THE RELATIONSHIPS OF PREPARTUM NUTRITION,

BODY WEIGHT CHANGE, BODY CONDITION

SCORE CHANGE, POSTPARTUM BLOOD

GLUCOSE AND INSULIN WITH

REPRODUCTIVE PERFORMANCE

IN BEEF COWS

By

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Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
DOCTOR OF PHILOSOPHY
May, 1986

Thesis
1986D
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ACKNOWLEDGEMENTS

I wish to express my appreciation to Dr. R. P.
Wettemann for his expert guidance, assistance, and patience
throughout the course of this study. In addition, I appre-
ciate the assistance and suggestions of Dr. David Buchanan,
Dr. Keith Lusby, and Dr. Larry Rice that helped to make this
manuscript worthwhile to me and understandable to future
readers. I wish to extend appreciation to Dr. James Oltjen
for his assistance and advice on statistical problems and
computer manipulations to solve those problems. Dr. Ron
McNew's suggestions of statistical analyses were greatly
appreciated. A special thank you goes to David Krohn, Mark
Anderson, and David Cox for the care of the animals in this
study. Also I appreciated the guidance and assistance of
Marion Ringwall and LaRuth Mackey in the laboratory analy-
ses.

Certainly, I will always be grateful to all my fellow
graduate students for their friendship and encouragement
throughout my graduate program. I especially must thank
Rick Rasby for his labor in the collection of samples and
for his knowledge and assistance with laboratory procedures
used to compile the first section of this thesis. Even more
I appreciate his friendship and encouragement during the
latter stages of the manuscript preparation when it was

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greatly needed. The assistance and friendship of James Goodrich during the course of this study also will not be forgotten. John Wagner deserves a special "thank you" for his friendship and particularly for his help, tutoring, and encouragement while we were studying biochemical pathways for hours and hours. The friendship of Jim and Angela Criswell is cherished now and will be for years to come.

I dedicate this manuscript to two ladies who have worked as long and deligently as I during this degree program.

My mother, Frances Jewel Selk, has spent countless hours providing companionship, nourishment, and encouragement for my father during his stay at Southview Manor Care Home. Her perseverence and continual striving to help others has been and always will be an inspiration.

I also dedicate this manuscript to my wife, Mary P. Selk, who has worked hard as Extension Home Economist in Logan County, Oklahoma. Her love, encouragement, and support throughout my graduate career were necessary ingredients in the completion of this study. I will be grateful to her forever.

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CHAPTER I

INTRODUCTION

Income derived from beef cattle is an important economic force. Optimum reproductive performance in the beef herd is a key factor in assuring that the beef animal remains a competitive source of protein in the human diet. The net calf crop is calculated by dividing the number of calves weaned by the number of cows in the breeding herd that produced the calves. This calculation gives an estimate of production efficiency because it approximates comparison of production with input. Estimates of the net calf crop in the United States range from 65 to 81%. An industry whose entire resources are founded on a base operating at 65 to 81% efficiency cannot be considered one that will remain competitive indefinitely.

Failure of the female to be pregnant at the end of the breeding season reduces the net calf crop by an estimated 17% and has a greater impact than all other factors combined. Establishment of a viable pregnancy depends on many complex processes, whether breeding is by natural or artificial service. Functional gametes of potentially high fertility must be produced and released by both sexes. The female must exhibit estrus, the estrus must be detected, and

mating must be completed within the functional lifespan of
the gametes. After conception, the female must provide a
suitable environment for embryonic and fetal development and
give birth to a live, vigorous calf that will grow rapidly
and attain an optimal weaning weight. These processes
involve numerous physiological, hormonal, nutritional,
growth, and behavioral factors that are poorly understood.

The bovine, being a ruminant, can convert feedstuffs of
little or no direct food value for humans into meat that is
important in meeting nutrient requirements. Recent esti-
mates indicate that 50% of the United States and 70% of the
world land mass is used for production of permanent improved
or native forages. Thus, the nutrient requirements of the
ruminant animal become complementary rather than competitive
to human nutrient needs.

Results of many studies have indicated that reproduc-
tive performance in beef cows can be improved by increased
availability and quality of feedstuffs consumed by cows.
These relationships indicate a need for a greater under-
standing of basic mechanisms underlying the effects of
nutrition on reproduction.

Nutritional intake, as reflected in body weight and
body condition during and following gestation is an impor-
tant factor affecting subsequent reproductive performance of
beef cows. Cows in moderate or thin body condition during
pregnancy generally have longer intervals from parturition
to estrus than those that maintain or gain body condition
throughout pregnancy. However, the specific mechanism by

which prepartum nutrition influences reproductive performance has not been elucidated.

Possible physiological links connecting nutrition, body energy status, and reproduction include energy sources such as glucose, fatty acids, and proteins. Hormonal regulators of concentrations of energy sources in blood are also plausible candidates for connections between nutrition and reproduction. Insulin is such a candidate.

The purposes of this research are to: 1) evaluate the influence of prepartum nutrient intake and weight loss on postpartum concentrations of glucose and insulin in blood, 2) examine the relationship of glucose and insulin concentrations postpartum with reproductive performance, 3) evaluate the effects of prepartum nutrition, weight change, and body condition score change on concentrations of LH in serum post partum, 4) evaluate the relationships among blood concentrations of LH, insulin, and glucose postpartum, 5) evaluate the relationships of prepartum supplementation, body weight, body condition score, and reproductive performance in beef cows, and 6) compare the relative importance of weight changes, condition score changes and peripartum body condition score as factors influencing reproduction.

CHAPTER II

LITERATURE REVIEW

Productivity in many livestock operations depends on reproductive efficiency. Reproductive efficiency often is measured by the number and weight of offspring per breeding animal unit per unit of time. The objective of this section is to review major factors affecting reproductive performance in beef and dairy cows, ewes, sows, and mares.

Factors Influencing Reproduction
in Beef Cows

One measure of production in beef cow herds is the net calf crop. Net calf crop is most often considered the number of calves weaned as a percentage of cows exposed in the breeding herd. Calf crop percentages rarely reach 100 percent, because losses of potential productivity per breeding animal unit occur. Bellows et al. (1979) categorized the reductions in calf crop percentage by beef herds into four categories: 1) females not pregnant at the end of the 45 d or 60 d breeding season, 17.4%; 2) perinatal calf deaths, 6.4%; 3) calf deaths between birth and weaning, 2.9%; and 4) fetal deaths during gestation, 2.3%. The four categories totalled 29% loss of the potential calf crop.

Dziuk and Bellows (1983) noted that the same factors reduce net calf crop regardless of geographic region. The high percentage of females not pregnant at the end of breeding season may result from: 1) an extended period of postpartum anestrus, 2) fertility failure of the female, or 3) fertility failure of the male.

Cows must conceive within 85 d after parturition to give birth to another calf within twelve months. More than 17% of beef cows are not pregnant after 60 d of the breeding season (Bellows et al., 1979). A major portion of the females not pregnant at the end of the breeding season is caused by anestrus. Maurer and Echternkamp (1985) classified the causes of repeat breeders in beef cows that mated as reproductive tract anatomical aberrations, 10.9%; anovulation, 3.6%; chromosomal abnormalities, 14.3%; nonrecovery of either an oocyte or embryo, 34.7% and endocrine dysfunction and other causes 36.5%. Calving difficulties may result in a female becoming a repeat breeder or may be another indicator of hormonal dysfunction. If females with anatomical and chromosomal aberrations were excluded, ovarian dysfunction appeared to be associated with the remaining 74.8% (Maurer and Echternkamp, 1985).

Not all reproductive failure can be attributed to the cow. Carroll et al. (1963) reviewed breeding soundness evaluations on over 10,000 bulls, and found that 20.2% would be classified as unsatisfactory.

Nutrition, both pre and postpartum, has been shown to have an affect on reproductive performance of the beef cow

(Wiltbank et al., 1964; Corah et al., 1975). This important factor in beef cow reproduction will be reviewed in another section.

The suckling stimulus incurred by the nursing beef cow increases the interval from parturition to first estrus (Wiltbank and Cook, 1958; Graves et al., 1968; Oxenreider, 1968; Short et al., 1972; Bellows et al., 1974; and LaVoie et al., 1981). The influence of suckling on the interval to first estrus is great. Short et al. (1972) found that cows that had calves removed at parturition returned to estrus 40 d before cows suckling a calf. Bastidas et al. (1984) reported twice-daily suckling improved the pregnancy rate in Brahman cows compared to normal-suckled controls.

The precise mechanism whereby suckling stimuli deter the postpartum return to estrus is yet to be elucidated. However, suckled cows have reduced frequency and amplitudes of luteinizing hormone (LH) episodic spikes in the serum compared to nonsuckled beef cows (Carruthers and Hafs, 1980; Carruthers et al., 1980; Dunlap et al., 1981). Concentrations of prolactin are greater in serum of suckled cows than nonsuckled cows (Han and Moody, 1974; Chang et al., 1981). However, suppressing the concentration of serum prolactin by the use of ergot alkaloids did not affect the length of the postpartum anestrous interval (Williams and Ray, 1981). Currently, prolactin is not

believed to be the controlling factor for the onset of postpartum estrus.

The time required for uterine involution can affect the interval from parturition to first estrus. Parturition is followed by a period when conception is not possible: about 1 week in sows and about 3 weeks in cows and ewes. This period of infertility is followed by 2 to 3 weeks when fertility is possible, but not optimal. (Kiracofe, 1980). Suckling, in contrast to nonsuckling, has been shown to promote uterine involution (Casida et al., 1968; Riesen, 1968;) or delay uterine involution (Wiltbank and Cook, 1958). Generally, uterine involution takes a few days longer in pluriparous cows than in primiparous cows (Marion and Gier, 1968; Araujo et al., 1974). Amount of energy and protein in the diet only slightly affect the rate of uterine involution, and the uteri of Angus cows involuted 3 d sooner than uteri of Hereford cows (Dunn, 1964). The net effect of nutrition on uterine involution appears to be minimal in the absence of specific deficiencies (Kiracofe et al., 1969).

Many factors can delay the normal process of uterine involution in the beef cow. These, in turn, will delay postpartum return to estrus. Uterine infections, retained fetal membranes (Marion and Gier, 1968; Morrow, 1969) and other periparturient diseases (Morrow, 1969) all result in lengthened time to uterine repair.

Fetal death during gestation has been estimated to reduce potential calf crops by 2.3% (Bellows et al., 1979).

Early embryonic deaths may be considered as fertilization failures and allow the female to recycle approximately on schedule. Therefore total embryonic losses are variable and a point of some disagreement in the literature. Diskin and Sreenan (1980) reported that major losses occur at 8 to 16 d post estrus. Ayalon (1978) prefers day 7 as the critical day on which embryonic death becomes most evident. Factors causing embryonic mortality as summarized by Boyd (1965) include: 1) genetic factors (e.g., breed, family, inbreeding, and blood groups), and 2) environmental factors (e.g., nutrition, age, climate, infections, hormonal imbalance, and uterine environment). Spitzer et al. (1978) concluded that reduced energy intake caused embryonic loss after 4 d postmating. Parity of the female influences embryonic deaths and when they occur (Maurer and Chenault, 1983). Hormonal imbalances preestrus may also affect embryonic survival in beef cattle (Henricks, 1971).

Bellows et al. (1979) indicated that calf losses at parturition (6.4%) ranked second in importance of the four factors summarized. Calving difficulty or dystocia is the major cause of perinatal calf losses (Anderson and Bellows, 1967). Cows with dystocia had reduced subsequent reproductive performance and decreased weaning weights, thus adding an additional dimension to the losses caused by calving difficulty (Brinks et al., 1973; Laster et al., 1973). Of the many factors affecting dystocia, heavy calf birth weight is the major causative factor (Bellows et al., 1971; Rice and Wiltbank, 1972; Laster et al., 1973). The heavier

birth weights result in a disproportion between the size of the calf and size of the pelvic opening of the dam. Fleck et al. (1980) found that heifers grown on a high plane of nutrition had larger pelvic openings and less dystocia than those raised on a lower nutrition level. Dystocia occurs most frequently in primiparous dams (Laster et al., 1979; Patterson, 1979). Efforts to predict dystocia by determining the size of the pelvic opening have been only partially successful because of the variability in calf birth weight.

Price and Wiltbank (1978) reviewed factors affecting birth weight. These included gestation diet of the cow, sex of the calf, length of the gestation, breed of sire and dam, inbreeding, age of the dam, and parity of the dam. All have been shown to affect birth weight but no effective and repeatable method of preventing dystocia is available at this time. Morrison et al. (1985) used discriminant analyses in an attempt to predict dystocia with precalving parameters. Discriminant analysis was statistically more appropriate than regression analysis for predicting dystocia because distinct group classification of the potential for dystocia was accomplished.

Timing of parturition, so as to maximize labor availability at this economically critical event, has received attention. Parturition can be induced by injection of glucocorticoids (Carroll, 1974), or prostaglandins (First, 1979). This practice allows for more accurate prediction of the time of parturition, but will not alter the incidence of dystocia and will increase the incidence of retain fetal

membranes. Feeding pregnant cows late in the day or evening
resulted in significantly less births from 0001 h to 0006 h
and more from 0600 to 1800 h (Lowman et al., 1981).

Crossbreeding can have an important effect on reproduc-
tive performance of the beef herd. Heterosis results in
hastened puberty in heifers and bulls (Joubert, 1963;
Bellows et al., 1964; Wiltbank et al., 1969; Laster et al.,
1976) and improved reproductive performance in cows
(Preston and Willis, 1974). Reynolds et al. (1982)
reported 3.8% more crossbred cows calved and produced a
5.3% greater net calf crop than straightbred cows.

<center>Factors Influencing Reproduction

in Dairy Cows</center>

Infertile services and the lack of detected estrus are
the most important causes of reproductive inefficiency in
dairy cattle. Hawk (1979) reported that the sources of
reproductive failure in dairy cattle can be categorized as:
anatomical abnormalities, 2%; ovulation failure, 2%; lost
or ruptured ova, 5%; fertilization failure, 13%; embryonic
mortality, 15%; and fetal mortality, 3%.

Fertilization failures may be more likely to occur in
multiparous cows than in first-service heifers (Boyd et
al., 1969). When cows were managed for high fertility,
fertilization failure rate was still 15% compared to 2%
found for heifers (Bearden et al., 1956, Kidder et al.,
1954). Sperm survival, storage, or transport in the
reproductive tract may be reduced in cows as compared to

heifers. Fertilization rates in heifers inseminated with semen from bulls of high, average or low fertility averaged 98%, (Bearden et al., 1956, Kidder et al., 1954), 82%, (Kidder et al., 1954) and 74%, (Bearden et al., 1956, Kidder et al., 1954).

Other factors known to decrease rate of fertilization include inseminations too early post partum, inseminations after ovulation, and inseminations following several previous infertile inseminations (Hawk et al., 1979). Absence of accessory sperm in uncleaved ova suggests that some fertilization failure results from absence of sperm in the oviducts (Britt et al., 1981). Milking frequency did not significantly affect the interval to the first postpartum ovulation (Carruthers and Hafs, 1980), however, unrestricted suckling by a calf delayed the first ovulation by nearly 20 d. The postpartum interval to first ovulation was lengthened to 64.5 d when multiple calves were allowed to nurse dairy cows (Moller, 1970). The affect of suckling on the dairy cow is similar to that noted earlier in the beef cow. Suckling reduced mean serum LH concentrations by 50%, but frequency of milking (12 vs. 6 h intervals) did not significantly alter LH concentrations in nonsuckled cows.

Cows of low fertility, (often identified as repeat breeders) are usually subfertile, not sterile. Subclinical uterine infection is apparently not an important cause of infertility (Hawk et al., 1958). Of the anatomically normal repeat breeders inseminated, ova were absent or already

ruptured in about 15%, and ova were not fertilized in 25 to 35% (Tanabe and Casida, 1949; Tanabe and Almquist, 1953; Casida, 1961; Graden et al., 1968). Progesterone therapy improved fertility to some degree in repeat breeders (Wiltbank et al., 1956).

A major limitation for dairy cattle fertility and reduction of calving interval is failure of estrous detection. Stevenson and Britt (1977) examined efficiency of detection in postpartum cows by visual observation, rump positioned mounting detectors, and dye marking by heifers treated with testosterone. All methods gave an estimated 50% detective efficiency. Williams et al. (1981) evaluated estrous detection methods including twice daily heat checks, heat mount detectors, and pedometers. Pedometers were used to measure increased activity associated with estrus. Efficiency of estrous detection (as determined by progesterone concentrations in plasma) ranged from 67% to 74%. Combinations of two techniques ranged in efficiency from 84% to 93%. Accuracy of twice daily heat checks and use of pedometer activity greatly exceeded the other techniques. Dairy cows present a markedly different nutritional situation than do beef cows. They are maintained on a high plane of nutrition in order to maintain a high level of milk production. Spalding et al. (1975) reported reduced reproductive performance of high producing cows compared to lower producing cows. Since high producing cows often lose weight early in lactation, inadequate nutrition may be associated with the decrease in fertility. The effects of

varying the protein content of diets during lactation for high producing dairy cows has recently attracted much controversy. Jordan and Swanson (1979) found that feeding high levels of protein (19.3% C.P.) to high producing cows shortened the postpartum interval by 18 and 9 d compared with the cows receiving 16.3% C.P. and 12.7% C.P., respectively. Treacher et al. (1976) fed 75% of the recommended protein requirements for 8 weeks prior to parturition and again for 8 weeks following parturition. The reduced protein intake resulted in lengthening the postpartum interval by 11 d. However, in both of these studies the interval from parturition to conception was shorter in the cows fed the lower levels of protein. Chew et al. (1984) fed 80% of NRC protein requirements to dairy cows prepartum and found similar reproductive performance to control cows. Howard (1985) reported the interval to first estrus, interval from calving to conception, services per conception and percentage pregnant were similar between cows on the high (20%) versus moderate (15%) levels of crude protein.

