertility.

The American Brahman was derived from a series of upgrades of Zebu males mated to Gulf Coast “native” cows in the late 1800s and early 1900s (Franke, 1980;

Sanders, 1980). Zebu genetics currently in the U.S. are of breeds originating in India, although the majority of the cattle came from Brazil. The Gray Brahman is the most prevalent strain of Brahman, and it is a mixture of mainly Guzerat and Nellore (Sanders, 1980). According to Sanders (1980), the Guzerat was the most important breed used to create the American Gray Brahman. The Guzerat originated in northern India, and is also maintained as a pure breed in Brazil. They are some of the largest cattle of India and are gray with lyre-shaped horns. The Nellore is also an Indian breed with a long narrow head and small ears. In their country of origin, Nellore are used for milk and draft purposes. Nellore herds are well established in Brazil; in fact, they are the most numerous breed of cattle. Until the beginning of the movement to create the American Gray Brahman (the 1920s), the Nellore was the most numerous of the Zebu in the U.S. It was primarily the grade Nellore females that were sired by Nellore bulls that had resulted from grading up programs that were used in the formation of the American Brahman (Sanders, 1980).

Present thinking of tropical adaptation in the United States typically only takes into account Brahman germplasm, when that is not the limitation. There are worldwide alternatives to Brahman cattle that are also highly heat tolerant and present unique production characters when used within crossbreeding systems (Chase et al., 2000).

Boran

The superior performance of F_1 *Bos indicus* X *Bos taurus* dams has been documented numerous times (Bailey, 1991; Cundiff et al., 2000; Jenkins and Ferrell, 2004). Further, Herring et al. (1996) stated that the inability of the F_1 Brahman-*Bos* *taurus* female to produce replacements that produce at the same level as herself has led to the interest in finding alternative suitable tropically adapted breeds such as the Boran or the Tuli. The Boran may be a suitable replacement for Brahman within some breeding programs due to the slightly smaller birth weights, carcass weights, and mature cow weights (Herring et al., 1996; Cundiff et al., 2000; Ducoing, 2002); that is, the Boran may produce a more moderately sized replacement while maintaining tropical adaptation.

The Boran breed of cattle originated in the region where Kenya, Southern Ethiopia and Somalia share borders. The Boran is a Zebu breed with a thoracic hump. It was originally used for milk and draft in Ethiopia (Porter, 1991). Since then, the Boran has been improved upon and has been categorized as a beef breed under tropical conditions (Epstein and Mason, 1984; Porter, 1991; Cundiff et al., 1995; Ducoing, 2002). The Boran, in its native region in Africa, is slow maturing, well-muscled, and can be polled or have small-thick horns. In a review by Hetzel (1988), Boran was second in terms of adaptability to various production environments to Brahman—far exceeding the adaptability of the Tuli. Improved strains of Boran cattle have a compact body of excellent depth, width, and capacity (Epstein, 1971). In animal breeding studies in Africa, the Boran has been used as the *Bos indicus* standard of comparison (Trail and Gregory, 1981).

Tuli

The Tuli is a Sanga breed of cattle that was developed in Rhodesia (now Zimbabwe) as part of a research project involving the Tswana cattle during the 1940s

(Cundiff et al., 1995). Sanga type cattle have cervico-thoracic (shoulder/neck) humps that are similar to the humps that result from crossing *Bos taurus* with Zebu (Ducoing, 2002). Epstein (1971) suggested that Sanga cattle are the result of crossing humpless cattle of Africa and thoracic humped Zebu. However, in more modern literature (Manwell and Baker, 1980; Meyer, 1984; Freeman et al., 2004), it is said that the difference is due to speciation events, and Hannotte et al (2000) found that the majority of all Sanga cattle sampled had the taurine Y chromosome.

Meyer (1984) noted biochemical differences that are not a result of the aforementioned cross. Sanga cattle have been shown to possess a submetacentric Y chromosome like that of the European breeds (Meyer, 1984; Stranzinger et al., 1987; Frisch et al., 1997) as compared to the acrocentric Y chromosome of Zebu breeds (Frisch et al., 1997). The chromosomal morphology of the Sanga suggests that they are more genetically similar to the *Bos taurus* breeds than to the *Bos indicus* breeds. Evolutionary evidence also suggests that Sanga cattle are more closely related to European *Bos taurus* than to any *Bos indicus* breeds (Manwell and Baker, 1980; Freeman et al., 2004).

The Tuli has been utilized in production and research in its native Africa for many years. In a study by Trail et al. (1977), that utilized straight bred Tuli and Tuli sires bred to Tswana females, the Tuli demonstrated a higher calving percentage and a lower calf mortality rate than either the Africander or the Tswana. This agrees with higher calving rate and weaning rate found in a comparison of the indigenous breeds in high-performance environments in Eastern and Southern Africa (Hetzel, 1988). The

Tuli also recorded the lowest pre-weaning mortality rate in the review among Tswana, Tuli, Bonsmara, and Brahman (Hetzel, 1988). Straight bred Tuli calves were significantly smaller at birth than Africander and Tswana; however, the Tswana calves weighed heavier at weaning than did either the Tuli or the Africander (Trail et al., 1977). The Tuli calves were heavier at 18 mo. than were the Tswana or Africander, (only significantly higher than the Africander). Researchers calculated the kilograms of weaned calf per cow per year and the Tuli was significantly heavier than the other breeds within the study (Trail et al., 1977); these findings are consistent with those reported by Hetzel (1988) that the Tuli was one of the most productive breeds per kilogram of cow weight in a high-performance production environment, even exceeding the production/cow/year of the Brahman. Additionally, in the same environment, Tuli females were more fertile than the Brahman. In a low-performance production scenario, the Tuli performed similarly to the Brahman, but below that of the Mashona (Hetzel, 1988).

Tuli genetics were first imported to the United States in the early 1990s as semen from Australia (Chase et al., 2000). When searching for a breed to use in conjunction with Brahman genetics in tropically adapted crosses, the Tuli could prove useful when moderation of size is desired (Herring et al., 1996; Cundiff et al., 2000). Herring et al. (1996) found that Tuli-sired calves gained similar to Boran-sired calves and both had less pre-weaning and feed yard average daily gain than Brahman-sired calves. Cundiff et al. (2000) found that a mating of Tuli with a larger sized, faster gaining breed should yield a moderately sized offspring that maintains tropical adaptation while having carcass characteristics close to those animals having British influence (Cundiff et al., 2000).

Crossbreeding of Beef Cattle

The beef industry within the US is likely the most variable of any, when compared to other food animal industries. There were 774, 630 beef cow operations in the US in 2004—supplying 33, 055, 000 head as of January 1, 2005. The majority of these operations have fewer than 49 cows (National Agriculture Statistics Service, 2002).

Performance characteristics of the beef animal are primarily due to breed differences (Cundiff et al., 1995). Breed differences allow cattle producers to select breeds according to the production system (Freetly and Cundiff, 1998). The magnitude of these breed differences is dependent upon how diverse the breeds contributing to the cross are. Cattle should be mated and produced to optimize genetic potential, which should be matched to 1) the environment, 2) available feed resources, and 3) market demands (Cundiff, 1993; Hammack, 1998). There are three primary reasons to propagate crossbred animals: breed combination, breed complementarity, and heterosis (Hammack, 1998). Hammack (1998) explained breed combination as combining breeds with different traits with the goal of producing a superior package. Heterosis is not necessarily a factor when considering combination, and he states that the most favorable combinations are one of the greatest benefits of crossbreeding. Hammack (1998) gave an example of breed combination as crossing females having high carcass quality and small body size and slow rates of gain mated to sires with genetics for fast growth, and large size and poorer carcass quality to produce calves that are moderate in all traits. Complementarity is slightly different than the aforementioned mating because complementarity is continually using a female of one genetic type mated to a different type of sire, and this concept is only applicable when used within a particular breeding system (Hammack, 1998). By selecting more divergent breeds, cattle producers will see greater amounts of heterosis.

Heterosis is the difference in performance of crossbred progeny compared to the average of the purebred parents. This is typically thought to be positive. The hybrid vigor seen in any animal is expected to be higher in the progeny of parents who are the least related. For instance, there would be greater heterosis seen from crossing *Bos indicus* X *Bos taurus* than there would be in a *Bos taurus* X *Bos taurus* cross (Hammack, 1998). Heterosis seen in a *Bos indicus* X *Bos taurus* cross is generally two times (Cundiff et al., 1989) or three times the hybrid vigor seen in a cross of *Bos taurus* breeds (Koger, 1980). The greatest amounts of heterosis are seen in traits that are lowly to moderately heritable. Lowly to moderately heritable traits are those such as early growth and those related to reproductive efficiency. The greatest effect of hybrid vigor may be expected to be improvements in maternal ability and fertility (Cundiff, 1970); however, heterosis affects most economic traits of beef cattle production (Gregory et al., 1966; Long and Gregory, 1974; Gregory et al. 1978).

Heterosis, breed combination, and complementarity are all strategies to consider when breeding livestock, especially in the beef industry of the Southern US. It is there that cattle need added heat adaptation for optimum performance. This region is where we see the largest concentration of Brahman germplasm, and thus, the greatest need for alternate or supplemental breeds like the Boran and the Tuli.

