COMPOSITIONAL CHANGES IN MATURE COWS USING REAL-TIME ULTRASONIC MEASUREMENTS

by

CAROLE LYNN HICKS

(Under the direction of T. Dean Pringle)

ABSTRACT

Eighty – four Angus and forty – four Hereford cows were used in this study to evaluate changes in body composition using real – time carcass ultrasound measures. Cows were scanned and weighed at four times during the course of a year: pre-breeding (March), between breeding and weaning (July), weaning (September), and pre-calving (December). Comparisons were made across age, YW EPD, and MILK EPD classes. Ribeye area (REA), back fat (BF), and rump fat (RF) and weight decreased from pre-breeding to weaning then increased to pre-calving. Changes in REA/kg and marbling were variable and few measures were significantly different ($P < 0.05$). Among the comparisons, old cows, high YW, and low MILK cows were generally heavier, had larger REA, and more fat cover (both BF and RF) than young, low YW, and high MILK cows. The analysis of the compositional changes in Hereford cows was inconclusive. The compositional changes measured by ultrasound were consistent with the expected changes in beef cows during a normal production cycle, suggesting that ultrasound is a viable, objective measure of mature cow composition.

INDEX WORDS: Body Composition, Mature Cows, Ultrasound

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INTRODUCTION

The goal of producers in the beef industry is to produce a uniform, consistent product for a consumer – driven industry. To do this, cattlemen must use all information available to continuously improve their herds. To produce calves that meet the demands of the industry, cattlemen must maintain a group of efficient, productive cows. One important factor that affects many aspects of a cow's efficiency is her ability to maintain adequate body condition throughout a calving interval. Body condition not only encompasses fat cover, but muscle expression, as well. Many cattlemen utilize body condition scores as a method to evaluate the composition of their cattle and relate composition to productivity. However, body condition score is a subjective trait that can vary based on the expertise and experience of the evaluator. Therefore, to objectively evaluate the changes in body composition of cows during a production cycle, this study investigated changes in beef cow body composition using real-time ultrasound measures of fat and muscling.

The objectives of this study were the following:

- To evaluate changes in cow body composition through different production stages using real – time ultrasound carcass measurements; and
- To compare changes in composition between cows of different ages, levels of growth, and levels of production.

LITERATURE REVIEW

Ultrasound has been utilized in the beef industry for over 40 years. The various applications of ultrasound in cattle have opened a wide range of opportunities for producers to utilize this tool for herd improvement. Ultrasound can be used to determine pregnancy in cattle earlier than traditional palpation. More recently demand has been placed on its use to sex the fetus before parturition. Producers, thereby, use ultrasound to more effectively market cows carrying a particular sex of calf. Ultrasound technology is also used to evaluate carcass characteristics in breeding cattle. Carcass measurements taken in live animals using ultrasound are used to compute expected progeny differences for carcass traits allowing seedstock and commercial producers to make informed sire selections. The results are an improvement in the genetic potential of their herd and production of a more marketable calf crop. Research is currently investigating the use of ultrasound to predict endpoints for slaughter cattle in the feedlot and to more accurately segregate cattle into uniform groups for harvest. In the last 10 years, ultrasound has emerged as the technology of choice for determining compositional changes in cattle (Whittaker et al., 1992). Determining mature cow composition allows producers to more accurately determine nutritional needs and evaluate cow efficiency.

Ultrasound is a non-destructive, humane method of quantifying muscle and fat tissues in live animals. Ultrasound has proven to be easier to use and more cost efficient compared to other objective means of measuring composition. The basic principle of ultrasound is to measure an echo of high frequency sound waves (generally 2 to 10 MHz), which are reflected from tissues with differing acoustic impedance. Diagnostic ultrasound is produced by a transducer housing crystals with piezoelectric (pressure-electric) properties. When the sound waves are reflected, they return to the transducer and a slight deformation of the crystals is produced. This generates an electric current which is displayed on an oscilloscope as an image of the tissue interfaces (Houghton and Turlington, 1992). Tissue interfaces are visible because reflection occurs at tissues with differing acoustic impedance or density. Sound waves travel through fat at approximately 1,450 m/s, whereas they travel through lean muscle and bone at 1,580 m/s and 3,100 m/s respectively (Whittaker et al., 1992).

There are three basic display formats or modes in ultrasound: a) amplitude mode (A-mode), b) time motion mode (M- or TM-mode), and c) brightness mode (B-mode). Amplitude mode is a one-dimensional display of returning echo amplitude and distance. It consists of vertical peaks along a horizontal axis where the height of a peak corresponds to the amplitude of the echo (Houghton and Turlington, 1992). Time motion mode is a one-dimensional format that displays dots. TM-mode is used to ultrasound moving organs. The display is printed on an oscilloscope or moving strip of white sensitive paper. Brightness mode is a two-dimensional display of dots that depicts a cross-sectional anatomy (Houghton and Turlington, 1992). The position of the dot on the screen is determined by the time it takes for an echo to return to the transducer and likewise, the brightness of the dot is proportional to the amplitude of the returning echoes (Houghton and Turlington, 1992). Real-time imaging is a version of B-mode ultrasound. In real-time ultrasound, echoes are recorded continuously on a non-storage cathode-ray display screen. Ultrasound units that produce real-time images are the most commonly accepted ultrasonic instrumentation for use with livestock (Cross and Belk, 1994).

Ultrasound measurements currently used in the beef industry

Subcutaneous fat

Subcutaneous fat is a measure of the depth of fat over the *longissimus dorsi* muscle between the 12th and 13th ribs. It consists of a measurement collected at a point ¾ of the lateral length of the *longissimus* muscle from the split chine bone. The *longissimus dorsi* is surrounded on the medial side by the backbone and the *multifidus dorsi* muscle. The subcutaneous fat layer is on the top of the *longissimus* muscle with a layer of connective tissue separating the two fat layers. This connective tissue layer may not be seen on cattle with less than 0.508 cm of fat, but becomes clearer as animals become fatter (Wilson, 1994). This is also the site where beef carcasses are evaluated by graders to determine USDA yield and quality grades.

Research has concluded that ultrasound fat measurements are generally accurate. Correlations between ultrasonic estimates of subcutaneous fat thickness and actual fat thickness have been reported as high as 0.90 (Brethour, 1992). Griffin et al. (1999) also reported that actual and ultrasound fat thickness were highly correlated ($r = 0.81$). Hamlin et al. (1995b) explained that the moderate to high correlations between ultrasonic fat thickness and carcass fat thickness indicated that ultrasound derived back fat measures could possibly predict final fat thickness with a respectable degree of accuracy. According to results reported by Faulkner et al. (1990), 72% of cattle included in their study had ultrasound to carcass fat differences of .2 cm or less. Perkins et al. (1992a,b) reported that ultrasonic estimates were within 0.25 cm of carcass fat thickness 70% of the time and within 0.50 cm 95% of the time. Similarly, Smith et al. (1992) found that 74% of the ultrasonic estimates of fat thickness were within 2.54 mm of carcass values ($r = 0.81$).

A study conducted by Hamlin et al. (1995b) examined the effects of weight, age, and breed on ultrasonic measures (back fat and ribeye area). The analysis of variance indicated that weight ($P < .001$) and age ($P< .05$) were significant sources of variation for ultrasonic measures of fat thickness. Furthermore, they determined that sire-breed effects ($P < .001$) were also prevalent for ultrasound fat thickness. Their study concluded that ultrasound could be applied on an industry wide basis for the assessment of compositional differences between animals.

Although high correlations between ultrasonic estimates of subcutaneous fat thickness and carcass fat thickness have generally been reported, there are several explanations for the variation that exists in the measurement of this trait. Results from Brethour (1992) showed that discrepancies between ultrasonic estimates for fat thickness and actual carcass fat thickness were larger when back fat was thicker. Smith et al. (1992) stated that extremes for traits prove the most difficult to estimate. In accordance, fat thickness in their study was underestimated in fatter cattle, which agrees with the findings of Robinson et al. (1992). They reported that scan measurements overestimated carcass values for animals with little fat and underestimated values for fatter animals. One explanation for these differences might be the fattening between scanning and slaughter times. There may also be differences due to misinterpretation of connective tissue layers that normally develop within fat to provide support and rigidity as an animal increases in fatness (Smith et al., 1992). Other factors contributing to the differences could be related to animal posture and subjectivity in selecting a measurement site. Occasionally, carcasses are quartered at a location that does not correspond to the live measurement site, resulting in a carcass back fat measure that is substantially higher than the live estimate. Researchers have also reported that fat thickness fluctuated with respiration on fatter cattle (Brethour, 1992).

Rump fat

Rump fat depth is measured from an image collected over the *gluteus medius* muscle. This image is collected approximately 2.5 cm dorsal to the hook bone (ileum) and parallel to the vertebral column. The rump fat measurement is collected immediately dorsal to the origin of the *biceps femoris*, usually 2/3 the length of the image (Wilson, 1994).

Research has indicated that subcutaneous fat thickness is the most accurate measurement of predicting carcass composition; however, measurements of fat at different locations have also proven useful in predicting beef carcass composition (Williams et al., 1997). Rump fat is an additional or alternative measure of external fat that could help to predict compositional endpoints. Realini et al. (2001) reported that ultrasound rump fat thickness was correlated with adjusted fat thickness ($r = 0.69$, $P < 0.01$). They also reported that ultrasound rump fat thickness accounted for additional variation when predicting trimmable carcass fat and enhanced the prediction accuracy for fat-based yield traits, particularly when yield is measured as a percentage. Robinson et al. (1992) found a correlation of 0.93 between scanned and carcass rump fat. Similarly, Bullock et al. (1991) reported a high correlation (r = 0.81) between ultrasound rump fat and the corresponding carcass measurement. In the same study, the correlation between carcass fat and percent lean with ultrasound measures of rump fat was 0.78 and -0.74, respectively.

Ribeye area

Ribeye area (REA) is the area of the *longissimus dorsi muscle* taken between the 12th and 13th ribs, which is the location at which a carcass would be split into quarters during typical U.S. fabrication procedures. It is also the location where beef carcasses are evaluated by trained graders to determine USDA yield grade and quality grade for carcass value determination. This measurement is used as an indication of the amount of muscling or lean product in the animal (Wilson, 1994).

Research conducted to asses the accuracy of ultrasound REA has been done mostly in slaughter age cattle of varying types and sexes. According to the literature, correlations between ultrasound REA and actual REA varied (0.17 – 0.94); however, the correlations were rarely below 0.5. Most research has shown that ultrasound ribeye measurements are correlated significantly to their corresponding carcass measurements (Miller et al., 1988; Turner et al., 1990; Houghton and Turlington, 1992; Perkins et al., 1992a; Smith et al., 1992; Hamlin et al., 1995a, 1995b).

There have been many explanations as to why correlations between ultrasound measured REA and actual *longissimus dorsi* areas have varied. Smith et al. (1992) reported that the relationship between ultrasonic and carcass *longissimus dorsi* areas were moderate to low depending on the method of determining the carcass values, which included standard dot grid (r=.43) and measurement of acetate tracings (r=.20). These findings were also reported by Henderson et al. (1966). Other explanations include differences in measurements taken on opposite sides of the animal (Henderson et al., 1966). Improper placement of the transducer by the technician, technician inexperience, inaccurate interpretation of the image, or poor image resolution (Cross, 1989) may also explain some of the low correlations (Perkins et al., 1992a). Improper cleaning and clipping of animals at the scanning location can result in poor image quality. Changes in muscle configuration during processing, onset of rigor mortis, and differences in muscle configuration that exist between standing animals and the hanging carcass may also have affected *longissimus dorsi* area and thus precision of ultrasonic estimates (Temple et al., 1965). Griffin et al. (1999) collected ultrasound measures (ribeye area and 12th rib fat thickness) immediately following exsanguination and before hide removal with the cattle hanging on the rail and found that the ultrasound measures contributed little to predicting carcass composition.

Estimates of REA, both carcass and ultrasonic, are usually predicted conservatively. Smith et al. (1992) reported that *longissimus* muscle area is generally over estimated for carcasses with areas of $< 71 \text{cm}^2$ and is under estimated for carcasses with areas $> 84 \text{ cm}^2$. They also concluded that ultrasonic estimates of REA generally were under estimated for more heavily muscled animals and reported that ultrasonic estimates were least accurate in determining *longissimus* muscle area for animals with areas $> 96 \text{ cm}^2$. Perkins et al. (1992a) found that ultrasound estimates were slightly more precise for cattle with *longissimus* muscle areas smaller than 83.9 cm^2 than for those with *longissimus* muscles greater than 83.9 cm^2. Hale, cited by Turner et al.

(1990), analyzed technician proficiency for ultrasound certification and found that REA generally was overestimated, particularly for fatter cattle.

Intramuscular fat (% IMF)

Along with measures of subcutaneous fat, measures of intramuscular fat can help estimate an animal's energy stores. When a beef animal is in a negative energy balance, intramuscular fat can be mobilized to help meet energy needs (Bullock, 1991). The ultrasonic estimate of intramuscular fat is taken from an image collected longitudinally along the *longissimus dorsi* muscle across the 11th – 13th ribs. The percentage of intramuscular fat or marbling is calculated by a computer program designed to quantitate the amount of speckle within a specified area in two designated locations on the image (Hassen et al., 1999). Marbling or intramuscular fat percentage is the predominant factor in determining USDA quality grades, since it has been proven to enhance the taste and palatability of beef (Smith et al., 1984). The amount of intramuscular fat seems to mainly be influenced by genetics, although nutrition, stress, and length of feeding play an important role. In carcasses, marbling can be determined in varying ways. One way is the determination of marbling score. While marbling score is the visual estimation of the amount of fat in the *longissimus* muscle on the 12th rib cut surface, it has been shown to be correlated to the percentage of intramuscular fat in the same location (Whitaker et al., 1992). The actual percentage of intramuscular fat can be determined through the use of organic solvents to extract and quantify muscle lipids (Folch et al., 1957).

Blumer et al. (1962) reported that intramuscular fat is deposited in a treelike pattern along the branches of the intercostal vascular network. Actual distributions of intramuscular fat (marbling) were found to be more heavily concentrated around areas of high vascular activity. They also found that ultrasonic images of intramuscular fat from live animals correlated better to visual marbling scores than images from slaughtered animals. The prediction from slaughter animals may have been skewed because of capillary blood loss and tissue changes due to the lack of oxygen during slaughter. When blood is removed from the animal during slaughter, capillaries collapse and may reduce the scattering effect of ultrasonic waves (Whitaker et al., 1992).

Correlations between actual percentage of intramuscular fat and ultrasound estimates of intramuscular fat have reportedly ranged from 0.74 to 0.80 (Brethour, 1990). Theses values are comparable to correlations between the actual percentage of intramuscular fat and visual marbling scores (0.82 to 0.95) in beef cattle (Herring, 1998). In studying the repeatability of ultrasound predicted percent intramuscular fat, Hassen et al. (1999) determined that increasing the number of images per animal plays a more significant role in reducing the standard error of prediction than taking multiple measurements within a single image.

It is important to note that the studies analyzing the correlations between actual percent intramuscular fat and ultrasonic estimates of percent intramuscular fat were conducted using cattle that were around 1 year of age. Cattle that are older tend to develop more connective tissue in the *longissmus* muscle that could skew results (Miller et al., 1996). Miller et al. (1996) concluded that it is difficult to differentiate between signals reflected by intramuscular fat and those reflected by other structures, such as connective tissue and veins and arteries, which permeate muscle tissue.

Errors in ultrasonic evaluation of beef cattle

There are many factors that affect the variability of ultrasound estimates. Considerable variation exists between species, technicians, and ultrasonic instrumentation in the ability of ultrasound to predict carcass traits (Houghton and Turlington, 1992). Perkins et al. (1992b) reported repeatability correlations for ribeye area of 0.83 and 0.84 for two different technicians, and correlations between successive ultrasound back fat thickness of 0.90 and 0.97. Similarly, Brethour (1992) found that the correlation (repeatability) between consecutive ultrasound back fat measurements was 0.975. The average difference between two ultrasound measures was 0.72 mm and error size was directly related ($P < .001$) to the level of back fat. The accuracy correlations reported by Herring et al. (1994) ranged from 0.39 to 0.72 between carcass and ultrasound ribeye area, and from 0.57 to 0.66 between carcass and ultrasound back fat thickness.

Most accuracies of ultrasound measurements are reported by correlation coefficients. Houghton and Turlington (1992) reported on the limitations associated with using correlation coefficients. These limitations included:

1) Population variation influences correlation coefficients (i.e. larger variation will produce higher coefficients, whereas a uniform population will result in much lower coefficients).

2) Correlation coefficients do not reflect bias (i.e. an ultrasonic technique that consistently over or underestimates measurements).

3) Correlation coefficients are not easily understood by most producer groups.

Decreased accuracy and repeatability in ultrasonic evaluation of lean and fat live cattle were found to be related to the following (Miller, 1996; Houghton and Turlington, 1992; Perkins et al., 1992b; Miles et al., 1972):

1) Animal variation: measures on fat animals tend to be underestimated.
2) Carcass deformation resulting from post-slaughter treatment: hanging, splitting, hide removal, and rigor mortis.
3) Image interpretation: failure to identify hide, fat and muscle boundaries.
4) Machine manipulation: placement of the transducer, machine settings for proper penetration or clearness of signals.
5) Technician experience: inexperienced technicians often confuse shadows and multiple reflections with anatomical features, leading to inaccurate diagnoses or faulty measurements.
6) Equipment: accuracy differs between types of equipment.

Application of Ultrasound for Mature Cow Compositional Estimation

The goal of cattlemen is to produce high quality beef for today's consumer. However, to do this, they have to have a starting point, which includes a group of efficient, productive females to produce calves. Many factors influence the efficiency of a cow including nutrition, genetics, phenotype, and management. The ability of a cow to maintain proper body condition is an important factor in determining continued productivity and production efficiency.

A combination of factors affects how well a cow will maintain her body weight. Developing the proper nutritional program for a group of cows, based on available resources, is an integral part of maintaining proper body condition. Feed costs for cow maintenance can make up 54 to 75% of the annual cost of keeping a cow (Houghton et al., 1990a). Energy is the feed component required in the greatest quantity by beef cattle, with about 70% of the required energy going to maintenance (Houghton et al., 1990a). The energy requirements of beef cows differ by the amount of body condition and not by the weight of the cow per se. Houghton et al. (1990c) suggest that weight alone does not accurately predict cow energy needs because an increase in weight due to fat deposition does not necessarily increase maintenance requirements as much as does added weight from muscle. This study also suggests that the accuracy of current energy systems might be improved if a practical measure of body condition could be assigned to individual cows. Houghton et al. (1990a), examining the effects of body composition on energy utilization by beef cows, determined that some indicator of body condition needs to be used in combination with weight or weight plus milk production to estimate the levels of energy needed to maintain beef cows during late gestation and early lactation. Energy storage relative to energy intake is of particular importance in studies involving producing cows (Gresham et al., 1986). Therefore, knowing the composition of the mature cow (i.e. body condition level) can help producers develop a more efficient and cost-effective nutritional program for their herd.

The maintenance of proper body composition also affects the cow's reproductive abilities. The ability of a cow to maintain adequate energy reserves throughout a calving interval is essential to her reproductive efficiency. A cow must have enough energy stores to not only maintain herself, but support a calf and recover to rebreed (Richards et al., 1986). A study conducted at Iowa State University analyzed the relationship between reproductive traits and body composition traits measured by ultrasound in beef heifers (Minick et al., 2001). They concluded that heifers that are further along in growth and development, as evidenced by heavier weights, larger ribeye areas and more rump fat, are more likely to have higher reproductive tract scores and to be cycling at one year of age (Minick et al., 2001). Dunn and Kaltenbach (1980) determined that poor body condition results in reduced conception rate and increased calving intervals. They found extensive evidence linking body condition to the duration of the postpartum interval and to variations in percent calf crop. In a similar study, it was determined that cows calving with a low body condition exhibit estrus later in the postpartum period regardless of energy offered postpartum, and therefore pregnancy is delayed (Richards et al., 1986). Houghton et al. (1990b) found similar results, concluding that thin cows had a longer postpartum interval. However, they also determined that thin cows had a higher first service conception rate than moderate and fleshy cows. Therefore, an accurate method for estimating body composition in the live beef cow is essential for determination of salvage value and determination of reproductive success (Gresham et al., 1986).

Because increasing selection emphasis is being placed on growth and milking ability in beef cattle, it is important to determine how these and other traits interact to affect cow composition and productivity. Lower body conditioned cows have been found to have lighter calves at birth when compared to calves from higher body conditioned cows (Houghton et al., 1990c). These lighter calves also tended to be lighter at 60 and

205 days, indicating that body composition of the cows not only affects their reproduction and milk production, but calf performance as well (Houghton et al., 1990b).

Several different methods for estimating body or carcass composition from the live animal have been used for research purposes. They have included measurement of weight, weight: height, ^{40}K content, dye dilution, urea dilution, tritium oxide dilution, deuterium oxide dilution and ultrasonic determination of physical dimensions (Faulkner et al., 1990). Comparing the use of ultrasound to other methods for determining cow composition has been the topic of many examinations. Characteristics to be considered in comparing techniques estimating composition are accuracy, precision, ease of measurement, cost, degree of disruption to animal performance, and application to a diverse (weight, age, breed, etc.) group of animals (Ferrell and Jenkins, 1984; Gresham et al., 1986). Ultrasound provides a fast, repeatable, relatively inexpensive and nondestructive measure of carcass components in the live animal. Real-time ultrasound technology has advanced to the point that accurate measurements of many body composition traits can be obtained, including 12th rib fat thickness, rump fat thickness, ribeye area, and intramuscular fat percentage (marbling) (Wilson, 1994).

Most of the techniques used to measure body composition have been applied to growing animals with limited application to the mature beef cow. Gresham et al. (1986) conducted research trails with mature cows to develop prediction equations for estimating carcass composition from live animal measures. They determined that objective (live weight, ultrasonic measurements of ribeye area and fat cover, hip height, carcass measurements, etc.) and subjective (frame and condition scores) measurements can be quite useful in predicting carcass composition, even for animals that cannot be characterized according to breed, age, or reproductive status. Bullock et al. (1991) conducted a similar study using mature cows to predict cow energy stores. Their results indicated that a combination of weight, hip height, and ultrasound measures (ribeye area and subcutaneous fat) could accurately and objectively estimate a cow's energy stores, both fat and protein. Faulkner et al. (1990) conducted an experiment with mature cows to develop prediction equations for estimating carcass composition from live animal measurements (including ultrasound). They found that live measurements including ultrasound (12th rib fat thickness), weight and hip height can be used to accurately and precisely estimate percentage of fat, kilograms of fat, kilograms of fat-free lean and percentage bone for mature cows. In research predicting cow composition, it was found that breed, age, cow type and pregnancy status did not affect the results (Ferrell et al., 1976; Ferrell and Jenkins, 1984).

It is important to understand the compositional changes a cow goes through during a production cycle. Rouse et al. (2001) conducted a study to evaluate body composition changes in heifers from initial breeding through second parturition and weaning using real-time ultrasound measurements (back fat, ribeye area, and percent intramuscular fat) and body weight. The cows were scanned and weighed five times including: 1 – before initial breeding (13-14 months of age), 2 – before first calving (2 years of age), 3 – weaning first calf, 4 – before second calving (3 years of age), and 5 – weaning second calf. Changes in weight indicated that heifers lost weight during their first calving and lactation, but then continued to gain weight through weaning their second calf. Ribeye area continued to grow in a linear pattern during the total time frame suggesting that weight loss or energy repartitioning was never enough to restrict muscle growth. Fat deposition followed a pattern very similar to changes in weight, although it took longer for intramuscular fat levels to recover from the stresses of first calving and lactation (Rouse et al., 2001). A similar study looked at the compositional changes in dairy cows using chemical determined composition measures (Andrew, 1994). These cows were evaluated at three physiological stages: pre-partum, early lactation, and late lactation. Andrew et al. (1994) reported that empty body fat was reduced 42.3 kg for the early lactation cows compared with pre-partum cows. During early lactation, body composition undergoes significant changes because of mobilization of tissues when nutrient intake is inadequate to meet the requirements for lactation. Estimates of the extent of mobilization are variable and depend on many factors, including feed intake, body condition at calving, milk production, and management factors. The repletion of mobilized tissues occurs during late lactation and the dry period (Andrew et al., 1994). Andrew et al. (1994) also found that the weight of protein as a whole did not change in relation to physiological stage, however, protein, expressed as a percentage of fat-free matter was lowest in early lactation cows. Tissue protein was apparently distributed away from carcass and towards tissues that support lactation.