Factors Influencing Reproduction
in Sows

Frequency of farrowing, litter size and piglet survival are the factors that determine the number of offspring produced per sow per year. Most sows exhibit estrus within 3 to 7 d after weaning (Thompson, et al., 1981) and the length of the period from weaning to estrus varies inversely with the length of the lactation period (Baker et al., 1953; Self

and Grummer, 1958; Moody and Speer, 1971). Before and during the postweaning estrus, plasma LH concentrations are increased compared to concentrations during lactation (Dyck et al., 1979). Suckling intensity and lactation stress seem to be responsible for the anestrous state during lactation in sows. Controlled, intermittent suckling designed to induce estrus during lactation has produced conflicting results. Smith (1961) reported that 12 h of litter separation per day beginning on day 21 post partum induced a fertile estrus during lactation, but Cole et al. (1972) did not observe estrus in sows subjected to litter separation. Thompson, et al (1981) found seven-day limited nursing (3 or 4 times per day) reduced the average interval from weaning to first estrus. Conception rates were not affected by the limited nursing regimes.

Nutrition post partum influences the return to estrus in sows. Reese et al. (1982) reported sows that had large weight and backfat losses (due to restricted energy in the diet) during lactation experienced a higher incidence of delayed estrus following weaning than those that maintained their weight. They concluded that body reserves were probably depleted in some sows to such a severe extent that reproductive dysfunction resulted. O'Grady et al. (1973) and Adam and Shearer (1975) reported that energy intake during lactation had no effect on days from weaning to first estrus in sows fed energy levels that met or exceeded the requirements of lactating sows according to the NRC (1979). However, MacLean (1968, 1969) observed that sows

exhibiting prolonged periods from weaning to first estrus were generally thin. A significant weight loss during lactation decreased the ovulation rate (Hardy and Lodge, 1969.) Heap et al. (1967) showed a highly significant relation between number of corpora lutea at the 28th day of pregnancy and weight of sow at service, so that for every increase of 10 kg in body weight at estrus, 0.73 more ova were shed.

In the gilt, a high level of energy intake prior to mating is associated with an increase in embryo mortality. Embryo loss increased with increasing feeding levels after mating and this loss was independent of the premating energy intake (Bazer et al., 1968). Conversely, a reduction in energy intake after breeding improved embryo survival (Bazer et al., 1968; Frobish, 1970; Frobish et al., 1973). In contrast to the results reported for the gilt, Brooks and Cole (1971), and Willis and Maxwell (1984) found that dietary protein and energy during gestation have no effect on embryo mortality in the sow. Also Tribble and Orr (1982) found that the feeding and management regimen of sows from weaning to breeding had little or no influence on the days from weaning to breeding or litter size.

Protein concentrations in the postpartum diet also may be involved with reproductive performance in swine. Pond et al. (1969) found that protein limitation has its greatest effect on pregnancy the first 3 or 4 weeks postbreeding. Jones and Maxwell (1974) found a linear increase in the number of corpora lutea at 30 d postbreeding as protein

intake was increased from 143 g to 345 g per day in gilts.
However, the number of live embryos and the embryo survival
rate at 30 d postbreeding were not significantly affected
(Jones and Maxwell, 1974, 1982). Greater (not significant)
anestrous rates were noted in gilts that had lower protein
intakes compared to control gilts receiving adequate
protein. Similarly, Svajgr et al. (1972) found that severe
protein restriction in gilts reduced the incidence of
estrus, increased the time interval to estrus, and reduced
the ovulation rate after weaning the first litter. These
results suggest protein deprivation may have adverse
effects on normal estrous function, even before gestation
performance is reduced.

The social environment of swine influences reproduction
such as age at puberty, incidence of estrus, and sexual
behavior (Rutledge, 1980). Alterations in normal social
experiences can affect reproduction. Gilts kept isolated
from boars show estrus and ovulate after considerable
delay. Some isolated gilts will remain anestrus for pro-
longed periods (Hemsworth et al., 1978).

Factors Influencing Reproduction
in Ewes

The length of interval from lambing to first postpartum
estrus in the ewe is affected by season, breed, presence of
rams, and lactation (Dunn and Kaltenbach., 1980). Nutri-
tional restriction during the spring and summer months has
failed to influence the onset of the breeding season (Hafez,

1952; Hunter and Lishman, 1967; Ducker and Boyd, 1974; Allison, 1977; Dufour and Wolynetz, 1977). Hunter and van Aarde (1973) examined the interaction of lactation, season and nutrition on the length of the postpartum interval in Merino ewes. Only season exerted a significant effect on the length of the postpartum interval in winter-lambing ewes. Winter-lambing ewes had a longer anestrous interval than either fall- or spring-lambing ewes. Lishman et al. (1974) noted an interaction between age and weight loss during lactation upon the percentage of anestrous ewes. A greater percentage of primiparous ewes losing weight during lactation remained anestrous than was noted in mature ewes. The most recent estimates of the energy requirements of a pregnant ewe may result in undernutrition in late pregnancy (Robinson, 1980). In the fetus of the adequately nourished ewe in late pregnancy, the metabolism of glucose, lactate, amino acids, acetate, and glycerol, account for approximately 50, 25, 20, 5, and 1 percent of the oxygen consumption (Robinson, 1980). By contrast, in conditions of undernutrition the corresponding percentages are 30, 15, 60, 0, and 1. The large relative contribution of amino acids in the undernourished ewe is at the expense of maternal tissue protein, which may be depleted by as much as 6 gm per day. This depletion has severe consequences on colostrum production and milking ability (Guada et al., 1976). Work by Shevah et al. (1974) with Finn x Dorset ewes questioned the concept that nutrition was more important than lactation. Only 3% of suckled ewes showed estrus by 21 d post partum

compared with 47% of the nonlactating ewes. Weight gains
were similar for ewes that exhibited estrus compared to
those that failed to show estrus. The lack of ovulation
during lactational anestrus in ewes during the breeding sea-
son is not mediated by hyperresponsiveness to estradiol neg-
ative feedback (Foster and Ryan, 1979) but this may be a
mechanism of seasonal anestrus (Legan et al., 1977). Lamb-
ing rates of July-mated ewes which had lactation terminated
before time of mating were higher than those of ewes lactat-
ing at time of mating. This effect of lactation was appar-
ent for ewes on both a high and low plane of nutrition
(Shevah et al., 1974). Lactating ewes shed a proportion of
the ova abnormally late in relation to the LH surge and
therefore those ova may not become fertilized (Cognie and
Pelletier, 1976).

Body condition at mating is positively related to ovu-
lation rate and embryo survival in Scottish Blackface ewes
(Gunn and Doney, 1975). In addition, Doney et al.
(1976a,b) found that ovulation rate and embryo survival
were decreased by severe environmental stress at the time
of estrus or in the first few days following mating. A
partial explanation for the decreased ovulation rate was
given by Rhind et al. (1984). Using a 2X2 factorial exper-
iment with body condition and environmental stress as the
treatments, they found that low-conditioned, stressed ewes

had reduced mean circulating concentrations of periovulatory follicle-stimulating hormone.

The ratio of light to dark during a day and the absolute periods of light and dark are known to influence reproduction in sheep (Hulet, 1979). Schanbacher (1980) found that ewes conceived at first estrus and maintain pregnancy after exposure to short day lengths. Application of light control to intensify lamb production has received some attention (Robinson, 1974; Vesely 1975, 1978). The possible antigonadotropic effects of prolactin on the reproductive activity of anestrous ewes were accessed by Schanbacher (1980) after treatment with ergocryptine. Ergocryptine was quite effective in reducing serum prolactin during summer anestrus. Yet, the average interval to first estrus was almost identical to that recorded for control ewes. Therefore, prolactin is not antagonistic to ovarian cyclicity because its presence or removal did not hasten the onset of estrus. Niswender (1974) also showed that prolactin does not play a role in the regulation of luteal function in normal cycling sheep.

<center>Factors Influencing Reproduction

in Mares</center>

The influence of season on the reproductive cycle of the mare has received considerable attention. Osborne (1966) determined the seasonal pattern of ovulation in mares. In the Temperate Zones, the number of mares ovulating is maximal in summer, decreases in fall, is minimal in

winter, and increases in spring. Duration of estrus decreased as the breeding season progressed whereas diestrus increased (Ginther et al., 1972; Back et al., 1974; Ginther, 1974;). Knowledge of the seasonal influence on the mare's reproductive cycle led to an attempt to modify the mare's cycle by artificial light. Approximately 20 yr lapsed between the original demonstration of the stimulatory effects of light (Burkhardt, 1947) and further study. Loy (1968) reported on the use of artificial lights in breeding farms to hasten the onset of the breeding season. Either a constant, fixed photoperiod (Kooistra and Ginther, 1975) or a gradually increasing photoperiod (Kooistra and Ginther, 1975; Sharp and Ginther, 1975) is effective.

Garcia and Ginther (1976) demonstrated that LH and FSH concentrations in ovariectomized mares followed a seasonal pattern with minimal concentrations during the anovulatory season and maximal amounts during the ovulatory season. Treatment with prolonged artificial daily photoperiod increased the LH and FSH concentrations approximately two months earlier than controls. Pregnant mares exposed to a 16 h photoperiod were shown to be easier to rebreed post-foaling than control mares (Hodge et al., 1982). Sharp et al. (1981) reported on the involvement of the pineal in seasonal reproduction. Melatonin secretion from the pineal has been shown to be affected by time of day (Kilmer et al., 1982) and may be involved in control of reproduction

The relationship of nutrition, body condition, and reproductive performance of the mare has been studied to a lesser extent than in the meat animal species. Zimmerman and Green (1978) reported that "fat" mares had a much lower conception rate than mares in "good" condition. However, Henneke et al. (1981) found mares that were in thin condition at foaling had reduced conception rates, longer post-partum intervals and increased cycles per conception. Mares that foaled in good condition but lost weight during lactation had similar conception rates to those mares in good or thin condition at foaling that maintained or gained weight during lactation (Heneke et al., 1981). Jordan (1982) observed that no reduction in conception occurred among pony mares fed to lose 20% of body weight during gestation but fed to gain weight during lactation. Banach and Evans (1981) reported that energy restriction during the last 3 months of gestation had no effect on foal birth weight and did not affect reproductive efficiency. Furthermore, they reported that "flushing" or free-choice feeding of lactating mares did not enhance reproductive performance. Jordan et al. (1975) found that calcium-phosphorus ratios ranging from 2:1 to 6:1 did not affect reproduction in Shetland pony mares.

Blood Metabolites As Factors
Influencing Reproduction

The physiological link between the energy status of cows and the onset of postpartum ovarian activity remains a

mystery. Several blood metabolites have received attention
as potential links between nutrition and reproductive func-
tion in beef cows. These include: glucose, non-esterified
and esterified fatty acids, cholesterol, ketones, and pro-
teins.

Glucose

Glucose is an important source of energy for many mammalian
cells including nervous and endocrine tissues (Martin,
1979). Glucose is the brain's most important substrate for
energy metabolism since, under normal conditions, 90% of the
oxidative metabolism is sustained by combustion of glucose.
Glucose reaches the brain via transport through the blood-
brain barrier, diffusion through the brain's extracellular
space, transport through nerve and glia cell membranes, and
to a lesser extent, transport over the choroid plexus (Lund-
Anderson, 1979). The major portion of the glucose has to be
supplied by gluconeogenesis since little glucose is normally
absorbed directly from the bovine gut (Baird et al., 1983).
Concentrations of glucose in the blood of cows increase just
before parturition, and decrease immediately after parturi-
tion and are constant for one to four weeks post partum
(Godden and Allcroft, 1932; Horrocks and Patterson, 1957).
This pattern of glucose concentrations is not consistent
with that found in the ewe. In ewes, circulating concentra-
tions of glucose and lactate and magnitudes of apparent
turnovers of glucose and lactate tend to be greater during
lactation than during pregnancy (Baird et al., 1983).

Restriction of energy in the diet can reduce blood glucose concentrations in ruminants (Patterson et al., 1964; Howland et al., 1966; Wagner and Oxenreider, 1971; Coggins and Field, 1976). Rasby (1983) concluded that pregnant beef cows with restricted protein supplement while grazing dry, winter range had reduced glucose in plasma.

Concentrations of blood glucose in postpartum cows are influenced by energy intake and lactation (Wagner and Oxenreider, 1971; Coggins and Field, 1976; Downie and Gelman, 1976). Wagner and Oxenreider (1971) fed low, medium, and high energy diets to postpartum cows and found plasma glucose concentrations were 61.9, 66.8, and 69.0 mg%, respectively. In addition, when Kellogg and Miller (1977) fed 30% of the energy necessary for production during the early postpartum period, blood glucose was reduced within 4 d. Nonlactating dairy cows had significantly greater plasma glucose concentrations than milked or suckled counterparts (69.1 vs. 64.1 or 64.9 mg%, respectively). Lactation also reduces plasma glucose in beef cows from 67 mg% to 61 mg% (Chang et al., 1984). Jenny et al. (1974) and Smith et al. (1976) found that plasma glucose concentration does not appear to be affected by diet in postpartum dairy cows, but is negatively related to milk production.

Hypoglycemia has been suggested as a cause of infertility in beef and dairy cows (McClure, 1968; Downie and Gelman, 1976; Patil and Deshpande, 1979). In addition, Oxenreider (1971), demonstrated that hypoglycemia is associated with decreased follicular development in dairy cows.

McClure (1970) and Downie and Gelman (1976) found when bodyweight and plasma glucose were decreasing, cows were infertile; when bodyweight was decreasing but when concentrations of glucose in plasma were increasing, cows were fertile. Estrus may be delayed past 90 d postpartum in cows with reduced glucose and body weights (Patil and Deshpande, 1979). McClure et al. (1978) found that the inhibition of glycolysis with the administration of a metabolic inhibitor, 2-deoxy-D-glucose, was associated with the failure of both estrus and formation of functional corpora lutea in heifers. Inhibition of glycolysis and oxidative phosphorylation with metabolic inhibitors led to inhibition of GnRH-stimulated LH release in rats, giving more evidence that LH release is dependent on an energy-dependent process (Sen et al., 1979). Abomasal infusions of proprionate (a glucose precursor) enhanced the ability of prepuberal Brangus heifers to respond to a GnRH challenge with increased peak LH concentrations and slightly increased area under an LH curve (Rutter et al., 1983). Carstairs et al. (1980), using dairy heifers, found weekly serum concentrations of glucose were negatively correlated (r = -.33) with the interval from parturition to the onset of ovarian activity. Kappel et al. (1984) examined blood glucose in dairy cows divided into three fertility groups based on days from parturition to conception. The highest fertility group had a greater precalving value of glucose. This observation emphasized the importance of precalving metabolic status of the cow. The least fertile cows also had reduced glucose

concentrations during early lactation compared to more fertile cows.

Direct relationships between blood glucose and individual hormones of reproduction have been elusive. Exogenous administration of estradiol increases concentrations of glucose in blood from 12 to 48 h after injection in ovariectomized ewes (Luthman, 1972). However, administration of progesterone had no effect on glucose concentrations in blood. Chang et al. (1984) fitted crossbred beef cows with progesterone releasing intravaginal devices and injected 6 mg of estradiol valerate. Treated cows consisted of both nonlactating and lactating cows 60 d post partum. Concentrations of glucose in plasma were not influenced by hormonal treatments. Blood glucose concentrations have been linked with the fatty liver syndrome in high producing dairy cows (Zamet et al., 1979). Serum glucose was reduced as much as 57% in cows inflicted with fatty liver syndrome compared to control cows.

Non-Esterified Fatty Acids

Non-esterified fatty acids (NEFA) are quantitatively a small portion of the blood constituents but have an important metabolic role in the energy homestasis of the ruminant. Adipose tissue is mobilized to form NEFA to supply energy in the ruminant with a negative energy balance. Holmes and Lambourne (1970) noted that NEFA values varied inversely with the level of energy intake. However, the practical application of this relationship was seriously

limited by short term diurnal fluctuations; NEFA values decreased after feeding and increased with starvation and mild excitement. Increased concentrations of NEFA are common in high milk-producing dairy cows in early lactation and reflect the relative energy deficiency and mobilization of adipose tissue reserves (Baird, 1982). Concentrations of NEFA in the blood of ruminants are usually negatively correlated with concentrations of glucose (Annison, 1960). Reid and Hinks (1962) also noted that ewes on ad libitum feed had decreased NEFA and greater glucose concentrations in the plasma than ewes that had restricted intake during late pregnancy. These same authors conclude that concentrations of NEFA in plasma are more accurate indicators of undernourishment during pregnancy in ruminants than glucose or ketones. Growth hormone may be an important modifier of NEFA concentrations in cattle. Observed increases in plasma NEFA in response to exogenous growth hormone were not acute, nor transient and resulted in an irreversible loss of plasma NEFA (Eisemann et al., 1984).

A relationship between NEFA and beef cattle reproduction has not yet been uncovered. Garmendia et al. (1984) reported that plasma concentrations of NEFA are correlated with body condition scores before calving and negatively correlated after calving with changes in body weight and body condition score from mid pregnancy. Chang et al. (1984) found no significant influence of lactation or exogenous progesterone and estradiol valerate on NEFA concentrations in crossbred beef heifers. In contrast, Scott

et al. (1971) treated ovariectomized cows with 5 mg per day of estradiol benzoate and 50 mg per day of progesterone and found a significant increase in serum NEFA. Intramuscular injections of 2.5 mg estradiol significantly increased the blood concentrations of NEFA after 24 to 48 hours, but no change in NEFA concentrations occurred after 2.5 mg injections of progesterone (Luthman et al. 1972).

Fatty infiltration of the liver (the fatty liver syndrome) has been linked with fat mobilization and increased concentrations of NEFA (Reid et al., 1983a). Cows with greater infiltration of fat into the liver had increased plasma NEFA. In addition, fatty infiltration of the liver was associated with real differences in reproductive performance of dairy cows (Reid et al., 1983b). The median time to onset of first estrus for the moderate (> 20% fat) fatty liver group was 26.5 d longer then for the mild (< 20% fat) fatty liver group in a herd of 38 cows.