Bos indicus *and Crossbreeding*

Scientists and cattle producers alike have witnessed the heightened levels of hybrid vigor that result from crossing *Bos indicus* and *Bos taurus*, when compared to *Bos taurus* x *Bos taurus*. This approach to crossbreeding has been in place in the Southern region of the United States for decades, primarily because of the inability of the straight *Bos taurus* animal to thrive in the warmer, more humid climate (Damon et al., 1959). This realization was responsible for the formation of the synthetic breeds with added heat adaptability and maternal performance (e.g. Santa Gertrudis and Brangus) (Cundiff, 1977). It was during this period that cattle producers and livestock breeders witnessed not only added heat adaptation, but increased cow longevity (Cundiff, 1977). Maternal characteristics and adaptation to sub-tropical environments are not the only traits of beef production that are affected in a *Bos indicus* X *Bos taurus* cross. The carcass quality of the straight Brahman is improved when *Bos indicus* animals are crossed with *Bos taurus*, especially the British breeds (Cundiff, 1977).

Freetly and Cundiff (1998) investigated reproductive characteristics of first calf heifers. They found the age of the heifer at parturition to be significantly different among the various breeds in the study. Belgian Blue-, Piedmontese-, and Boran-sired females were all markedly younger at the time of first calving when compared to the females sired by Hereford, Angus, Tuli, and Brahman. Within the same study, Tuli- and

Brahman-sired females had lower ($P < 0.05$) body condition scores than the Boran-sired cows.

Birth weight is important and it should be taken into consideration in beef cattle production. Birth weight has been shown to affect calf survival. There is somewhat of a threshold point where increases in birth weight increase the incidence of dystocia, which leads to an increase in calf mortality (Cundiff et al., 1995). Gregory et al. (1979) found that Brahman-sired calves were the heaviest ($P < 0.01$) within a study consisting of Hereford, Angus, Brahman, Sahiwal, Pinzgauer, and Tarentaise bulls bred to Angus or Hereford females. Brahman-sired calves out of *Bos taurus* cows have been found to be heavier at birth than Tuli-or Senepol-sired calves (Butts, 1987; Baker, 1996; Herring et al., 1996; Chase et al., 2000). However, Jenkins and Ferrell (2004) reported that calves out of females sired by Brahman or Boran were lighter than those animals whose dam was sired by a bull of British descent.

Birth weight can increase with the amount of Brahman in the sire compared to the amount in the dam. Brahman-sired calves were heavier than those sired by F_1 Brahman x Hereford or straight bred Hereford bulls and out of Hereford or F_1 Brahman x Hereford females (Roberson et al., 1986). In the same study, there were large effects of breed type of cow on birth weight, as calves out of Brahman cows were consistently lighter than calves out of Hereford or F_1 dams for three different sire types: Brahman, Hereford and F_1. The amount of calving ease increases as the amount of Brahman in the dam increases (McCarter et al., 1991). This supports the findings of Olson et al. (1991). They found that calving ease was increased in *Bos indicus* X *Bos taurus* dams over that of *Bos taurus* F_1 females by Chianina, Maine Anjou and Simmental bulls and out of Angus or Hereford cows. Further, Riley et al. (2001a) documented that calves from Gir- (34.81 kg) and Nellore- (36.68 kg) cross females were lighter than those out of Angus- (39.35 kg), Gray- (37.1 kg) and Red Brahman- (37.23 kg), and Indu-Brazil- (37.16 kg) sired cows.

Birth weight of *Bos indicus* influenced calves is a unique trait to consider. Calves out of straight *Bos indicus* or *Bos indicus* X *Bos taurus* females are generally lighter at birth than those calves out of *Bos taurus* females. Calving records spanning years 1950-1970 at the Texas A&M University Agricultural Research Center in McGregor reflect a large difference in birth weight in Brahman-Hereford F_1 calves out of Hereford and Brahman females—37.5 kg and 30.5 kg respectively (Sanders, 1994). That is, *Bos indicus*-sired F_1 calves are, on average, about 6.8 kg heavier than calves of the same cross having *Bos indicus* dams, with the bull calves being notably heavier than the heifers. The difference between male and female calves that are straight *Bos indicus* or straight *Bos taurus*, is only about 2.3 kg, and the difference between sexes is smaller than that when F_1 calves are out of Brahman cows. The problem with birth weight is most noticeable when F_1 calves are sired by Brahman bulls. In this situation, bull calves are 5.5 to 6.8 kg heavier at birth than heifers (Sanders, 1994). This reciprocal difference has been previously investigated. Baker et al. (1989) put embryos sired by Brahman and Hereford bulls and out of Brahman and Hereford cows into Hereford and Brahman recipients. Calves produced by Brahman recipients were lighter at birth than those by Hereford recipients. Their most unique discovery was that the F_1 calves sired by

Brahman bulls were larger than those sired by Hereford bulls no matter which type of recipient. The difference in reciprocal F_1 calves for birth weight was 9.5 kg. Thallman et al. (1992) concluded that Brahman females have a tendency to produce light birth weight calves no matter the sire breed; *Bos taurus* cows bred to Brahman bulls will have calves that are about 6.8 kilograms heavier than those calves resulting from the reverse cross. The differences seen in birth weight of calf are proportional to the amount of Brahman in the parent (e.g. the more Brahman in the bull, the heavier the calf (when the cow is *Bos taurus*), and the greater amount of Brahman in the dam, the lighter the calf). The average difference between sexes is at least 5.5 kg when Brahman bulls are bred to *Bos taurus* cows; when *Bos taurus* bulls are bred to Brahman cows the difference between bull and heifer calves is quite small. Breed of dam aside, McCarter et al. (1991) found that as the age of dam increased, from 3 to 5 years of age, the birth weight of calf increased significantly. This is in agreement with Roberson et al. (1986) who found birth weight to increase as the cow's age increased to approximately 7 years of age, after which, the birth weight began to decline in older females.

The reproductive efficiency of the cow herd is important to determining the overall productivity of a beef cattle operation. The pregnancy rate of females could be considered the beginning step in estimating cow reproductive efficiency. Riley et al. (2001a) found there to be a strong interaction ($P < 0.05$) between sire breed of cow and age of cow. They found that the Nellore-sired females had the highest percent pregnant when compared to the Gray Brahman-, the Gir-, the Indu-Brazil-, and the Angus-sired females within the study. The Angus crossbred pregnancy rate (87.4%) was also lower

(*P* < .05) than that of both the Gray Brahman and the Gir crossbred females 97.0 and 96.4, respectively. Additionally, the Indu-Brazil- and Angus-sired females showed the most variation or fluctuation in pregnancy rate from year to year, and as the females became older than 10 years of age, pregnancy rates were more variable within breed (Riley et al., 2001a).

Closely associated with pregnancy rate is percent calf crop born, an additional measure of the reproductive efficiency. Riley et al. (2001a) found that figures for calf crop born closely resembled those for pregnancy rate, and the values among the *Bos indicus*-sired females were not significantly different . In a study from Botswana, that compared performance of straight bred females, the calving percentage of the Tuli (85.0) far exceeded that of the Twsana (70.6) or the Africander (64.5) (Trail et al., 1977). Gregory et al. (1979) found Hereford X Angus and Angus X Hereford calves to have a greater ($P < 0.05$) percentage of calf crop weaned than did the Brahman-crosses or the Sahiwal-cross calves; in that study, calf crop weaned was defined as the fraction of calves born that survived to weaning.

Weaning weight is a measure of primary product (Roberson et al., 1986). It is nothing more than birth weight combined with preweaning gain. Preweaning gain should be thought of the calf's own ability to grow, plus all maternal contributions provided by the dam. According to Sanders (1994), weaning weight is important to the cattle industry because it is representative of the sale weight of calves for many producers.

For decades, livestock breeders witnessed the improved weaning gain and maternal ability of *Bos indicus* X *Bos taurus* cross calves and females (Damon et al., 1959). They found that calves out of Brangus or Brahman dams were heavier at weaning when compared to calves out of Angus or Hereford dams in Louisiana. They attributed the advantage in gain of the calves out of *Bos indicus* influenced dams to the mothering ability of the *Bos indicus* cow above that of a Hereford or Angus cow in this particular region. Riley et al. (2001a) found at weaning that the male calves out of *Bos indicus*-sired F_1 females were anywhere from 16.1 kg to 20.2 kg heavier on average than were their female contemporaries. The calves out of *Bos indicus*-sired cows had weaning weights ranging from 255.5 kg to 261 kg versus the mean weaning weight of 227 kg for calves out of Angus-sired cows. In the same study, the steer calves out of Angus-sired cows were just over 8 kg heavier than the heifers at weaning.

Preweaning gain and weaning weight were larger for calves out of Brahman- or Boran-sired females when compared to calves whose maternal grandsires were Tuli or Angus/Hereford (Jenkins and Ferrell, 2004). The heavier calves out of Brahman-sired cows could be due to the greater milk yields of the Brahman-influenced dam and/or the additional hybrid vigor seen in a Brahman X *Bos taurus* cross (Jenkins and Ferrell, 2004).