Although the use of ultrasound to evaluate changes in cow composition provides reliable data for research purposes, a more inexpensive method for the producer to evaluate cow composition is to use visual body condition scores (BCS). Houghton et al. (1990c) suggest that BCS plus cow weight could be useful in determining body composition of cows in various body conditions. Research has determined that although

BCS alone can be beneficial, combined with weight, hip height, or the ratio of weight to hip height, producers can get an accurate measure of body condition (Houghton et al, 1990c). Domecq et al. (1995) conducted research that validated body condition scores of dairy cows with ultrasound measurements of subcutaneous fat. They found that ultrasound measurements of subcutaneous fat in the thurl, lumbar, and tailhead regions had a significant relationship ($P < 0.05$) with BCS, and BCS estimates were as valid as ultrasound in determining compositional changes over time. However, BCS is a subjective measurement that producers may be reluctant to apply in cattle (Bullock et al., 1991).

MATERIALS AND METHODS

Eighty-four Angus cows and forty-four Hereford cows were included in this study. All cows were part of the research herd at the Wilkins Beef Unit, University of Georgia. Cows ranged in age from 2 to 12 years of age. Cows were maintained on mixed fescue pastures throughout the year and supplemented with bermuda hay as needed. During the spring, cows were grazed on rye and fescue pastures. Cows generally calved beginning in January and ending in March. After calving, cows were maintained on mixed fescue pasture and fed a supplement consisting of primarily soybean hulls and corn gluten at about 2.3 kg per head per day for approximately 60 days. First calf heifers were maintained in separate pastures from older cows to allow for more intensive observation, but were managed under a similar program to mature cows.

Live Animal Measures

Real – time ultrasound scans and weights were collected serially on the cows over the course of a production cycle. Scan times included the following:

1. Before breeding (March, 2002)
2. Midway between breeding and weaning (July, 2002)
3. Weaning (September, 2002)
4. Before calving (December, 2002)

Ultrasound images were collected using an Aloka 500V real – time ultrasound machine (Corometrics Medical Systems, Wallingford, CT) equipped with a 17.2 cm, 3.5 MHz linear array transducer. To establish good animal contact the measurement area was clipped to within 1.5 cm, oiled with vegetable oil, brushed free from dirt and re-oiled. To achieve optimum image quality, a superflab guide was used to ensure proper contact between the rigid ultrasound transducer and the animal's back. The following ultrasound measures were collected: back fat (BF), rump fat (RF), ribeye area (REA), and intramuscular fat percentage (PIMF). Images were collected in a restraining chute with animals standing as still as possible.

The site for image collection for REA and BF was determined by physical palpation between the 12th and 13th ribs on the right side of the animal. The transducer was placed between the 12th and 13th ribs following the contour of the ribs toward the midline. The transducer was adjusted so that presence of well-defined intercostal muscles under the *longissimus dorsi* were visible. Their presence is an indication that the transducer is properly aligned. For RF thickness the site for image collection was between the hook and pin bones parallel to the backbone approximately 2.5 cm dorsal to the hookbone. The corresponding image contained the juncture of the *gluteus medius* and the *biceps femoris* muscles. The image for estimation of PIMF was taken parallel to the backbone, longitudinally along the *longissimus* muscle from the 11th to the 13th rib. The transducer was adjusted so that the *spinalis* muscle did not extend greater than 1/3 the length of the image. Images of acceptable quality included a clearly visible hide and subcutaneous fat layer, an even speckle or texture pattern in the muscle area, and well-defined rib outlines.

The technician collecting the images was certified by the Annual Proficiency and Training Certification (APTC) committee. The same technician who collected the original image interpreted them. Images were interpreted using Beef Information Manager^{TM} software, version 3.0 (Critical Vision, Inc., Atlanta, GA). When interpreting images, BF measures were made at point three-quarters of the distance from the medial side of the *longissimus dorsi* muscle to the lateral side and an imaginary tangent line running through the interface between the hide and the subcutaneous fat. Ribeye area measures included the area of the *longissimus dorsi* muscle. Rump fat measures were made as the fat thickness immediately dorsal to the apex of the juncture of the *gluteus medius* and *biceps femoris* muscles. Two PIMF images were collected and percentage fat was measured on both sides of the 12th rib. PIMF was calculated by the Beef Information Manager^{TM} software.

Cow weights were collected on the same days as ultrasound images. The most current expected progeny differences (EPD) for yearling weight (YW) and milk (MILK) along with current breed averages were retrieved from respective breed association web sites.

Statistical Analysis

For statistical analysis, comparisons of changes in composition were made across age (young cows: 2 years and less v old cows: 3 years and older), a measure of growth (low YW EPD v high YW EPD), and a measure of production (low MILK EPD v high MILK EPD). The divisions for age groups were similar for both breeds. Cows were divided around breed averages for their respective EPD. For growth comparisons, cows were divided into a low YW EPD group (Angus: values 40 to 62; Hereford: values 41 to 58) and a high YW EPD group (Angus: values 70 to 95; Hereford: values 69 to 89). For production comparisons, cows were divided into a low MILK EPD group (Angus: values 4 to 16; Hereford: values 7 to 15) and a high MILK EPD group (Angus: values 20 to 34; Hereford: values 17 to 30). The cows close to breed average were omitted from the analysis to achieve a distinct difference in the groups. The numbers of observations in each comparison group for Angus cows is listed in Table 1 and for Hereford cows in Table 2.

All statistical analyses were conducted using SAS (SAS Institute, Cary, NC). Means, standard deviations, minimum, and maximum values were generated for both breeds at scan times comparison groups (age, growth, and production). The effects of age (< 3 vs ≥ 3 years), growth (low YW EPD vs. high YW EPD), and production (low MILK EPD vs. high MILK EPD), at each of the four scan times, were compared using GLM procedures of SAS. Means were generated and separated using the least squared means procedure. Regression procedures (PROC REG) were conducted to determine whether changes in ultrasound measures overtime showed significant linear and (or) quadratic responses.

RESULTS AND DISCUSSION

Angus Analyses. Means, standard deviations, minimum, and maximum values for Angus cows by scan times are listed in Tables 3, 4, 5, and 6. Changes in weight (Figure 1) indicated that old cows (3 years and older) are generally heavier than young cows (2 years and less). When comparing high YW EPD vs. low YW EPD (Figure 7) cows, the high YW cows looked to be slightly heavier than the low YW cows, but differences were not significant. Perry and Arthor (1998), comparing the body composition of cattle selected for growth rate, found that the High Line cattle were 154 kg heavier than the Low Line at maturity. The steers used in the study conducted by Perry and Arthor (1998) showed a greater difference between High and Low groups because of 12 years of selection for growth, while this study used only an estimate of growth to make comparisons. In the comparison of MILK EPD (Figure 13), low MILK cows were heavier than high MILK cows across all scan times, suggesting increased production and more nutritional stress for high MILK cows resulting in lower weights. The changes in weight for all comparison groups were similar. All cows gained a small amount of weight from pre-breeding (March) to the mid (July) scan, then lost weight until weaning (September). After weaning, cows recovered and weights reached levels above pre-breeding measures. The fourth scan was conducted pre-calving so weights represent cow plus fetus and fetal tissues. The weight loss during the interval from the July scan to weaning is most probably caused from lower energy and protein intake because of lower forage quality. After the calves are weaned, cows can repartition nutrients from milk production to regaining weight, primarily in the form of fat. These results agree with the study conducted at Iowa State University which reported that cow weights dropped between calving and weaning and then increased to rebreeding (Rouse et al., 2001). Measures for weight were significantly different ($P < 0.01$) across age and MILK EPD comparisons and while YW EPD comparisons were not significant, they followed a pattern similar to the other comparisons. Regression analyses indicated that changes in weight of old ($P < 0.01$), young ($P = 0.03$), and low MILK ($P = 0.02$) cows were quadratic in nature. Regression analyses of the other changes in weight showed no significance. It is important to note that changes in weight can be highly variable depending on differences in nutritional programs. Body weight is also affected by the amount of shrink and gastrointestinal tract fill at the time of weighing. Based on this, weight alone should not be used as a measure of a cow's ability to maintain condition. In accordance, Houghton et al. (1990c) suggests that weight alone does not accurately predict cow energy needs because an increase in weight due to fat deposition does not necessarily increase maintenance requirements as much as does added weight from muscle.

Changes in REA were again similar across all comparison groups. Overall, old cows (Figure 2) had numerically had larger muscle areas than young; however, only pre-breeding measures were statistically different ($P \leq 0.01$). Numerically, high YW (Figure 8) cows had larger areas than low YW with no measurement times showing statistical difference. Low MILK (Figure 14) cows had larger areas than high MILK cows with all measures but pre-calving being statistically different ($P \leq 0.05$). Old cows showed a decrease in REA from pre-breeding to the mid scan then an increase to pre-calving, while young cows showed an increase through all four scans. This should be expected since the young cows had not reached mature size at the completion of the study. Rouse et al. (2001) also reported an increase in REA for young cows over time. They suggested that energy repartitioning was never severe enough to restrict muscle growth. Changes in REA of high and low MILK cows followed a similar pattern as the old vs. young comparison. Andrew et al. (1994) compared changes in total protein levels of dairy cows at different production stages, and discovered that the percentage of total protein in the carcass was lower in early lactation cows than in prepartum and late lactation cows. They suggested that tissue protein was redistributed away from carcass and towards tissues that supported lactation, primarily the gastrointestinal (GI) tract and mammary glands. They reported that approximately 14.7 kg of carcass protein was mobilized toward GI tract and mammary tissues for cows during the first 8 weeks of lactation. Chilliard et al. (1984) determined that protein mobilization (similar to fat mobilization) is affected by the milk potential of the cow. In times of strict nutrient restriction, when requirements of the cow are higher than intake, muscle tissue is mobilized once fat and other nutrient stores have been depleted (Hardin, 1990). As with live weight, REA in the high vs. low YW comparison was not significantly different. Change in REA for old cows was found to be quadratic in nature ($P = 0.02$), but none of the other responses were significant over time.

In all comparison groups (Age: Figure 3, YW: Figure 9, MILK: Figure 15), REA/kg of live weight decreased from pre-breeding to the mid scan, increased from mid to weaning, and then decreased from weaning to pre-calving. The decrease in REA/kg of live weight from weaning to pre-calving may have been due to a faster increase in weight, including the fetus, during this time than the increase in REA. The only times found to be significantly different were mid, weaning, and pre-calving ($P < 0.01$) for age comparisons. Regression analyses indicated that changes in REA/kg for young cows were both linear ($P = 0.02$) and quadratic ($P = 0.01$). No other responses were significant.

Changes in back fat, showed a similar pattern across all comparisons. The comparison of back fat in old vs. young (Figure 4) indicated that old cows had more back fat than young cows at all four scan times; however, both groups showed a decrease in back fat from breeding to weaning and fat accumulation from weaning to pre-calving. Yearling weight (Figure 10) and Milk EPD (Figure 16) comparisons showed the same decrease in fatness to weaning followed by increased fatness through calving. A similar pattern was reported by Rouse et al. (2001) in their analysis of changes in the subcutaneous fat of young Angus cows. They reported a .25 cm decrease in back fat from calving to weaning and a .65 cm increase from weaning to calving. Houghton et al. (1990c) also observed an increase in total body lipids from 190 days into gestation to parturition. They suggested that the weaning of the calf reduced lactation energy requirements of beef cows and therefore, made more energy available for storage of body energy reserves (condition). In the YW and MILK EPD comparisons, high YW and low MILK cows had more back fat than low YW and high MILK groups, respectively. Andrew et al. (1994) also reported that empty body fat was lower in early lactation (high producing) cows than in late lactation and prepartum cows. They suggested that lactating cows have a large capacity to mobilize fat during early lactation. This agrees with the findings in this study comparing the responses in back fat across high and low MILK.

The nutrient demands for beef cows in order of priority are body maintenance, lactation, growth, and fetal development (Hardin, 1990). The nutrient intake of the cow is partitioned to meet these requirements. As nutrient requirements exceed intake, nutrients are shifted from lower priority requirements (Hardin, 1990). Beef cattle store excess energy as fat. The fat stores are mobilized when nutrient demands exceed those available from intake. Many beef cows have such high maintenance and lactation requirements that adding body fat during the nursing stage is impossible. For the cows in this study, protein and energy intake were restricted during this time due a summer drought causing limited grass. The most efficient time to add fat is from weaning to calving, when the nutrient requirements for lactation are minimized. During this phase, the only demands are for body maintenance and fetal development (Hardin, 1990). The nutritional level for cows in this study between weaning and calving was more than adequate to meet requirements. This was during the fall of the year, which is when fescue in the Athens area really begins to flourish. The data showed that the greatest loss of body fat occurred during the time when cows were nursing calves (calving to weaning) followed by accumulation of body fat stores from weaning to calving. These changes are consistent with the nutritional needs of cows as they move through a production cycle. Although back fat measures in this trial followed expected patterns across all comparisons, back fat was significantly different only across age and at weaning ($P < 0.05$) and pre-breeding ($P < 0.01$) scans.

Comparisons of the change in rump fat also showed that old (Figure 5), high YW (Figure 11), and low MILK (Figure 17) cows had greater fat depth than their comparative groups, respectively. The pattern of change, however, was slightly different from changes in back fat. Rump fat measures decreased to the mid scan and then began increasing to pre-calving, particularly in the older, high YW, and low MILK cows. Young cows showed no significant gain in rump fat after weaning, unlike the significant gain in post-weaning back fat noted earlier. Low YW and high MILK cows increased in rump fat after weaning, although not to the same level as the high YW and low MILK cows, respectively. Fat is deposited in the beef animal from front to rear and fat mobilization happens in the opposite direction (Rouse and Wilson, 1999). This could help explain the pattern of change in rump fat compared to back fat. Once again, only the weaning ($P < 0.05$) and pre-breeding ($P < 0.01$) measures across age were significantly different. Regression analyses indicated that significant linear ($P = 0.02$) and quadratic ($P < 0.01$) changes in RF occurred over time in the older cows. Changes in RF of low YW cows also showed a quadratic ($P < 0.01$) response over time. For MILK EPD comparisons, the change in RF over time for high MILK cows was quadratic ($P = 0.03$) and for low MILK cows both linear ($P = 0.03$) and quadratic ($P = 0.01$) in nature.

Analysis of the changes in marbling (Age: Figure 6, YW: Figure 12, MILK: Figure 18) indicated very little change occurred across any of the comparison groups. A slight numerical decrease occurred from pre-breeding to weaning in all cows, but no measures were found to be significantly different and regression analyses indicated no significant linear or quadratic responses in marbling over time. When fattening, a beef cow does so in a specific order: internal fat, seam fat, subcutaneous fat, and intramuscular fat (Rouse and Wilson, 1999). Intramuscular fat is a very mobile body tissue and therefore, marbling is the most variable ultrasound measure (Rouse and Wilson, 1999). When measuring marbling in older cows, it is also difficult to distinguish between intramuscular fat and connective tissue; therefore, higher marbling percentages can be misleading (Miller, 1996). Because marbling is a very metabolically active tissue, one would expect changes in marbling to meet the nutritional needs of cattle. However, in this study, changes were not observed possibly due to difficulty in accurate measurement and not measuring frequently enough to observe any potential changes over time.

Hereford Analyses. Means, standard deviations, minimum, and maximum values for Hereford cows by scan times are listed in Tables 7, 8, 9, and 10. Although the response of weight across comparison groups (Age: Figures 19 -24, YW: Figures 25 - 30, and MILK: Figures 31 - 36) was similar for Hereford and Angus cows, analysis of compositional data revealed several differences from the Angus results. Weights increased from pre-breeding to the mid scan, decreased from mid scan to weaning, then increased to pre-calving. Likewise, old cows, high YW EPD, and low MILK EPD cows were generally heavier than young, low YW, and high MILK cows. Weight measures were significantly different ($P \leq 0.05$) across comparison groups, except at pre-breeding, mid, and weaning measures for the MILK EPD comparison. Regression analyses showed that the changes in weight of old cows ($P = 0.01$) and low MILK cows ($P = 0.05$) were quadratic, while changes in the weight of young cows ($P = 0.05$) were found to be linear.

Changes in composition across the age and MILK comparison groups, except changes in weight, were somewhat different from the expected changes found in the Angus analysis. Thee YW comparisons of Hereford cows were more representative of the expected compositional changes than those observed in the Angus cows, although regression analysis showed no significant responses over time. The variability in responses across breeds may be due to the reduced numbers of observations of Hereford cows for analysis. The differences could also be due to biological differences between breeds. Although compositional differences across breed were somewhat different, the general trends reported in the Angus analysis were evident in the analysis of the Hereford cows. Older cows, high YW, and low MILK cows were generally heavier, had larger REA, and more fat cover (both BF and RF) than their respective counterparts.

IMPLICATIONS

Based on the ultrasound data obtained in this study, cows showed that the greatest loss of body fat while nursing calves (calving to weaning) followed by accumulation of body fat stores from weaning to calving. These changes were consistent with the nutritional needs of cows as they progress through a production cycle. Thus it would appear that real – time ultrasound can be used to evaluate compositional changes in mature cows. Using a more specific method of evaluating composition, compared to body condition scoring, can assist cow – calf producers in understanding and meeting the nutritional needs of their calves. Also, knowing the extent to which a cow maintains condition can serve as a factor when making culling decisions. Scanning cows can be labor intensive; however, there appears to be adequate advantages to the use of ultrasound verses a subjective body condition scoring system.

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Table 1. - Numbers of observations for Angus compositional analyses

Age Comparison Young v Old		**Growth Comparison Low YW v High YW**		**Production Comparison Low MILK v High MILK**	
Young	Old	Low YW	High YW	Low MILK	High MILK
17	67	26	25	27	24

Table 2. – Numbers of observations for Hereford compositional analyses

Age Comparison Young v Old		**Growth Comparison Low YW v High YW**		**Production Comparison Low MILK v High MILK**	
Young	Old	Low YW	High YW	Low MILK	High YW
5	39	15	15	18	17

Table 3. – Means, standard deviations, minimums, and maximums for Angus cows at the pre-breeding (March) scan.

Variables	**Mean**	**SD**	**Min**	**Max**
Weight (kg)	522.1	82.7	376.8	726.4
REA (cm^2)	62.5	11.8	34.1	92.5
REA/kg (cm^2/kg)	0.12	0.014	0.08	0.16
Back fat (cm)	0.64	0.27	0.13	1.30
Rump fat (cm)	0.66	0.41	0.18	2.10
Marbling (%)	5.1	1.1	2.8	8.6

Table 4. - Means, standard deviations, minimums, and maximums for Angus cows at the mid (July) scan.

Variables	**Mean**	**SD**	**Min**	**Max**
Weight (kg)	544.8	69.3	419.5	690.1
REA (cm^2)	61.2	10.3	35.9	97.7
REA/kg (cm^2/kg)	0.11	0.014	0.08	0.15
Back fat (cm)	0.61	0.32	0.13	1.40
Rump fat (cm)	0.61	0.37	0.13	1.70
Marbling (%)	5.0	1.1	2.9	8.6

Table 5. – Means, standard deviations, minimums, and maximums for Angus cows at the weaning (September) scan.

Variables	**Mean**	**SD**	**Min**	**Max**
Weight (kg)	513.9	67.7	382.3	678.7
REA (cm^2)	62.2	9.9	32.1	91.6
REA/kg (cm^2/kg)	0.12	0.014	0.08	0.15
Back fat (cm)	0.58	0.31	0.13	1.40
Rump fat (cm)	0.64	0.42	0.13	2.10
Marbling (%)	4.7	1.1	3.0	8.6

Table 6. - Means, standard deviations, minimums, and maximums for Angus cows at the calving (December) scan.

Variables	**Mean**	**SD**	**Min**	**Max**
Weight (kg)	587.9	69.6	472.2	785.4
REA (cm^2)	65.4	8.5	43.2	86.1
REA/kg (cm^2/kg)	0.11	0.012	0.09	0.14
Back fat (cm)	0.71	0.31	0.18	1.60
Rump fat (cm)	0.89	0.49	0.18	2.20
Marbling (%)	5.0	1.0	2.7	7.8

Table 7. - Means, standard deviations, minimums, and maximums for Hereford cows at the pre-breeding (March) scan.

Variables	Mean	SD	Min	Max
Weight (kg)	538.0	58.6	420.0	653.8
REA (cm^2)	57.5	8.8	32.9	81.2
REA/kg (cm^2/kg)	0.11	0.013	0.07	0.13
Back fat (cm)	0.59	0.29	0.18	1.60
Rump fat (cm)	0.84	0.51	0.13	2.10
Marbling (%)	4.4	0.98	2.7	8.0

Table 8. - Means, standard deviations, minimums, and maximums for Hereford cows at the mid (July) scan.

Variables	Mean	SD	Min	Max
Weight (kg)	561.9	53.2	467.6	676.5
REA (cm^2)	57.8	8.9	36.2	76.6
REA/kg (cm^2/kg)	0.10	0.016	0.07	0.13
Back fat (cm)	0.57	0.33	0.18	1.90
Rump fat (cm)	0.75	0.44	0.15	2.10
Marbling (%)	4.5	1.0	3.0	8.6

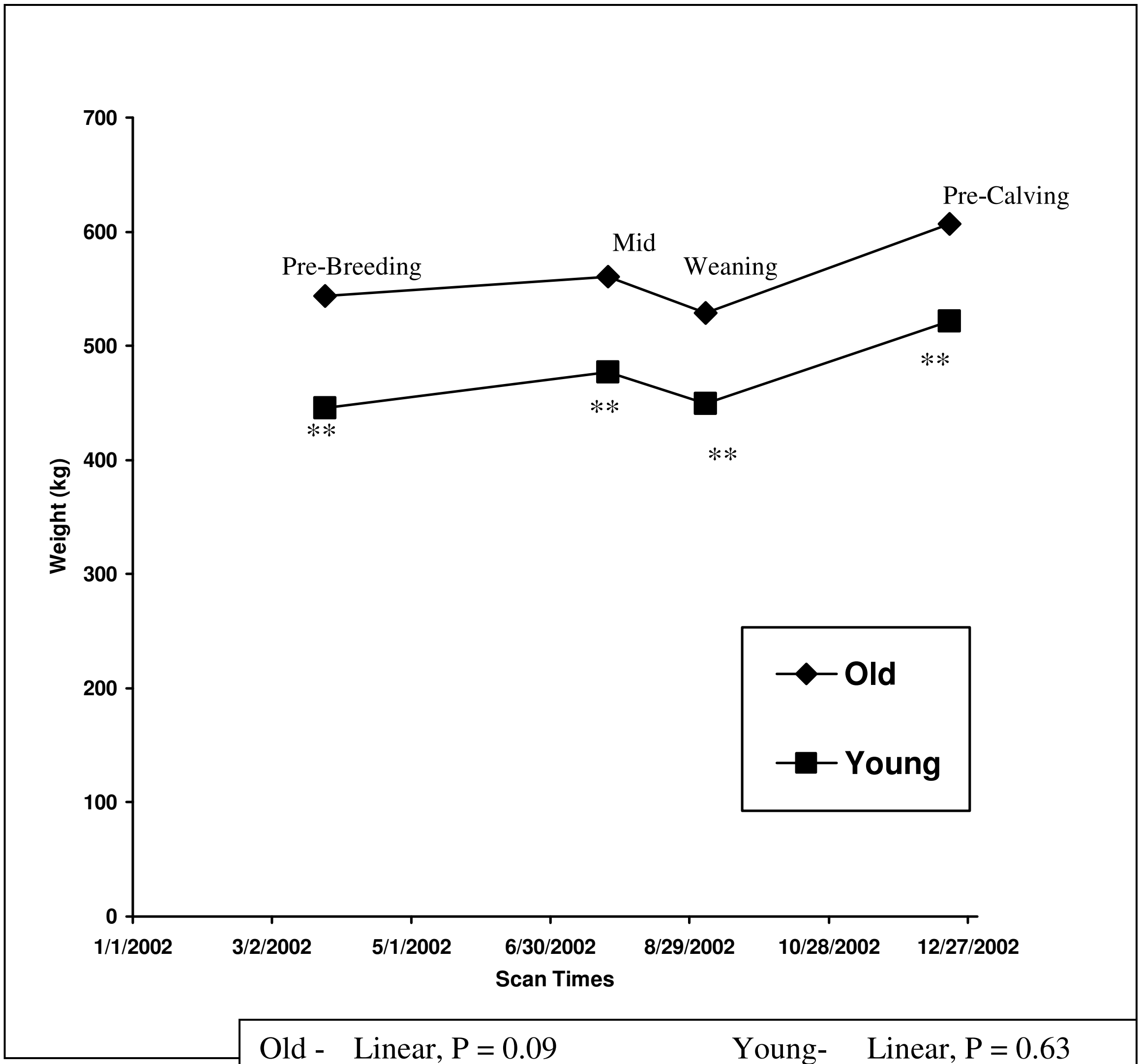
Table 9. – Means, standard deviations, minimums, and maximums for Hereford cows at the weaning (September) scan.