Ketones

Concentrations of ketones in the plasma tend to increase as ruminants are in a negative energy balance (Annison, 1960). Therefore, the increase in ketone concentrations prior to parturition, and further increases during the postpartum lactation (Horrocks and Patterson, 1957, 1960) are expected. The elevated ketone concentrations remain for long periods (up to 56 d) in high producing dairy cows (Horrocks and Patterson, 1957). Elevated concentrations of hydroxybutyrate were also found in cows with the

fatty livers syndrome (Reid et al., 1983a), but no direct link between blood ketones and reproductive function has been shown.

Cholesterol

Concentrations of cholesterol in serum may be increased for dairy cows requiring more than 4 services per conception (Rowlands et al., 1977). However, cholesterol in serum varied with calving dates and nutrition within cows with low fertility. This indicates that low fertilty may not be associated with changes in cholesterol in serum. Kappel et al. (1984) collected serum pre and postpartum from 97 Holstein heifers and cows. Cholesterol concentrations were directly related to milk production from 25 to 88 d postpartum. Cows in their second lactation had greater concentrations than first-calf heifers, and cows in their third or later lactation had intermediate cholesterol concentrations. The number of days from parturtion to conception was significantly and inversely related to serum cholesterol. Estradiol concentrations have been related to serum cholesterol in ovariectomized ewes (Luthman, 1972). Intramuscular injections of 2.5 mg of estradiol benzoate decreased cholesterol in serum after 24 h and thereafter the concentration increased.

Blood Proteins

Concentrations of proteins in blood plasma are stable and have not been related to fertility (Treacher et al.,

1976). Concentrations of protein in plasma were similar for lactating beef cows fed low (90% NRC) medium (125% NRC) or high (175% NRC) energy diets and averaged 7.3, 7.8, and 7.4 percent, respectively (Coggins and Field, 1976). Total proteins in the blood are only slightly affected by protein restriction in the diet of the pregnant beef cow (Rasby, 1983). Total plasma proteins decrease typically as parturition nears (Zamet et al., 1979). A decrease of 30% in total protein in blood occurs prepartum because of transfer of albumin and globulins to colostrum.

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The Influence of Nutrition on

Endocrine Function

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An investigation into the physiological relationship between nutrition and reproductive performance must focus on nutritional effects on hormonal concentrations and interrelationships.

Insulin

All of the known vertebrate insulins consist of a 20 or 21 amino acid 'A chain' joined by two disulfide bridges to a 29-31 amino acid 'B chain'; a third disulfide bridge is formed by cysteine moieties of the 'A chain'. An approximately 25 amino acid sequence appears to be identical in all species (Martin, 1979). Glucose provides the major stimulus for insulin secretion in mammals that regularly consume carbohydrates and absorb glucose from the small intestine. Glucose, however, is absorbed in much smaller proportions

from the ruminant digestive tract than in the nonruminant.
Ruminant blood glucose concentrations are about half that of
nonruminants and must be maintained at about 40-60 mg/100 ml
to maintain normal function in many body tissues. In man,
the nervous system may utilize 80% of the total glucose sup-
ply in the postabsorptive period. Very much less glucose is
used by the sheep brain (only 5-6% of the glucose entry
rate; Lindsay, 1971), with a similar utilization by the
testes in rams (Setchell and Waites, 1964). The rat and
human brain are able to use ketone bodies as an alternative
energy source during starvation, but this opportunity does
not exist in the sheep (Lindsay and Setchell, 1976).

The major short-term control of glucose homeostasis is
exercised by the pancreatic hormones, insulin and glucagon.
The largely opposing actions of these two hormones has led
to the suggestion that the molar concentration ratio of the
hormones may be more important than the absolute level of
either hormone (Bassett, 1975). The pattern of metabolite
changes after feeding in sheep indicated that a slow
increase in plasma glucose concentrations after feeding is
associated with the absorption of volatile fatty acids from
the reticulo-rumen and a decreased reliance on non-esteri-
fied fatty acids as an energy source (Bassett, 1975).
Insulin concentrations remain fairly constant in sheep fed
at frequent intervals, but at concentrations related to the
digestible organic matter intake (Bassett, 1975). A bipha-
sic increase in insulin secretion occurs in sheep and cat-
tle fed once or twice daily (Trenkle, 1978). An initial

rapid rise in insulin concentration within 1 h of feeding is probably mediated by reflex vagal nervous mechanisms and may result in a moderate fall in plasma glucose concentration at this time.

In ruminants, the relationships between insulin and glucagon are not well documented. A balance of insulin and glucagon may be important in glucose homeostasis (Bassett, 1975). The extent of endogenous insulin release during alimentation is determined largely by the integrated action of vagal reflex activity, gastrointestinal hormones and pancreatic glucagon. Glucagon causes insulin release from the beta-cells and increases concentrations of glucose in blood, first by glycogenolysis and second by gluconeogenesis (Deetz and Wangsness, 1981). Glucagon acts primarily on the liver to increase gluconeogenesis (Trenkle, 1981). Its action on adipose tissue is lipolytic when insulin concentrations are minimal. In fasting animals, when the ratio of glucagon to insulin is increased in plasma because of a large decrease in insulin concentrations relative to the fed state, glucagon may contribute to the overall lipolytic response associated with fasting (Brockman, 1976). Perfused into ovine liver, exogenous glucagon caused a 75% increase in glucose synthesis and a 19% increase in labeled carbon dioxide production from carbon-14 propionic acid while decreasing carbon-14 threonine utilization by 76% (Gill et al., 1985). Glucagon may also serve as a feedback control of feed intake in ruminants. Exogenous glucagon alone and glucagon plus proprionate

decreased 24 h feed intake by 15.8 and 11.8%, respectively (Deetz and Wangsness, 1981). A relationship between glucagon and reproduction in ruminants has not yet been documented.

The stimulus for insulin secretion in ruminants is unclear. Unlike monogastrics, plasma glucose concentrations may not be the normal regulator of insulin secretion in ruminants (Trenkle, 1978). Trenkle (1972) reported concentrations of insulin in blood of ruminants is not correlated with blood glucose. However, Garnsworthy and Topps (1982) found nearly identical correlations of .29 and .289 between insulin and plasma glucose in two trials with lactating dairy cows. Intravenous infusion of glucose will stimulate insulin secretion as will intravenous injection of several amino acids (Bassett, 1974). Insulin secretion often is coincidental with the rise of volatile fatty acids (VFAs) after feeding and propionate, butyrate, and valerate, but not acetate, can stimulate insulin release from the ruminant pancreas (Bassett, 1975).

A direct link between insulin concentrations and reproductive performance in ruminants is yet to be discovered. However, reproductive failure invariably accompanies experimentally induced diabetes in laboratory animals (Davis et al., 1947; Sinden and Longwell, 1949; Levi and Weinberg, 1949; Lawrence and Contopoulos, 1960; Hunt and Bailey, 1961; Foglia et al., 1963; Schoffling et al., 1967; Liu et al., 1972; Paz and Homonnai, 1979). Although the deleterious effect of insulin deficiency may be exerted at multiple

sites, decreased gonadotropic function constitutes a major feature of the insulin-deficient state (Shipley and Danley, 1947; Howland and Zebrowski, 1972; Paz, et al., 1978; Kirchick et al., 1978, 1979). Anovulation in diabetic female rats treated with pregnant mare's serum gonadotropin was not related to a decreased ovarian secretion of estradiol nor to a diminished hypothalamic release of GnRH, but rather was due to a decrease in the responsiveness of the pituitary to GnRH (Kirchick et al., 1979). In contrast, Paz et al. (1978) did not observe any change in pituitary sensitivity in diabetic male rats. Adashi et al. (1981) conducted in vitro experiments in which the role of insulin in the regulation of basal and GnRH-stimulated release of gonadotropins in cultured rat anterior pituitary cells was studied. Their findings indicate that insulin has an augmenting effect on both basal and GnRH-stimulated release of LH and FSH. This effect of insulin was time- and dose-related, but independent of the ambient glucose concentrations as well as of changes in cell number and protein or LH content. McCann (1985) found that supraphysiological concentrations of insulin and acute insulin-induced increases in glucose utilization did not affect progesterone concentrations but suppressed LH production in dairy heifers. One potential problem with a theory suggesting that insulin interacts with the central nervous system or the pituitary in particular is that most of the brain is known not to require insulin for glucose uptake and utilization. However, insulin receptors are widely dis-

tributed in the central nervous system. Of 16 sites studied in the central nervous system, the olfactory bulb has the greatest number of insulin receptors, the preoptic nucleus and anterior hypothalamus had the fourth greatest number, and the pituitary had the least insulin receptors (Havrankova and Roth, 1978). Van Houten et al. (1979) demonstrated the presence of specific insulin binding sites in the brain. These receptors were found mainly in areas of the brain with a reduced blood-brain barrier, including the ventral hypothalamus (Van Houten et al., 1979, Baskin et al., 1983).

The long-term effects of nutrition on insulin concentrations have received limited attention in ruminants. Hove and Blom (1973) examined diurnal patterns of insulin in seven cows from each of two dairy herds. One herd was moderately underfed and the second herd adequately fed. No differences in insulin concentrations or secretion patterns were found. Hall et al. (1984) found that postpartum energy deprivation decreased insulin and LH concentrations in beef cows. Likewise, Rutter and Manns (1985) found increased concentrations of insulin and glucose for a week postpartum in ewes that received ad lib feed prepartum compared to ewes that received restricted feed and lost weight prepartum. Harrison and Randel, (1985) paired 26 beef heifers by weight and body condition, then assigned them to treatment groups receiving 75% or 180% of NRC requirements for dietary energy for maintenance. On day 10 of the first estrous cycle subsequent to 45 d of feeding, heifers were

infused twice daily with 20 IU insulin or saline. The
energy restriction or insulin did not alter serum LH or
progesterone concentrations but exogenous insulin did
increase ovulation rate in energy deprived beef heifers.
Dietary crude protein restriction had no effect on insulin
concentrations in gestating dairy cows (Chew et al., 1984).
During lactation, lower insulin coupled with increased
growth hormone is essential for partitioning nutrients to
the mammary gland for milk synthesis (Bines and Hart,
1982). Nutritionally obese cattle appear to respond dif-
ferently to exogenous and endogenous insulin than do lean
counterparts (McCann and Reimers, 1985). Obese heifers
were less sensitive to the glucoregulatory effects of
exogenous insulin. In addition, the mean secretion rates
of insulin were greater in obese than lean heifers.

Nutritional Influences on Gonadotropins
and Reproductive Steroids

Gonadotropin secretion is a limiting factor in the
onset of follicular growth and estrus after calving. Treat-
ment of anestrous cows with PMSG results in increased estra-
diol (Echternkamp, 1974; Wettemann et al., 1978). Pituitary
content of LH increases during the first 30 d after parturi-
tion in the cow (Saiduddin et al., 1968; Wagner et al.,
1969). The increase in concentrations of LH is due to an
increase in the number and magnitude of LH peaks preceding
the first postpartum ovulation (Stevenson and Britt, 1979).
A reduction in plasma progesterone in undernourished rats

has been linked to decreased gonadotropin release (Leatham, 1966; Howland, 1971, 1972; Howland and Ibrahim, 1971). The effects of restricting energy intake on concentrations of LH in the ruminant are unclear. Gombe and Hansel (1973) reported progressive increases in average levels of LH when heifers were on low levels of energy for three successive estrous cycles. However, Hill et al. (1970) and Dunn et al. (1974) reported no change in blood levels of LH during periods of restricted energy intake. Spitzer et al. (1978) fed yearling beef heifers one-third of recommended energy requirements. No significant differences were found in blood concentrations of progesterone or LH compared to control heifers fed 100% of recommended energy requirements. Lishman et al. (1977) conducted an experiment to determine whether plane of nutrition or prior treatment with FSH would alter the pattern of release of LH in response to GnRH. The profile of LH increased to a maximum more rapidly (30 minutes earlier) in cows on the high plane of nutrition.

Attempts to relate nutrient intake to steroid secretion in ruminants have been futile. Corah et al. (1974) found no effect of nutrition on peripheral concentrations of progesterone or estradiol either prior to or following parturition. Plasma concentrations of progesterone and estrone during the last month of pregnancy were greater in cows that maintain body weight and were in moderate condition, compared to cows losing weight that were in thin body condition (Mobley et al., 1983). Rone et al. (1982) suggested that increased substrate availability to the ovary may

affect gonadotropin release via enhanced ovarian steroid production. During the first cycle after energy was reduced, concentrations of serum progesterone in cows increased (Donaldson et al., 1970; Dunn et al., 1974), decreased (Hill et al., 1970), or remained the same (Gombe and Hansel, 1973). Effects of underfeeding for more than one cycle on systemic levels of progesterone are better understood. Donaldson et al. (1970) and Gombe and Hansel (1973) reported reductions in serum progesterone during successive cycles in cows on restricted energy intake. Also, Imakawa et al. (1983) found that long term restriction of energy intake of cycling heifers reduced luteal function and progesterone secretion.

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The Effects of Prepartum Nutrition,

Postpartum Nutrition and Body

Condition on Reproduction

in Beef Cattle

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Both subjective and objective evalutions of body condition or body fatness have been used to assess vigor and healthiness in all the meat animal species, plus dairy cows and horses. Visual attempts to assess body condition have usually led to subjective scoring systems. Several different body condition scoring systems for beef cattle have emerged. A six-point system was proposed by Lowman et al. (1976) whereby a score of 0 was given to a cow that was emaciated, had no fatty tissue that could be detected and the neural spines and transverse processes were very sharp

to touch. A score of 5 was given to a cow when the bone structure was no longer noticeable and the tail head was almost comletely buried in fatty tissue. A 9-point system is commonly used by researchers in the United States (Cantrell et al., 1982; Warner and Spitzer, 1982; Dunn et al., 1983; Wagner, 1985). Cattle described by the nine condition scores would appear as follows (Wagner, 1985):

Score 1. The cow is severely emaciated and physcially weak with all ribs and bone structure easily visible.

Score 2. The cow appears emaciated, similar to 1 above but not weakened. Muscle tissue seems severely depleted through the hindquarters and shoulder.

Score 3. The cow is very thin with no fat on ribs or in brisket and the backbone is easily visible. Some muscle depletion appears evident through the hindquarters.

Score 4. The cow appears thin, with ribs easily visible and the backbone showing. Muscle tissue is not depleted through the shoulders and hindquarters.

Score 5. The cow may be described as moderate to thin. The last two or three ribs can be seen and little evidence of fat is present in the brisket, over the ribs or around the tail head.

Score 6. The cow exhibits a good smooth appearance throughout. Some fat deposition is present in the brisket and over the tail head. The back appears rounded and fat can be palpated over the ribs and pin bones.

Score 7. The cow appears in very good flesh. The brisket is full, the tail head shows pockets of fat and the

back appears square due to fat. The ribs are very smooth
and soft handling due to fat cover.

Score 8. The cow is obese. Her neck is thick and short
and her back appears very square due to excessive fat. The
brisket is distended and she has heavy fat pockets around
the tail head.

Score 9. These cows are very obese and are rarely seen.
They can be described as similar to 8's but taken to
greater extremes. They also have a heavy deposition of
udder fat.

Wright and Russel (1984) related body condition score
directly to the chemically determined composition of 73
mature, nonpregnant, nonlactating Hereford x Friesian,
Blue-Grey, Galloway, Luing and British Friesian cows. Con-
dition score accounted for over 90% of the variation in
body fat. Wagner (1985) related visual body condition
score (CS) to total carcass energy (in mcal.) and calcu-
lated a linear prediction equation ($Y = -221.5 + 128.19$
CS) which accounted for 85% of the variation found in 71
non-pregnant, nonlactating Hereford cows. Dunn et al.
(1983) conducted a similar study on 55 mature beef cows
that ranged in body condition score from 2 to 9 (where
1 = emaciated, and 9 = very obese). Fat in the carcasses
ranged from 4.5% to 30.2%. Live animal body condition score
was strongly correlated to carcass fatness (r = .86) and to
total carcass energy (r = .77).

The importance of body condition at the time of calving
on subsequent reproductive performance has been documented.

Whitman (1975) noted that over 80% of cows in good (>7) body condition at calving displayed estrus by 60 d postpartum regardless of weight gain or loss before or after calving. Dunn and Kaltenbach (1980) reviewed the effects of nutrition pre and postpartum as well as the resulting weight and body condition changes on the anestrus interval in the beef cow. They summarized volumes of data by noting that body condition at calving and prepartum weight changes are important factors that affect the length of the postpartum interval in beef cows. Postpartum weight gains are essential only in cows thin at calving or cows that lost weight prior to calving.

Wettemann et al. (1982) analyzed the percent weight change and body condition score change from November to calving in March on 35 Hereford cows. The percentage decrease in body weight from November until just prior to calving was correlated with days to first estrus (r = .58) and days to conception (r = .60). The percentage decrease in body condition score was correlated to days to first estrus (r = .61) and to days to conception (r = .62). A 20 percent decrease in body condition score from November to calving in March and April was associated with an additional 15 d to first estrus after calving compared to cows that maintained the fall body condition. Similarly a 20 percent decrease in body weight from November to calving was associated with an additional 17 d to first estrus. The mean body condition score just prior to calving was 5.1 and ranged from 3.8 to 6.5. These cows were considerably

thinner at parturition than those studied by Whitman (1975) and the difference in body condition at calving may account for the different response to precalving weight and condition score change.

Reduced energy intake following parturition delays the onset of estrus in dairy cows (Reid, 1960; Gardner et al., 1969) and beef cows (Wiltbank, et al., 1964; Somerville et al., 1979; Lowman, et al., 1979). In contrast to previous studies, Rutter and Randel (1984) found that postpartum diets affected the interval to first estrus in Brangus cows that calved in good to excellent body condition (mean score for heifers was 5.8 and for mature cows was 7.3; 1 = very thin, 10 = very fat). Regardless of the nutrient intake, females in this study that were able to maintain body condition after calving, had an approximately 30 d shorter postpartum interval than females that lost body condition. Although increasing dietary nutrient level decreased the postpartum interval, there was no apparent change in pituitary function, as measured by both endogenous and stimulated LH release (Rutter and Randel, 1984). These latter results conflict with Beal et al. (1978) who reported a positive effect of increased dietary nutrient level on pituitary function.