Calf crop weaned is determined solely by calf crop born and calf survival combined (Riley et al., 2001a). When comparing *Bos indicus* X Hereford females for reproductive and maternal characters, Riley et al. (2001a) found that Nellore-cross cows had a higher percentage calf crop born and greater calf survival, and therefore had a larger percentage calf crop weaned than Red Brahman-, Angus-, and Indu-Brazil-sired cows. The Nellore- and Gir-sired cows had the highest calf survival rates, which is seen in their high weaning rates. The Indu-Brazil-sired females had the lowest calf survival rate, and they also had the lowest weaning rates. As heifers and young cows, both Red and Gray Brahman-cross dams had the lowest percent calf crop weaned of any *Bos indicus* breed; however, from four to nine years of age, these females had a calf crop weaned not lower than the other breeds in the study (Riley et al., 2001a). McCarter et al. (1991) found that the percent of cows that were exposed to bulls at breeding that actually weaned a calf was affected by her season of calving, but more importantly, her genotype (crossbred cow group). Those females that were sired by Brahman or Brahman-cross bulls had a higher percent calf crop weaned as a group than any other sire of dam breed group (McCarter et al., 1991).

The longevity of a female within the beef herd is a measure of operational success and a direct assessment of her reproductive lifespan—the longer that female is productive, the more room there is for potential profit. Longevity is the absolute value of survival (Núñez-Dominguez et al., 1991).

Physical soundness of a female is a determining factor when assessing her lifetime productivity. An animal's ability to harvest forage directly affects his/her capability to maintain body condition, and in the case of the female, her ability to maintain reproductive soundness. The condition of a cow's incisors will affect successful forage intake (Riley et al., 2001b). Her reproductive life can be evaluated through the number of mating seasons per dam, lifetime total number of full-term calves born dead or alive, and the total number of progeny weaned in her lifetime (Bailey, 1991). The breed composition of the female in question is a large determinant of her reproductive life span. Significant breed differences have been found where Brahman influenced cows had a greater number of mating seasons, more calves born, and weaned more progeny, (Bailey, 1991). It has also been documented that crossbred females can, and will, out last purebred females managed under similar conditions (Bailey, 1991).

In the study by Núñez-Dominguez et al. (1991), crossbred females were found to have a longer productive life than were straight bred females. Differences in longevity are likely due to the breeds involved in the cross, and the crossbreds lived 1.36 years longer than did the straight breds (Núñez-Dominguez et al., 1991). When Riley et al. (2001b) evaluated the lifetime productivity of the F_1 *Bos indicus* female, they found the Nellore crosses to have the greatest percentage (60%) of original cows remaining, when the oldest females in the study were potentially 17 years old, compared to Gir (40%), Red Brahman (23.8%), Gray Brahman (19.1%), Angus (13.3%), and Indu-Brazil (5.3%).

Núñez-Dominguez et al. (1991) found that there is a distinct advantage in the size and condition of incisors in older crossbred females, where straight bred cows were missing more teeth or had shorter teeth, thus allowing less feed intake. Riley et al. (2001b) analyzed mouth soundness of aged females (14 years old) with two separate models. In both models, the trait was analyzed as a binary trait. One method was to assign a 0 to all smooth mouthed females and a 1 to any individual having a broken or solid mouth. Broken mouths were those having one or more teeth loose or missing, versus smooth mouths having no incisors remaining. With this first model, there was a significant number of Angus-sired females called smooth mouthed compared to females in the other F_1 sire groups (Gray and Red Brahman, Gir, Indu-Brazil, and Nellore). Among the *Bos indicus*-sired females, there were no significant differences using the first method of analysis. The second method of analysis assigned a 0 to all smooth or broken mouths and a one to solid mouthed females, and no differences ($P > 0.10$) were found among any of the sire breed groups involved; however, the Angus-sired cows had the fewest incisors remaining.

In the study by Núñez-Dominguez et al. (1991) crossbred females had longer and higher quality teeth than did straight breds at an age greater than 12. They found that 7.1% of straight breds were culled due to emaciation and concluded that it was likely due to poor incisor condition compared to only 1.7% of crossbred females removed. The number and condition of incisors is very important to a cow's plane of nutrition. An unsound mouth may not allow an animal to meet their full nutritional requirement because of inability to efficiently ingest feed, especially in range conditions (Núñez-Dominguez et al., 1991).

Changing market demands and ecosystems require cattle producers to constantly be looking for new or different crossbreeding options that will enhance beef herd productivity, while maintaining profitability. The objective of this study is to evaluate F_1 cows sired by Brahman, Boran, and Tuli bulls in order to compare these three tropically adapted breeds in Central Texas for the traits that represent reproductive and maternal performance.

MATERIALS AND METHODS

One hundred forty three F_1 Brahman X Hereford, Brahman X Angus, Boran X Hereford, Boran X Angus, Tuli X Hereford, and Tuli X Angus cows born at the Texas A&M Research Center (TAES) at McGregor in 1992 (77) and in 1993 (66) were evaluated for maternal and reproductive characters. Initially, mature Hereford and Angus cows were artificially inseminated to Tuli (n = 9), Boran (n = 8), and Brahman (n = 15) sires. Boran and Tuli semen was imported into the United States from Australia. The Brahman semen, representative of the breed in the early 1990s, was obtained from U.S. purebred breeders and commercial breeding services. Herring et al. (1996) reported birth, weaning, and post weaning performance of F_1 animals in the study, as well as, the carcass characteristics of the steers produced from the same matings. Ducoing (2002) analyzed the maternal and reproductive performance of these F_1 females that were sired by Brahman, Boran, and Tuli bulls as 7 and 8 year olds and included the traits cow weight, pregnancy rate, percent calf crop born, birth weight, calving ease, nursing success, calf vigor, calf survival rate, percent calf crop weaned, and weaning weight in the report.

In 1993 and 1994, the F_1 yearling heifers were bred to Angus bulls. In 1994, females born in 1992 were bred to Brangus bulls. All 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 in 2003 and 2004. Although cows have been bred to bulls of different breeds across the years, all females were bred to the same breed of sire within each year. Calving occurred from approximately February 15 to May 5 each year. Calves born to these F_1 heifers and cows from 1994 to 2004 were also evaluated. Each calf was weighed and tagged for identification within 48 h of birth. Male calves were castrated when birth measures were recorded. Calves were weaned in October or November of each year at approximately seven months of age. At the time of weaning, calves were weighed and assigned a body condition score, and heifers were vaccinated for brucellosis. 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 for pregnancy diagnosis at weaning, each year, with their weights taken and body condition scores assigned. Females were culled for severe injuries, poor health or at least two failures to have or wean a calf. Cows were also culled for poor udders, if udders/teats appeared so large or pendulous that future calves would clearly have trouble nursing. In addition to palpation for pregnancy in the fall 2004, the incisor condition of F_1 cows was evaluated and mouth scores were assigned. Initially, there were five scores assigned (solid, short and solid, weak, broken, and smooth) which were eventually condensed into 3 scores for analyses—solid, broken, and smooth. Solid mouthed females had no teeth loose or missing. Broken mouths consisted of one or more loose or missing teeth, and those with smooth mouths had no incisors remaining or those remaining were small and very deteriorated. Mouth score was analyzed as a binary trait of all females remaining in the study.

Statistical Analysis

The variables considered in this study were analyzed using the mixed model procedure of SAS. Calves' birth weight (n = 1,107) and weaning weight (n = 1,024) were evaluated using model components sire breed of dam, dam breed of dam, calf birth year/age of dam, and sex of calf as fixed effects. Sire of dam within sire breed of dam and dam within sire of dam within sire breed of dam were used as random effects. Weaning age of calf nested within birth year of calf/age of dam was included in the weaning weight model as a covariate.

Cows' weight at palpation (n = 1,403), body condition score of cow at palpation (n = 1,400), pregnancy rate (n = 1,255), calf crop born (n = 1,232), and calf crop weaned (n = 1,225) were evaluated using a model that included sire breed of dam, dam breed of dam, and calf birth year/age of dam as fixed effects. Sire of dam within sire breed of dam and dam within sire of dam within sire breed of dam were used as random effects. Models including lactation status and body condition score of cow were also evaluated in order to study their effects on pregnancy rate, calf crop born, and calf crop weaned. Sire of dam within sire breed of dam was used as an error term in order to test for differences among sire breed of dam least squares means. Sire breed of calf was confounded with birth year of calf; therefore the birth year of calf was used in all analyses. All-possible two-way interactions between main effects were tested for significance. Those interactions having a P-value equal or less than 0.25 were included in final models.

Mouth scores (n = 71), as a measure of cow longevity, were analyzed in two different ways. The first method of analysis was to assign a value of zero to smooth mouthed cows and a value of one to all females having a broken or solid mouth. Alternatively, a zero was assigned to all smooth and broken mouthed cows and a value of one was assigned to solid mouths. Incisor condition was assessed only once, and therefore, it was analyzed as a binary trait with a model including only the fixed effects of dam of dam breed and sire of dam breed. Sire of dam within sire breed of dam and dam within sire of dam within sire breed of dam were used as random effects.