Variables	Mean	SD	Min	Max
Weight (kg)	533.0	48.9	435.8	649.2
REA (cm^2)	59.2	9.4	37.1	89.3
REA/CWT (cm^2/kg)	0.11	0.014	0.08	0.14
Back fat (cm)	0.57	0.31	0.10	1.50
Rump fat (cm)	0.76	0.47	0.13	2.10
Marbling (%)	4.2	0.78	2.8	6.4

Table 10. – Means, standard deviations, minimums, and maximums for Hereford cows at the calving (December) scan.

Variables	Mean	SD	Min	Max
Weight (kg)	598.8	50.9	518.5	701.4
REA (cm^2)	62.2	7.9	49.6	75.8
REA/CWT (cm^2/kg)	0.10	0.014	0.07	0.13
Back fat (cm)	0.70	0.31	0.28	1.80
Rump fat (cm)	1.10	0.54	0.18	2.30
Marbling (%)	4.6	1.1	3.0	7.9

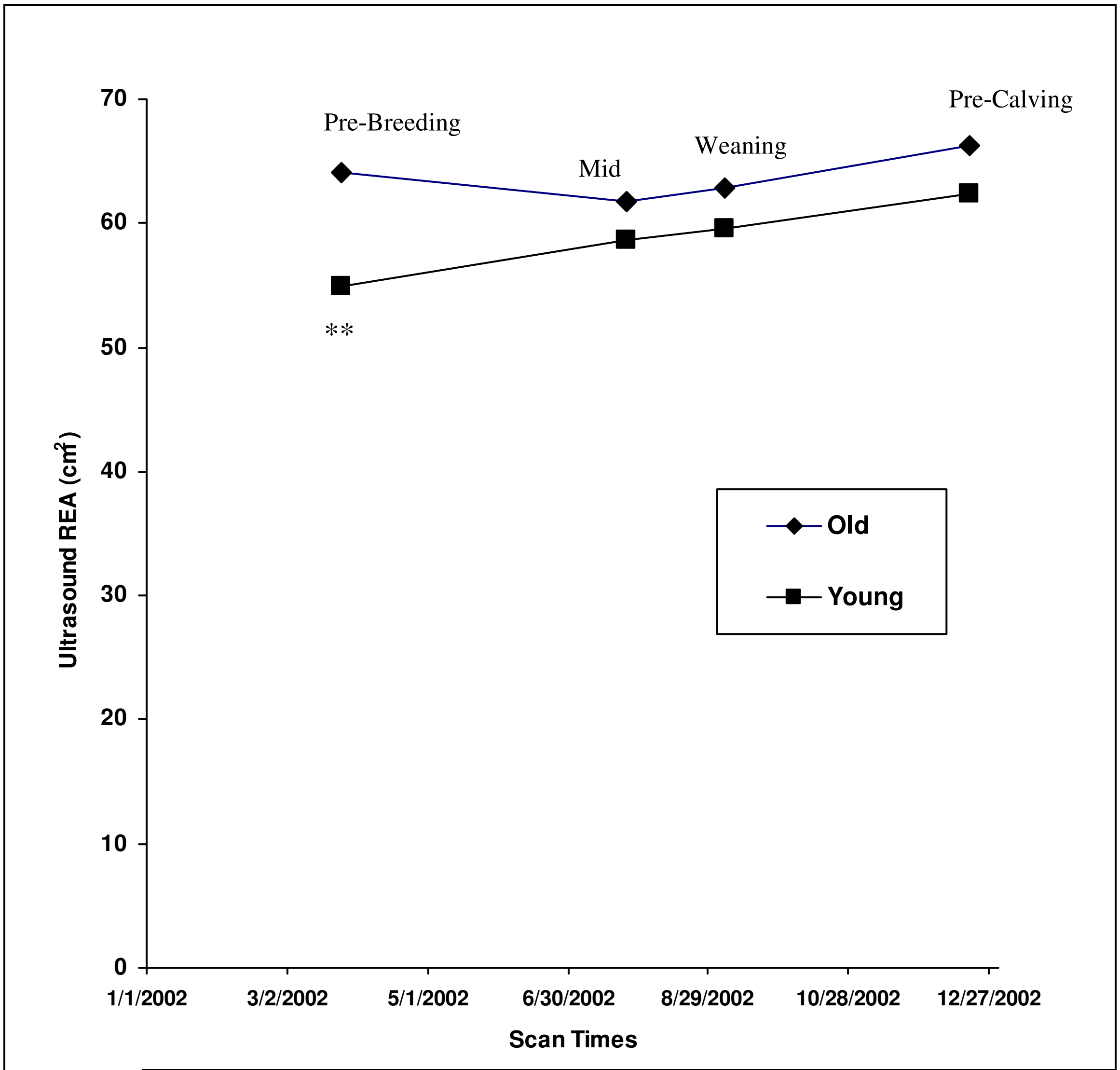
Figure 1. – Changes over time in weight of Angus cows, comparing old vs. young.



Old - Linear, P = 0.09 Young- Linear, P = 0.63
Quadratic, P < 0.01 Quadratic, P = 0.03

* P ≤ 0.05
** P ≤ 0.01

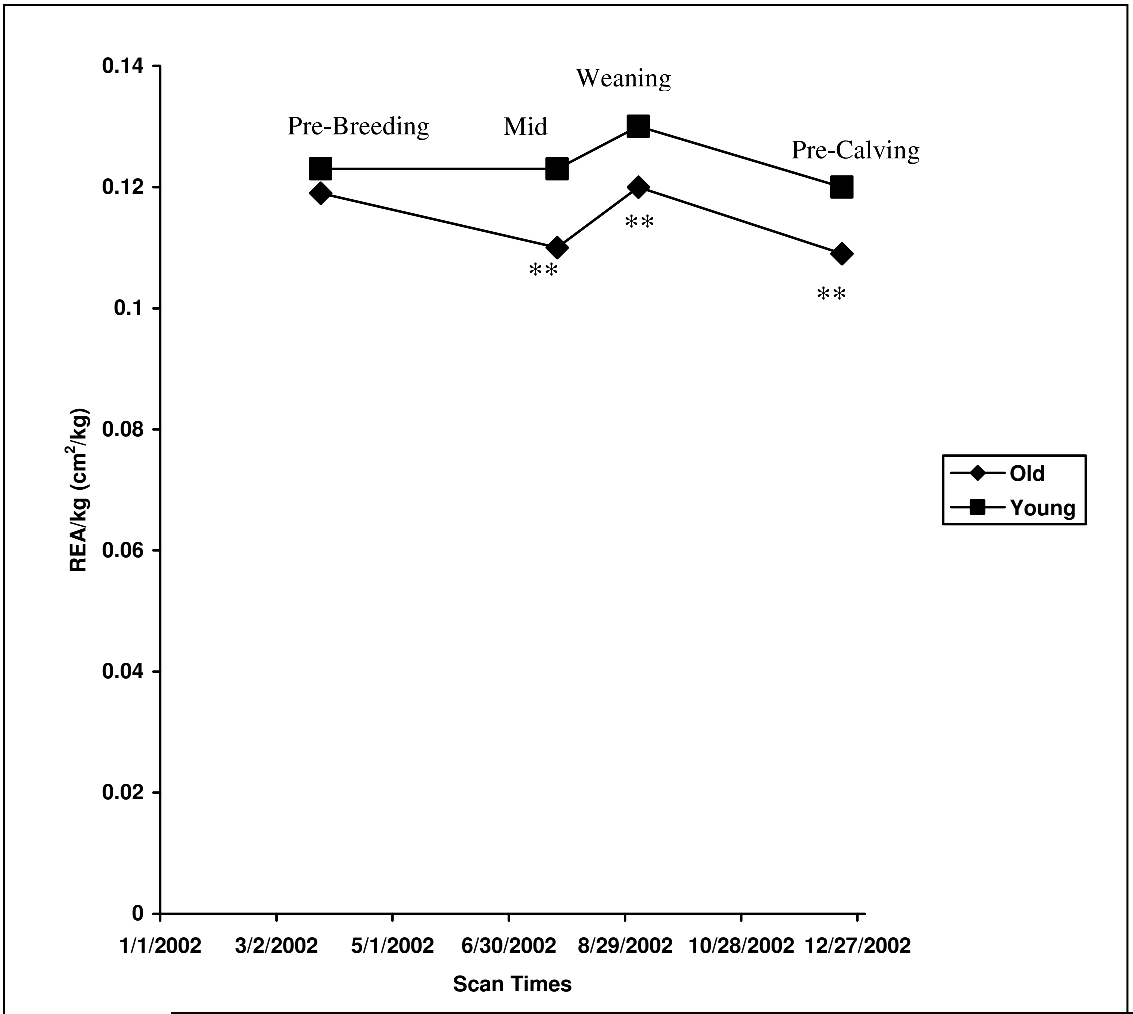
Figure 2. – Changes over time in REA of Angus cows, comparing old vs. young.



Old -	Linear, $P = 0.05$ Quadratic, $P = 0.02$	Young – Linear, $P = 0.16$ Quadratic, $P = 0.70$

* $P \leq 0.05$
** $P \leq 0.01$

Figure 3. – Changes over time in REA/kg of Angus cows, comparing old vs. young.



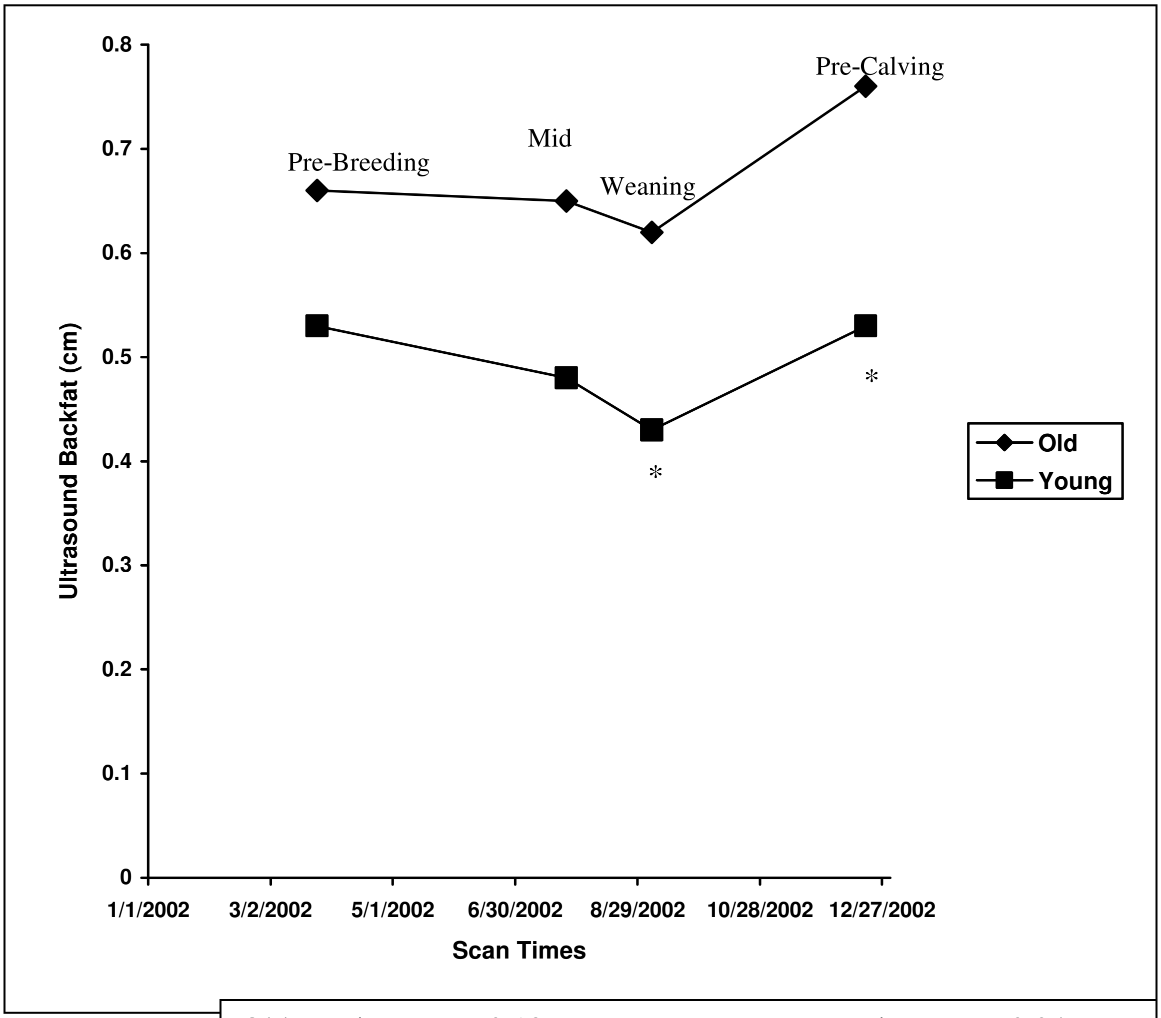
Old - Linear, $P = 0.31$ Young – Linear, $P = 0.02$

Quadratic, $P = 0.99$ Quadratic, $P = 0.01$

* $P \leq 0.05$

** $P \leq 0.01$

Figure 4. – Changes over time in back fat of Angus cows, comparing old vs. young.

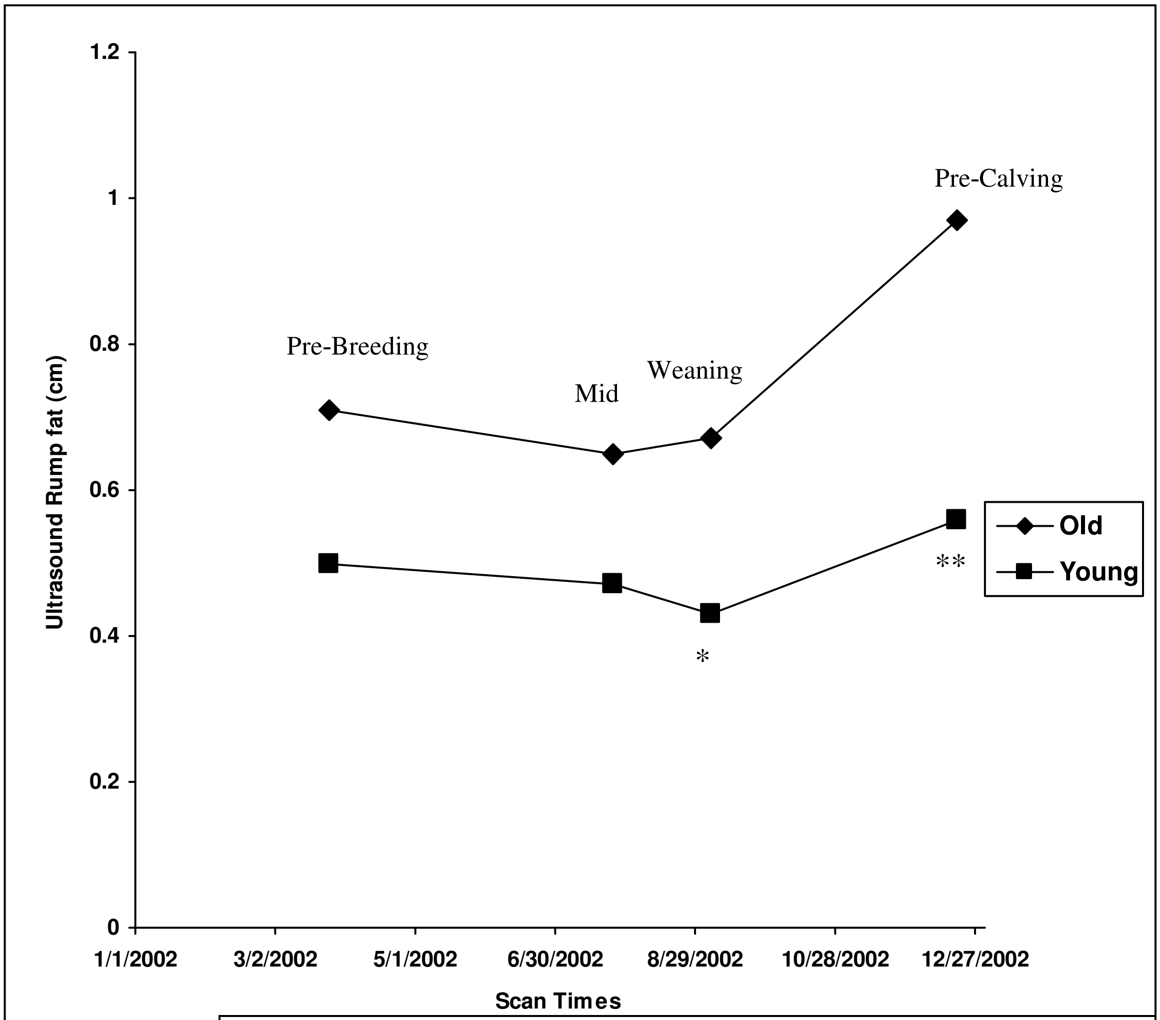


* P ≤ 0.05
** P ≤ 0.01

Old - Linear, P = 0.18
Quadratic, P = 0.06

Young - Linear, P = 0.24
Quadratic, P = 0.24

Figure 5. – Changes over time in rump fat of Angus cows, comparing old vs. young.

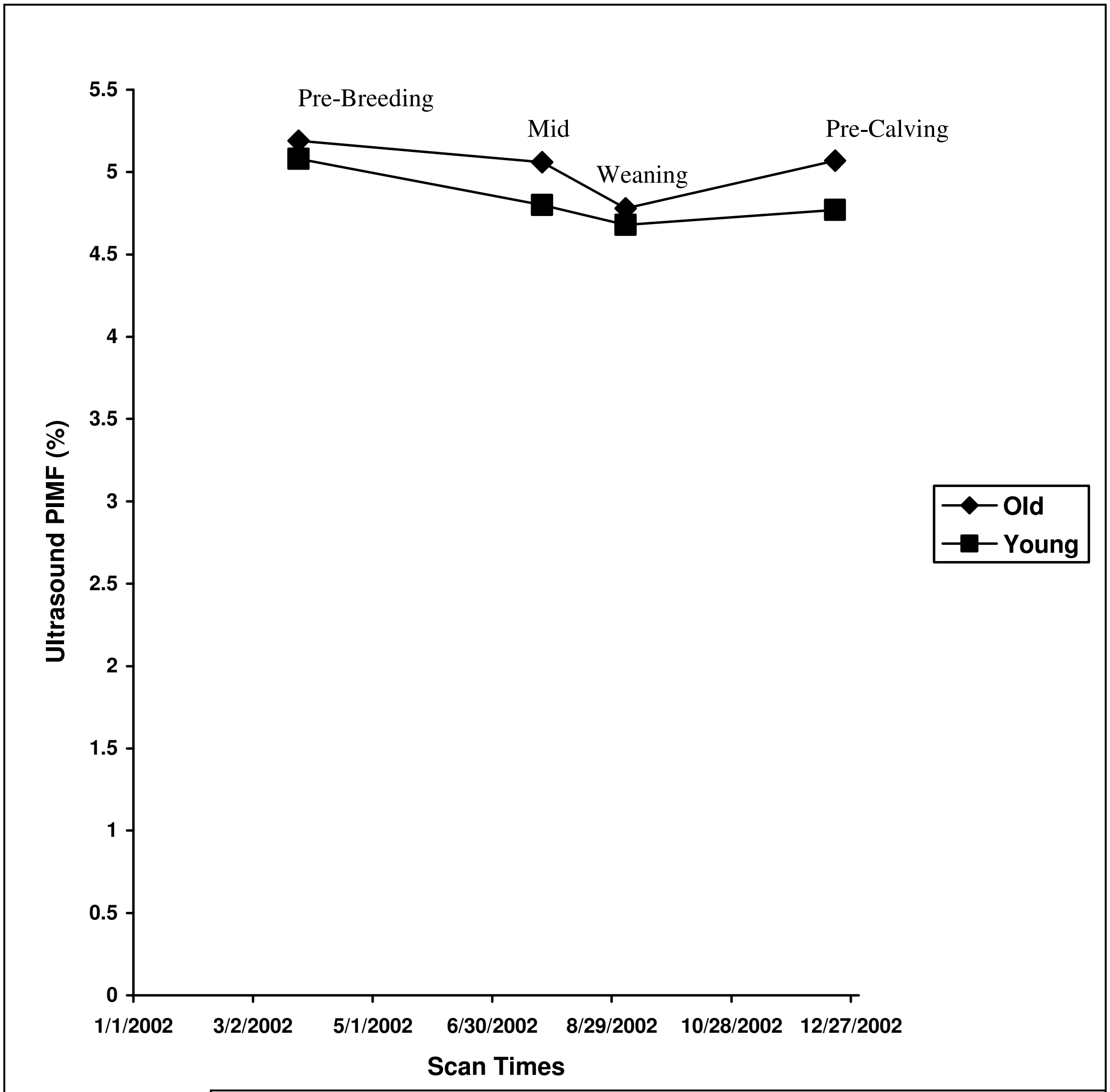


Old - Linear, $P = 0.02$
Quadratic, $P < 0.01$

Young - Linear, $P = 0.31$
Quadratic, $P = 0.20$

* $P \leq 0.05$
** $P \leq 0.01$

Figure 6. – Changes over time in marbling of Angus cows, comparing old vs. young.