The response to postpartum energy level is dictated by prepartum energy level and body condition (Wiltbank et al. 1962; Dunn and Kaltenbach, 1980). Wiltbank, et al. (1962) fed cows 100% NRC before calving then fed either 100% or 50% NRC post partum and found no differences in the inter-

vals from calving to first estrus. Cows fed 50% NRC before calving then fed either 50% or 100% NRC postpartum had longer postpartum intervals than cows fed 100% NRC prepartum. Wiltbank et al. (1964) also fed 100% NRC prepartum and 75, 100, or 150% NRC postpartum. Cows fed 100% NRC throughout the experiment had a significantly shorter interval to first estrus and a greater percentage exhibited estrus by 50 d post partum than other cows. Garmendia et al. (1984) reported cows fed to maintain body weight prepartum had a greater conception rate than cows fed to lose weight during mid to late pregnancy. In contrast, Corah et al. (1975) found no effect of prepartum energy level on the postpartum interval to first estrus in cows and heifers that were in good body condition throughout the trial. An increased level of nutrition postpartum may cause increased milk production and increased suckling intensity resulting in longer postpartum anestrous intervals. Bellows and Short (1978) observed increased postpartum intervals in cows underfed precalving but given increased nutrition after calving. Richards et al. (1985) found that increased postpartum nutrition for cows calving in thin (score < 4) body condition increased the percentage of cows conceiving in a restricted breeding season.

Responses to prepartum and postpartum nutrition depend on body condition before the supplement period begins or at calving. Therefore, when nutritional effects on reproduction, endocrine or metabolic function are evaluated, it is imperative to estimate the amount of body energy reserves.

The most practical, yet inexpensive, method to estimate
live animal body energy reserves is a visual, body condi-
tion scoring system.

CHAPTER III

RELATIONSHIPS AMONG PREPARTUM NUTRITION,

POSTPARTUM BLOOD GLUCOSE, LH, INSULIN,

AND REPRODUCTIVE PERFORMANCE

IN RANGE BEEF COWS

Abstract

Hereford range cows calving in Feb, Mar and Apr during two years were used to evaluate the effects of prepartum nutritional treatments on reproduction, body condition, (scale of 1=thin to 9=obese; BCS), serum insulin, and plasma glucose post partum. Cows calving in 1983 (n=71) and 1984 (n=45) were assigned to one of four nutritional treatments about 115 d prepartum. Mod cows were supplemented to maintain body weight until calving. LL, LM, and LH groups were supplemented to lose 5% of the fall weight by 45 d prepartum. Amount of supplemental protein and hay was then changed so LL cows continued to lose another 5% by calving. LM cows were fed similar to Mod cows and LH cows were fed 140% of that fed to Mod cows. All cows received the same supplement and were allowed to graze the same pasture after calving. Blood samples were obtained weekly during the first 85 d post partum and concentrations of glucose, insulin and luteinizing hormone (LH) were determined. Prepartum treatments did not influence reproductive performance. Response curves for plasma glucose in 1983 were depressed for cows calving early in the calving season that did not become pregnant compared to cows that conceived. A similar trend (P>.1) existed for cows calving later in the spring. Insulin response curves were different for Mod and LL cows that became pregnant when compared to those counterparts that did not conceive. LH concentrations were increased in those cows that became pregnant compared to cows that did not conceive. These results suggest that the concentrations of glucose in plasma may be related to subsequent conception rate when cows are nutritionally deprived and thin.

Introduction

The effects of nutrition on postpartum reproduction of beef cows have been reviewed by Dunn and Kaltenbach (1980). Based on regression analysis, 91% of multiparous cows that had no prepartum weight loss exhibited estrus by 60 d post partum. For each kilogram weight loss prepartum the percentage of cows that exhibited estrus by 60 d postpartum decreases by .5%. Body condition or energy status of the cow at the time of calving affects reproductive performance (Wiltbank et al., 1964; Whitman, 1975; Dunn and Kaltenbach, 1980; Richards et al., 1985).

The physiological link between the energy status of cows and reproductive function has not been elucidated. Glucose is an important source of energy for most mammalian cells including nervous and endocrine tissues (Martin, 1979) and diabetic laboratory rodents have impaired reproductive function (Davis et al., 1947; Sinden and Longwell, 1949; Levi and Weinberg, 1949; Lawrence and Contopoulos, 1960; Hunt and Bailey, 1961; Foglia et al., 1963; Schoffling et al., 1967; Liu et al., 1972; Paz and Homonnai, 1979). Concentrations of glucose in plasma may be related to fertility in the bovine (McClure, 1968; Payne, 1970; Downie and Gelman, 1976; Patil and Deshpande, 1979; Kappel et al., 1984). Most of the studies evaluating the relationship between glucose and fertility in cattle have used dairy cows.

Insulin is a primary regulator of concentration of glucose in plasma of mammals (Martin, 1979). Insulin secretion from the normal monogastric pancreas is stimulated by increased concentration of glucose in plasma (Martin, 1979). Concentration of glucose in plasma is not the only normal regulator of insulin in ruminants (Trenkle, 1972; Garnsworthy and Topps, 1982), however, concentrations of insulin and glucose are moderately correlated in dairy cows. Insulin can enhance basal and GnRH-stimulated LH release from cultured rat pituitary cells (Adashi et al., 1981). Limited information is available concerning the relationship between glucose in plasma and reproductive performance in beef cows.

The purposes of this research were to: 1) evaluate the influence of prepartum nutrient intake and weight loss on postpartum concentrations of glucose and insulin in blood in beef cows; 2) examine the relationship of glucose and insulin concentrations post partum with reproductive performance; 3) evaluate the effects of prepartum nutrition on concentrations of LH in serum post partum; and 4) evaluate the relationships among blood concentrations of LH, insulin, and glucose post partum.

Materials and Methods

Pregnant Hereford cows grazing native range near Stillwater, Oklahoma were assigned to one of four nutritional treatment groups. On November 12, 1982 (71 cows), and on November 16, 1983 (45 cows) cows were assigned by age and

body condition score to treatments. Group 1 (Moderate) cows were supplemented to maintain their November weights until calving in March and April. Groups 2, 3, and 4 were restricted in supplementation so as to lose 5 percent of their November weights by approximately 60 d prior to the average expected calving date. After January 20, 1983 and January 26, 1984 Group 2 (Low-Low) cows were continued on the restricted diet so they would lose another 5% of their November weight before calving. Group 3 (Low-Moderate) cows were supplemented the same as Group 1 cows the last 60 d prior to calving. Cows in Group 4 (Low-High) were given 140 percent the supplemental feed given to Group 1 cows during the last 60 d of gestation (Table 1). In 1982-83 cows were 3 to 6 years old, and in 1983-84 all first or second-calf heifers were used. Differing amounts of cottonseed meal were used as protein supplement. Tables 2 and 3 outline the supplementation regimes used in 1982-1983 and 1983-1984, respectively. During the first year, cows were fed in groups and during the second year cows were individually fed 3 d per week.

During November to January, grass hay (Bermuda or native) or "haygrazer" forage sorghum was fed as supplemental hay when the wind chill index was less then -12 C or when ambient temperature was less then 4.4 C and there was precipitation. From late January until calving, (in 1983) Moderate (MOD), Low-Moderate (LM), and Low-High (LH) cows were given 4.5 - 6.8 kg of hay per day. Low-Low (LL) cows

received approximately 3 kg of hay per day. The next year, cows were fed hay only during inclement weather and 11 kg on Fridays. After calving, cows were maintained on range pasture and fed approximately 1.8 kg of 40% protein cubes daily plus supplemental hay free choice. In 1983, the severity and length of the winter season depleted hay supplies by May and forage quality and quantity was limited, therefore 2.3 kg of 20% crude protein range cubes were fed from April 28 to May 16, then supplemental feeding was discontinued. In the early spring of 1984, standing forage and hays were both available, consequently the protein supplement was reduced from 1.8 kg/d to .9 kg/d on May 14 and supplemental protein was no longer fed after May 30. All cows in 1983-1984 were treated on December 29 with Benzelmin (37.8 mg/ml) at a dosage rate of 15 ml/226 kg body weight to reduce internal parasites. The breeding seasons commenced May 3 each year (20 cows/bull). Bulls were removed from the breeding pasture on August 1, 1983 and July 30, 1984. The date of onset of ovarian luteal activity was estimated by plasma progesterone quantifications. The first of two successive weekly bleeding dates when concentrations of progesterone were greater than 1 ng/ml was considered the onset of ovarian luteal activity. Conception dates were estimated from the subsequent calving date minus 281 days. Pregnancy was determined by rectal palpation at least 60 days after the end of the breeding season.

Cows were weighed and body condition scores were assigned biweekly from the beginning of the trial until 85 days post partum. Body condition scores were determined by at least two individuals and utilized a scale of 1 = emaciated, to 9 = very obese (Table 4.) Wagner (1985) found a strong relationship between body condition score and carcass fat content (r=.88). Tail vein blood samples (20ml) were obtained weekly after calving until 85 days postpartum. Cows were removed from feed and water for approximately 16 h prior to weighing and/or blood sampling. An anticoagulant (16 mg of oxalic acid) was added to each sample in vacutainer blood tubes. Five ml of each sample was removed and added to test tubes containing .08 g sodium fluoride (NaF) to inhibit metabolism of glucose. All samples were cooled in an ice bath until returned to the laboratory. Samples were centrifuged (5000 x g) and plasma was decanted within 6 h of bleeding. Samples containing NaF were stored at -20 degrees C until assayed for glucose. Sixty (60) µl of a 100 mg/ml $CaCl_2$ solution was added to each of the remaining samples (approximately 6 ml plasma per sample) and allowed to coagulate at 4 C for 20 h. After centrifugation, these samples were stored at -20 C until quantified for insulin, luteinizing hormone, and progesterone via radioimmunoassay.

Glucose Assays

Glucose concentrations were determined by an enzymatic, colormetric procedure (No. 510, Sigma Chemical Company, St.

Louis). The procedure is based upon two coupled enzymatic reactions:

1) Glucose + 2 H_2O + O_2 $\xrightarrow{\text{Glucose Oxidase}}$ Gluconic Acid + 2 H_2O_2

2) H_2O_2 + o-Dianisidine $\xrightarrow{\text{Peroxidase}}$ oxidized o-Dianisidine. The intensity of the brown color of the oxidized o-Dianisidine is proportional to the original glucose concentration. Within each assay, standard curves were developed with 0, 25, 50, 75, 100 and 150 mg% glucose solutions for calculation of concentrations of unknown samples. Intraassay and the interassay coefficients of variations averaged 1.6% and 4.5%, respectively.

Luteinizing Hormone Assays

Luteinizing hormone (LH) concentrations were determined on all samples taken in 1984 using a double-antibody radioimmunoassay, similar to that reported by Niswender et al. (1969). Standard bovine LH (NIH-LH-B9) was diluted in 1% egg white-phosphate buffered saline (EWPBS) in concentrations (n=9) ranging from .025 to 3.2 ng/tube was included in each assay. Radiolabeled ligand was prepared from LER-1374A-ovine LH and I^{125}. At a dilution of 1:100,000 the antisera (#15, supplied by Dr. G. D. Niswender, Colorado State University, Fort Collins, Colorado) bound approximately 8% of ^{125}I-LH in the absence of nonlabeled LH and had less than 2% crossreactivity with bovine growth hormone

(NIH-GH-B18), bovine follicle stimulating hormone (NIH-FSH-B1), and bovine prolactin (NIH-P-B4). Crossreactivity with bovine TSH (NIH-TSH-B7) was 31%; however, when cows were treated with exogenous TRH, to induce release of endogenous TSH, concentrations of LH were constant for 4 h. This crossreactivity could be caused by contamination of the TSH with immunologically active LH since these two hormones are immunologically related (Guillemin, 1967). Dose response curves for cow serum were parallel to the standard curve (Rasby, personal communication). Interassay and intraassay coefficients of variation averaged 18 and 3%, respectively.

Insulin Assays

Concentrations of insulin were quantified by a double-antibody radioimmunoassay. Crystalline bovine insulin (Lot 615-70N-80, generously supplied by Dr. M. A. Root, Lilly Research Laboratories, Indianapolis, Indiana) was used to prepare standards and I^{125}radio-labeled ligand. Iodination of bovine insulin was achieved by the method of Greenwood et al. (1963) as modified by Rasby (personal communication). The potency of the purified insulin was 26.6 U/mg and contained less than .001% proinsulin or glucagon. Standards were prepared as .0097, .0195, .039, .078, .156, .312, .625, 1.25, 2.5, and 5 ng/tube in .5 ml of .1% Gel-PBS and stored at -20 C in 12x75 tubes until used in assays. The antiserum (guinea pig anti-bovine insulin, lot GP 23; Miles-Yeda, Ltd. Research Products, Elkhart, Indiana)

was diluted 1:40,000 in .05 M PBS-ethylenedinitrilotetra-acetic-acid (PBS-EDTA, pH 7.0) to which normal guinea pig serum had been added (1:200 NGPS, PBS-EDTA).

Duplicates (200 µl) of each serum sample were assayed in 12x75 tubes containing 300 µl of .1% Gel-PBS plus 1 IU of sodium heparin. Heparin was added to prevent clotting pro-teins (that had not been removed by CaCl and previous cen-trifugation) from producing nonspecific precipitation. After addition of 200 µl of antiserum to each tube (except the non-specific binding tubes) tubes were incubated for 24 h at 4 C. Then, 100 µl ^{125}I-b Insulin in .01% Gel-PBS (approx. 25,000 cpm) were added to all tubes. After incuba-tion of tubes for 24 h at 4 C, 200 ul sheep anti-guinea pig gamma globulin diluted in .1% Gel-PBS (1:20) was added to all tubes and tubes were incubated for 48 h at 4 C. Sheep anti-guinea pig gamma globulin was produced by inoculating a dorset wether monthly with guinea pig gamma globulin (No. 2638, Sigma Co., St. Louis, Mo.) and Freund's adjuvnant (Sigma Co., St. Louis, Mo.) All reagents were added to assay tubes while at 4 C, then the tubes were shaken vigorously in the rack for 30 sec. After the final 48 h incubation, PBS (1 ml; 4 C) was added to each tube and tubes were centrifuged (2800 x g) for 30 min. The supernatant was decanted, inverted tubes were allowed to dry while inverted and the radioactivity in the precipitate was quantified using a spectrophotometer (Packard Multi-Prias, Packard Instrument Co., Inc.).

Triplicate serum samples with and without heparin added demonstrated no significant effect due to heparin. A serum sample with heparin had .58 $\pm$ .11 ng/ml ($\bar{X} \pm$ S.E.), whereas the same sample without heparin contained .60 $\pm$ .09 ng/ml. The serum sample with 1 ng/ml of added insulin and 1 IU heparin had 1.55 $\pm$ .32 ng/ml compared to 1.43 $\pm$ .15 ng/ml for the same sample without heparin.

Increasing volumes (50, 100, 150, 200 and 250 μl) of cow serum and plasma were parallel to the standard curve (Figures 1 and 2). When 0, .5 and 1.0 ng/ml of bovine insulin were added to serum samples (n = 4), the concentrations determined were .34 $\pm$ .04, .86 $\pm$ .07, and 1.48 $\pm$ .12 ng/ml, respectively. Recovery of 1.0 ng of bovine insulin added to serum samples in six assays averaged 1.1 $\pm$ .1 ng/ml. A physiological response of insulin to a glucose challenge was demonstrated by Rasby (personal communication). Interassay and intraassay coefficients of variation were 18 and 22%, respectively.

Progesterone Assays

Concentrations of progesterone in serum were used to determine the onset of ovarian luteal activity. Concentrations of progesterone in serum were determined by a single antibody radioimmunoassay. Validation of the assay in this laboratory has been described (Lusby et al., 1981).

Statistical Analyses

Treatment effects on 12 weekly postpartum samples for plasma glucose, serum LH, and serum insulin were analyzed in a split-plot analysis of variance over time (Gill and Hafs, 1973). All cows were identified as "early" or "late" calving cows depending on when they calved in relation to the median calving date for that season. In this analysis, "pregnant" cows are those that became pregnant during the subsequent breeding season and compared to "nonpregnant" cows that were not pregnant when palpatated the following fall. Full regression models with week, $week^2$, $week^3$, and $week^4$ and their interactions with main effects were "reduced" by examining the sequential sums of squares and removing higher order interactions that had a probability of significance greater than .2. Main plot effects and interactions were left in the model and tested using the partial sums of squares of cow (treatment*pregnancy*calving season) divided by degrees of freedom as the error mean square. Polynomial response curves for concentrations of insulin and glucose of cows that became pregnant were compared with those that failed to conceive, in early and late calving cows, within each treatment group. Heterogeneity of response curves was examined by testing the reduction in error sums of squares when more than one curvilinear regression model was used to describe the data. Within class partial correlation coefficients were calculated to study the association of hormone and glucose concentrations.

Results and Discussion

<u>1983 Results</u>

Body weights of the cows that calved in 1983 are
depicted in Table 5. Due to nontreatment related health
problems (prolapsed uteri and anaplasmosis), some cows
originally assigned to be in the LL, LM, and Mod treatments
were eliminated after the start of the trial, resulting in
disparity in mean fall body weights. Cows in the LL group
had lighter body weights than the LH cows in the fall
(P<.05). Body weights were similar for all other groups in
the fall. Body condition scores were similar for cows on all
treatment groups in November. Cows on all treatments lost
weight by January 20. Mod cows lost 2.7% of the fall weight
whereas LL, LM, and LH cows (fed as a group) lost 5% of
their November weight. Low-High cows had gained 1.8% of the
fall weight from Jan. 20 to before parturition and Mod and
LL groups had lost an additional 6% of the fall weight.
Low-Mod cows lost 5% of the fall weight from treatment
change in January to before calving.