RESULTS AND DISCUSSION

Cow Longevity

Cow Weight and Body Condition Score

Cow weight and body condition score are important considerations because they both affect cow maintenance, calf growth, and reproductive ability. The F_1 females were the heaviest in the fall of 2003, when the 1992 born cows were about 11.5 (552.0 kg) and those born in 1993 were about 10.5 years of age (571.1 kg). The sire breed of dam was strongly significant, with the Brahman-sired cows being heavier (517.2 kg) than those sired by Boran or Tuli bulls (450.0 and 446.0 kg, respectively) across all ages (including 1.0 and 1.5 yr of age). The dam of dam breed effect was not significant ($P = 0.3252$). Birth year of calf/age of dam was also important ($P < 0.001$) in explaining cow weight. Least squares means for cow weight by sire of dam breed and calf's birth year/age of dam (including yearling weight and weight at 1.5 yr of age)) are presented in Table 1.

The interaction between the dam of dam breed and the sire of dam breed was important ($P = 0.0324$) and is presented in Table 2. The trend of Brahman-sired females being heavier than the Boran- and Tuli-sired females was significant regardless of dam type; however, Brahman-sired cows from Angus dams were significantly heavier than those from Hereford dams. There was no difference in cow weight for the Boran- and Tuli-sired cows from Angus or Hereford dams. The interactions of sire of dam breed x year/age ($P < 0.001$) and dam of dam breed x year/age ($P = 0.0701$) were also important, although the statistical differences were not determined among individual means.

Table 1. Least squares means (LSM) and standard errors (SE) of cow weight (kg) by sire breed of dam, and calf's birth year/age of dam (including yearling weights).

	LSM ± SE, kg	n
Sire breed of dam		
Brahman	$517.2^{a} \pm 5.9$	539
Boran	$450.0^{b} \pm 8.0$	361
Tuli	$446.0^{b} \pm 6.8$	503
Calf's birth year/age of dam		
1993/1[c]	278.5 ± 6.6	66
1994/1[c]	306.5 ± 5.8	78
1994/2[d]	388.7 ± 6.6	66
1995/2[d]	387.9 ± 5.8	77
1995/3[e]	390.8 ± 6.6	66
1996/3	428.3 ± 5.9	75
1996/4	486.8 ± 6.6	65
1997/4	424.8 ± 5.9	73
1997/5	470.1 ± 6.7	64
1998/5	505.3 ± 5.9	71
1998/6	512.9 ± 6.7	62
1999/6	480.9 ± 6.0	70
1999/7	489.4 ± 6.7	62
2000/7	543.2 ± 6.0	67
2000/8	545.9 ± 6.9	57
2001/8	479.3 ± 6.2	58
2001/9	476.9 ± 7.1	48
2002/9	513.8 ± 7.2	54
2002/10	512.9 ± 6.3	45
2003/10	550.6 ± 6.3	53
2003/11	536.7 ± 7.2	45
2004/11	571.1 ± 6.5	47
2004/12	552.0 ± 7.6	34

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

[c] Values for 1993/1 and 1994/1 were obtained from weights measured as yearling heifers in spring of the respective year (1993 and 1994).

[d] Values for 1994/2 and 1995/2 were obtained from weights measured at palpation time when heifers were 1.5 years of age (1993 and 1994, respectively).

[e] Values for 1995/3 to 2003/11 were obtained from weights measured at palpation time in fall of the previous year (e.g., 1995/3 refers to the weight in the fall of 1994, when the cow was about 2.5 years of age).

Table 2. Least squares means and standard errors for cow weight (kg) for interaction of dam of dam breed x sire of dam breed (including yearling weight).

	Dam's sire breed		
	Brahman	Boran	Tuli
Dam of dam breed			
Angus	527.76^{ay} $\pm$ 7.99	455.83^{az} $\pm$11.04	438.92^{az} $\pm$ 8.91
Hereford	506.64^{by} $\pm$ 7.19	444.16^{az} $\pm$ 9.53	453.00^{az} $\pm$ 7.93

^{a,b} Least squares means in the same column without common superscript differ (P < 0.05).
^{y,z} Least squares means in the same row without common superscript differ (P < 0.05).

The least squares means and standard errors for the mature weight and body condition score of cows sired by Brahman, Boran, and Tuli bulls in the fall of 2002, at the time of palpation for pregnancy, when the 1992 born females were about 10.5 and the 1993 born cows were about 9.5 years old are in Table 3. The Boran-sired cows were assigned slightly higher (P < 0.05) body condition scores (5.5) than were the Brahman- and Tuli-sired females (5.3 and 5.1, respectively). As aged-females, these F_1 cows were heavier than in the previous analysis by Ducoing (2002) when they were 7 and 8 years old. The Brahman-sired cows had larger (P < 0.05) least squares means for mature weight (in 2002) at 9.5 and 10.5 years of age (594.29 kg) than did the cows sired by Boran and Tuli bulls (519.38 and 517.30 kg, respectively).

The least squares means and standard errors for cow body condition score by sire breed of dam and calf's birth year/age of dam are found in Table 4.

Table 3. Least squares means (LSM) and standard errors (SE) for mature F_1 cow palpation weight (kg) and condition score by sire breed of cow

Sire breed of cows	Cow weight [a]	Cow body condition score [b]	
	LSM $\pm$ SE, kg	LSM $\pm$ SE	n
Brahman	$594.29^{c} \pm 10.30$	$5.3^{c} \pm 0.2$	37
Boran	$519.38^{d} \pm 13.32$	$5.5^{d} \pm 0.2$	26
Tuli	$517.30^{d} \pm 11.20$	$5.1^{c} \pm 0.2$	35

[a] Adjusted means in the fall of 2002, when the cows born in 1992 and 1993 were about 10.5 and 9.5 years of age, respectively.
[b] Adjusted means in the fall of 2002.
[c,d] Means in the same column without common superscript differ ($P < 0.05$).

Table 4. Least squares means (LSM) and standard errors (SE) of cow body condition score[a] by sire breed of dam and calf's birth year/age of dam

	LSM $\pm$ SE, kg	n
Sire breed of dam		
Brahman	$5.22^{e} \pm 0.04$	539
Boran	$5.45^{f} \pm 0.05$	360
Tuli	$5.16^{e} \pm 0.04$	501
Calf's birth year/age of dam		
1993/1[b]	5.20 ± 0.08	66
1994/1[b]	5.41 ± 0.08	78
1994/2[c]	5.66 ± 0.08	66
1995/2[c]	5.00 ± 0.08	77
1995/3[d]	4.90 ± 0.08	66
1996/3	5.24 ± 0.08	75
1996/4	5.80 ± 0.08	65
1997/4	4.52 ± 0.08	71
1997/5	5.18 ± 0.09	64
1998/5	5.58 ± 0.08	71
1998/6	5.77 ± 0.09	62
1999/6	5.16 ± 0.08	70
1999/7	5.22 ± 0.09	62
2000/7	5.79 ± 0.08	67
2000/8	6.02 ± 0.09	57
2001/8	4.83 ± 0.09	58
2001/9	4.87 ± 0.10	48
2002/9	4.84 ± 0.09	54
2002/10	5.04 ± 0.10	45
2003/10	5.42 ± 0.09	53
2003/11	5.22 ± 0.10	45
2004/11	5.36 ± 0.10	47
2004/12	5.36 ± 0.12	33

[a] Body condition scores were assigned at the time of palpation in the fall of the previous year.

[b] Values for 1993/1 and 1994/1 were obtained from weights measured as yearling heifers in spring of the respective year (1993 and 1994).

[c] Values for 1994/2 and 1995/2 were obtained from weights measured at palpation time from two year old heifers in fall of the previous year (1993 and 1994, respectively).

[d] Values for 1995/3 to 2003/11 were obtained from weights measured at palpation time in fall of the previous year.

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

As yearling heifers, these same F_1 females demonstrated the same trend for weight, where Brahman-sired females were heavier ($P < 0.05$) than heifers sired by Boran or Tuli bulls (Herring et al., 1996). Further, in an analysis of the same group females as seven and eight year olds by Ducoing (2002), the Brahman-influenced cows had higher unadjusted weight means than did the other two sire groups. Riley et al. (2001a) found both Gray and Red Brahman-sired females to be heavier at seven years of age than those sired by Angus, Gir, Indu-Brazil, or Nellore. A review by Hetzel (1988) noted that the Tuli, in their native region in Africa, were lighter as mature straight bred females than mature straight Brahman females, but were heavier than the mature Boran straight breds, understanding that Tuli and Brahman were evaluated in the same region (Botswana), and the Boran was evaluated in Zambia.

Mouth Scores

As cows age, the deterioration of incisors affects grazing ability and therefore affects the ability to maintain a body condition adequate to reach optimum levels of production. In the fall of 2004, at the time of palpation, incisor condition of the cows was evaluated by assigning mouth scores to assess cow longevity. Two separate models were used to evaluate overall incisor condition.

In the first analysis, incisor condition was scored as a zero for smooth mouths and one for either broken or solid mouths. The least squares means for the Boran and Brahman crossbred females were much higher for both models (Table 5). In the first analysis, the Boran crosses averaged 1.0 (i.e., none of the Boran crosses were scored as smooth), the Brahman crosses averaged 0.96 and were scored significantly higher than the Tuli crosses which averaged 0.756. In the second model, when both smooth and broken mouths were scored as zero and only solid mouths were scored as one, the breed rankings were the same, with least squares means of 0.67 (i.e., 67% were scored as having solid mouths), 0.55, and 0.28, respectively, with the Boran and the Brahman crosses having much higher percentages (P < 0.10) than the Tuli crosses.