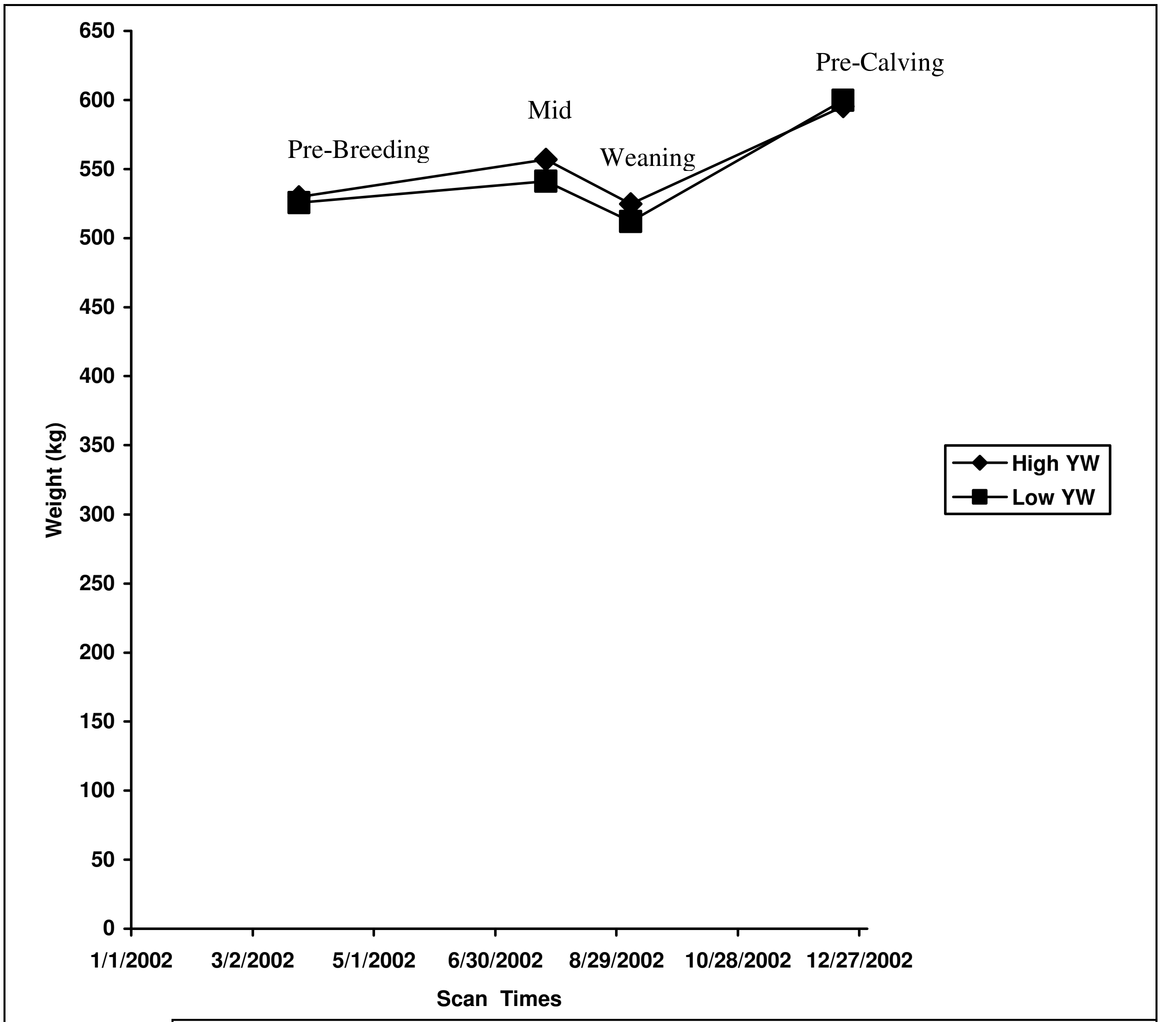


* P ≤ 0.05
** P ≤ 0.01

Old - Linear, P = 0.15
Quadratic, P = 0.21

Young - Linear, P = 0.40
Quadratic, P = 0.59

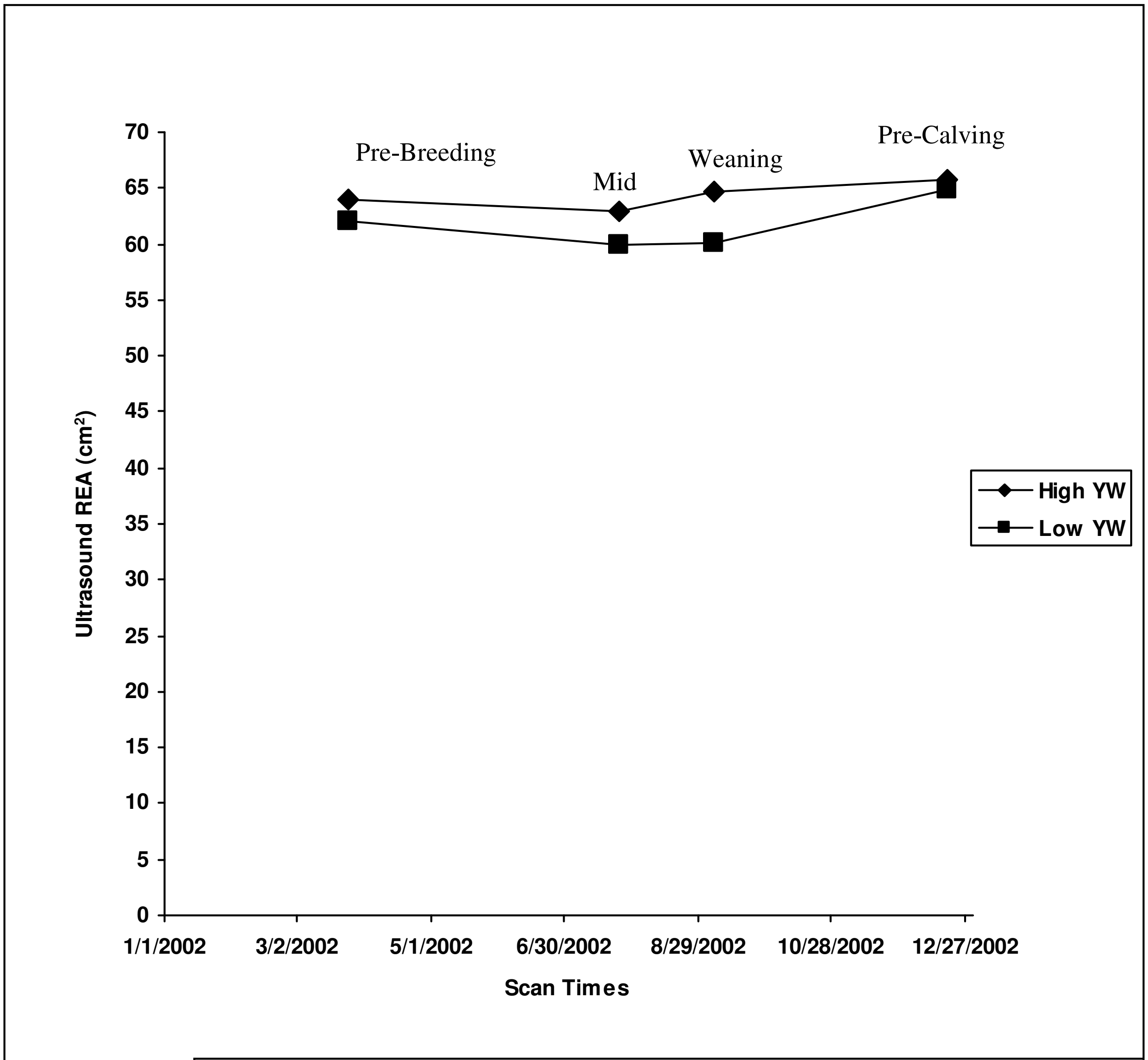
Figure 7. – Changes over time in weight of Angus cows, comparing high YW vs. low YW EPD.



High YW-	Linear, P = 0.46 Quadratic, P = 0.07	Low YW -	Linear, P = 0.28 Quadratic, P = 0.05

* $P \leq 0.05$
** $P \leq 0.01$

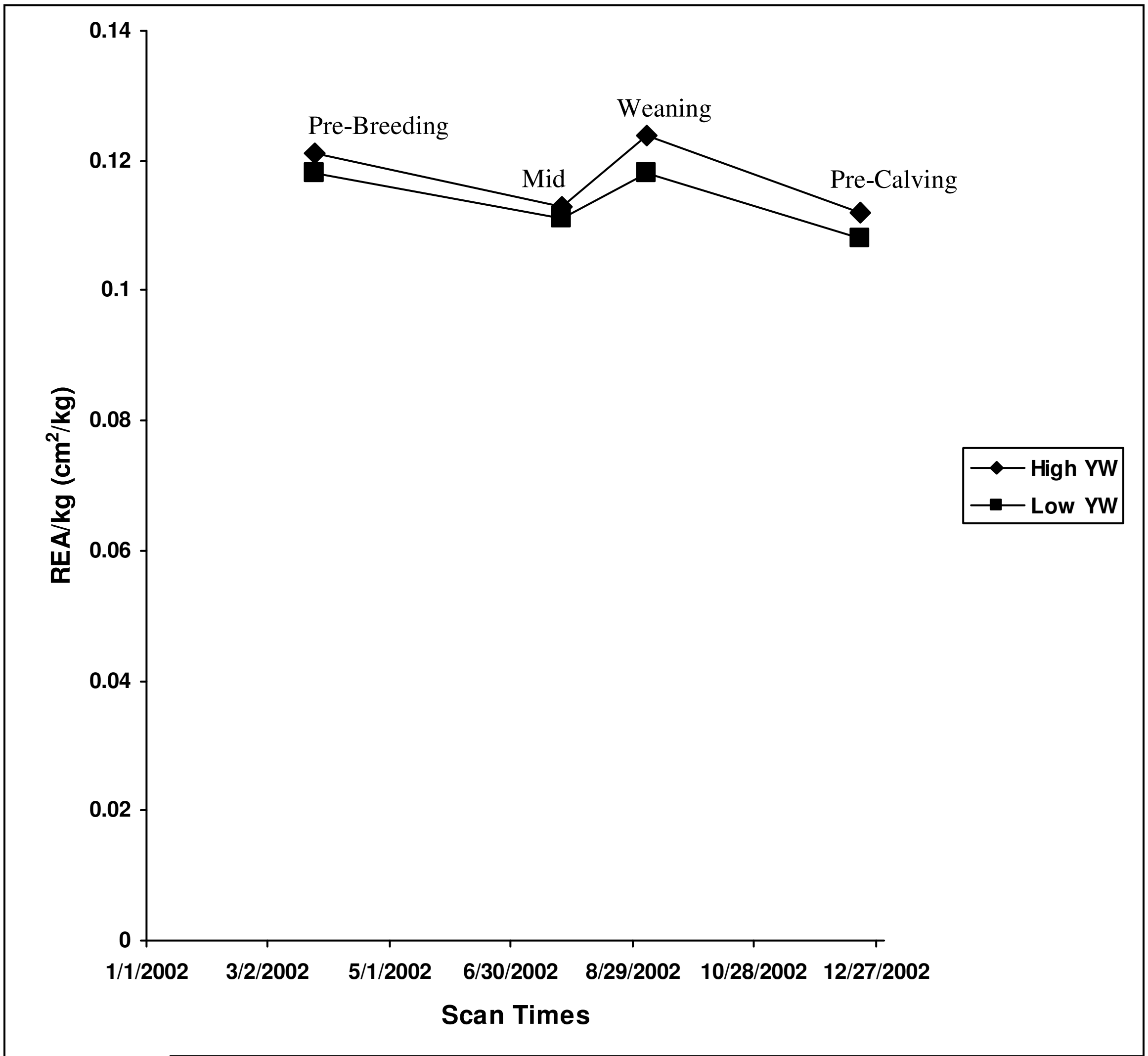
Figure 8. – Changes over time in REA of Angus cows, comparing high YW vs. low YW EPD.



High YW -	Linear, P = 0.48	Low YW -	Linear, P = 0.25
	Quadratic, P = 0.33		Quadratic, P = 0.14

* $P \leq 0.05$
** $P \leq 0.01$

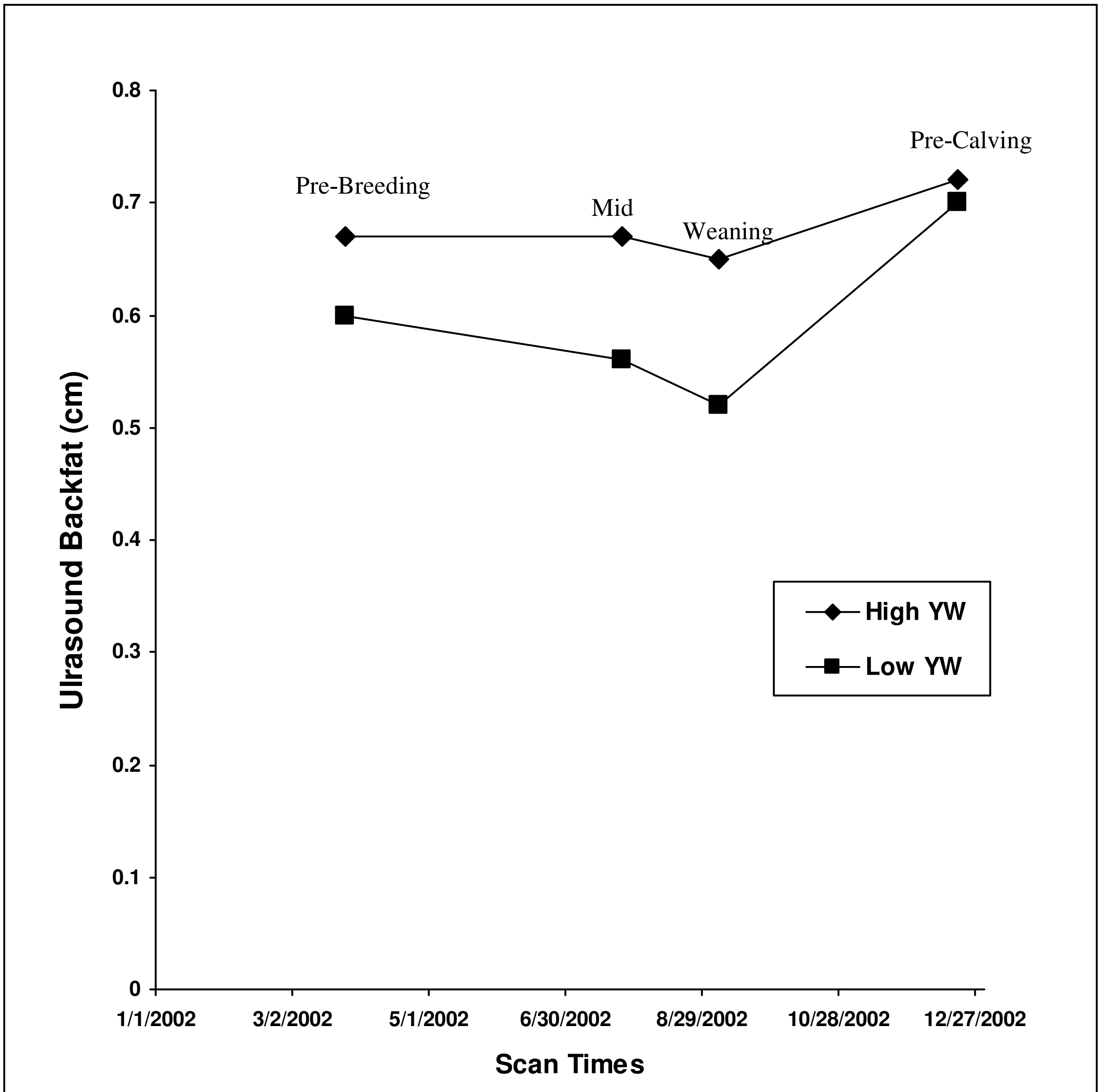
Figure 9. – Changes over time in REA/kg of Angus cows, comparing high YW vs. low YW EPD.



High YW - Linear, $P = 0.87$ Low YW - Linear, $P = 0.70$
Quadratic, $P = 0.50$ Quadratic, $P = 0.92$

* $P \leq 0.05$
** $P \leq 0.01$

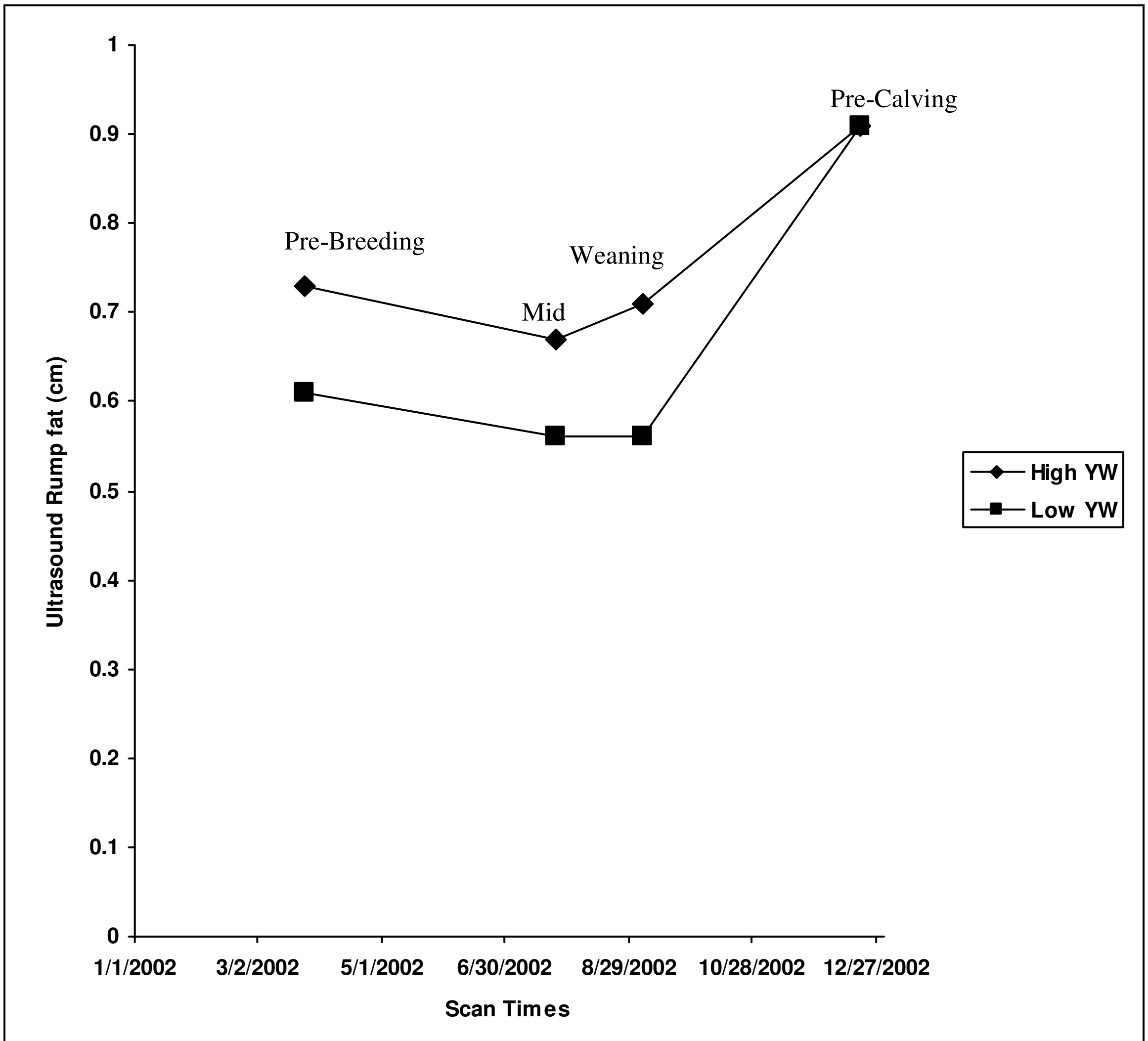
Figure 10. – Changes over time in back fat of Angus cows, comparing high YW vs. low YW EPD.



High YW -	Linear, $P = 0.51$	Low YW -	Linear, $P = 0.23$
	Quadratic, $P = 0.38$		Quadratic, $P = 0.11$

* $P \leq 0.05$
** $P \leq 0.01$

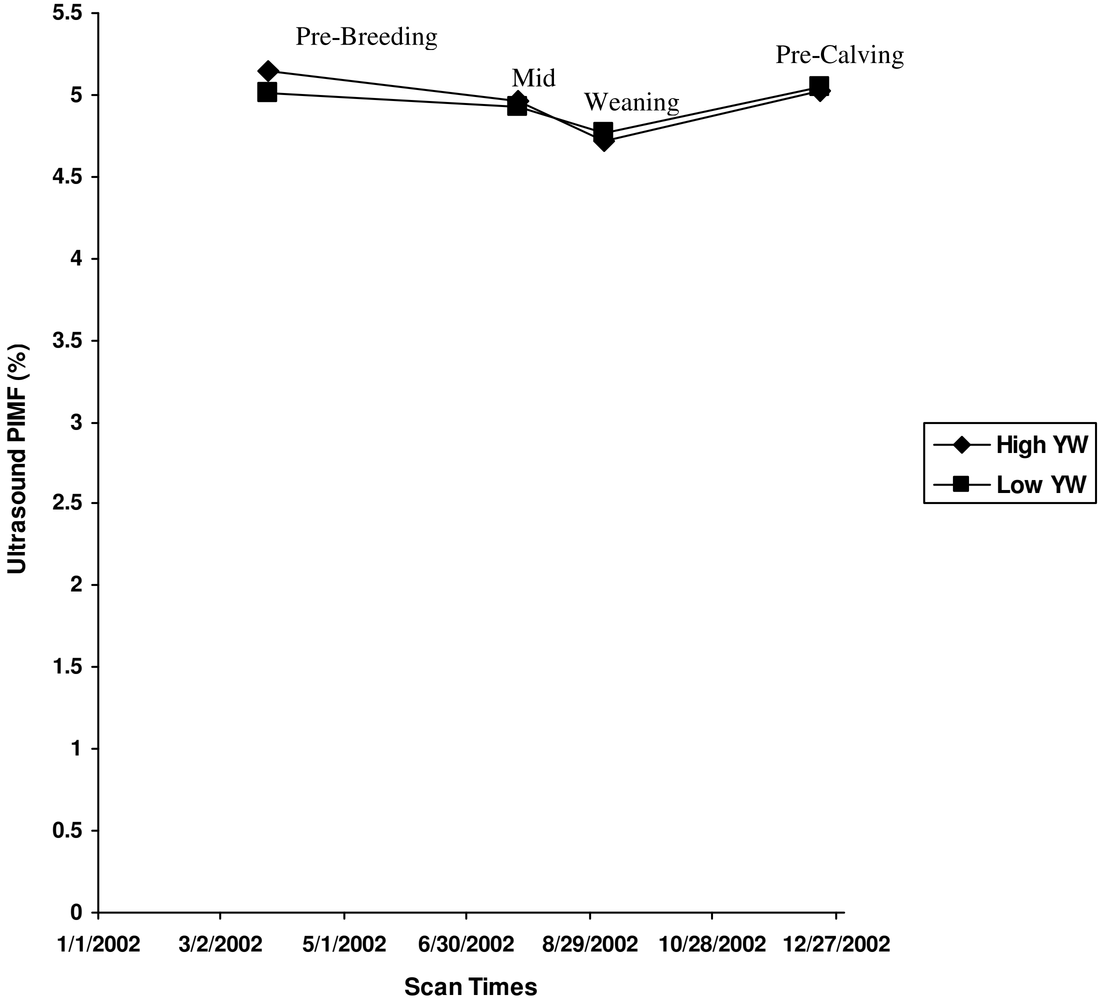
Figure 11. – Changes over time in rump fat of Angus cows, comparing high YW vs. low YW EPD.



High YW - Linear, $P = 0.19$ Low YW - Linear, $P = 0.06$
Quadratic, $P = 0.05$ Quadratic, $P < 0.01$

* $P \leq 0.05$
** $P \leq 0.01$

Figure 12. – Changes over time in marbling of Angus cows, comparing high YW vs. low YW EPD.