Body condition scores (Table 6) indicated that the 1983
cows were in a negative nutritional state until calving.
Initial body scores (November) were similar for all groups
(mean = 5.6). However, the LH cows had a slightly greater
body condition precalving and at the start of the breeding
season. Mod, LL, and LM groups had average condition scores
less than 5.0 precalving and at the start of the breeding
season. A particularly long, late winter season delayed the

availability of summer grasses until late May and prematurely depleted the hay supplies. Additional supplemental energy was provided in late spring in an attempt to alleviate the insufficient energy availability (Table 2). The minimal recovery in body weights and loss in body condition scores after calving is evidence of the weather-related nutritional stresses. The undesireable reproductive performance of the cows in 1983 (Table 7) reflects the weight and condition losses incurred by all groups before calving and minimal weight gains after calving. Postcalving weight changes and condition score changes were correlated ($r = .52$, $P<.01$). Pregnancy rate, days to ovarian luteal activity, or days to conception were not significantly influenced by treatment. As might be expected, Mod cows tended to have the greatest pregnancy rate, and LL cows had the smallest pregnancy rate.

Regression models for glucose and insulin concentrations included nutritional treatment (trt), success or failure to become pregnant during the breeding season (preg), and time of calving during the calving season (cs), week (wk), wk^2, wk^3, wk^4, plus all two-way and three-way interactions alone and with week. The reduced model for plasma glucose in 1983 is in Table 8. No main effects were significant. An interaction of trt x preg x cs x wk^2 ($P<.003$) suggested that quadratic equations among trt, preg, and cs

would best describe these data. Since one cell (LL, pregnant, late calving cows) was devoid of data, and other cells had very few cows if 16 treatment combinations were evaluated, and our major interest was the effects of potential pregnancy, the values were pooled across treatments. To examine differences in response curves for pregnant (P) and nonpregnant (NP), early (EC) and late calving (LC) cows, four quadratic response curves were developed (Figure 3).

Tests of heterogeneity of response curves indicated that four individual curves described the glucose response more accurately than one curve ($P<.01$). Comparisons were made within calving seasons. Early-calving, nonpregnant cows (EC-NP) had decreased ($P<.025$) concentrations of glucose compared compared with early-calving cows that became pregnant (EC-P). Therefore, concentrations of plasma glucose are related to the potential for pregnancy in cows that have ample time between parturition and the start of the breeding season. Cows that have a reduced concentration of glucose in plasma due to metabolism or environmental conditions are candidates for reduced fertility. Although LC-P tended to have greater glucose concentrations than LC-NP, the response curves were not significantly different. These data support the findings (mostly in dairy cows) of McClure, 1968; Payne, 1970; Downie and Gelman, 1976; Patil and Deshpande, 1979; Kappel et al. 1984. Oxenreider (1971) demonstrated that hypoglycemia is associated with decreased follicular development in dairy cows. The reduced glucose

for those cows in the NP groups may negatively influence
ovarian activity.

A regression model (Table 9) similar to that for plasma
glucose was developed for insulin in 1983 cows. After model
reduction, a trt x cs x preg interaction was significant.
Also the wk^3 x preg interaction (P<.01) indicated that cubic
equations best fit the insulin values over the 12 week
period. Third order regression equations predicted insulin
patterns for the four treatment groups as early or late
calving and pregnant or nonconceiving cows. Eight curves
for trt x preg cows are depicted in Figure 4. A test of
heterogeneity of all eight curves indicates that differences
between curves existed, therefore, orthogonal comparisons of
response curves for pregnant and nonpregnant cows within
each treatment group were made. Moderate, nonconceiving
(Mod-NP) cows had different insulin response curves (P<.01)
over time than did Mod-P cows (Figure 5). Likewise, LL-NP
cows were different (P<.05) from LL-P in insulin response
over the twelve weeks (Figure 6). Only two cows in the LL
group, however, became pregnant. An interesting similarity
exists between Mod and LL groups as the lines for conceiving
and nonconceiving cows follow similar patterns and cross at
approximately the seventh week postpartum. In addition,
concentrations of insulin for cows on all treatments that
became pregnant tended to be greater during week 8 through
11 post partum. Reproductive failure invariably accompanies

experimentally induced diabetes in laboratory animals (Davis et al., 1947; Sinden and Longwell, 1949; Levi and Weinberg, 1949; Lawrence and Contopoulos, 1960; Hunt and Bailey, 1961; Foglia et al., 1963; Schoffling et al., 1967; Liu et al., 1972; Paz and Homonnai, 1979). Kirchick et al. (1979) demonstrated a decreased responsiveness of the pituitary to GnRH in diabetic rats. Likewise, Adashi et al. (1981) found a time and dose dependent response to insulin presence on GnRH-induced LH secretion in cultured rat pituitary cells. Hypoinsulinemia may have occurred for the NP cows during a period near the beginning of the breeding season, creating a "diabetic-like" condition in those cows that failed to conceive.

Figure 7 illustrates the eight response curves of early and late calving cows in each of the four treatment groups. The EC-LL cows differed ($P<.05$) from their later calving counterparts (LC-LL) and had reduced concentrations of insulin (Figure 8). However, the EC-LH cows had greater concentrations of insulin and a different insulin response curve ($P<.05$) than did the LC-LH cows (Figure 9). Early calving cows had decreased insulin in the LL group, whereas the EC-LH cows had greater insulin concentrations than the later calving counterparts. The nutritionally stressed LL-LC cows may have been compensating as warmer weather and green pasture forages slowly became available, whereas the early calving LL cows had only the limited supplied feed provided by caretakers. This concept would be in agreement

with Hall et al. (1984) who reported that postpartum energy deprivation decreased insulin and LH concentrations in beef cows.

Prepartum nutrition had minimal effect on postpartum serum insulin concentrations. Insulin appears to respond to the current nutritional situation as evidenced by the increase in insulin concentrations after 9 weeks post partum in LL late calving cows. A common pattern of lowest concentrations of insulin early in the postpartum period and increased insulin at 6 to 8 weeks post partum was apparent in LL and Mod cows that became pregnant.

1984 Results

For cows on the 1984 trial, weight losses were similar from November until the time of nutrition change in January to those in the previous year (Table 10). Mod cows maintained their body weight from November until January 26. LL, LM, and LH cows lost 5% of the fall weight by January 26. Weight changes were similar for all four groups from January until the start of the breeding season. Contrary to the postpartum weight changes in 1983, all groups calving in 1984 consistently gained weight after calving and continued to gain during the breeding season. The condition scores of the cows in 1984 further indicate less nutritional stress after calving than in 1983 (Table 11). Mean body condition scores for three of the four Groups were above 5.0 by

precalving. The relationship between body weight change and condition score change from fall to postcalving weigh days was similar to that in 1983 (r = .52, P<.01). As was observed in 1983, treatment prepartum again had no significant effect on reproductive performance. The greater conception rates for cows of all groups is testimony to the more favorable nutrition in 1983-84 (Table 12). Greater numbers of cows per treatment group would be necessary to evaluate reproductive traits. As might be expected, Mod cows tended to have the greatest pregnancy rate and the most cows with ovarian luteal activity by 85 d post partum compared to the other treatments.

Similar regression model reduction was used for the 1984 glucose concentrations as was described for the previous year (Table 13). The reduced model indicated that a quartic expression best fit the concentrations of glucose over the twelve week period. The trt x wk interaction suggested that comparisons between treatments be made (Figure 10). However, a test of heterogeneity of response curves for the treatments, indicated that four individual curves did not better describe the glucose trends than did one fourth order equation (P>.05).

The reduced regression model for 1984 concentrations of insulin is presented in Table 14. The significant trt x preg x wk^3 interaction indicates that comparisons of third order response curves between conceiving and nonconceiving cows within a treatment group should be made. Tests for

heterogeneity of insulin response curves over the twelve
week period indicated that concentrations of insulin for
those cows becoming pregnant were similar to those that
failed to conceive in all four treatment groups (Figure 11).
The smaller number of nonpregnant cows in 1984 caused
increases made finding statistical differences in insulin
concentrations less likely. A trt x cs x wk^3 interaction
suggests different insulin trends of early vs. late calving
cows within treatment groups (Figure 12). Only in the Mod
group, were the response curves for early calving cows (Mod-
EC) different (P<.05) when compared to late calving coun-
terparts (ModLC) (Figure 13). The response curves for
insulin in early and late calving cows in the Mod group were
very dissimilar and concentrations tended to be greater dur-
ing the first 4 weeks or during weeks 11 and 12 postpartum
in late calving compared to early calving cows. The
increases in concentrations of insulin for late calving cows
in the latter weeks may be related to the onset of summer
and the emergence of warm season grasses.

A split-plot analysis of variance for concentrations of
luteinizing hormone (LH) (Table 15) revealed that there was
no significant effect of prepartum treatment, or calving
season on concentrations of LH postpartum. Cows that later
became pregnant had increased (P<.05) LH concentrations over
most of the twelve week bleeding period compared to cows
that did not conceive. LH concentrations decreased linearly
over time in the cows that became pregnant (Figure 14). As

a greater number of cows conceived, LH ovulatory surges disappeared. In contrast, those cows that did not conceive had fewer ovulatory surges and the response of LH over the 12 weeks was near basal concentrations. When samples with increased LH that may be associated with an ovulatory surge, (those greater than 2 ng/ml) were removed from the data, there was no relationship between concentrations of LH with the eventual success or failure to conceive. However the occurrence of samples that contained greater than 2 ng/ml LH was greater (P<.05) in those cows that subsequently became pregnant. Within-class partial correlation coefficients among LH, glucose, and insulin are given in Tables 16, 17, and 18. Within those cows that became pregnant glucose and insulin are positively correlated (r=.20; P<.001). Since plasma glucose is the result of gluconeogenesis in the ruminant (Baird et al., 1983), this relationship suggests that stored energy was available in those cows that became pregnant and insulin increased when glucose was produced. The lack of a relationship between glucose and insulin in cows not pregnant implies that more of the energy for cellular oxidation may have come from nongluconeogenic sources such as fatty acids or amino acids. Nutritionally obese cattle also respond differently to endogenous insulin than do lean cattle (McCann and Reimers, 1985). Those cows that failed to become pregnant are thinner and may be less sensitive to the glucoregulatory effects of insulin. Within those cows that failed to become pregnant, glucose was

related to LH (r=.21; P<.05). The infrequency of ovulatory surges in those cows that did not become pregnant provide a greater likelihood of a close association between a blood energy source and LH secretion. Abomasal infusions of proprionate (a glucose precursor) enhanced the ability of pre-puberal Brangus heifers to respond to a GnRH challenge with increased peak LH concentrations and slightly increased area under an LH curve (Rutter et al., 1983). The pulsatile nature of LH secretion should give little opportunity for close relationships with other parameters when only weekly blood samples are analyzed.

In 1983, cows suffered severe weight and condition loss especially during late gestation. In addition, plasma glucose for NP cows were decreased compared to the cows that became pregnant. These two biological events are probably linked to reproduction. Our findings then concur with McClure (1970) and Downie and Gelman (1976) that found when body weight and plasma glucose were decreasing, cows were infertile; when glucose was increased even under conditions where body weight decreased, cows were fertile. The early postpartum period may be very critical for the interaction of concentration of glucose with reproductive function. Kappel et al. (1984) noted that the least fertile dairy cows had reduced glucose concentrations during early lactation compared to more fertile cows. The longer period from parturition to first estrus in beef cows (compared to dairy

cows) might suggest that the critical time for plasma glucose to reach a "threshold" is at four to six weeks post partum. During this time, a substantial advantage exists for pregnant cows in either the EC or LC groups for concentrations of glucose. It is also during this time frame that LC cows that do become pregnant have equal or greater concentrations of glucose than the EC-NP cows.

In 1984, the more favorable weather resulted in improved nutritional status of all cows compared to 1983. The advantage of earlier availability of pasture grasses is apparent when reviewing the reproductive records of 1984 cows compared to the previous year. The improved nutritional state of cows on all treatments in 1984 may have been the cause of similar plasma glucose patterns among treatment groups as well as between conceiving cows and those that failed to conceive. The smaller number of nonconceiving cows (n=11) also reduced the likelihood of observing statistical differences in parameters as variable as blood constituents. Furthermore, a possible relationship between basal concentrations of glucose and insulin (since they were determined on postfasting blood samples) and LH becomes less probable due to the pulsatile nature of LH. Although no direct relationship of glucose or insulin with LH could be documented under these range conditions, a relationship of plasma glucose with potential pregnancy remains a viable possibility in beef cows.

Information in dairy cows and the results of early calving range cows in 1983 cited above indicate the concentration of glucose as well as its regulator, insulin, should remain candidates as the physiological link between nutrition and reproduction in beef cows.

Blood glucose, insulin, and LH concentrations are quite variable within a single cow or between different cows due to the many physiological factors regulating these blood constituents. One blood sample will not give an accurate indication of the long-term glucose, or endocrine status of the cow sampled.

TABLE 1. EXPERIMENTAL TREATMENTS FOR COWS CALVING IN
1983 AND 1984

Treatment	Fall-Jan. 20(26)	Jan. 20(26)-Calving	Postpartum
Group 1 (Mod)	Maintain Fall weight	Maintain Fall weight	NRC for lactating cow
Group 2 (LL)	Lose 5% of Fall weight	Lose 5% of Fall weight	Same as Group 1
Group 3 (LM)	Lose 5% of Fall weight	Same as Group 1	Same as Group 1
Group 4 (LH)	Lose 5% of Fall weight	Fed 140% of Group 1	Same as Group 1

TABLE 2.   SUPPLEMENTATIONS REGIMEN FOR COWS CALVING IN 1983

Treatment Group	Interval	Nutritional Program
Moderate	Nov. 11 - Dec. 16	.9 kg csma/d
	Dec. 16 - Jan. 20	1.4 kg csm/d
	Jan. 20 - calving	1.4 kg csm + 4.5 - 6.8 kg hay/d
Low-Low	Nov. 11 - Dec. 2	.45 kg csm/d
	Dec. 2 - Dec. 16	.9 kg csm/wk
	Dec. 16 - Dec. 30	.9 kg csm/wk for cows 5 (BCSb) or greater; .68 kg csm/d for cows less than 5 (BCS)
	Dec. 30 - Jan. 20	.45 kg csm/d for cows 5 (BCS) or greater; .9 kg csm/d for cows less than 5 (BCS)
	Jan. 20 - calving	.9 kg csm/d
Low-Moderate	Nov. 11 - Jan. 20	Same as Low-Low
	Jan. 20 - calving	Same as Moderate
Low-High	Nov. 11 - Jan. 20	Same as Low-Low
	Jan. 20 - calving	2.3 kg csm + 4.5 - 6.8 kg hay

a Cottonseed meal, 41% crude protein
b Body condition score

TABLE 3.   SUPPLEMENTATION REGIMEN FOR COWS CALVING IN 1984

Treatment Group	Interval	Nutritional Program
Moderate	Nov. 16 - Dec. 1	1.4 kg csm[a]/d
	Dec. 1 - Jan. 26	1.8 kg csm/d
	Jan. 26 - calving	1.8 kg csm/d
Low-Low	Nov. 16 - Jan. 26	.68 kg csm/d
	Jan. 26 - calving	.9 kg csm/d
Low-Moderate	Nov. 11 - Jan. 20	Same as Low-Low
	Jan. 20 - calving	Same as Moderate
Low-High	Nov. 11 - Jan. 20	Same as Low-Low
	Jan. 20 - calving	2.72 kg csm/d

[a]Cottonseed meal, 41% crude protein.

TABLE 4. BODY CONDITION SCORING SYSTEM USED TO EVALUATE
ENERGY STATUS OF COWS

Score	Description
SCORE 1	The cow is severely emaciated and physcially weak with all ribs and bone structure easily visible.
SCORE 2	The cow appears emaciated, similar to 1 above but not weakened. Muscle tissue seems severely depleted through the hindquarters and shoulder.
SCORE 3	The cow is very thin with no fat on ribs or in brisket and the backbone is easily visible. Some muscle depletion appears evident through the hindquarters.
SCORE 4	The cow appears thin, with ribs easily visible and the backbone showing. Muscle tissue is not depleted through the shoulders and hindquarters.
SCORE 5	The cow may be described as moderate to thin. The last two or three ribs can be seen and little evidence of fat is present in the brisket, over the ribs or around the tail head.
SCORE 6	The cow exhibits a good smooth appearance throughout. Some fat deposition is present in the brisket and over the tail head. The back appears rounded and fat can be palpated over the ribs and pin bones.
SCORE 7	The cow appears in very good flesh. The brisket is full, the tail head shows pockets of fat and the back appears square due to fat. The ribs are very smooth and soft handling due to fat cover.
SCORE 8	The cow is obese. Her neck is thick and short and her back appears very square due to excessive fat. The brisket is distended and she has heavy fat pockets around the tail head.
SCORE 9	These cows are very obese and are rarely seen. They can be described as similar to 8's but taken to greater extremes. They also have a heavy deposition of udder fat.