The percentage of females remaining in the herd in 2004 (simple means), under the culling procedure that had been practiced, were higher for the Boran crosses (69%) than either the Brahman (51%) or Tuli (50%) crosses (Table 5). Females were removed from the herd for severe injuries, poor health or at least two failures to have or wean a calf. Cows were also culled for poor udders (those udders/teats so large or pendulous that future calves would clearly have trouble nursing).

Table 5. Least squares means (LSM) and standard errors (SE) for mouth scores and percentage of cows remaining in the herd through 2004 for F_1 cows

Sire breed	Mouth score [a] LSM ± SE	Mouth score [b] LSM ± SE	% of original cows remaining in 2004
Boran	1.00 ± 0.060^c	0.67 ± 0.105^c	69
Brahman	0.96 ± 0.058^c	0.55 ± 0.101^c	51
Tuli	0.76 ± 0.059^d	0.28 ± 0.103^d	50

[a] Analyzed as a binary trait, where smooth = 0 and broken or solid = 1.
[b] Analyzed as a binary trait, where smooth or broken = 0 and solid = 1.
[c,d] Means in the same column without common superscript differ (P < 0.10).

Nuñez-Dominguez et al. (1991) stated that longevity is the ultimate value of cow survival, and found that incisor condition and size were more favorable in crossbred cows compared to straight breds in a study involving cows of Angus, Shorthorn, and Hereford breeding. Riley et al. (2001b) performed a similar analysis on 14 year old cows where smooth mouths were scored a zero and both solid and broken mouths were scored a one; the least squares means for the *Bos indicus* crosses were 0.92 to 1.01 compared to the least squares means for the Angus crosses of 0.65. When the smooth and broken mouths were scored as zero and solid as one, the least squares means for the *Bos indicus* crosses ranged from 0.32 to 0.57 and the mean for the Angus crosses was 0.13. An important determinant to survival is nutritional status, which can be at least partially dependent upon incisor condition. In the study by Nuñez-Dominguez et al. (1991), more straight bred cows were culled from the herd for emaciation than were crossbred females. This emaciation could be partly due to incisor condition and the resulting decreased ability to take in forage.

Pregnancy Rate

Pregnancy rate was analyzed using three alternative models. The first included only the sire breed of cow, the dam breed of cow, and the calf's birth year/age of dam as fixed effects. The second analysis included the effects in the first model, plus the lactation status of the cow at weaning time nested within birth year/age of dam. The third analysis consisted of the effects in the first statistical model and included the condition score of cow (at the time of palpation) nested within the birth year of calf/age of dam. The least squares means and standard errors for pregnancy rate for all three analyses are presented in Table 6.

Sire of dam breed and dam of dam breed were not significant sources of variation for pregnancy rate. However, the effect of birth year of calf/age of cow was significant in all three analyses, where it was important at a level of $P < 0.001$ for models one and three and at a level of $P < 0.05$ in the second. In the second model that included lactation status nested within birth year/age of dam, the nested effect was important ($P = 0.0061$). Likewise, condition score of cow nested within year/age was significant ($P = 0.0296$) in the third analysis.

Table 6. Least squares means (LSM) and standard errors (SE) for pregnancy rate obtained after the analyses of the three alternative models [a].

	Model 1 LSM ± SE	n	Model 2 LSM ± SE	n	Model 3 LSM ± SE	n
Sire of dam breed						
Brahman	0.914 ± 0.012	483	0.929 ± 0.018	428	0.913 ± 0.016	482
Boran	0.945 ± 0.015	324	0.952 ± 0.021	288	0.943 ± 0.019	323
Tuli	0.920 ± 0.013	448	0.924 ± 0.019	396	0.932 ± 0.017	445
Lactation status						
Dry	---	---	0.937 ± 0.030	167	---	-
Wet	---	---	0.933 ± 0.009	945	---	-
Calf's birth year/age of dam						
1994/2[b]	0.940 ± 0.031	66	---	---	0.953 ± 0.085	66
1995/2	0.899 ± 0.029	77	---	---	0.898 ± 0.028	77
1995/3	0.591 ± 0.031	66	0.712 ± 0.049	66	0.496 ± 0.068	66
1996/3	0.948 ± 0.029	74	0.948 ± 0.033	74	0.977 ± 0.046	74
1996/4	0.832 ± 0.031	65	0.846 ± 0.031	65	0.835 ± 0.061	65
1997/4	0.780 ± 0.030	72	0.875 ± 0.042	72	0.808 ± 0.038	70
1997/5	0.938 ± 0.032	64	0.957 ± 0.034	64	0.959 ± 0.056	64
1998/5	0.988 ± 0.030	70	0.975 ± 0.034	70	0.989 ± 0.034	70
1998/6	0.952 ± 0.032	62	0.912 ± 0.050	62	0.973 ± 0.052	62
1999/6	0.988 ± 0.030	70	0.921 ± 0.053	70	0.980 ± 0.065	70
1999/7	0.984 ± 0.032	61	0.993 ± 0.053	61	0.987 ± 0.064	61
2000/7	0.958 ± 0.031	67	0.929 ± 0.044	67	0.888 ± 0.068	67
2000/8	0.949 ± 0.033	58	0.969 ± 0.047	58	0.957 ± 0.057	57
2001/8	0.967 ± 0.033	57	0.981 ± 0.089	57	0.968 ± 0.063	57
2001/9	0.977 ± 0.037	47	0.990 ± 0.125	47	0.988 ± 0.045	47
2002/9	0.965 ± 0.035	55	0.982 ± 0.064	55	0.995 ± 0.064	54
2002/10	0.978 ± 0.038	45	0.990 ± 0.125	45	0.933 ± 0.072	45
2003/10	1.001 ± 0.035	53	1.002 ± 0.058	53	0.999 ± 0.057	53
2003/11	0.955 ± 0.038	45	0.970 ± 0.089	45	0.977 ± 0.055	45
2004/11	0.958 ± 0.037	47	0.821 ± 0.074	47	0.968 ± 0.054	47
2004/12	0.968 ± 0.043	34	0.989 ± 0.090	34	0.987 ± 0.088	33

[a] Model 1: sire breed of dam, dam breed of dam, birth year/age of dam; model 2: model 1 plus dam's lactation status nested within birth year/age of dam; model 3: model 1 plus cow's condition score nested within birth year/age of dam.
[b] Values for 1994/2 refer to pregnancy percentage for calving as two-year olds in 1994, based on palpation in the fall of 1993.

The differences among the least squares means for the effect of sire of dam breed on pregnancy rate were not significant in any of these models. In the first model, the Boran-sired females ranked the highest for pregnancy rate (0.945) followed by Tuli- (0.920) and Brahman-sired (0.914) cows. In the second model containing the effect of lactation status within year/age, the Boran-sired cows still ranked highest for pregnancy rate (0.952), than the Brahman (0.929) and the Tuli sired (0.924) females. Finally, in the third and final model, the females sired by Boran bulls still continued to rank first for pregnancy rate (0.943), but the Tuli- (0.932) and the Brahman-sired (0.913) cows reversed rank from the second to the third model.

There were no differences ($P = 0.8831$, 0.7063, and 0.9487, respectfully) in least squares means between the dam of dam breed on pregnancy rate for models 1-3. Neither was there a difference ($P = 0.8835$) between the lactation status of the females in the second model, when considered across all years. Birth year of calf/age of dam, however, was important ($P < 0.05$) in all models. There were obvious differences among the means for year/age, although statistical differences were not determined among individual means. The 1992-born cows showed a distinct drop in pregnancy rate as three year olds or after their second breeding season (model 1 = 0.6591, model 2 = 0.712, and model 3 = 0.496). These same females demonstrated lower least squares means for the following year (1996) when compared to other years as well (0.832, 0.846, and 0.835, for the three models respectively). The 1993-born cows did not show a drop in pregnancy rate until they were 4 and in their third season (0.780, 0.875, and 0.808, respectfully across models 1-3). Beginning in 1998, the least squares means for the two age groups of cows grew closer together. These patterns are similar to those found by Ducoing (2002) in a previous analysis when the females were seven and eight years old. Ducoing (2002) attributed the differences between the 1992 born and the 1993 born females to differences in environment or nutrition and/or management of the two groups as heifers. As the females began to get older, beginning in 2004, pregnancy rates of the 1993 born females began to drop (0.821) in the analysis including lactation status nested in year/age.

The reproductive soundness of a cow herd is the base measure of productivity in a beef herd, and pregnancy rate is a measure of this. Riley et al. (2001a) found an interaction between the sire breed of dam and the age of dam. The Brahman-crosses ranked intermediate to the other crossbreds in the study (Nellore, Gir, Indu-Brazil, and Angus); the pregnancy rate for the Brahman-sired females was larger ($P < 0.05$) than that of the Angus-cross cows. Additionally, within the same study, as cows became older, pregnancy rate became more irregular.