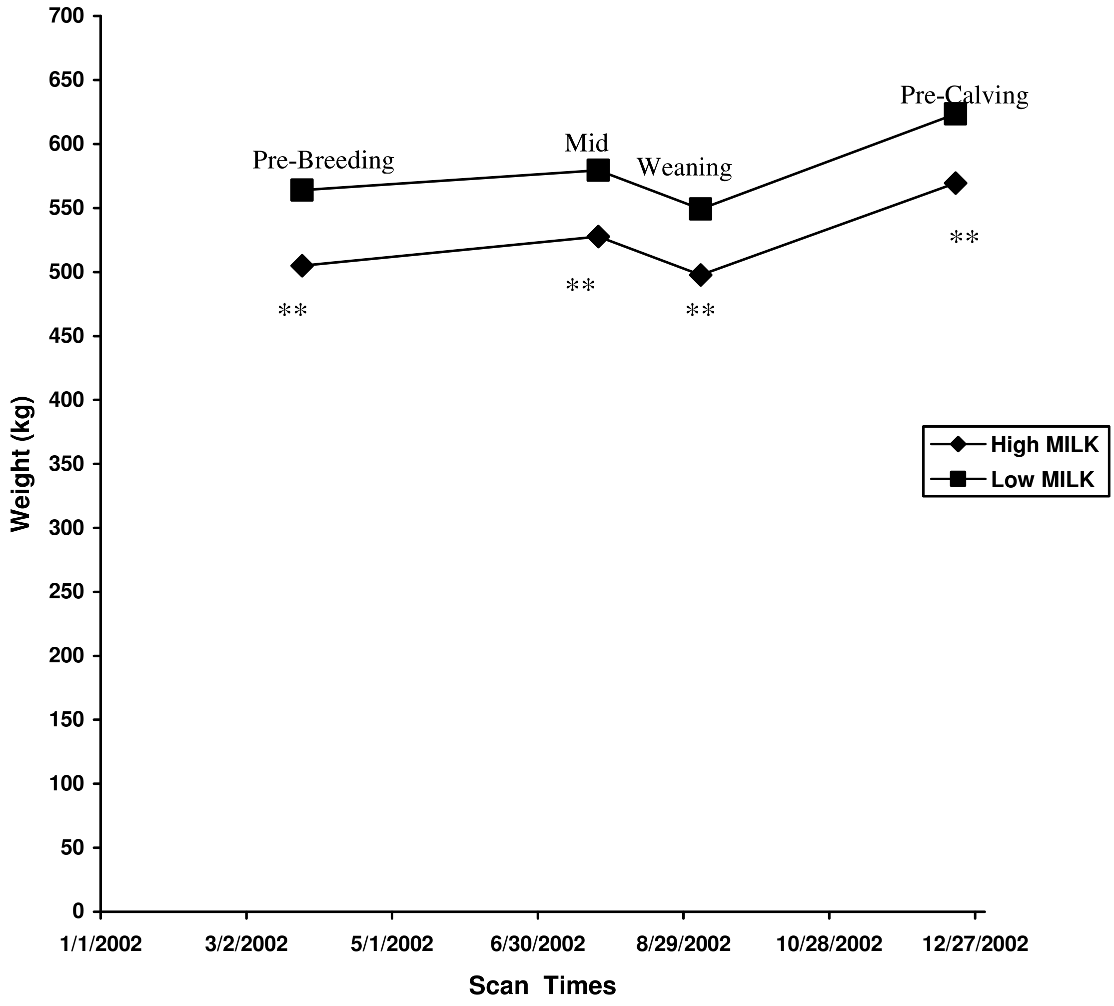


High YW - Linear, P = 0.22
Quadratic, P = 0.26

Low YW - Linear, P = 0.42
Quadratic, P = 0.41

* $P \leq 0.05$
** $P \leq 0.01$

Figure 13. – Changes over time in weight of Angus cows, comparing high MILK vs. low MILK EPD.

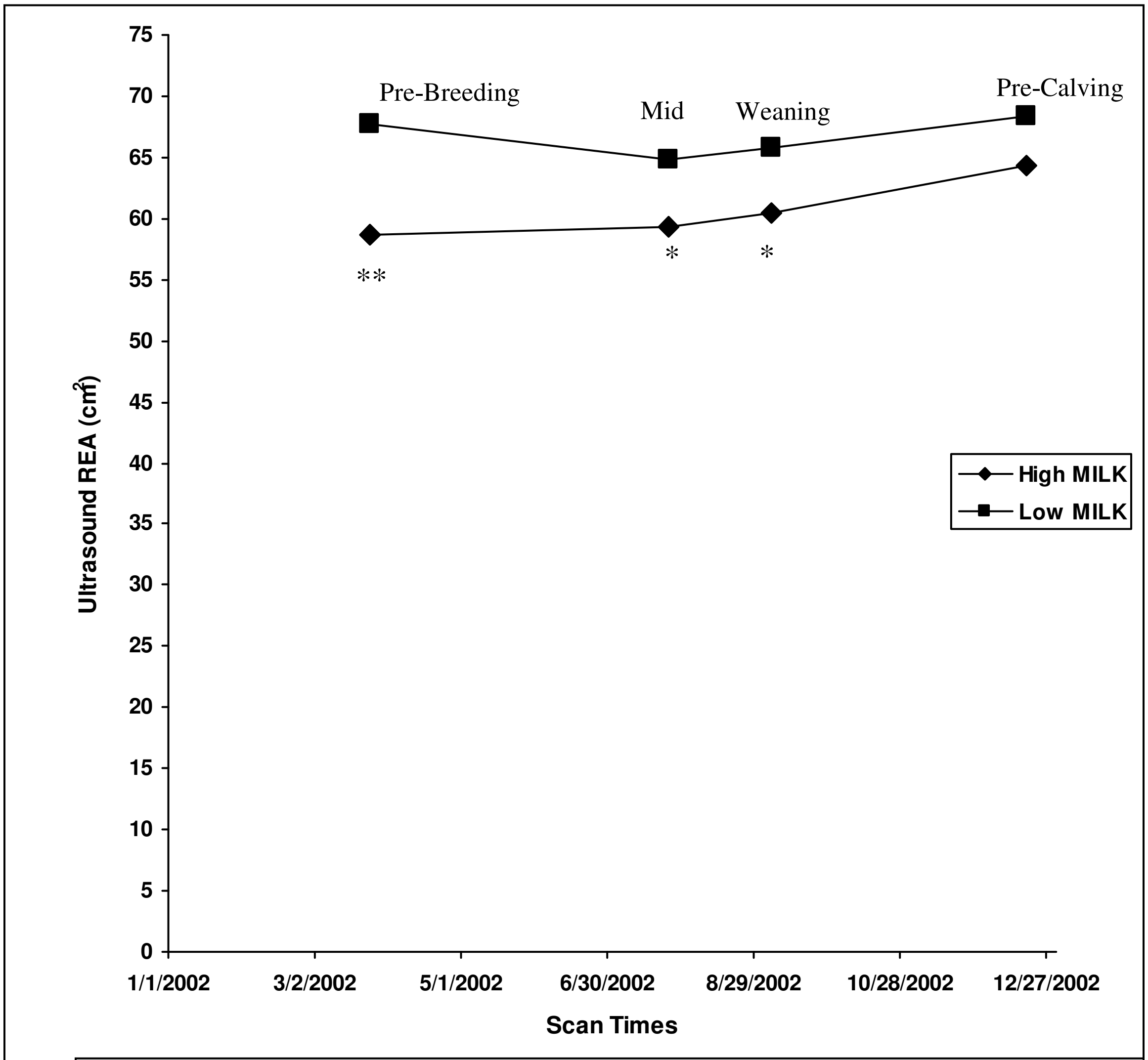


High MILK- Linear, $P = 0.38$
Quadratic, $P = 0.05$

Low MILK - Linear, $P = 0.15$
Quadratic, $P = 0.02$

* $P \leq 0.05$
** $P \leq 0.01$

Figure 14. – Changes over time in REA of Angus cows, comparing high MILK vs. low MILK EPD.

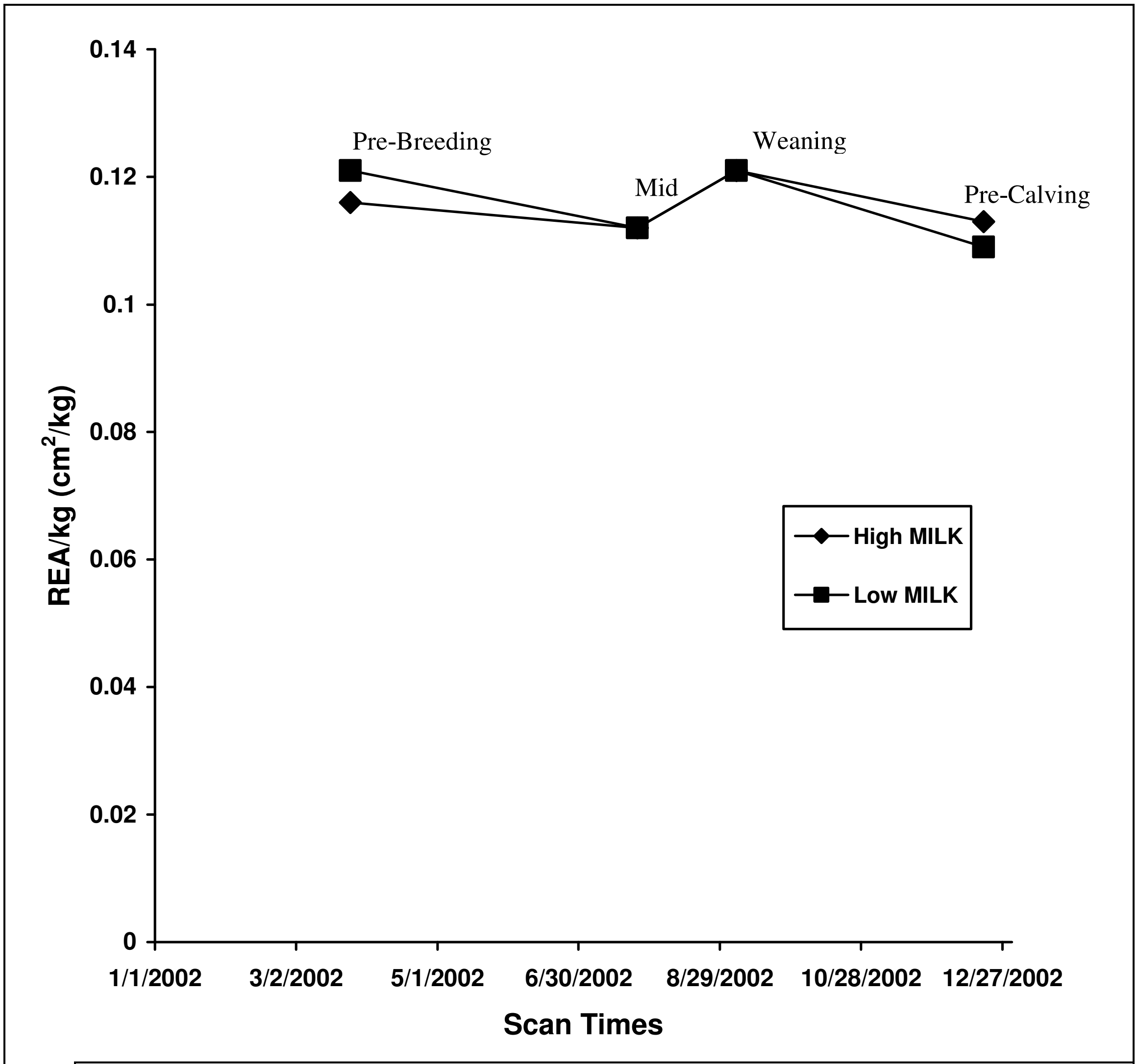


High MILK - Linear, $P = 0.89$
Quadratic, $P = 0.41$

Low MILK - Linear, $P = 0.05$
Quadratic, $P = 0.05$

* $P \leq 0.05$
** $P \leq 0.01$

Figure 15. – Changes over time in REA/kg of Angus cows, comparing high MILK vs. low MILK EPD.

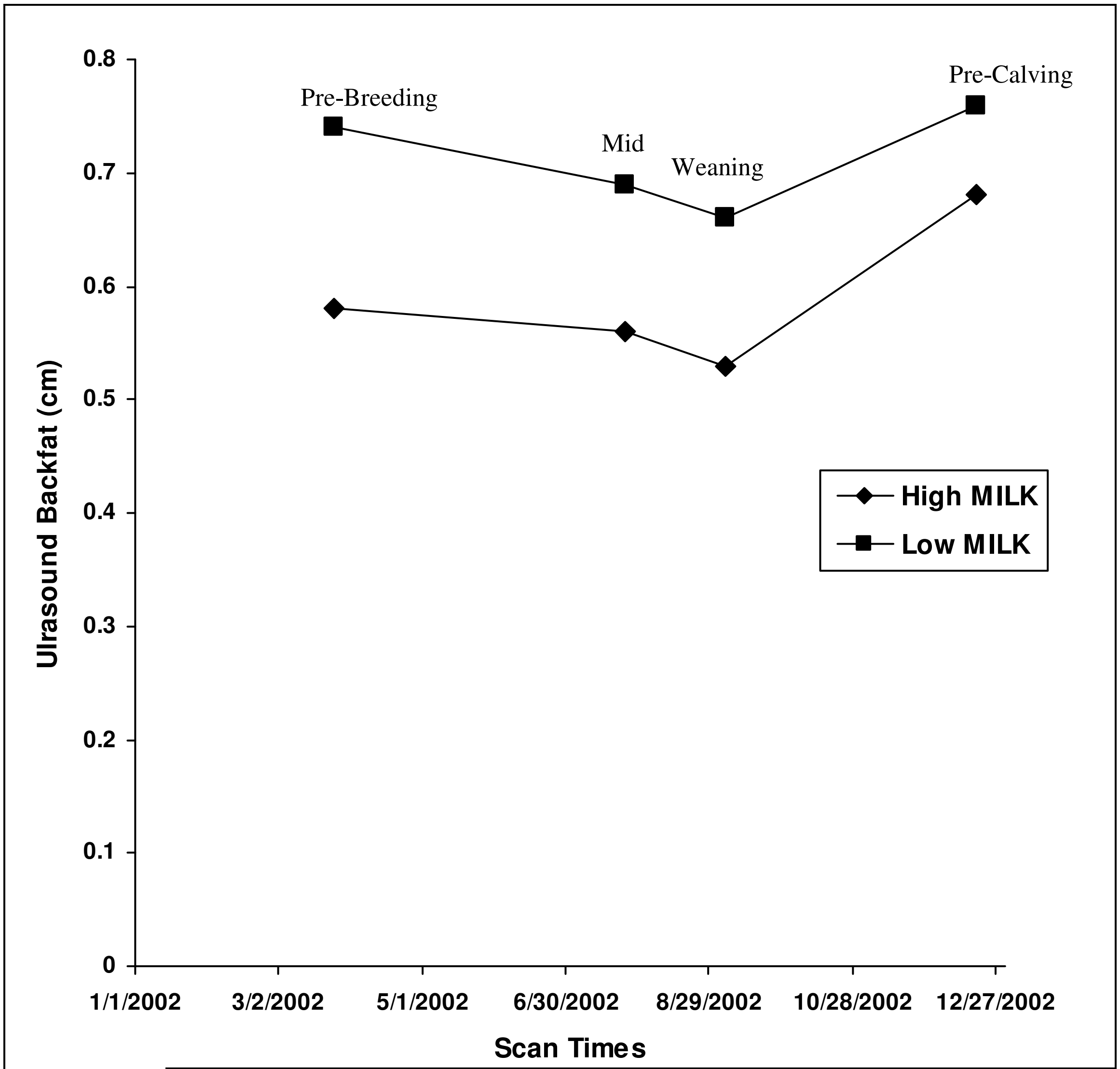


High MILK - Linear, $P = 0.46$
Quadratic, $P = 0.38$

Low MILK - Linear, $P = 0.33$
Quadratic, $P = 0.92$

* $P \leq 0.05$
** $P \leq 0.01$

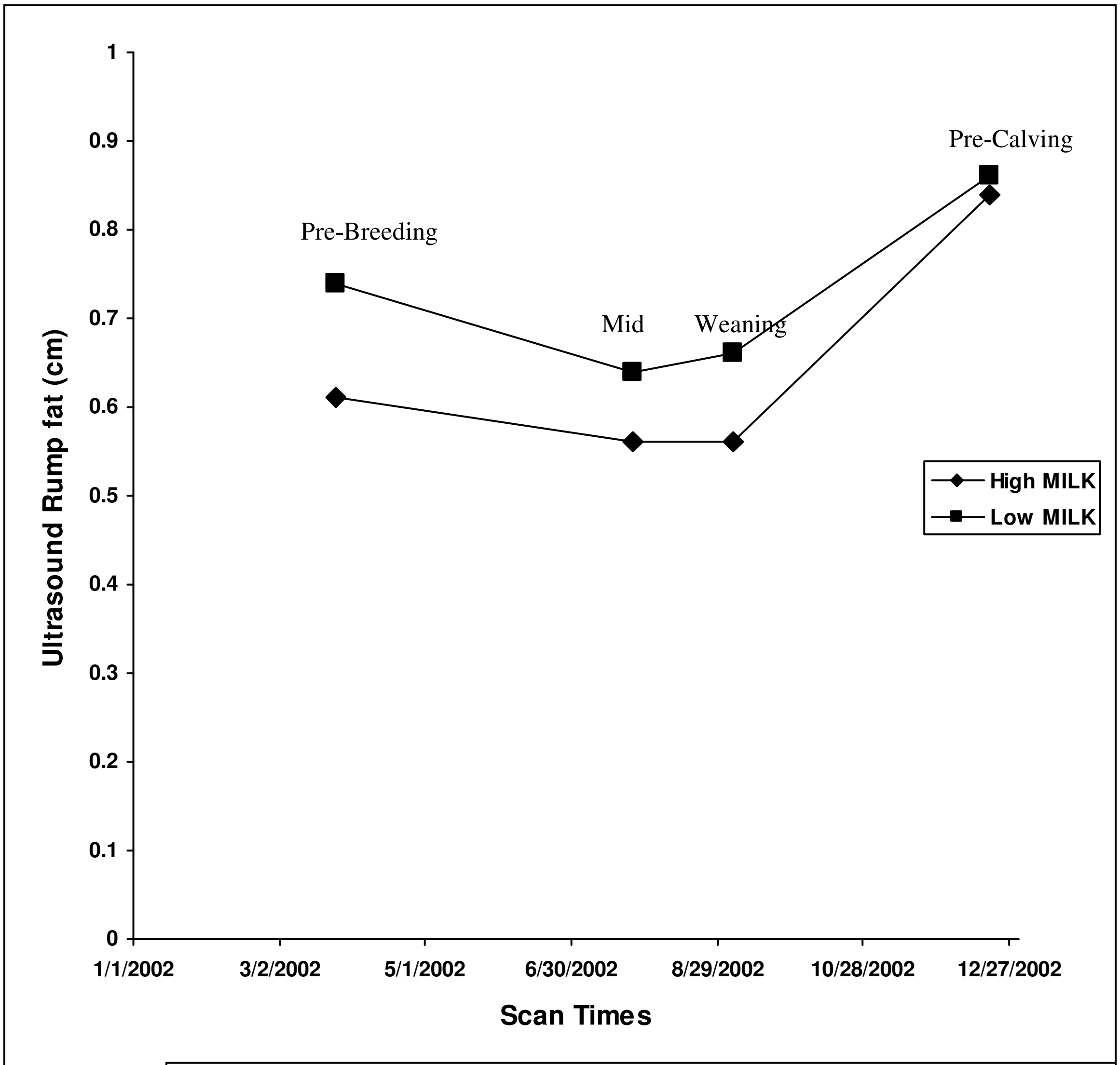
Figure 16. – Changes over time in back fat of Angus cows, comparing high MILK vs. low MILK EPD.



High MILK -	Linear, P = 0.24	Low MILK -	Linear, P = 0.29
	Quadratic, P = 0.12		Quadratic, P = 0.23

* P ≤ 0.05
** P ≤ 0.01

Figure 17. – Changes over time in rump fat of Angus cows, comparing high MILK vs. low MILK EPD.

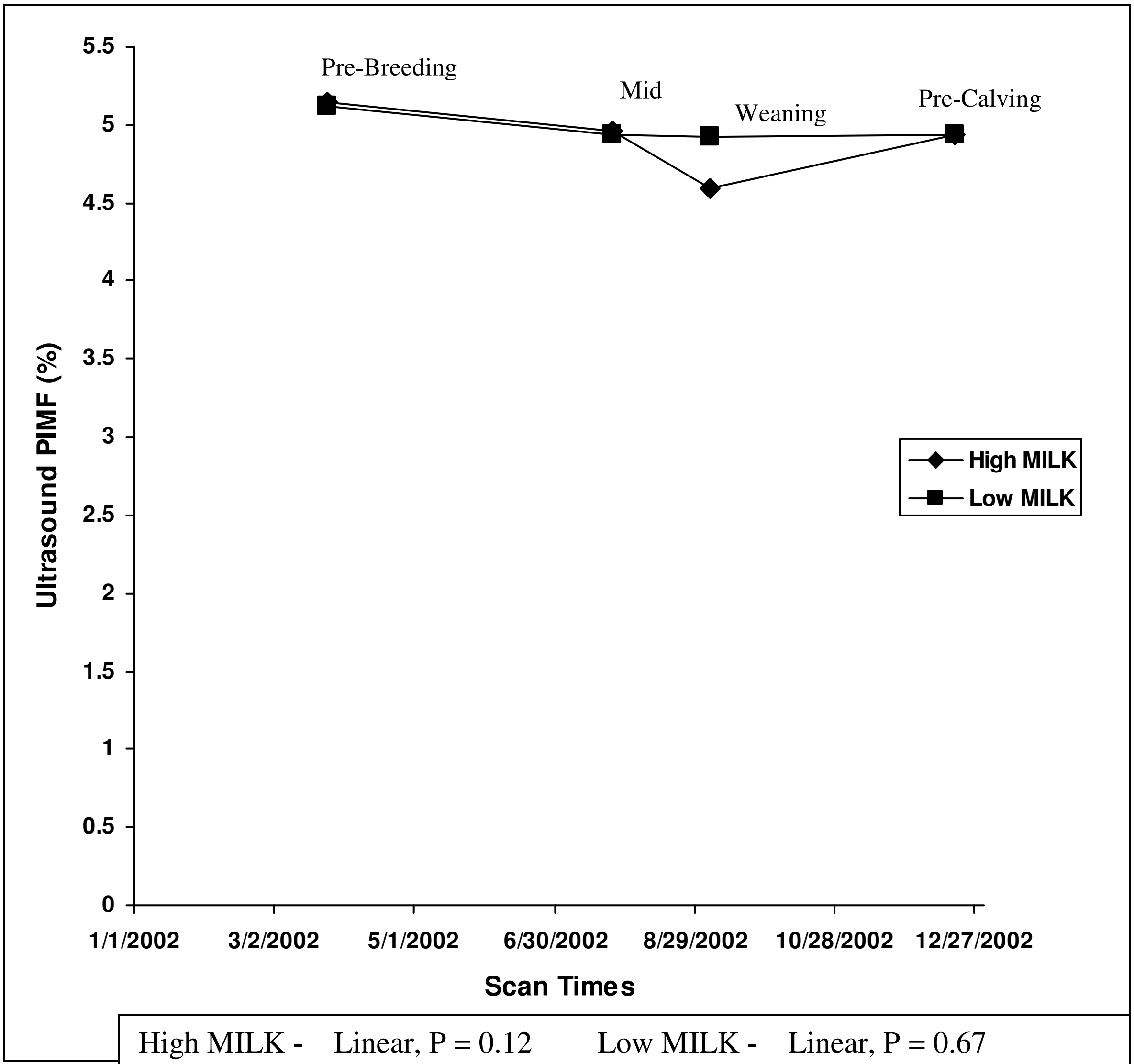


* P ≤ 0.05
** P ≤ 0.01

High MILK - Linear, P = 0.16
Quadratic, P = 0.03

Low MILK - Linear, P = 0.03
Quadratic, P = 0.01

Figure 18. – Changes over time in marbling of Angus cows, comparing high MILK vs. low MILK EPD.