TABLE 5. LEAST SQUARES MEANS FOR BODY WEIGHTS (KG) OF 1983
COWS IN FALL (NOV. 11, 1982), AT TREATMENT CHANGE JAN. 20,
1983), PRECALVING, AND START OF BREEDING SEASON

Criteria Cows (No.)	Treatment				E.M.S.
	Mod (17)	LL (17)	LM (17)	LH (20)	
Nov. 11 (Fall)	447[ab]	441[a]	447[ab]	470[b]	3730
Jan. 20 (Nutritional Change)	431	428	421	438	2946
Precalving	400[a]	402[a]	400[a]	447[b]	3902
May 1 (Start of Breeding)	365[a]	365[a]	358[a]	390[b]	2561

[ab]Means in the same row not sharing common superscripts are
different (P<.05)

TABLE 6. LEAST SQUARES MEANS FOR BODY CONDITION SCORES OF
1983 COWS IN FALL (NOV. 11, 1983), AT TREATMENT
CHANGE (JAN. 20, 1984), PRECALVING, AND
START OF BREEDING SEASON

Criteria Cows (No.)	Treatment				E.M.S
	Mod (17)	LL (17)	LM (17)	LH (20)	
Nov. 11 (Fall)	5.6	5.4	5.6	5.8	.50
Jan. 20 (Nutritional change)	5.5^a	5.1^b	5.2^b	5.2^b	.26
Precalving	4.9^{ab}	4.6^a	4.8^a	5.3^b	.45
May 1 (Start of breeding)	4.9^{ab}	4.7^{ab}	4.6^a	5.0^b	.23

^{ab}Means in the same row not having common superscripts are
different (P<.05)

TABLE 7. LEAST SQUARES MEANS FOR PREGNANCY RATE, DAYS FROM PARTURITION TO CONCEPTION, DAYS FROM PARTURITION TO OVARIAN LUTEAL ACTIVITY, AND PERCENTAGE OF COWS WITH LUTEAL ACTIVITY BY 85 D POST PARTUM

| Criteria | Treatment | | | | |
	Mod	LL	LM	LH	E.M.S.
% Pregnant	41.1 (17)[a]	11.7 (17)	29.4 (17)	40.0 (20)	
Days to conception	107.5 (6)	98.5 (2)	102.3 (3)	85.0 (5)	643.06
Days to ovarian luteal activity	70.2 (4)	77.2 (5)	78.0 (5)	69.4 (9)	79.46
% with ovarian luteal activity by 85 d post partum	23.5 (17)	29.4 (17)	29.4 (17)	45.0 (20)	

[a]Numbers in parentheses refer to number of observations

TABLE 8. REDUCED ANALYSIS OF VARIANCE TABLE FOR PLASMA
GLUCOSE IN 1983 AFTER NONSIGNIFICANT INTERACTIONS
WITH WEEK WERE REMOVED

Source	D.F.	M.S.
Preg	1	37.61
Trt	3	29.74
CS	1	110.36
CSxPreg	1	26.43
TrtxPreg	3	34.22
CSxTrt	3	65.70
CSxTrtxPreg	2	177.06
Cow(CSxTrtxPreg)	57	166.45
Wk	1	55.16*
WkxCS	1	.11
WkxTrt	3	38.00
WkxPreg	1	35.60
WkxTrtxPreg	3	21.51
WkxCSxPreg	1	43.14
WkxCSxTrt	3	24.46
WkxCSxTrtxPreg	2	118.25***
Wk^2	1	31.32
Wk^2xCS	1	11.57
Wk^2xTrt	3	44.12*
Wk^2xPreg	1	43.91
Wk^2xTrtxPreg	3	20.83
Wk^2xCSxPreg	1	74.00
Wk^2xCSxTrt	3	19.29*
Wk^2xCSxTrtxPreg	2	113.46***
Residual	684	20.05

*(P<.1)
***(P<.01)

TABLE 9. ANALYSIS OF VARIANCE TABLE FOR INSULIN
CONCENTRATIONS IN 1983 AFTER NONSIGNIFICANT
INTERACTIONS WERE REMOVED

Source	D.F.	M.S.
Preg	1	$.26^{**}$
Trt	3	.03
CS	1	$.08$
CSxPreg	1	$.13^{*}$
TrtxPreg	3	.06
CSxTrt	3	$.23^{***}$
CSxTrtxPreg	2	$.18^{*}$
Cow(CSxTrtxPreg)	57	.048
Wk	1	.005
WkxTrt	3	.05
WkxPreg	1	$.24^{***}$
Wk^2	1	.003
Wk^2xTrt	3	$.09^{**}$
Wk^2xPreg	1	$.26^{***}$
Wk^3	1	.002
Wk^3xPreg	1	$.25^{***}$
Residual	702	.036

*(P<.1)
**(P<.05)
***(P<.01)

TABLE 10.   LEAST SQUARES MEANS FOR BODY WEIGHTS (KG) OF 1984
     COWS AT FALL (NOV. 16, 1983), AT TREATMENT CHANGE
          (JAN. 26, 1984), PRECALVING, AND AT
          START OF THE BREEDING SEASON

| Criteria Cows (No.) | Treatment | | | | E.M.S. |
	Mod (12)	LL (10)	LM (10)	LH (13)	
Nov. 16 (Fall)	408	416	419	402	5785
Jan. 26 (Nutritional Change)	406	397	399	385	5416
Precalving	419	411	412	409	4720
May 1 (Start of Breeding)	350	340	352	342	3961

TABLE 11.   LEAST SQUARES MEANS FOR BODY CONDITION SCORES OF
1984 COWS AT FALL (NOV. 16, 1983), AT TREATMENT
CHANGE (JAN. 26, 1984), PRECALVING, AND AT
START OF BREEDING SEASON

Criteria Cows (No.)	Mod (12)	LL (10)	Treatment LM (10)	LH (13)	E.M.S
Nov. 16 (Fall)	6.1	6.2	6.2	6.2	.26
Jan. 26 (Nutritional change)	5.4	5.2	5.0	5.2	.24
Precalving	5.3^a	5.2^{ab}	4.9^b	5.4^a	.11
May 1 (Start of breeding)	5.0	4.8	4.8	4.9	.20

[ab]Means in the same row not having common superscripts are different
(P<.05)

TABLE 12. LEASTS SQUARE MEANS FOR PREGNANCY RATE, DAYS FROM
PARTURITION TO CONCEPTION, DAYS FROM PARTURITION TO
OVARIAN LUTEAL ACTIVITY, AND PERCENTAGE OF COWS
WITH LUTEAL ACTIVITY BY 85 D POST
PARTUM IN 1984 COWS

Criteria		Treatment			E.M.S.
	Mod	LL	LM	LH	
Cows (No.)	(12)	(10)	(10)	(13)	
% Pregnant	91.7	80.0	60.0	69.2	
Days to conception	100.4	104.3	114.2	107.14	629.74
Days to ovarian luteal activity	64.0	77.0	67.0	63.2	126.67
% with ovarian luteal activity by 85 d	50.0	40.0	30.0	30.7	

TABLE 13. ANALYSIS OF VARIANCE TABLE FOR GLUCOSE
CONCENTRATIONS IN 1984 AFTER NONSIGNIFICANT
(P>.2) INTERACTIONS WERE REMOVED

Source	D.F.	M.S.
Preg	1	161.45
Trt	3	73.66
CS	1	14.53
CSxPreg	1	49.31
CSxTrt	3	52.28
TrtxPreg	3	235.66
CSxTrtxPreg	2	53.86
Cow(CSxTrtxPreg)	30	188.85
Wk	1	29.71
WkxCS	1	31.07
WkxTrt	3	54.54^*
Wk^2	1	48.32
Wk^2xCS	1	49.93
Wk^3	1	62.46^*
Wk^4	1	71.29^*
Residual	428	21.93

*(P<.1)
**(P<.05)
***(P<.01)

TABLE 14. ANALYSIS OF VARIANCE TABLE FOR INSULIN
CONCENTRATIONS IN 1984 AFTER NONSIGNIFICANT
INTERACTIONS WERE REMOVED

Source	D.F.	M.S.
Preg	1	.0006
Trt	3	.0007
CS	1	.00008
TrtxPreg	3	.025
CSxPreg	1	.0037
CSxTrt	3	.005
CSxTrtxPreg	2	.015
Cow(CSxTrtxPreg)	30	.033
Wk	1	.002
WkxCS	1	.006
WkxTrt	3	.002
WkxPreg	1	.002
WkxTrtxPreg	3	.030
WkxCSxTrt	3	.016
WkxCSxPreg	1	.005
WkxCSxTrtxPreg	2	.016
Wk^2	1	.001
Wk^2xCS	1	.022
Wk^2xTrt	3	.005
Wk^2xPreg	1	.003
Wk^2xTrtxPreg	3	.040**
Wk^2xTrtxCS	3	.021
Wk^2xCSxPreg	1	.006
Wk^2xCSxPregxTrt	2	.017
Wk^3	1	.002
Wk^3xCS	1	.037
Wk^3xTrt	3	.009
Wk^3xPreg	1	.009
Wk^3xTrtxPreg	3	.05**
Wk^3xTrtxCS	3	.04**
Residual	702	.0085

**($p < .05$)

TABLE 15. ANALYSIS OF VARIANCE TABLE FOR LH CONCENTRATIONS
         IN 1984 AFTER NONSIGNIFICANT INTERACTIONS WERE REMOVED

Source	D.F.	M.S.
Trt	3	11.07
Preg	1	58.39**
CS	1	28.21
Cow(TrtxPregxCS)	39	12.29
Wk	1	79.31**
Residual	390	16.62

**(P<.05)

TABLE 16. POOLED WITHIN TREATMENT AND CALVING SEASON
PARTIAL CORRELATION COEFFICENTS FOR LH, GLUCOSE,
AND INSULIN CONCENTRATIONS IN PREGNANT
COWS (N=34); ADJUSTED FOR WEEK.

	Insulin	Glucose
LH	.030	.055
Insulin		.20**

**(P <.01)

TABLE 17. POOLED WITHIN TREATMENT AND CALVING SEASON
PARTIAL CORRELATION COEFFICENTS FOR LH, GLUCOSE,
AND INSULIN CONCENTRATIONS IN NONPREGNANT
COWS (N=11); ADJUSTED FOR WEEK

	Insulin	Glucose
LH	.21*	-.009
Insulin		.12

*(P<.05)

TABLE 18. POOLED WITHIN TREATMENT AND CALVING SEASON
PARTIAL CORRELATION COEFFICENTS FOR LH, GLUCOSE,
AND INSULIN CONCENTRATIONS IN ALL COWS (N=45);
ADJUSTED FOR WEEK

	Insulin	Glucose
LH	.054	.051
Insulin		.18**

**(P <.01)

Figure 1.   Displacement of ^{125}I labeled
bInsulin (Lilly Research 615 70N 80) by
nonlabeled bInsulin and cow plasma
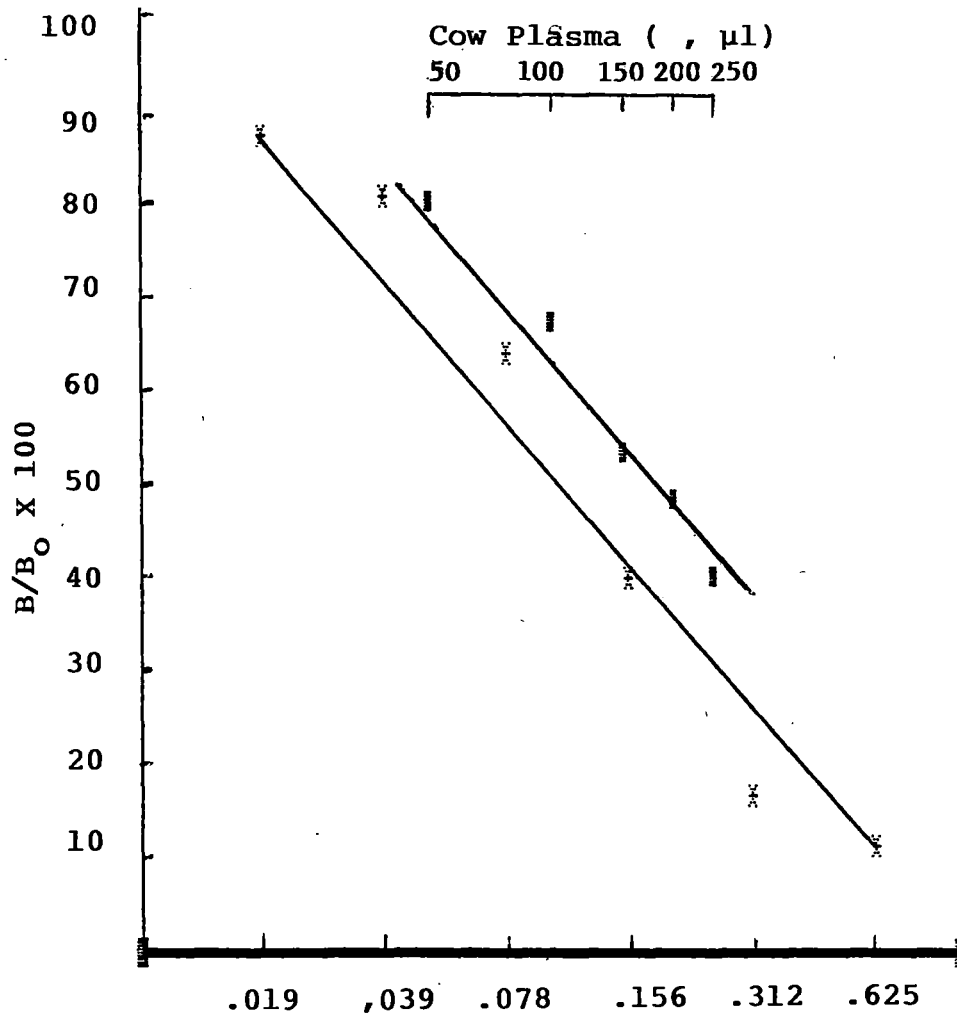
Lilly research 615-70N-80-bin

Figure 2.   Displacement of ^{125}I labeled
bInsulin (Lilly Research 615 70N 80) by
nonlabeled bInsulin and cow serum
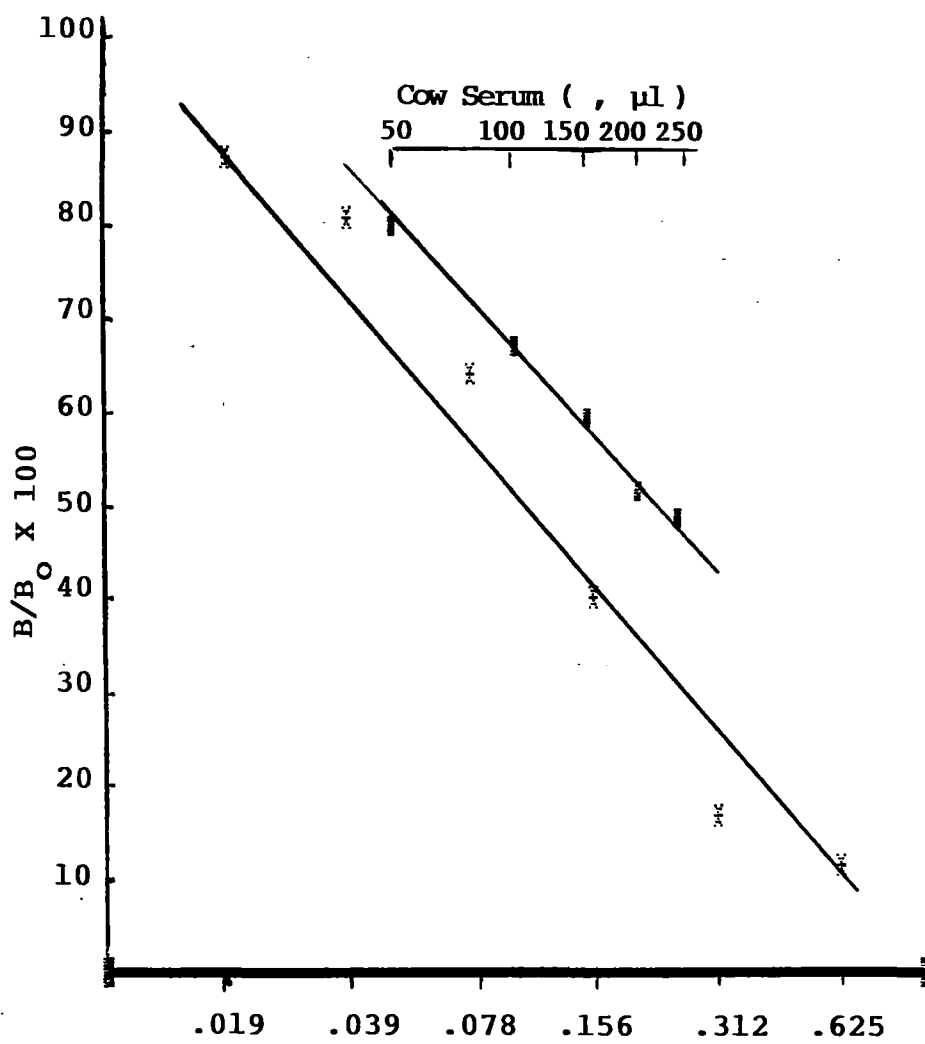
Lilly Research 615-70N-80-bin

Figure 3. Predicted plasma glucose (mg/100ml) for 1983 early-calving, non-conceiving (EC-NP; n=21), late-calving, nonconceiving (LC-NP; n=30), early-calving, conceiving (EC-P; n=13), and late-calving, pregnant cows (LC-P; n=7) for 12 weeks post partum
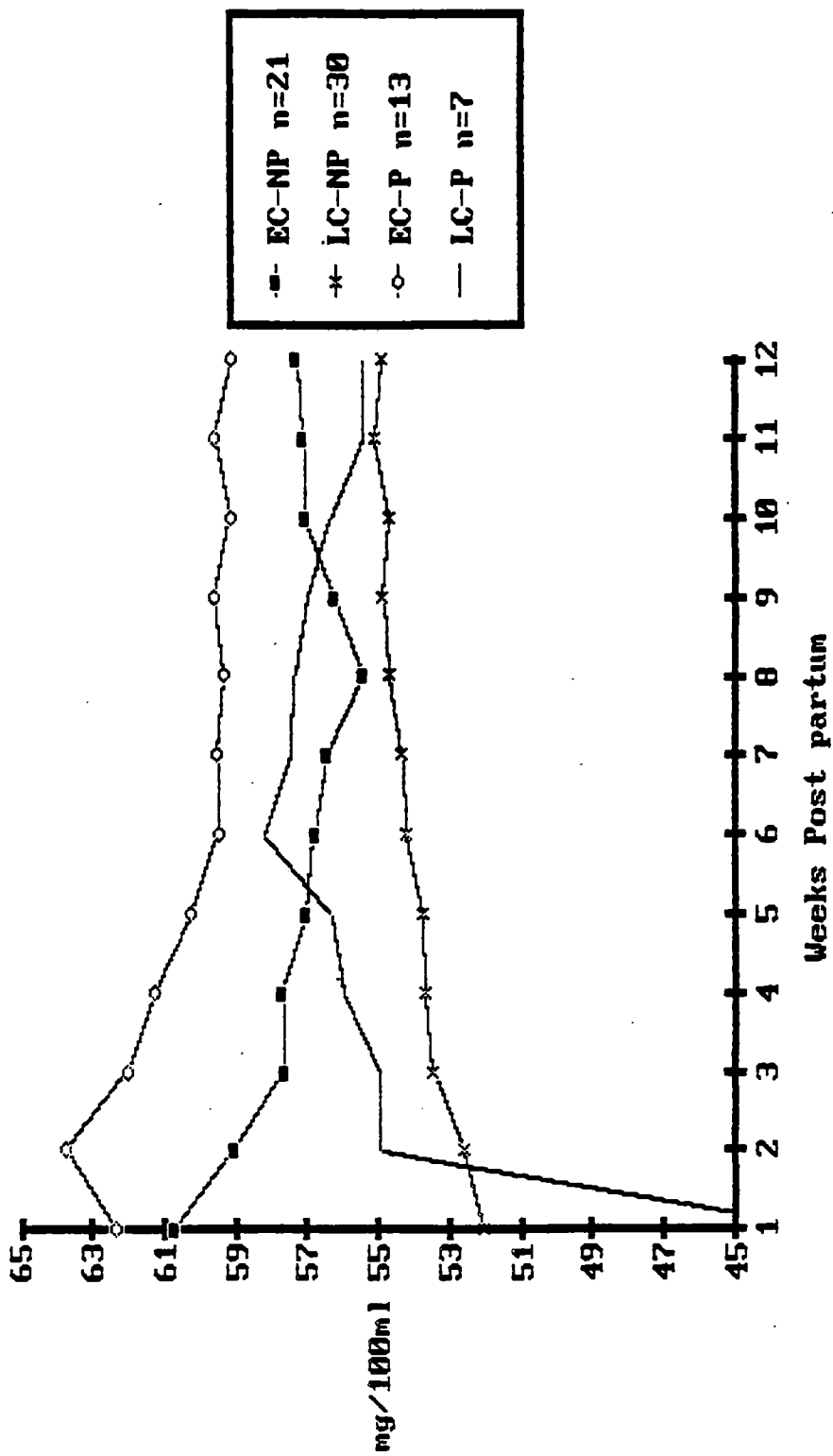
Figure 4.   Predicted serum insulin con-
centrations (ng/ml) for 1983 conceiving
(P) and nonconceiving (NP) cows in each
of the four treatments (MOD, LL, LM, and
LH) for 12 weeks post partum