Calf Crop Born

Calf crop born was analyzed similar to pregnancy rate; however, only the first and third models were used in the final analyses that included sire of dam breed, dam of dam breed, and birth year/age of dam as model 1, and the same effects included in model 1 plus cow condition score within year/age as model 2. Least squares means and standard errors for calf crop born are listed in Table 7.

In the first analysis, the effect of sire breed of dam was important ($P = 0.0609$). The Boran-sired females had the highest adjusted mean (0.943), followed by the Tuli-sired cows (0.910) and the Brahman-sired cows (0.890). The Boran-sired cows were different ($P < 0.05$) from those sired by Brahman. The effect of birth year of calf/age of dam was significant in affecting calf crop born. In the alternate model, sire of dam breed was not important ($P = 0.3887$); however, the same trend was seen as in model I. The Boran-sired cows still had the highest adjusted mean (0.896), followed by the Tuli-sired group (0.875), and the Brahman-sired females ranked third (0.867). None were statistically different from one another. Birth year of calf/age of cow and the nested effect of cow condition score within year/age were both important ($P < 0.001$) in influencing calf crop born.

Like in the analysis for pregnancy rate, the least squares means for calf crop born for 1992 born cows was notably lower in 1995 (0.609, model 1 and 0.478, model 2) when the females were three year olds, but statistical differences were not determined. This same group of females had lower least squares means again in 1996 (0.733 and 0.873). By comparison, the 1993 born cows' least squares means (0.740 and 0.737) for

Table 7. Least squares means (LSM) and standard errors (SE) for calf crop born obtained from the analyses of two alternative models[a].

	Model 1 LSM ± SE	n	Model 2 LSM ± SE	n
Sire of dam breed				
Brahman	0.890[b] ± 0.013	474	0.867 ± 0.018	474
Boran	0.943[c] ± 0.016	322	0.896 ± 0.020	321
Tuli	0.910[bc] ± 0.014	439	0.875 ± 0.019	437
Calf's birth year/age of dam				
1994/2	0.948 ± 0.036	66	0.952 ± 0.096	66
1995/2	0.874 ± 0.032	77	0.873 ± 0.032	77
1995/3	0.609 ± 0.036	66	0.478 ± 0.077	66
1996/3	0.910 ± 0.033	75	0.960 ± 0.050	95
1996/4	0.733 ± 0.037	65	0.773 ± 0.068	65
1997/4	0.740 ± 0.034	72	0.737 ± 0.043	90
1997/5	0.944 ± 0.037	64	0.948 ± 0.063	64
1998/5	0.976 ± 0.034	7	0.974 ± 0.038	90
1998/6	0.949 ± 0.037	62	0.974 ± 0.058	62
1999/6	0.948 ± 0.034	70	0.940 ± 0.072	90
1999/7	0.944 ± 0.038	61	0.961 ± 0.072	61
2000/7	0.911 ± 0.036	62	0.670 ± 0.080	62
2000/8	0.960 ± 0.041	53	0.952 ± 0.064	53
2001/8	0.969 ± 0.038	57	0.970 ± 0.071	57
2001/9	0.973 ± 0.044	46	0.990 ± 0.050	46
2002/9	0.966 ± 0.039	54	0.969 ± 0.072	54
2002/10	0.970 ± 0.044	45	0.735 ± 0.081	45
2003/10	1.004 ± 0.040	50	1.001 ± 0.064	50
2003/11	1.003 ± 0.046	40	1.002 ± 0.062	40
2004/11	0.960 ± 0.042	46	0.967 ± 0.060	46
2004/12	0.914 ± 0.050	34	0.636 ± 0.098	33

[a] Model 1: sire breed of dam, dam breed of dam, birth year/age of dam; model 2: model 1 plus cow's condition score nested within birth year/age of dam.

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

calf crop born were lower as four year olds in 1997, and as seven year olds in 2000 (0.911 and 0.670). This same pattern was observed in the previous analysis when the females were 7 and 8 years of age (Ducoing, 2002). The 1992 born cows also had lower least squares means for calf crop born for the model that included condition score within year/age as 10 year olds (0.735) and as 12 year olds (0.636). Riley et al. (2001a) found higher least squares means for *Bos indicus*-cross females for percent calf crop born than in the current study. In the study by Riley et al. (2001a), females were exposed to calve at 2.5 years of age versus 2.0 years of age in the current study.

In their native region of Africa, the Tuli and the Boran had lower least squares means than those seen here according to Hetzel (1988) in a review comparing the breeds as straight breds. The adjusted means reported by Hetzel (1988) were lower than those seen here, at least partly because the cattle evaluated within the African study were purebreds and the present involved crossbred females. The Brahman was also reviewed by Hetzel (1988), and was found to have lower adjusted means for calf crop born as straight breds than calculated in the present study. Hetzel compared two environments—high and low performance, where the separation was based on animal performance. In a high-performance environment, Tuli far exceeded the Boran and the Brahman for percent calf crop born. In an alternate, low-performance environment, the Boran females had a higher estimate for calving rate than did the Tuli and the Brahman. In a study involving straight bred Tuli, Africander, and Tswana (Trail et al., 1977), the Tuli's calving percentage (85.0) far exceeded that of the other two breeds (Africander—64.5 and Tswana—70.6).

The overall calving rate in the current study was nearly equal to that found by Bailey and Moore (1980); the least squares mean for the Brahman-sired females out of Angus and Hereford dams (0.87) was similar to that for the Brahman-cross cows in the present research (0.89). Peacock and Koger (1980) found no difference ($P > 0.01$) among the dam types— purebred Brahman, Charolais, and Angus (85%, 77%, and 82%, respectfully). In that same study, Angus x Brahman and Brahman x Angus dams had the largest mean for calf crop born (92%) compared to other crossbreds in the study (Angus x Charolais and Charolais x Brahman and their reciprocal crosses (82% and 90%, respectfully)) when bred to Angus, Brahman, and Charolais sires.

Similar to current findings for the 1992 born F_1 females, a drop in the calving rate (0.948 to 0.609) of females in their second season (0.722 to 0.549) was also witnessed by Comerford et al. (1987). Comerford et al. (1987) attributed this drop in the percentage of calves born to the lowered pregnancy rates in lactating 2-year old females, where they blamed the lower calf crop born to the physiological and nutritional stresses seen in young females.

Birth Weight

Birth weight is an indicator of calving ease and calf survival. Calf gender was strongly significant in affecting birth weight, where the male calves were 2.43 kg heavier than their female contemporaries. Neither sire breed of dam ($P = 0.9194$), nor dam breed of dam ($P = 0.8028$) was an important source of variation for birth weight. The adjusted means for the effect of sire of dam breed on birth weight were very similar among the three F_1 cow types: Brahman- (35.66 kg), Boran- (35.38 kg), and Tuli-sired

(35.59 kg). There was more variation of means among the birth weights of the F_1 calves sired by Brahman, Boran, and Tuli (Herring et al., 1996). The Brahman-sired calves were the heaviest (44.01 kg), followed by those sired by Boran (40.25 kg), and Tuli (36.36 kg), and all were different ($P < 0.05$) from one another.

Birth year of calf/age of dam was an important effect ($P < 0.001$) on birth weight. Although the statistical difference among means was not tested, adjusted means for birth weight were the lowest when the cows were first calf heifers at two years of age in 1994 and 1995. The least squares means and standard errors for birth weight by sire breed of dam, year/age, and sex of calf are presented in Table 8.

There was a significant interaction between sex of calf and dam of dam breed ($P = 0.0040$). The female calves out of Angus-cross dams were 3.18 kg lighter ($P < 0.001$) than the males calves out of Angus-cross dams. The heifers out of Hereford-cross females were 1.68 kg lighter than their male contemporaries out of Hereford-cross dams. There was no difference ($P > 0.05$) within sex for the two dam of dam types.

In the analysis by Ducoing (2002), when these F_1 females were 7 and 8 years old, the sire of dam breed was not important ($P = 0.413$) with adjusted means for birth weight ranging from 34.78 to 35.53 kg across sire of dam breeds. The range of calf's weight at birth within the current study has tightened 35.38 to 35.69 kg. The calves from Brahman-sired cows ranked the heaviest in both analyses (2002 and 2005), just as calves from Boran-sired cows ranked the lightest. When compared to Cundiff et al. (2000), who also evaluated F_1 females sired by Brahman, Boran, and Tuli bulls for reproductive and maternal traits, the least squares means for birth weight were heavier than those found here, but compared similarly. Riley et al. (2001a) found within a study of F_1 females by Angus, Gray Brahman, Gir, Indu-Brazil, Nellore, and Red Brahman sires, that birth weights of calves out of Gray and Red Brahman females were intermediate to all others, with the Angus-sired cows delivering the heaviest calves and the Gir-sired cows having the lightest calves at birth.

Long and Gregory (1974) found birth year of calf/age of dam to have a significant effect on pre-weaning traits, one of which was birth weight. They attributed differences among year/age adjusted means to weather, forage availability, management, and any other occurrences that may have an effect on the conditions within a year. McCarter et al. (2001) found that as age of dam increased, birth weights increased significantly in females out of Angus and Hereford dams having various levels of Brahman breeding. Roberson et al. (1986) found similar results in Brahman, Hereford, and Brahman-Hereford crosses, and they reported that birth weight increased to a cow age of seven years and began to decline as the cows got older.