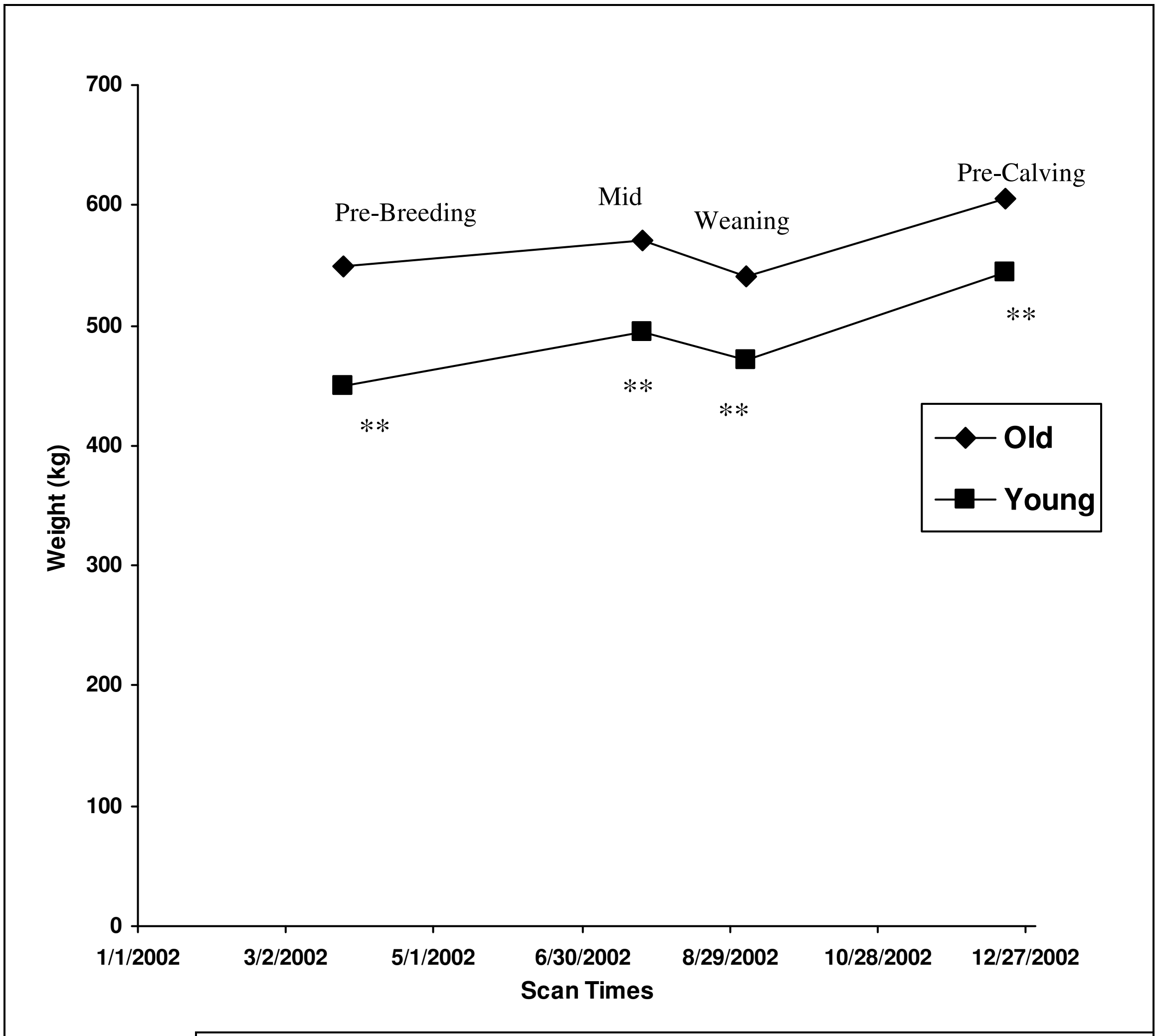


High MILK -	Linear, P = 0.12	Low MILK -	Linear, P = 0.67
	Quadratic, P = 0.21		Quadratic, P = 0.74

* $P \leq 0.05$

** $P \leq 0.01$

Figure 19. – Changes over time in weight of Hereford cows, comparing old vs. young.

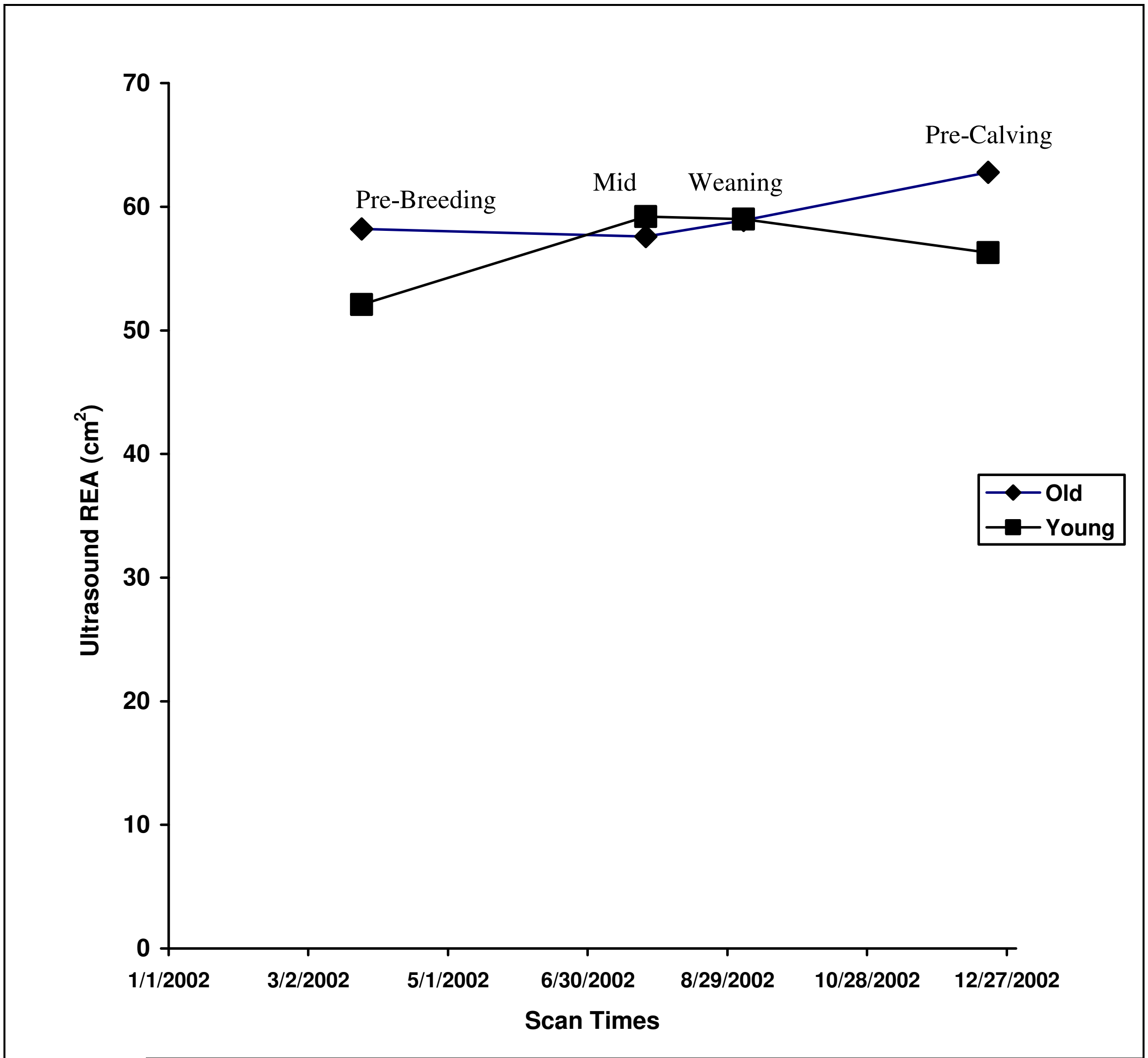


Old - Linear, P = 0.28
Quadratic, P = 0.01

Young- Linear, P = 0.05
Quadratic, P = 0.22

* $P \leq 0.05$
** $P \leq 0.01$

Figure 20. – Changes over time in REA of Hereford cows, comparing old vs. young.

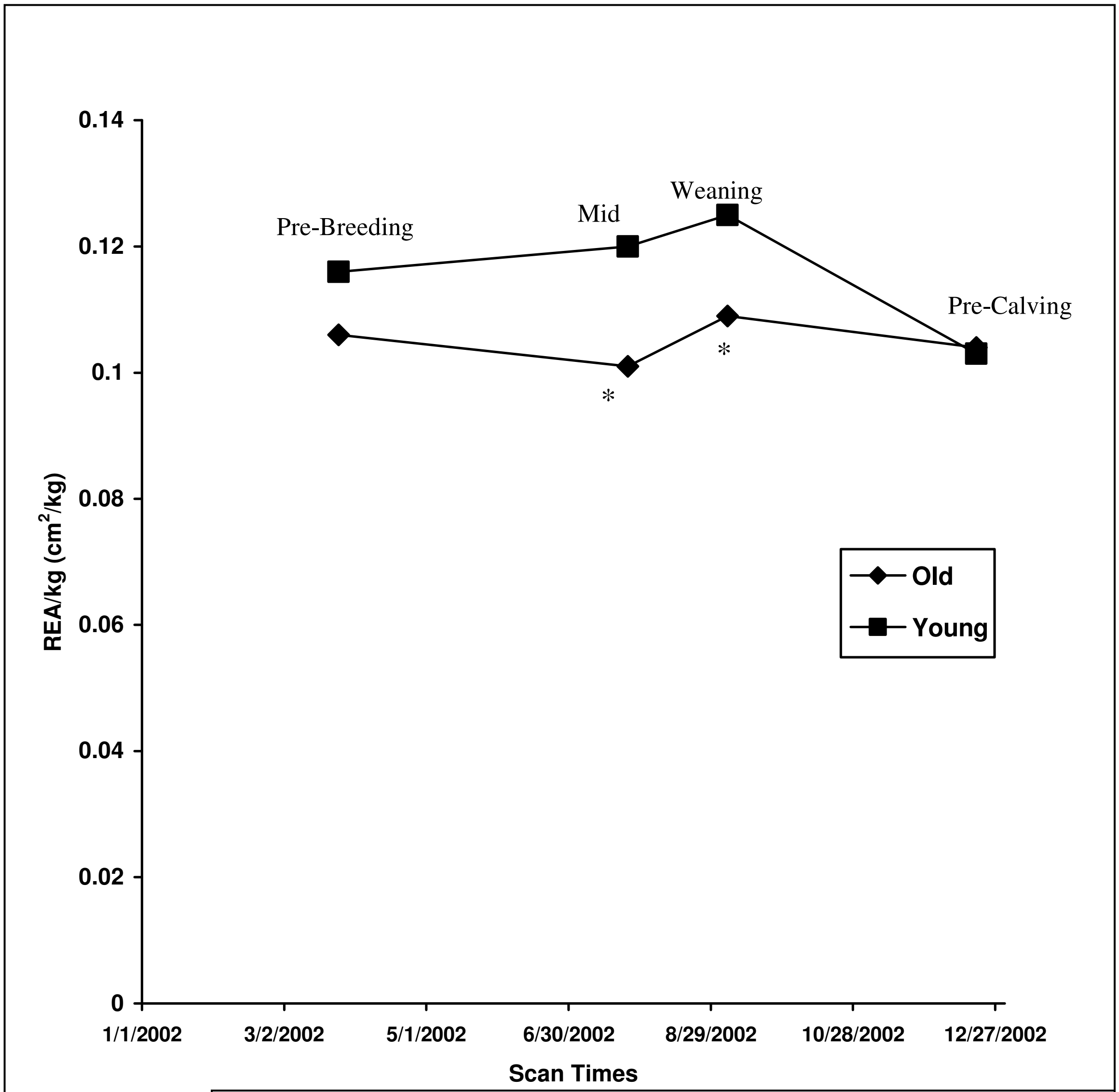


Old - Linear, $P = 0.24$
Quadratic, $P = 0.66$

Young - Linear, $P = 0.05$
Quadratic, $P = 0.22$

* $P \leq 0.05$
** $P \leq 0.01$

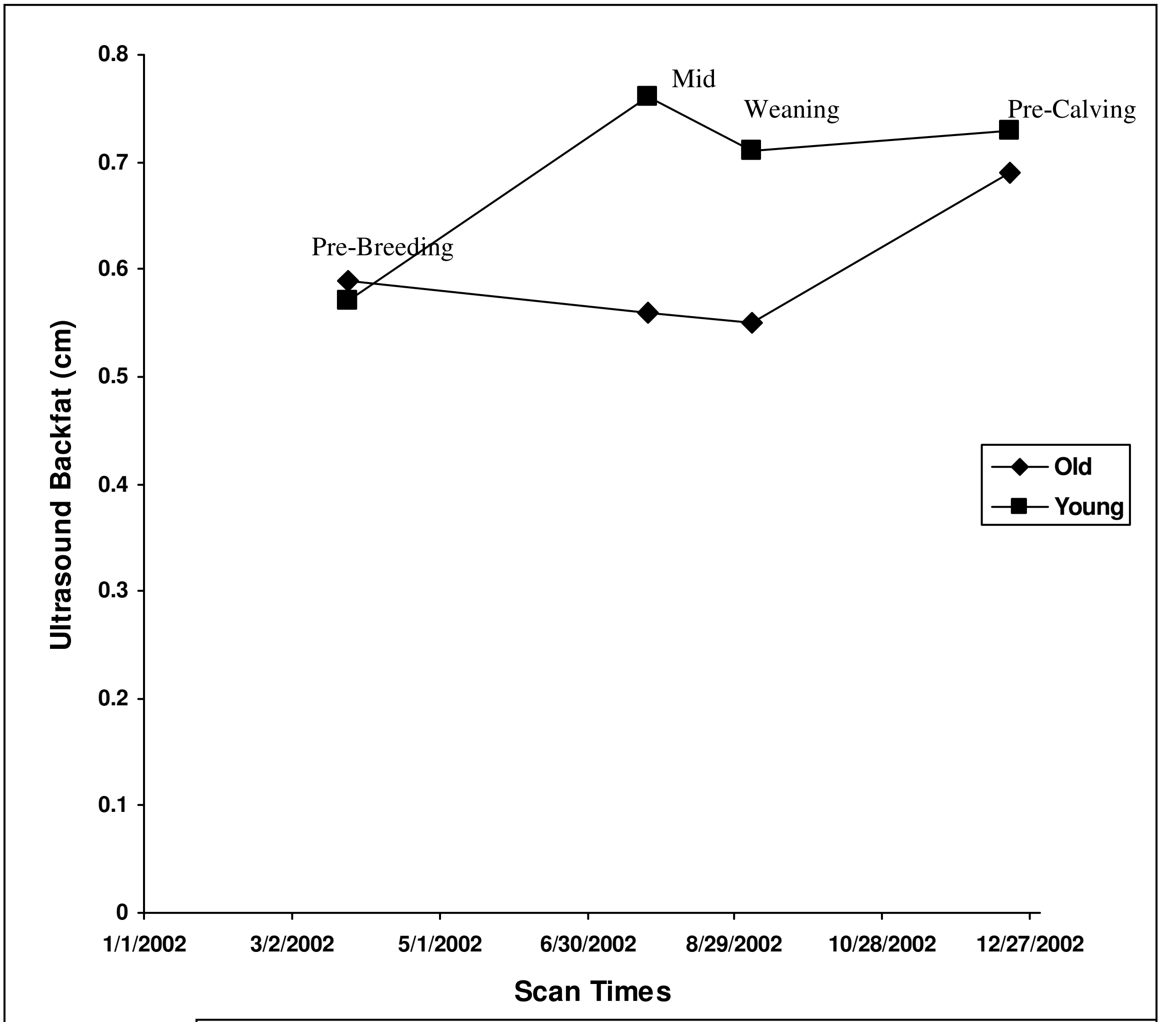
Figure 21. – Changes over time in REA/kg of Hereford cows, comparing old vs. young.



* $P \leq 0.05$
** $P \leq 0.01$

Old -	Linear, P = 0.84	Young -	Linear, P = 0.06
	Quadratic, P = 0.79		Quadratic, P = 0.04

Figure 22. – Changes over time in back fat of Hereford cows, comparing old vs. young.

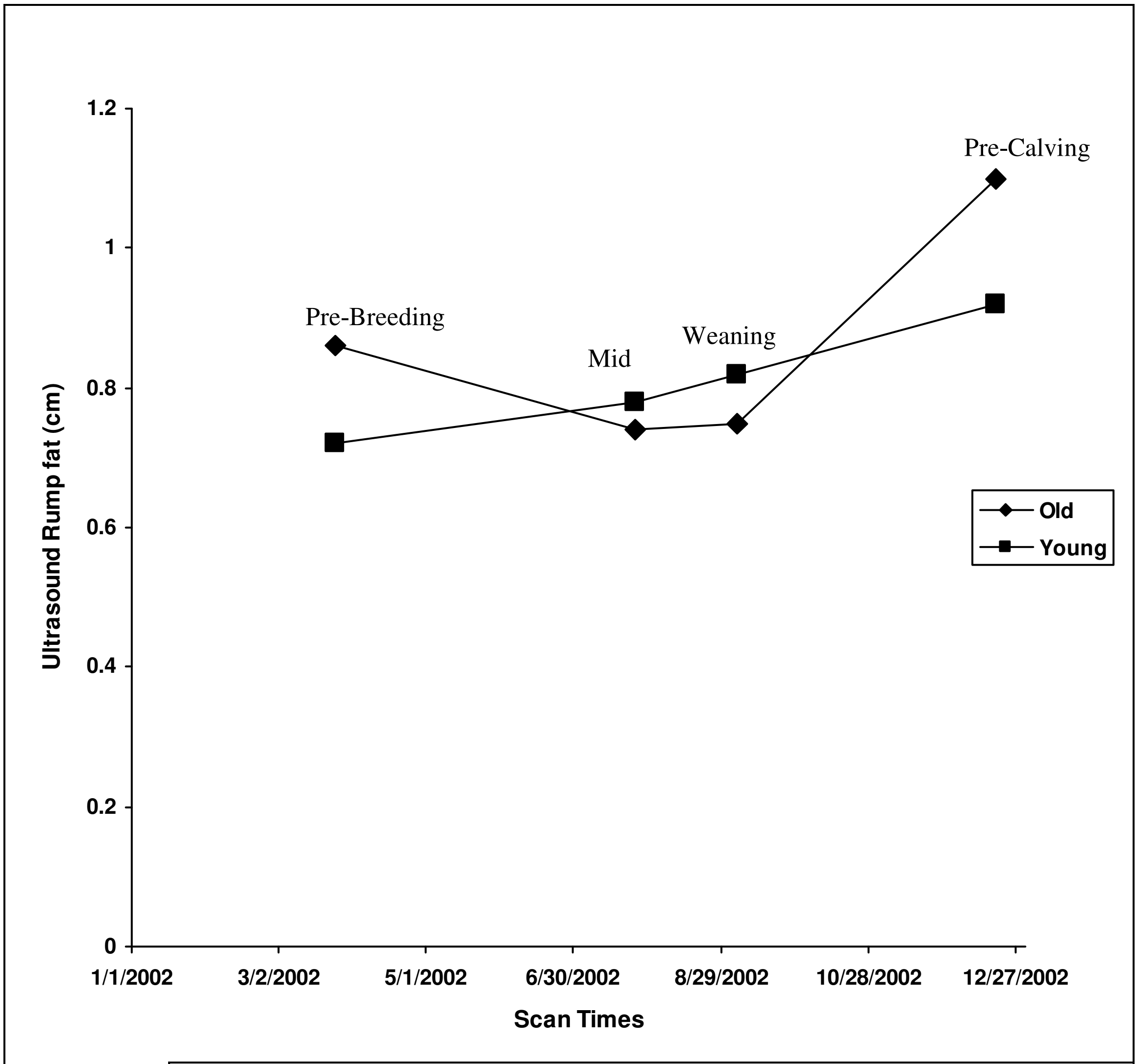


Old - Linear, P = 0.25
Quadratic, P = 0.12

Young - Linear, P = 0.49
Quadratic, P = 0.79

* P ≤ 0.05
** P ≤ 0.01

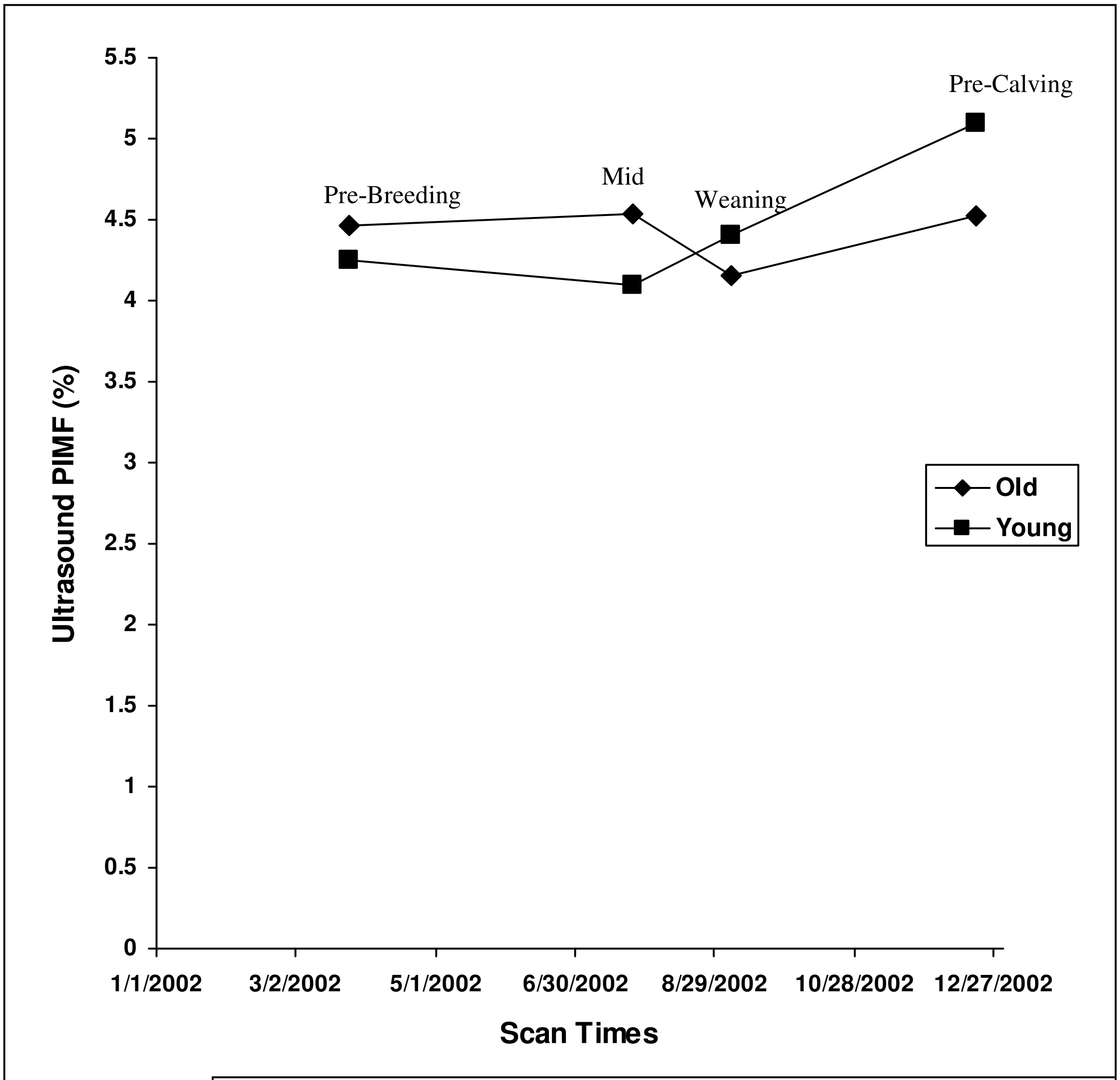
Figure 23. – Changes over time in rump fat of Hereford cows, comparing old vs. young.