Figure 5.   Predicted serum insulin con-
centrations (ng/ml)   for   1983   moderate
cows that become pregnant (MOD-P; n=7)
and moderate cows that fail to conceive
(MOD-NP; n=11)
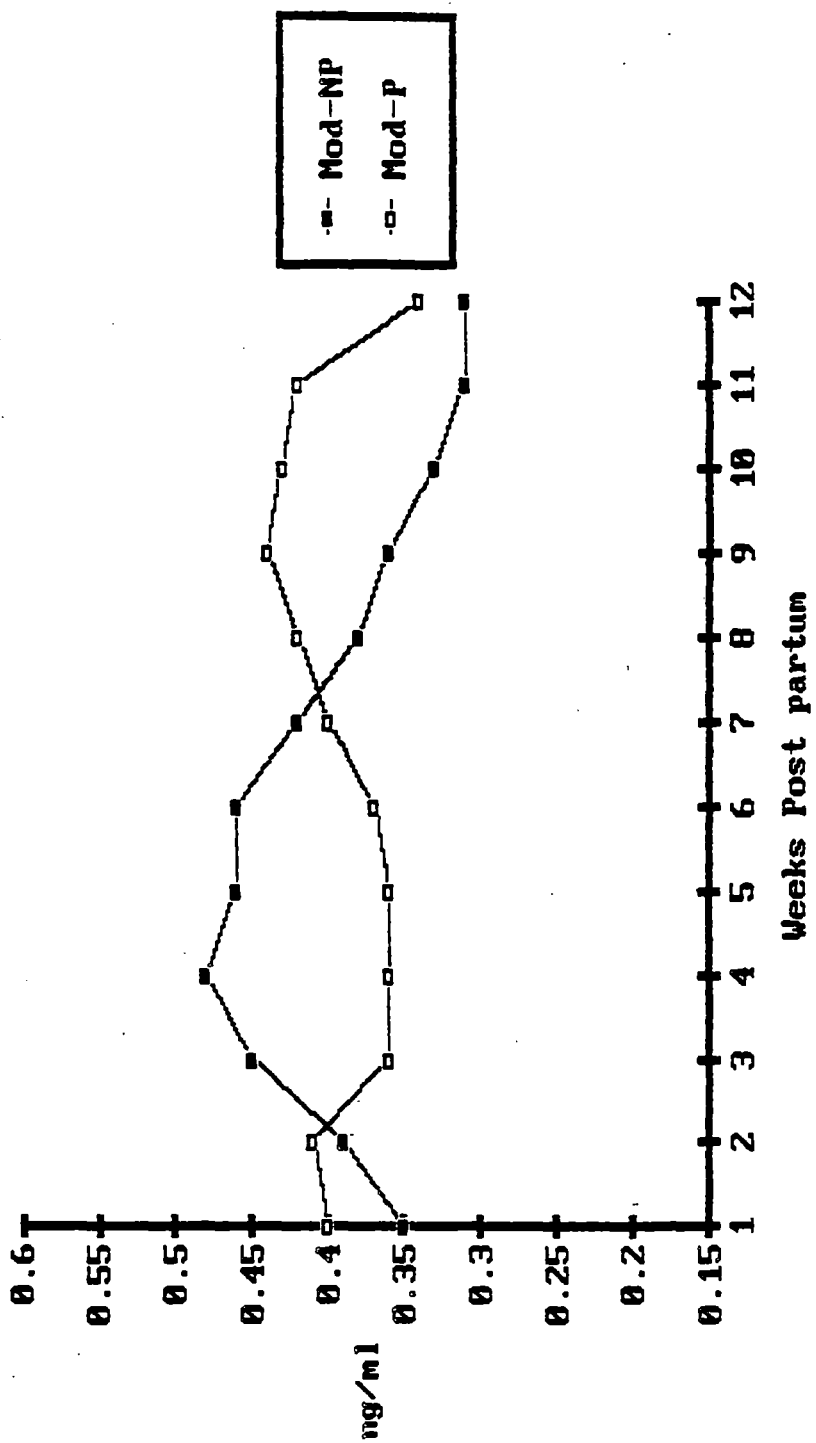
Figure 6.   Predicted serum insulin con-
centrations (ng/ml) for 1983 LL cows that
become pregnant (LL-P; n=2 and LL cows
that fail to conceive (LL-NP; n=15)
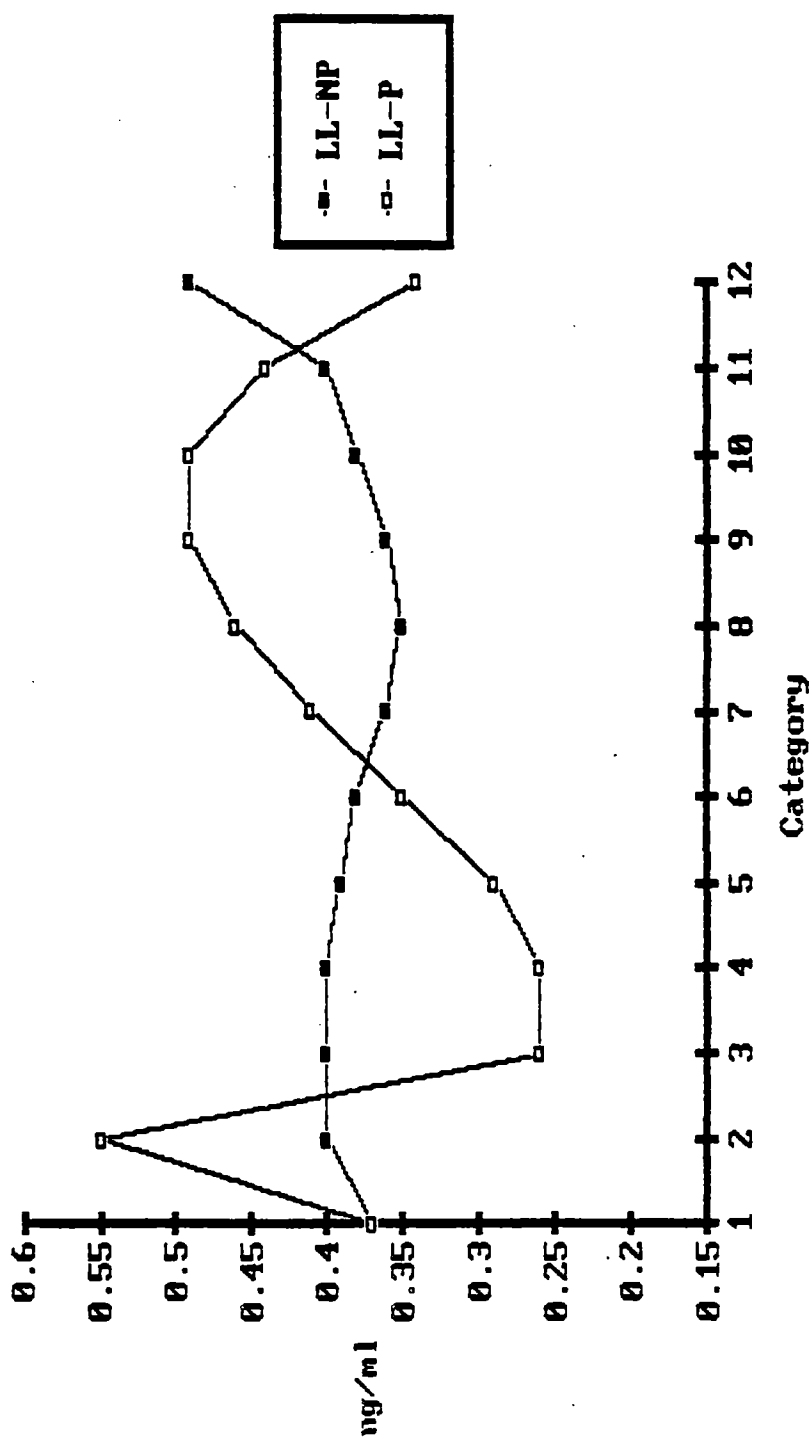
Figure 7.   Predicted serum insulin con-
centrations (ng/ml) for 1983 early-calv-
ing (EC) and late-calving (LC) cows in
each of the four treatments (Mod, LL, LM,
and LH) for 12 weeks post partum

Weeks Post partum

ng/ml

Mod—EC
LL—EC
LM—EC
LH—EC
Mod—LC
LL—LC
LM—LC
LH—LC

Figure 8.   Predicted serum insulin con-
centrations (ng/ml) for 1983 early-calv-
ing, LL cows (LL-EC; n=8) and late-calv-
ing, LL cows (LL-LC; n=10) for 12 weeks
post partum
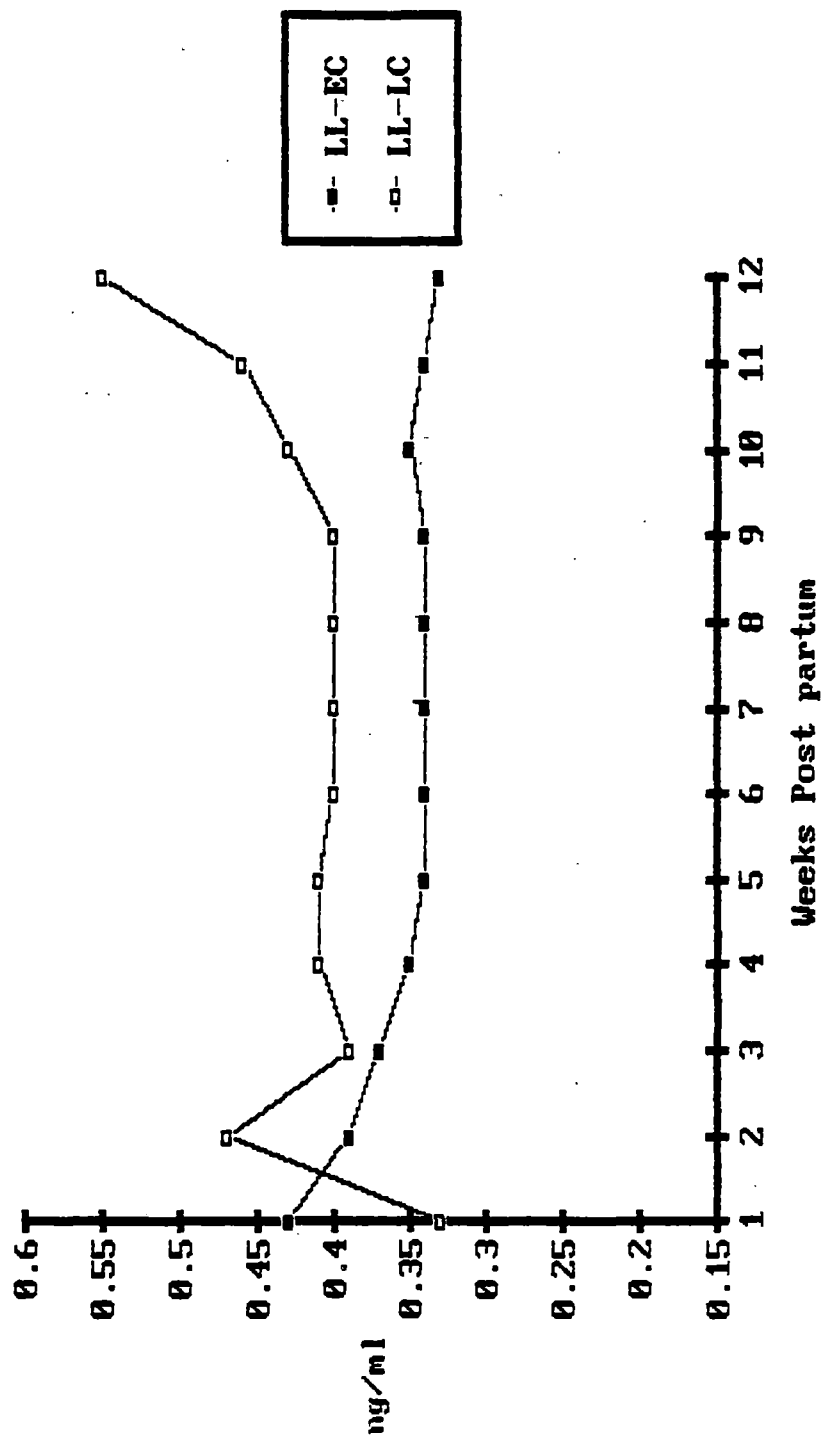
Figure 9. Predicted serum insulin con-
centrations (ng/ml) for 1983 early-calv-
ing, LH cows (LH-EC; n=9) and late-calv-
ing, LH cows (LH-LC; n=11) for 12 weeks
post partum
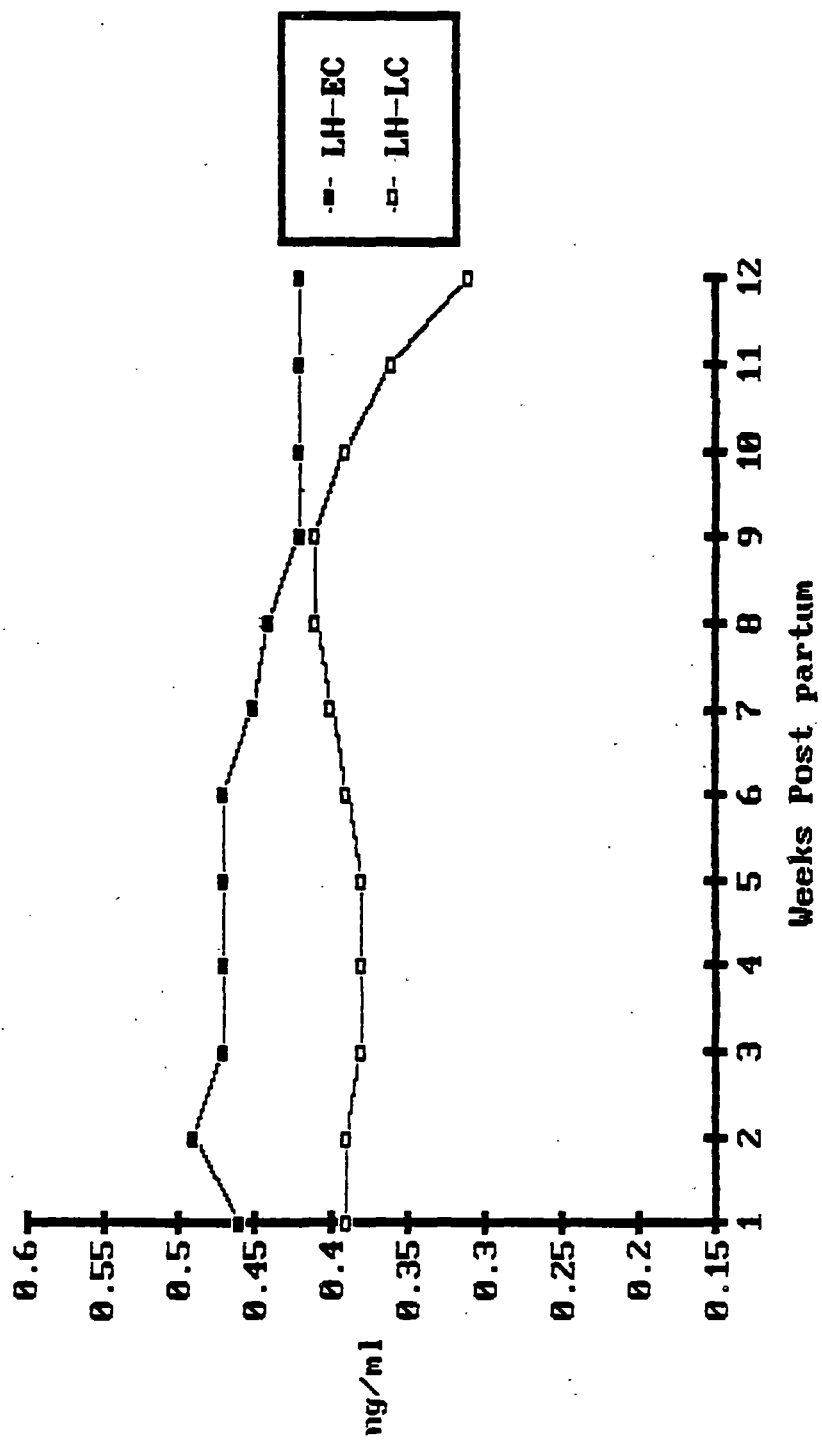
Figure 10. Predicted plasma glucose
concentrations (mg/ml) for Mod (n=12),
LL (n=10), LM (n=10), and LH (n=13) cows
in 1984
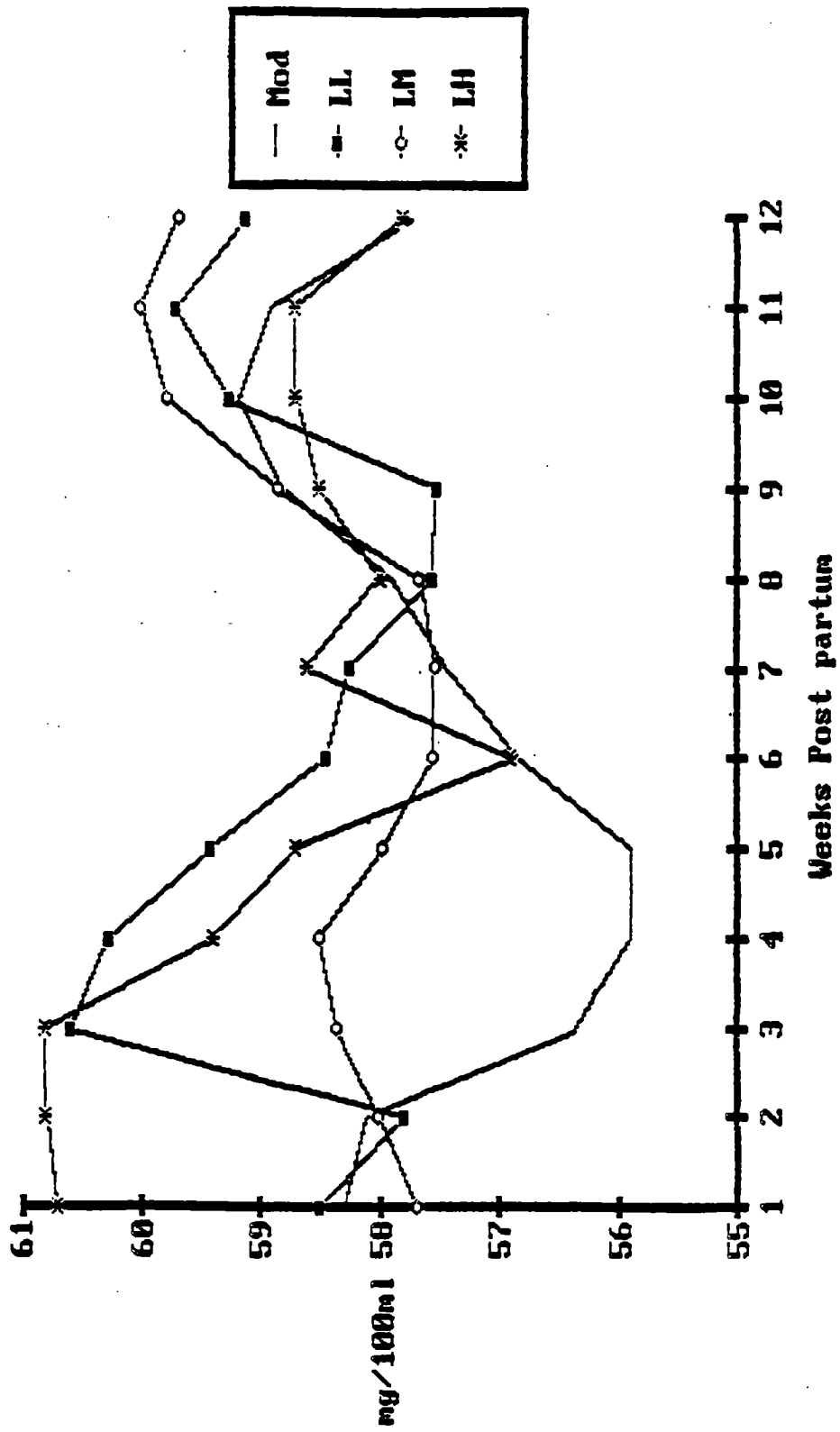
Figure 11.   Predicted serum insulin con-
centrations (ng/ml) for 1984 conceiving
(P) and nonconceiving (NP) cows in each
of the four treatments (Mod, LL, LM, and
LH) for 12 weeks post partum