Table 8. Least squares means (LSM) and standard errors (SE) of birth weight by sex of calf, sire breed of dam, dam of dam breed by sex of calf interaction, and calf's birth year/age of dam.

	LSM ± SE, kg	n
Sex of calf		
Female	34.33[a] ± 0.31	554
Male	36.76[b] ± 0.31	553
Sire breed of dam		
Brahman	35.66 ± 0.41	417
Boran	35.38 ± 0.55	295
Tuli	35.59 ± 0.47	395
Dam breed of dam x sex of calf		
Female x Angus	33.91[a] ± 0.40	255
Male x Angus	37.09[b] ± 0.41	299
Female x Hereford	34.75[a] ± 0.37	224
Male x Hereford	36.43[b] ± 0.36	329
Calf's birth year/age of dam		
1994/2	31.08 ± 0.61	62
1995/2	30.09 ± 0.57	66
1995/3	34.23 ± 0.74	38
1996/3	34.33 ± 0.57	67
1996/4	35.39 ± 0.68	47
1997/4	34.22 ± 0.64	51
1997/5	35.07 ± 0.62	58
1998/5	37.20 ± 0.57	68
1998/6	36.53 ± 0.62	59
1999/6	36.79 ± 0.58	66
1999/7	36.20 ± 0.63	57
2000/7	36.42 ± 0.62	56
2000/8	36.55 ± 0.66	50
2001/8	38.46 ± 0.62	56
2001/9	38.26 ± 0.69	45
2002/9	35.23 ± 0.71	52
2002/10	34.48 ± 0.64	43
2003/10	37.71 ± 0.64	51
2003/11	35.72 ± 0.75	40
2004/11	36.77 ± 0.69	44
2004/12	35.66 ± 0.81	31

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

Calf Crop Weaned

The analysis of calf crop weaned utilized the same two models that were used to analyze percent calf crop born. In the first model, only sire of dam breed, dam of dam breed and calf birth year/age of dam were included as sources of variation. Sire of dam breed was not significant ($P = 0.1299$), although the Boran-sired cows (0.887) weaned more calves ($P < 0.05$) than the Brahman-sired cows (0.834). Year/age was the only significant effect ($P < 0.001$).

In model II, in the analysis of variance, sire of dam breed was not significant ($P = 0.1314$), but the least squares mean for the Brahman-sired cows was lower ($P < 0.05$) than for the Boran- and Tuli-sired cows. The trend remained the same, where Boran (0.864) and Tuli-sired cows (0.828) ranked above those cows sired by Brahman (0.811). Year/age was significant ($P < 0.001$), as was the effect of cow condition score nested within year/age ($P = 0.001$). The least squares means of calf crop weaned by the two alternative models are presented in Table 9.

As with pregnancy rate and calf crop born, statistical comparisons within year/age were not analyzed. However, the adjusted means in 1995, when the 1992 born cows were three and producing their second calf, were lower for both models I and II (0.564 and 0.475, respectively) than those for other year/age combinations. These low least squares means were a reflection of the pregnancy rates and calving rates within the particular year. A similar trend was seen in the previous analysis (Ducoing, 2002). All adjusted means in the current study are higher than those found in 2002 by Ducoing.

Table 9. Least squares means (LSM) and standard errors (SE) for calf crop weaned obtained from the analyses of the two alternative models[a].

	Model 1		Model 2	
	LSM ± SE	n	LSM ± SE	n
Sire of dam breed				
Brahman	0.834[b] ± 0.016	468	0.811[b] ± 0.022	468
Boran	0.887[c] ± 0.020	321	0.864[c] ± 0.025	320
Tuli	0.857[bc] ± 0.017	436	0.828[c] ± 0.023	434
Calf's birth year/age of dam				
1994/2	0.913 ± 0.043	66	0.942 ± 0.118	66
1995/2	0.731 ± 0.040	77	0.732 ± 0.039	77
1995/3	0.564 ± 0.043	66	0.475 ± 0.095	66
1996/3	0.855 ± 0.041	74	0.928 ± 0.062	74
1996/4	0.712 ± 0.043	65	0.766 ± 0.084	65
1997/4	0.712 ± 0.041	72	0.719 ± 0.053	70
1997/5	0.879 ± 0.044	64	0.916 ± 0.078	64
1998/5	0.946 ± 0.042	69	0.953 ± 0.047	69
1998/6	0.907 ± 0.044	62	0.933 ± 0.071	62
1999/6	0.848 ± 0.042	70	0.867 ± 0.089	70
1999/7	0.824 ± 0.045	61	0.874 ± 0.089	61
2000/7	0.889 ± 0.045	61	0.663 ± 0.099	61
2000/8	0.925 ± 0.049	52	0.944 ± 0.080	52
2001/8	0.897 ± 0.047	56	0.951 ± 0.075	56
2001/9	0.934 ± 0.052	45	0.946 ± 0.063	45
2002/9	0.912 ± 0.048	54	0.789 ± 0.090	54
2002/10	0.960 ± 0.052	45	0.735 ± 0.100	45
2003/10	0.924 ± 0.049	50	0.903 ± 0.079	50
2003/11	0.900 ± 0.056	39	0.912 ± 0.077	39
2004/11	0.934 ± 0.053	44	0.950 ± 0.075	44
2004/12	0.878 ± 0.061	33	0.622 ± 0.122	32

[a] Model 1: sire breed of dam, dam breed of dam, birth year/age of dam; model 2: model 1 plus cow's condition score nested within birth year/age of dam.
[b, c] Least squares means in the same column without common superscripts differ ($P < 0.05$).

Hetzel (1988) reported that, in a low-performance environment, the ranking of the three breeds as straight breds, Boran, Tuli, and Brahman (0.67, 0.64, and 0.58, respectively), was the same as that resulting from the present analysis. In the high-performance environment the Tuli females had the highest weaning rate (0.82) followed by Boran (0.69) and Brahman (0.63). Hetzel was reviewing the performance of straight bred dams, versus the current study of F_1 dams sired by Brahman, Boran, and Tuli.

Gregory et al. (1978) found breed of sire (Red Poll, Brown Swiss, Hereford, and Angus) effects to be non-significant, but they found breed of dam (Red Poll, Brown Swiss, Hereford, and Angus) to be significant for percent calf crop weaned. Furthermore, their results found year and age of dam (4 to 7, 8, or 9 years of age, depending upon breed) to be significant sources of variation. They also found a significant interaction between breed of sire with breed of dam effects for weaning rate; in the current analysis no interactions were found to be significant and as a result were left out of the final model. In another study, Gregory et al. (1979), found age of cow to be important in Angus and Hereford females. Cows that were five years old and older weaned more calves ($P < 0.01$) than the four year olds. In that study, calf crop weaned was defined as the fraction of calves born that survived to weaning. Riley et al. (2001a) also found an interaction of sire breed of cow x age of cow to be of importance ($P < 0.10$), where the percent calf crop weaned was the lowest for heifers and young cows sired by Gray or Red Brahman bulls; as these females got older, their percentage of calves weaned was not lower than other breeds in the comparison. McCarter et al. (1991) found a greater percentage of calves weaned from Brahman-cross females when compared to Angus x Hereford dams. Peacock and Koger (1980) found both age of cow and year to be significant effects on calf crop weaned.

Weaning Weight

Sex of calf was important ($P < 0.001$) for weaning weight, where the male calves were 13.1 kg heavier than were their heifer mates (Table 10). Different from birth weight, the effect of sire of dam breed was significant for weaning weight ($P < 0.001$). The calves out of Brahman-sired cows were 13.3 kg heavier ($P < 0.001$) than those out of cows sired by Boran and 25.2 kg heavier ($P < 0.001$) than calves out of cows sired by Tuli (Table 10). The Boran-sired cows had calves with a higher ($P < 0.05$) adjusted mean (220.1 kg) than Tuli-sired cows (208.2 kg). Birth year of calf/age of dam was not significant ($P = 0.1130$). The differences in least squares means of year/age were not tested, but are presented in Table 11.

The regression of weaning weight on weaning age of calf within year/age ranged from 0.217 to 1.080 kg/d. The regression coefficients and standard errors of weaning weight within year/age on weaning age are listed in Table 12.

Table 10. Least squares means (LSM) and standard errors (SE) of weaning weight by sex of calf, sire breed of dam and sire breed of dam by sex of calf interaction.

	Weaning weight, kg	n
Sex of calf		
Female	$214.0^{a} \pm 1.7$	512
Male	$227.1^{b} \pm 1.7$	512
Sire breed of dam		
Brahman	$233.4^{a} \pm 2.2$	380
Boran	$220.1^{b} \pm 2.9$	279
Tuli	$208.2^{c} \pm 2.5$	365
Sire breed of dam x sex of calf[d]		
Female x Brahman	$225.1^{a} \pm 2.4$	194
Male x Brahman	$241.7^{b} \pm 2.4$	186
Female x Boran	$213.8^{a} \pm 3.1$	132
Male x Boran	$226.4^{b} \pm 3.1$	147
Female x Tuli	$203.2^{a} \pm 2.7$	186
Male x Tuli	$213.2^{b} \pm 2.7$	179

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

Table 11. Least squares means (LSM) and standard errors (SE) of weaning weight by calf's birth year/age of dam.