Old -	Linear, $P = 0.25$	Young -	Linear, $P = 0.80$
	Quadratic, $P = 0.12$		Quadratic, $P = 0.41$

* $P \leq 0.05$
** $P \leq 0.01$

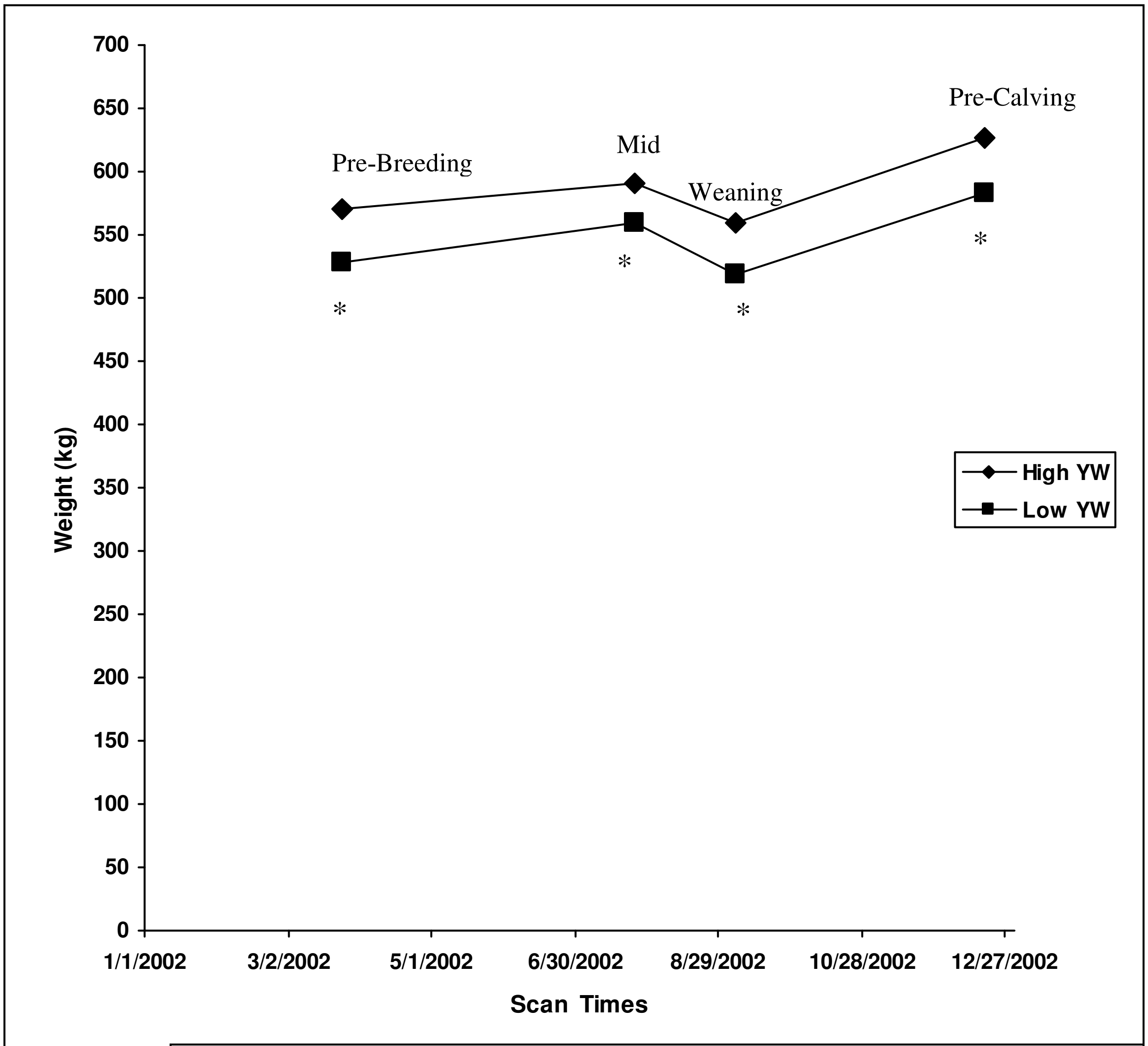
Figure 24. – Changes over time in marbling of Hereford cows, comparing old vs. young.



Old -	Linear, P = 0.43	Young -	Linear, P = 0.15
	Quadratic, P = 0.44		Quadratic, P = 0.02

* P ≤ 0.05
** P ≤ 0.01

Figure 25. – Changes over time in weight of Hereford cows, comparing high YW vs. low YW EPD.

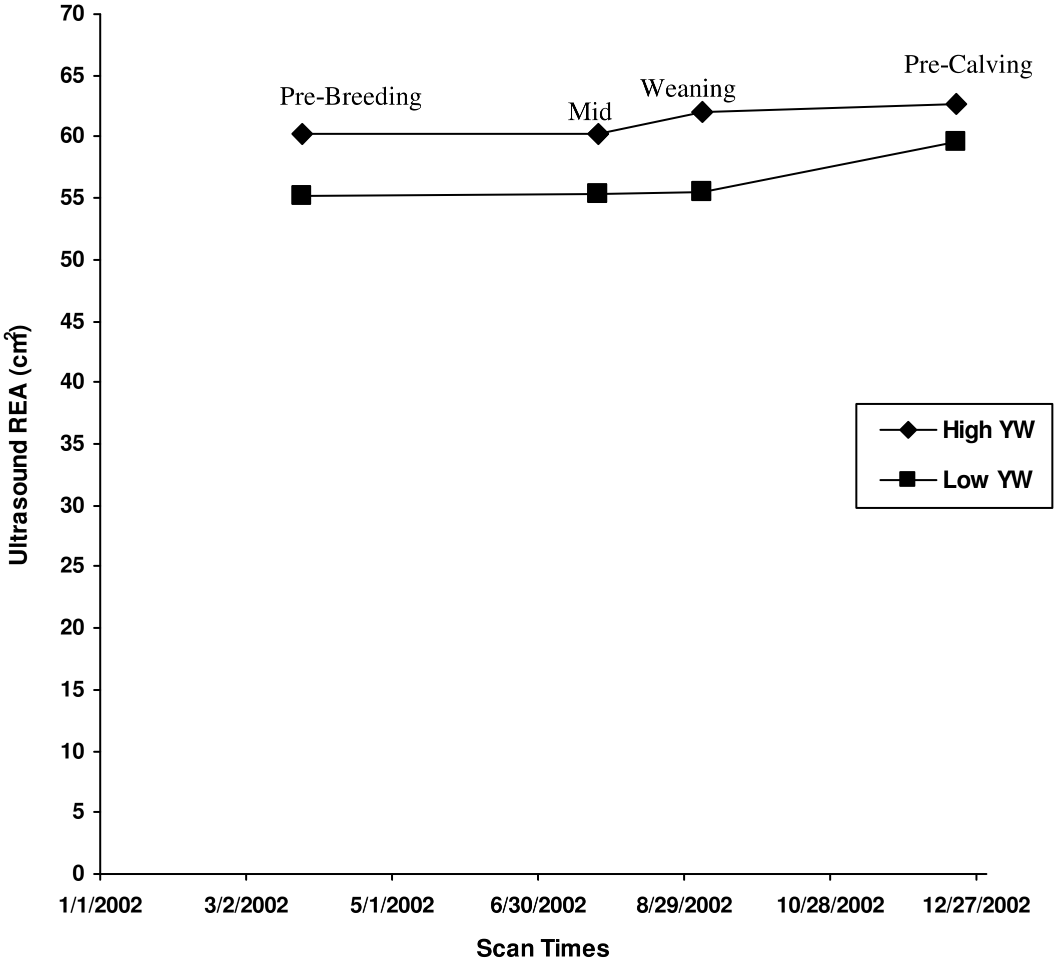


High YW- Linear, $P = 0.39$ Quadratic, $P = 0.11$

Low YW - Linear, $P = 0.37$ Quadratic, $P = 0.07$

* $P \leq 0.05$
** $P \leq 0.01$

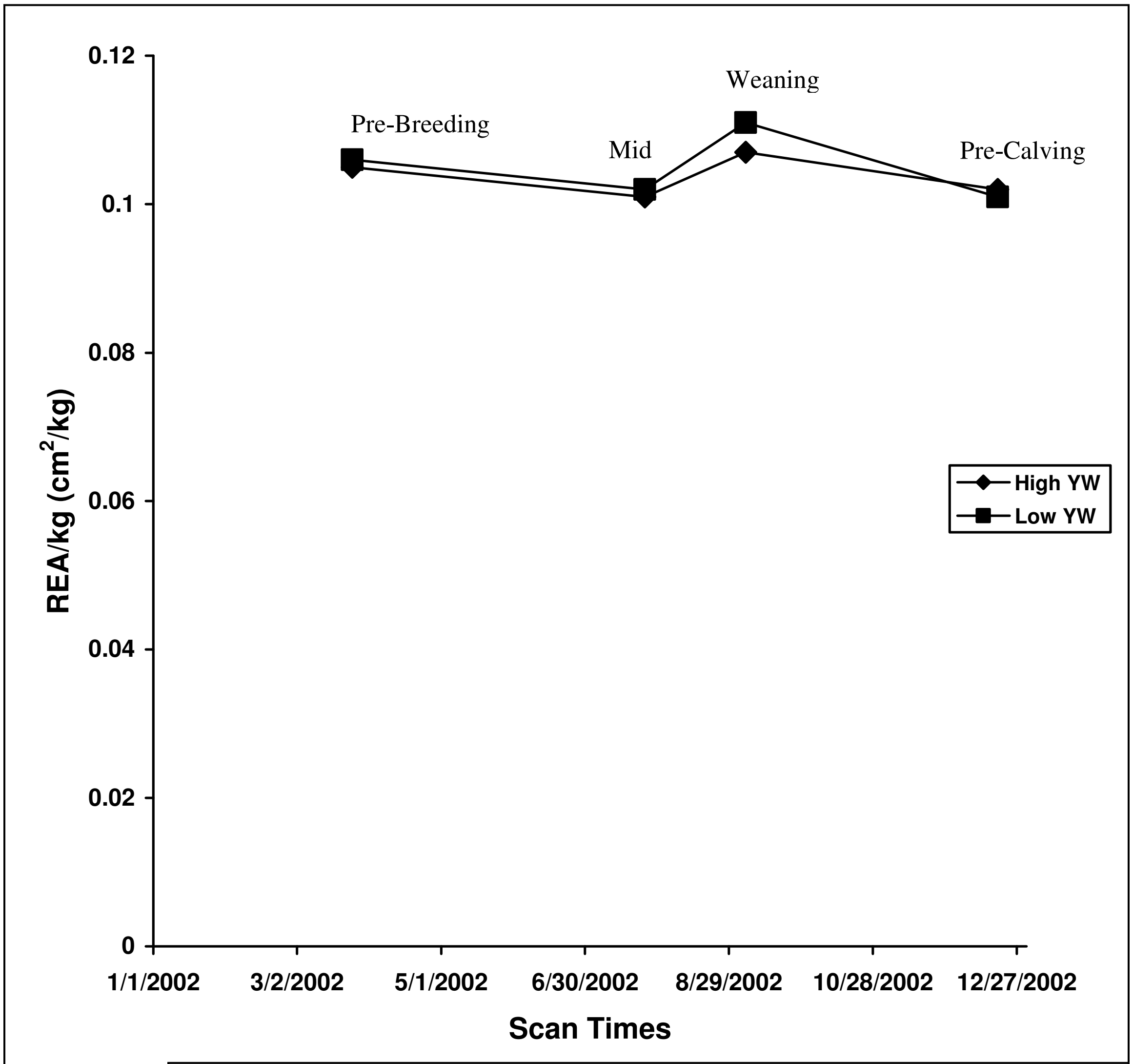
Figure 26. – Changes over time in REA of Hereford cows, comparing high YW vs. low YW EPD.



High YW -	Linear, P = 0.72	Low YW -	Linear, P = 0.92
	Quadratic, P = 0.43		Quadratic, P = 0.88

* $P \leq 0.05$
** $P \leq 0.01$

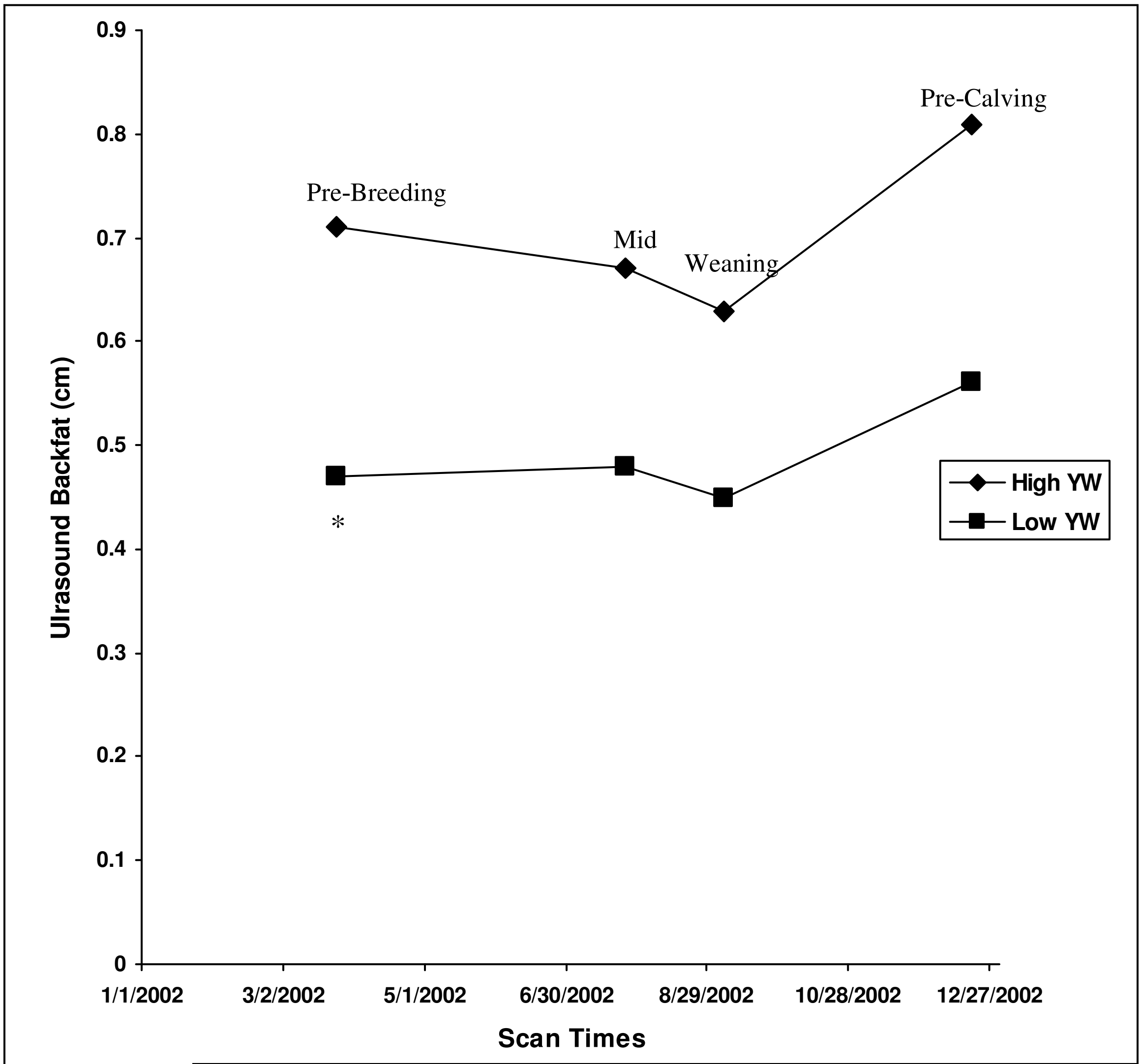
Figure 27. – Changes over time in REA/kg of Hereford cows, comparing high YW vs. low YW EPD.



High YW -	Linear, P = 0.71 Quadratic, P = 0.58	Low YW -	Linear, P = 0.52 Quadratic, P = 0.39

* $P \leq 0.05$
** $P \leq 0.01$

Figure 28. – Changes over time in back fat of Hereford cows, comparing high YW vs. low YW EPD.



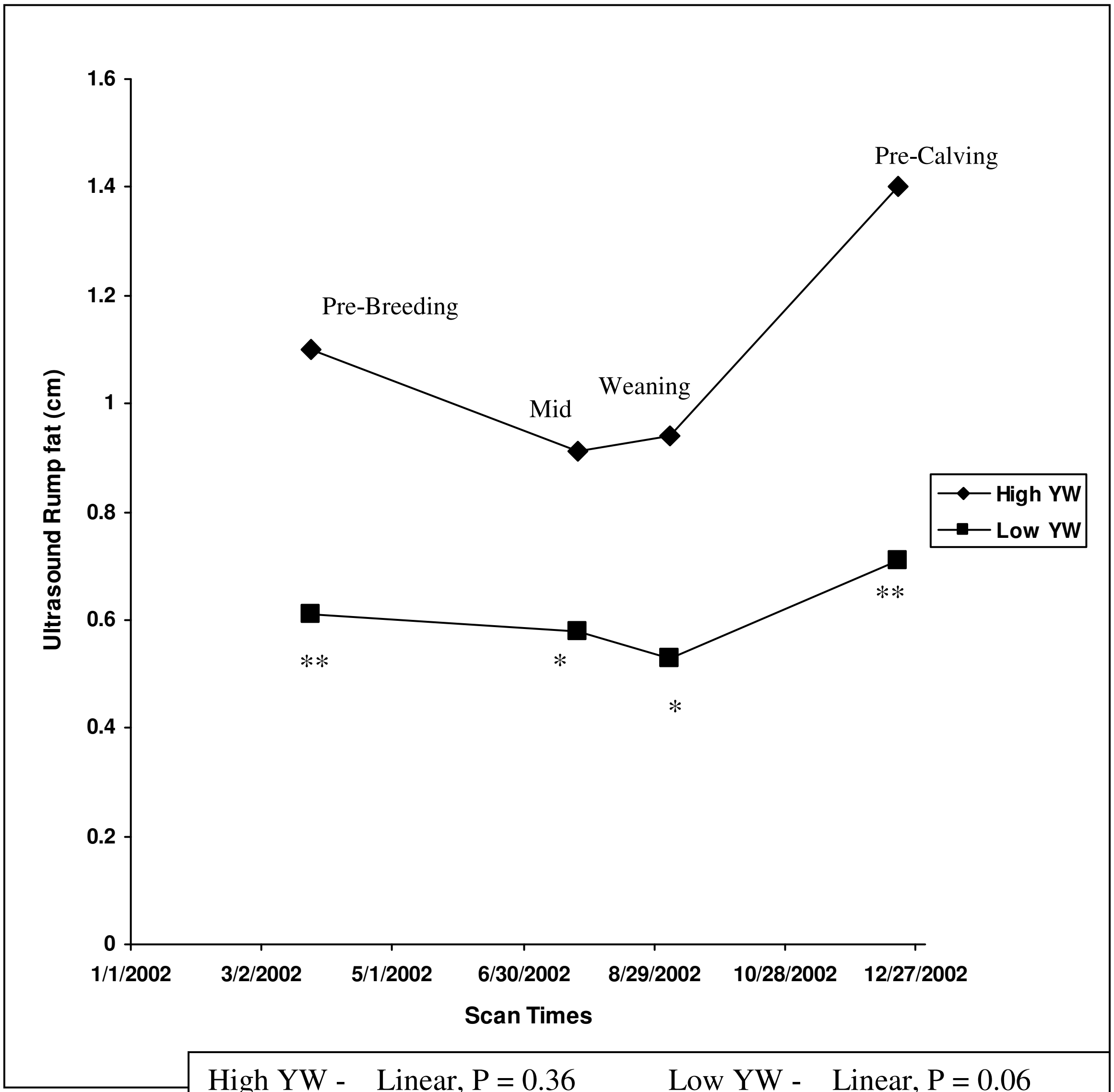
High YW - Linear, $P = 0.81$; Quadratic, $P = 0.67$

Low YW - Linear, $P = 0.42$; Quadratic, $P = 0.31$

* $P \leq 0.05$

** $P \leq 0.01$

Figure 29. – Changes over time in rump fat of Hereford cows, comparing high YW vs. low YW EPD.

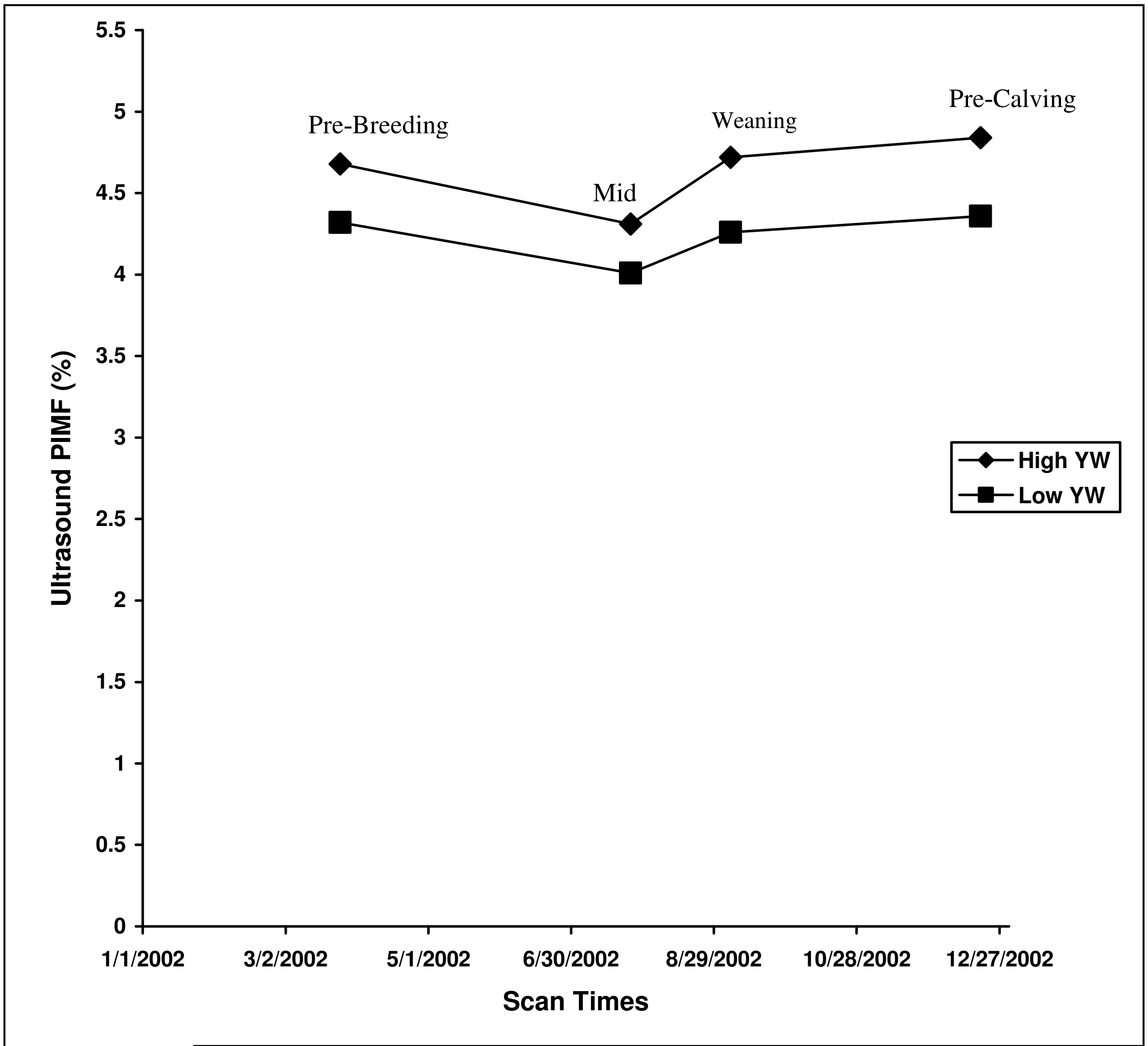


High YW - Linear, $P = 0.36$
Quadratic, $P = 0.21$

Low YW - Linear, $P = 0.06$
Quadratic, $P = 0.02$

* $P \leq 0.05$
** $P \leq 0.01$

Figure 30. – Changes overtime in marbling of Hereford cows, comparing high YW vs. low YW EPD.