	Weaning weight, kg	n
Calf's birth year/age of dam		
1994/2	188.8 ± 3.0	60
1995/2	208.0 ± 3.0	56
1995/3	218.1 ± 9.0	26
1996/3	192.1 ± 3.0	63
1996/4	206.7 ± 3.1	47
1997/4	222.0 ± 4.3	50
1997/5	232.0 ± 3.1	56
1998/5	238.5 ± 3.7	65
1998/6	231.2 ± 4.1	55
1999/6	237.5 ± 2.9	59
1999/7	234.2 ± 3.8	50
2000/7	206.8 ± 4.2	54
2000/8	207.2 ± 5.3	48
2001/8	228.0 ± 3.4	50
2001/9	217.9 ± 4.4	42
2002/9	224.1 ± 3.3	49
2002/10	231.0 ± 2.9	43
2003/10	225.0 ± 3.8	46
2003/11	220.1 ± 3.9	35
2004/11	231.9 ± 4.0	41
2004/12	230.6 ± 6.8	29

Table 12. Regression coefficients (b) and standard errors (SE) of weaning weight on weaning age within calf's birth year/age of dam.

	b ± SE, kg/d (year/age)	n
Calf's birth year/age of dam		
1994/2	0.793 ± 0.157	60
1995/2	0.620 ± 0.132	56
1995/3	0.706 ± 0.181	26
1996/3	0.782 ± 0.109	63
1996/4	0.658 ± 0.134	47
1997/4	0.552 ± 0.157	50
1997/5	1.025 ± 0.166	56
1998/5	0.741 ± 0.115	65
1998/6	0.495 ± 0.156	55
1999/6	1.010 ± 0.151	59
1999/7	0.854 ± 0.198	50
2000/7	0.805 ± 0.149	54
2000/8	0.634 ± 0.190	48
2001/8	1.020 ± 0.150	50
2001/9	1.080 ± 0.224	42
2002/9	0.559 ± 0.175	49
2002/10	0.677 ± 0.174	43
2003/10	0.838 ± 0.162	46
2003/11	0.510 ± 0.132	35
2004/11	0.853 ± 0.165	41
2004/12	0.217 ± 0.333	29

There was also a significant interaction between sex of calf and sire breed of dam (P = 0.0505). There was a 16.6 kg difference (P < 0.001) between male and female calves out of Brahman-sired dams. The male calves from Boran-sired cows were 12.6 kg heavier (P < 0.001) than their heifer mates. Tuli-sired cows weaned males that were 10 kg heavier (P < 0.001) than females. Least squares means and standard errors of weaning weight by sex of calf, sire of dam breed, and the interaction of sire breed of dam x sex of calf are represented in Table 10.

The same ranking of sire of dam breeds for weaning weight reported by Ducoing (2002) was seen here. However, adjusted means for weaning weight are heavier in the current analysis (Brahman 233.4 kg, Boran 220.1 kg, and Tuli 208.2 kg), when the dams were 11 and 12 years old, compared to the analysis in 2002 (Brahman = 229.6 kg, Boran = 214.6 kg, and Tuli = 200.4 kg), when cows were 7 and 8 years old. The effects of sex, sire of dam breed, and year/age were also significant in the analysis performed when the F_1 cows were 7 and 8 years old. In the current analysis, calves from Tuli-cross females were 18.6 kg lighter than the average of the other two group means. As calves the F_1 Brahman-, Boran-, and Tuli-crosses displayed the same trend where the Brahman-cross calves were significantly heavier (234.3 kg) than the Boran- (217.1 kg) and the Tuli-sired (209.1 kg) calves (Herring et al., 1996). The Tuli-sired F_1 calves were 16.6 kg lighter than the average of the other two group means.

As in the current study, Riley et al. (2001a) found a significant interaction of sire breed of cow x sex of calf (P = 0.242) on weaning weight. Riley et al. (2001a) also reported the male calves out of F_1 *Bos indicus* cows were much heavier than their heifer mates (16 to 20 kg). The steer calves by Angus x Hereford cows were 8.2 kg heavier than the heifers from the same matings. The overall range of weaning weight by sire of dam breed was lower in the present study than that found by Riley et al. (2001a). In another study where calves were out of dams sired by tropically adapted breeds, Cundiff et al. (2000) found calves out of Brahman-sired females to have the largest weaning weights (236.8 kg) when compared to calves out of females sired by Belgian Blue (228.2 kg), Boran (221.8 kg), Angus (224.1 kg), Piedmontese (216.4 kg), Hereford (215.5 kg), and Tuli (214.1 kg) bulls.

SUMMARY

Reproductive and maternal performance was evaluated in F_1 cows sired by Brahman, Boran, and Tuli bulls for the traits of cow's weight and body condition score at palpation, pregnancy rate, calf crop born, and calf crop weaned, and birth weight and weaning weight of their calves. The results were compared to those from previous analyses. In addition to reproductive and maternal traits, cow longevity was investigated, along with the evaluation of incisor condition.

The differences among sire breeds were significant for cow weight at palpation. In 2002 at the time of palpation, when the females were about 9.5 and 10.5 years old, the Brahman-sired cows were heaviest (594.3 kg) compared to Boran- (519.4 kg) and Tuli-sired cows (517.3 kg). Birth year of calf/age of dam also had a significant effect on cow weight; and, the interactions of sire of dam breed x year/age and dam of dam breed x year/age were both important ($P < 0.05$ and $P = 0.070$, respectfully). The Boran-sired females were assigned higher ($P < 0.05$) body condition scores than were the Brahman- or Tuli-sired cows. The differences due to year/age were due, at least partly, to the variation in the availability of nutritional resources, and the differences in how the different cow types respond to these environmental conditions.

The assessment of incisor condition found a greater percentage ($P < 0.10$) of Boran- and Brahman-sire cows to have solid mouths as 11 and 12 year olds when compared to Tuli-sired cows. This could be one reason why there are 69% of the original Boran-sired females remaining in the study as compared to 51% of the Brahman-sired females and only 50% of the original Tuli-sired cows.

For pregnancy rate, sire of dam breed and dam of dam breed were not significant sources of variation, but birth year of calf/age of dam was. The differences seen between year/age combinations could be due to rainfall differences, available forage, and differences in management of the two groups as heifers. The Boran-sired females had the highest pregnancy rate (0.945) followed by the Tuli- (0.920) and Brahman-sired (0.914) females in the model including only sire of dam breed, dam of dam breed, and year/age. This ranking remained the same in the two alternative analyses for pregnancy rate.

Unlike pregnancy rate, sire of dam breed had a significant effect on calf crop born. The Boran-sired cows had the highest adjusted mean (0.941), followed by Tuli- (0.910) and Brahman-sired (0.893) females. There was also a significant effect of year/age on percent calf crop born. In the alternative model, including cow body condition score nested within year/age, breed of sire of cow was not significant, but the ranking of sire of dam breed remained the same.

There was not a significant effect of sire of dam breed or dam of dam breed on birth weight of calf. The birth weights were very similar across all dam types (Brahman = 36.7 kg, Boran = 35.4 kg, and Tuli = 35.6 kg). However, calf gender was strongly significant, where male calves were on average, 2.4 kg heavier than their female counter parts at birth. Year/age was also significant. The birth weights of calves out of these F_1 cows were lightest in 1994 and 1995 when the females were first calf heifers and the calves were sired by Angus bulls. Any further variation between year/age for birth weight of calf could be due to weather conditions, forage availability, and management between years. There was also a significant interaction between dam of dam breed and sex of calf.

The Boran-sired cows had the highest adjusted mean for calf crop weaned (0.887) followed by Tuli-sired (0.857) cows. Both were higher ($P < 0.10$) than the Brahman-sired (0.834) cows.

The effect of sex of calf was also important ($P < 0.05$) on weaning weight. Males were 13.1 kg heavier than the females. There was also a significant effect of sire of dam breed on weaning weight, where calves out of Brahman-sired cows were 13.3 kg heavier than were those out of Boran-sired cows and 25.2 kg heavier than calves out of Tuli-sired females. The calves out of Boran-sired cows were also significantly heavier than those out of Tuli-sired dams. There was also an interaction involving calf sex and sire of dam breed where the males out weighed females by 16.6 kg, 12.6 kg, and 10.0 kg from Brahman-, Boran-, and Tuli-sired cows, respectfully.

The Boran-sired cows had higher reproductive rates than those sired by Brahman and Tuli bulls. However, the Brahman-sired females consistently weaned heavier calves when compared to the other two dam types. This advantage in weaning weight of calf could offer some compensation for their lower reproductive capabilities; however, the Brahman-sired cows were about 75 kg heavier at maturity than cows sired by Boran and Tuli. If there is a need for a more moderate sized cow that does not give up reproductive performance or heat adaptation, Boran- or Tuli-sired cows could be a useful alternative or complement to Brahman. The Tuli-cross cows weaned significantly lighter calves than both the Brahman- and Boran-sired cows. Also, the Tuli-sired cows had more deterioration of incisors than both the Brahman- and Boran-sired cows and shorter productive lives than the Boran-crosses.

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