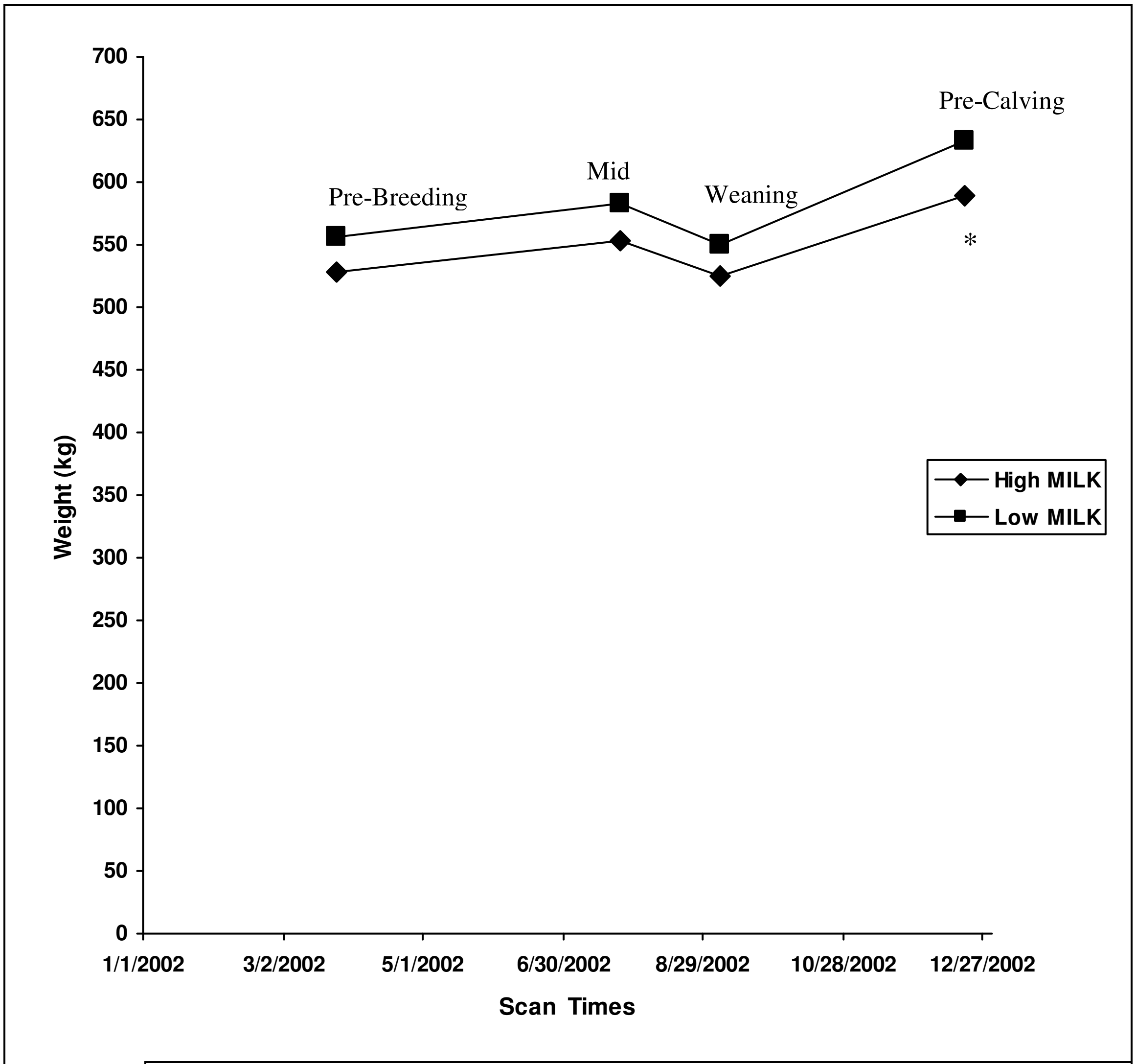


High YW - Linear, $P = 0.39$
Quadratic, $P = 0.40$

Low YW - Linear, $P = 0.49$
Quadratic, $P = 0.45$

* $P \leq 0.05$
** $P \leq 0.01$

Figure 31. – Changes over time in weight of Hereford cows, comparing high MILK vs. low MILK EPD.

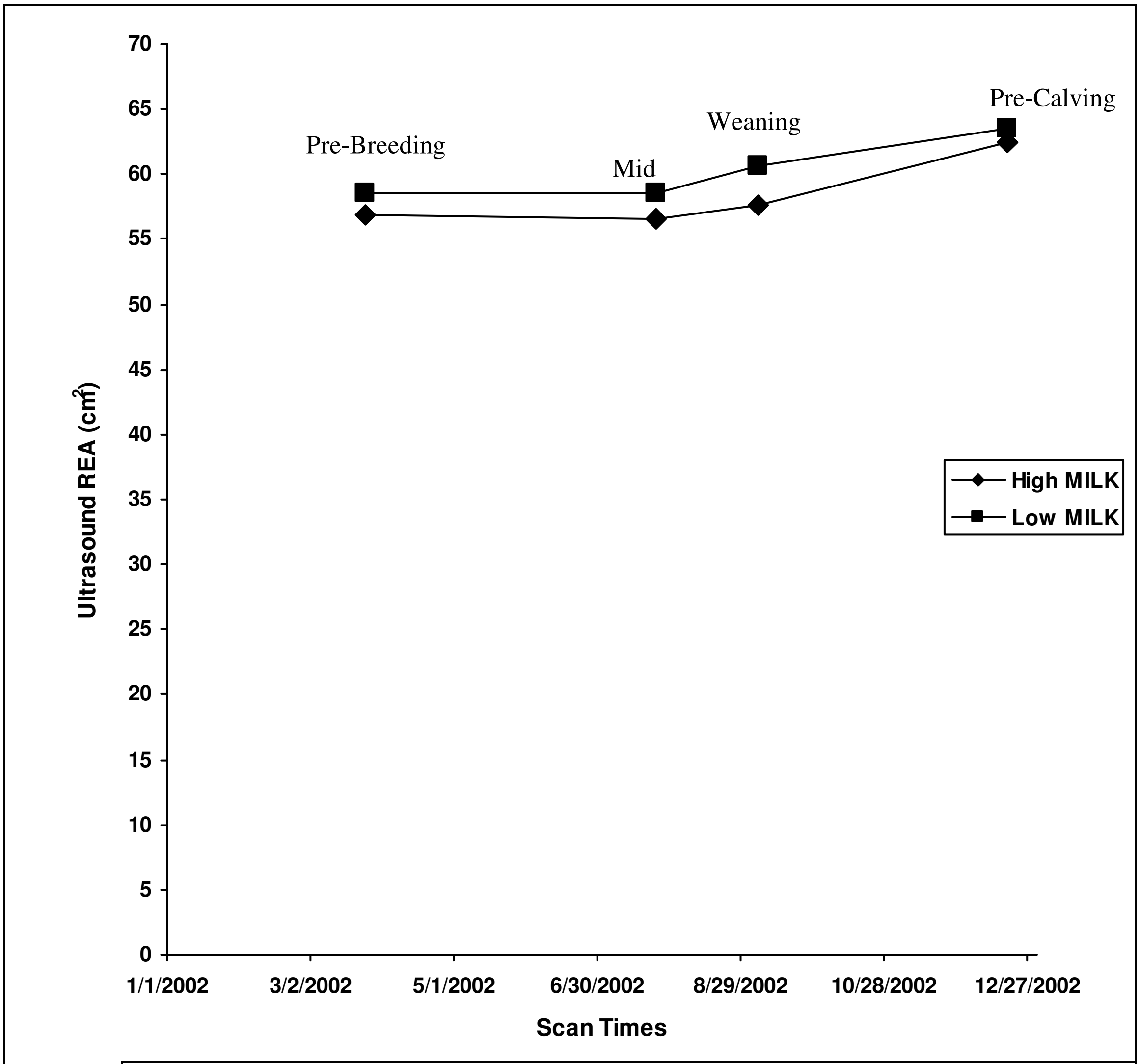


High MILK- Linear, P = 0.48
Quadratic, P = 0.06

Low MILK - Linear, P = 0.47
Quadratic, P = 0.05

* P ≤ 0.05
** P ≤ 0.01

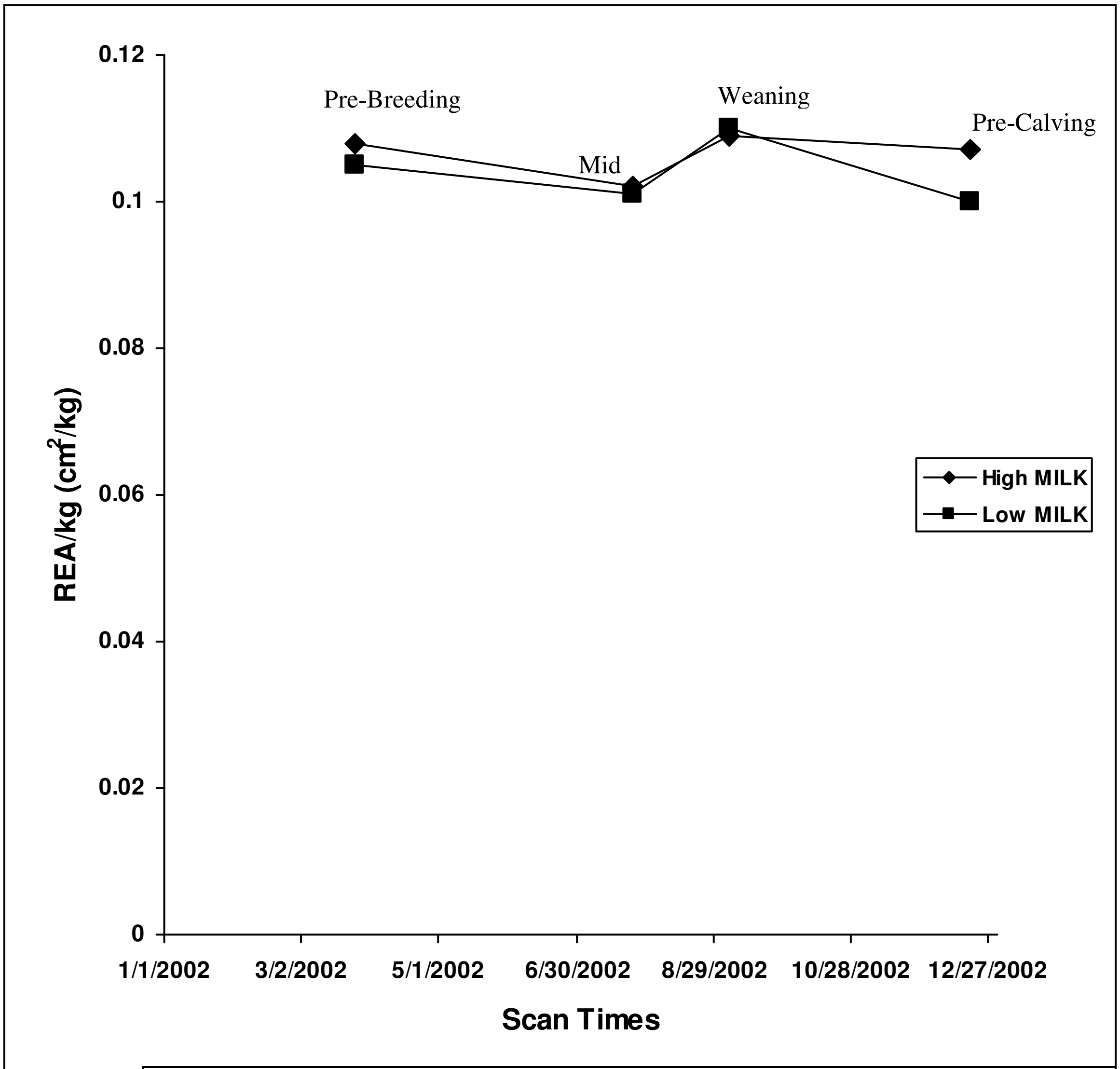
Figure 32. – Changes over time in REA of Hereford cows, comparing high MILK vs. low MILK EPD.



High MILK -	Linear, P = 0.68	Low MILK -	Linear, P = 0.92
	Quadratic, P = 0.35		Quadratic, P = 0.45

* $P \leq 0.05$
** $P \leq 0.01$

Figure 33. – Changes over time in REA/kg of Hereford cows comparing high MILK vs. low MILK EPD.

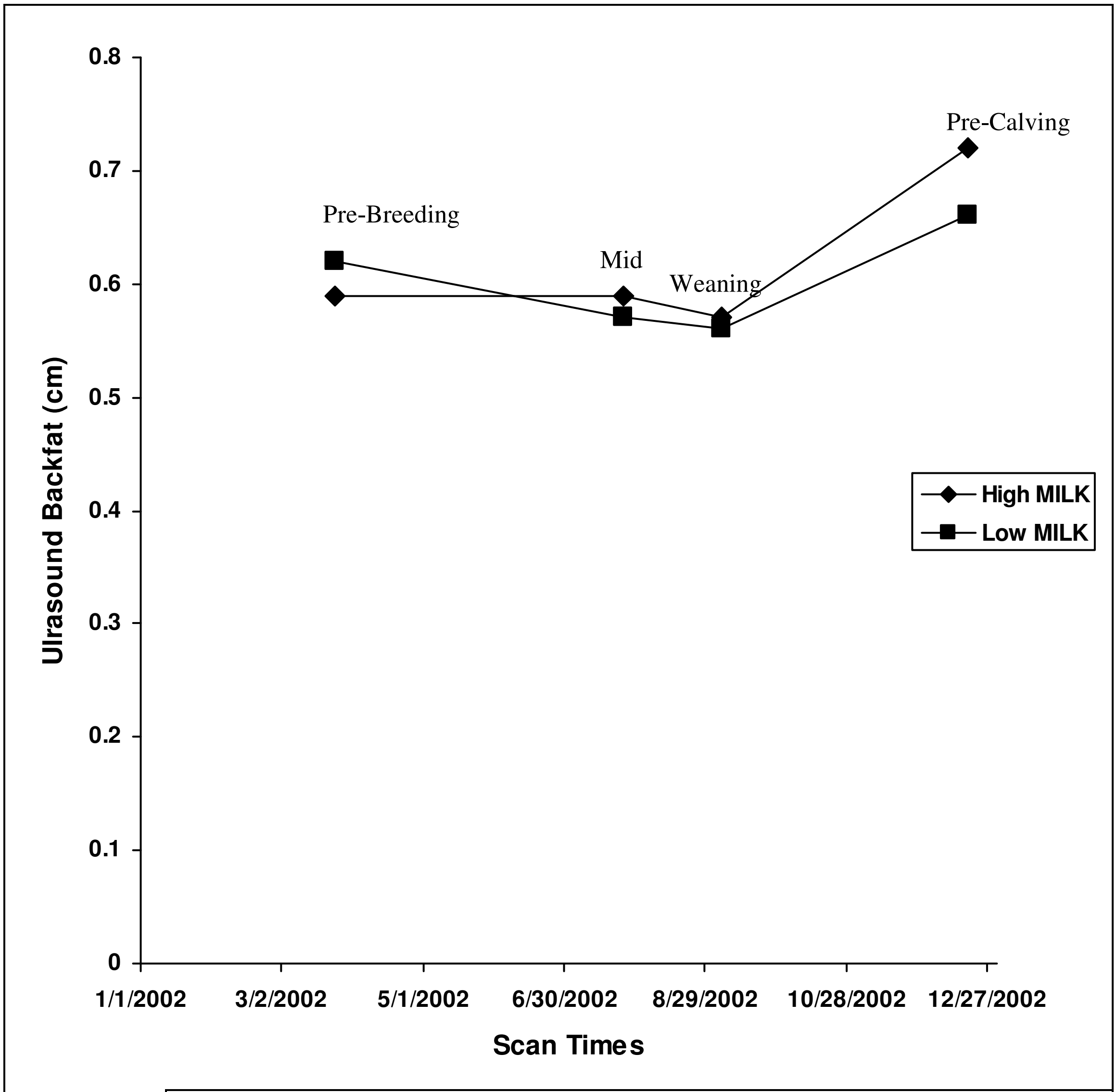


High MILK - Linear, $P = 0.97$
Quadratic, $P = 0.92$

Low MILK - Linear, $P = 0.64$
Quadratic, $P = 0.56$

* $P \leq 0.05$
** $P \leq 0.01$

Figure 34. – Changes over time in back fat of Hereford cows, comparing high MILK vs. low MILK EPD.

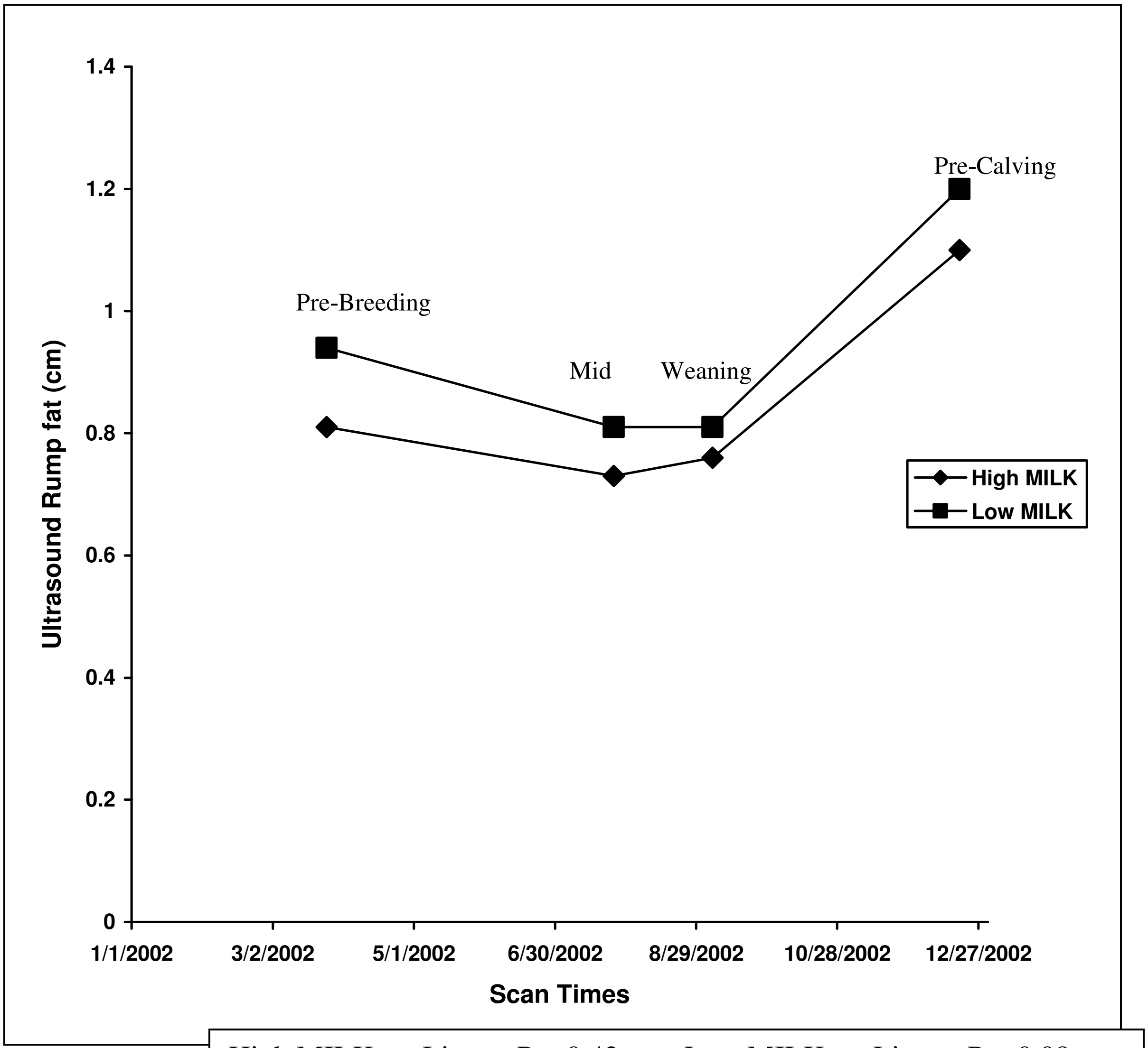


High MILK - Linear, $P = 0.75$
Quadratic, $P = 0.55$

Low MILK - Linear, $P = 0.37$
Quadratic, $P = 0.29$

* $P \leq 0.05$
** $P \leq 0.01$

Figure 35. – Changes over time in rump fat of Hereford cows, comparing high MILK vs. low MILK EPD.

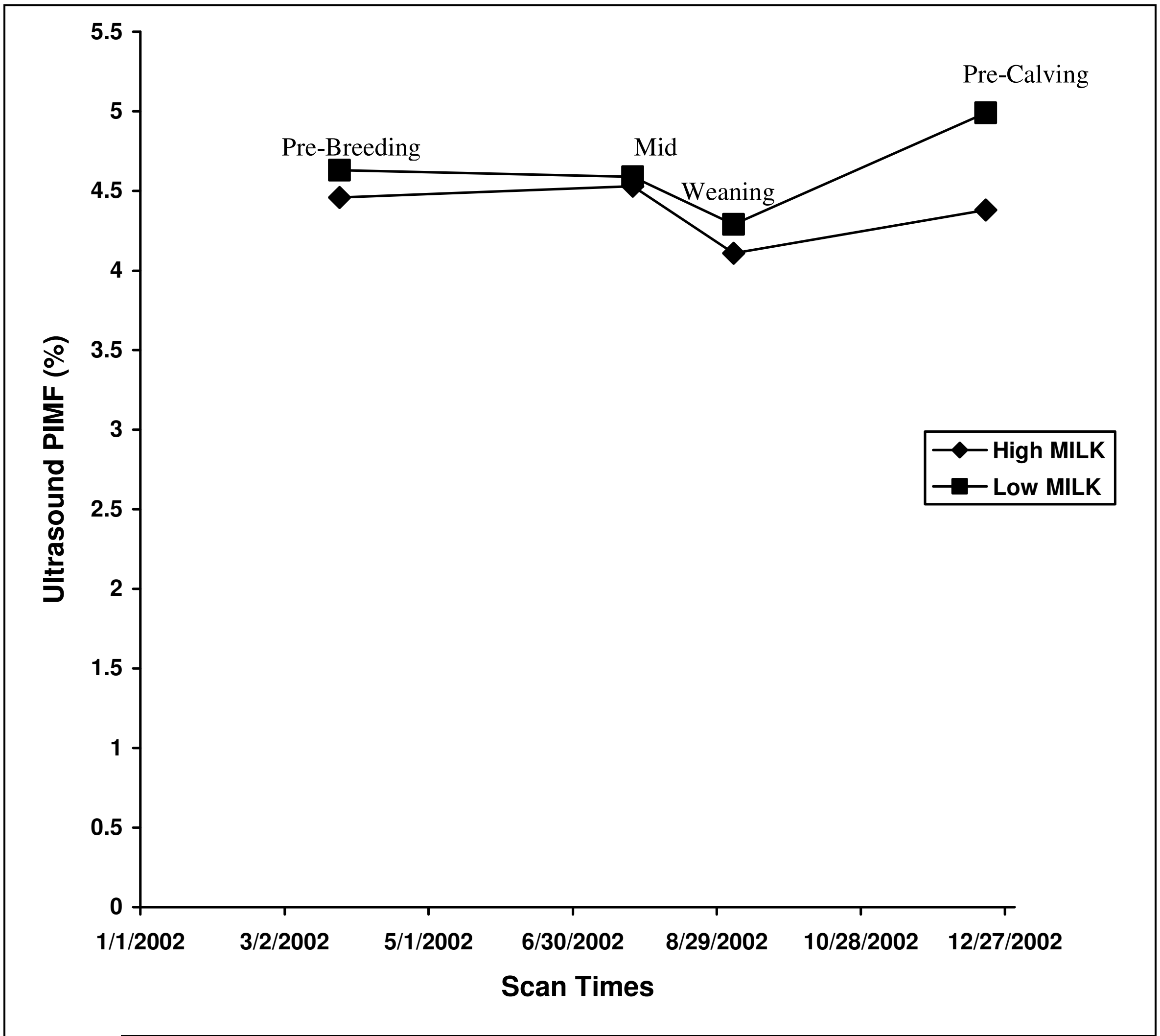


High MILK - Linear, $P = 0.42$, Quadratic, $P = 0.25$

Low MILK - Linear, $P = 0.08$, Quadratic, $P = 0.02$

* $P \leq 0.05$
** $P \leq 0.01$

Figure 36. – Changes over time in marbling of Hereford cows, comparing high MILK vs. low MILK EPD.



High MILK - Linear, $P = 0.52$, Quadratic, $P = 0.63$

Low MILK - Linear, $P = 0.34$, Quadratic, $P = 0.26$

* $P \leq 0.05$

** $P \leq 0.01$