Figure 12. Predicted serum insulin con-
centrations (ng/ml) for 1984 early-calv-
ing (EC) and late-calving (LC) cows in
each of the four treatments (Mod, LL, LM,
and LH) for 12 weeks post partum
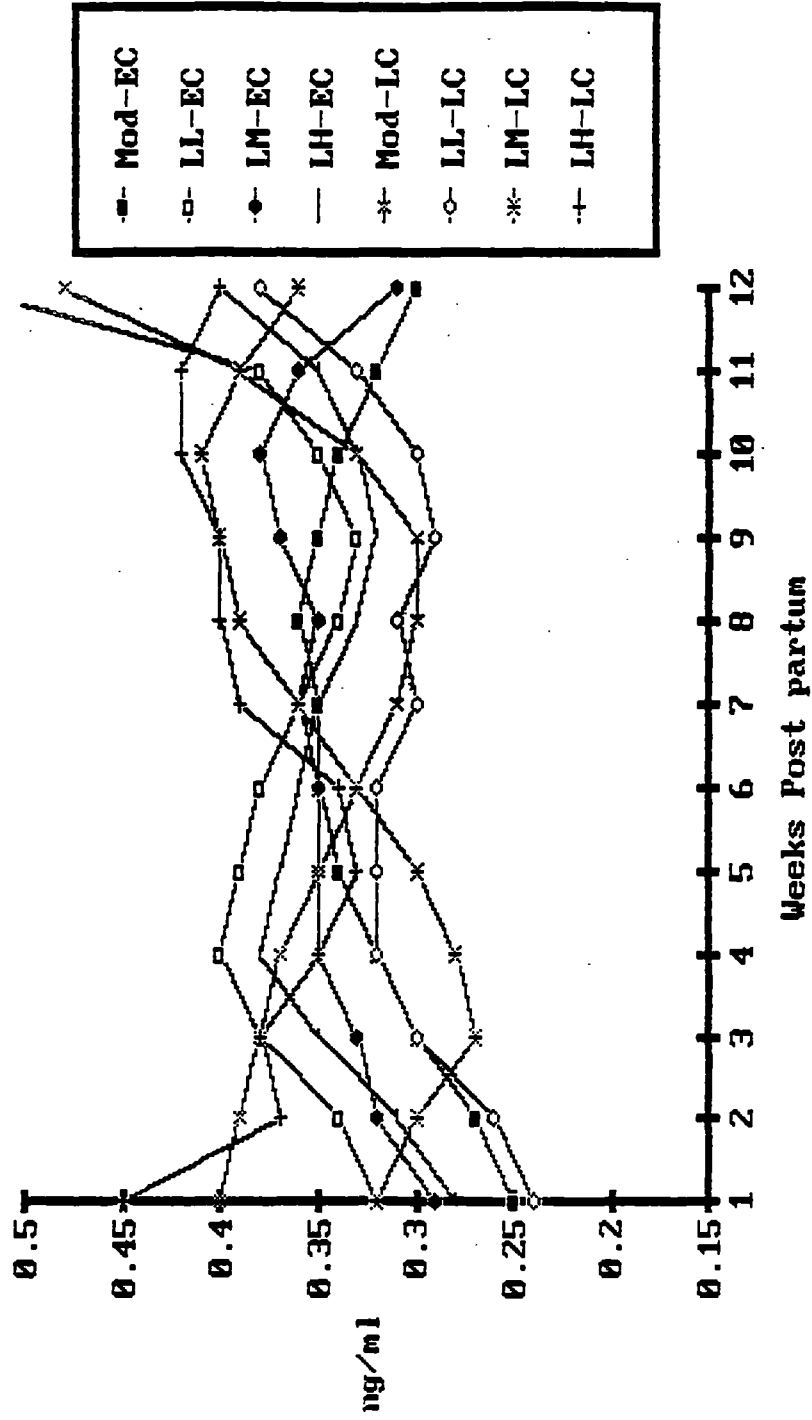
Figure 13. Predicted serum insulin con-
centrations (ng/ml) for 1984 early-calv-
ing, Mod cows (Mod-EC; n=6) and late-
calving, Mod cows (Mod-LC; n=6) for 12
weeks post partum
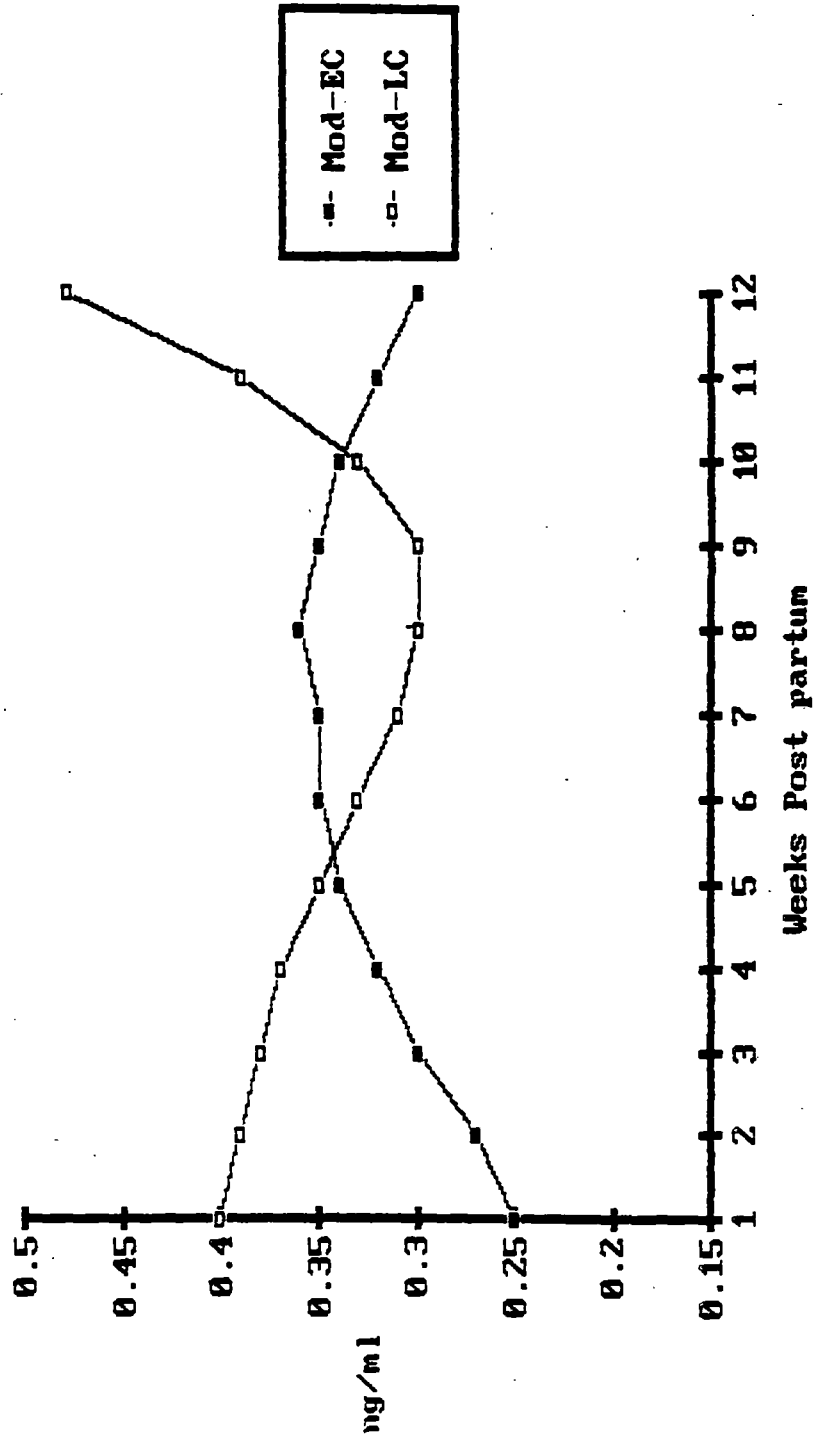
Figure 14. Serum LH concentrations (ng/ml) for 1984 pregnant (P) cows (n=34) and nonconceiving (NP) cows (n=11) for 12 weeks post partum
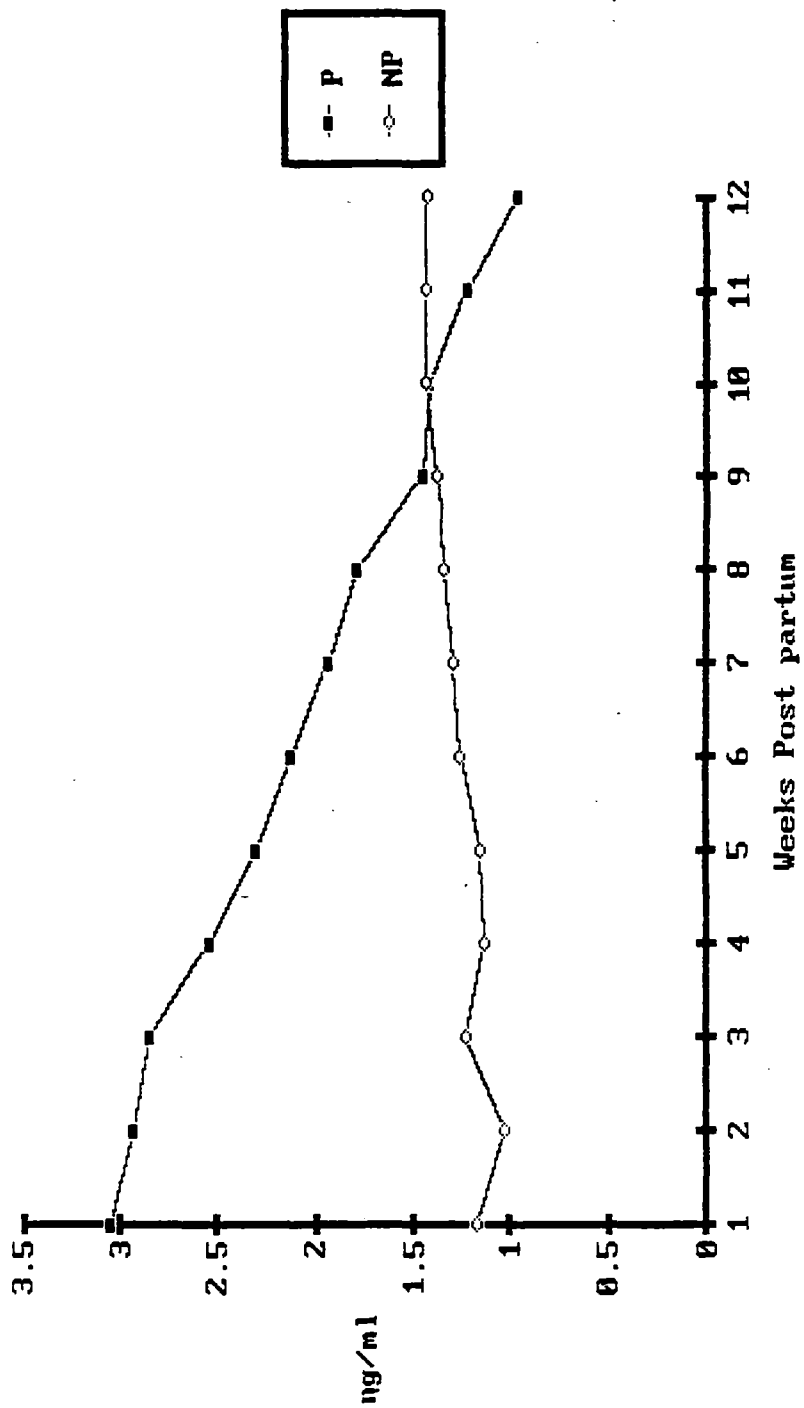
CHAPTER IV

RELATIONSHIPS AMONG BODY WEIGHT CHANGE AND BODY

CONDITION AND REPRODUCTIVE PERFORMANCE

OF RANGE BEEF COWS

Abstract

A five year study with 329 spring-calving Hereford
range cows examined the influence of prepartum nutritional
treatments on body weight change, body condition change, and
reproductive performance. Supplementation treatments were:
(Mod) cows fed to maintain fall body weight until calving,
(LL) cows fed to lose 5% of fall body weight by 60 days
prepartum and another 5% by precalving, (LM) cows fed the
same as LL until 60 days prepartum then fed the same as Mod,
and (LH) cows fed the same as LL until 60 days prepartum and
then fed 140% of Mod cows. All cows were fed NRC require-
ments for lactating cows after calving. Mod cows had a
greater pregnancy rate (P<.05) than other groups. LH and LM
cows had similar but greater pregnancy rates than LL cows.
Precalving body condition score (BCS) and weight change from
fall to Jan. were associated (P<.05) with pregnancy rate.
Treatments did not influence the days from calving to con-
ception or to the onset of ovarian luteal activity. BCS
precalving was negatively correlated (r=-.18) with the days
from parturition to onset of ovarian luteal activity. BCS
and weight change from fall to Jan. were correlated with the
days from parturition to conception.

Introduction

Reproductive performance of cows is a major factor

affecting biological efficiency and potential profitability

of a cow-calf production system. To maximize efficient use

of comparatively inexpensive standing pasture forages, cows

are allowed to accumulate energy reserves during the warm,

growing season and these stored reserves are mobilized during winter to supply a portion of the cows' nutrient requirements. Reduced energy intake before parturition, increases the interval from calving to first estrus (Joubert, 1954; Wiltbank et al., 1962; Wiltbank et al., 1964; Bellows and Short, 1978). The body condition of the cows in many of these trials was not assessed and/or reported. Energy reserves of beef cows at parturition have an important role in their subsequent reproductive performance (Wiltbank et al., 1964; Whitman, 1975; Richards, et al., 1985). Since changes in body weight and body condition score are both measures of the energy status of cows, these parameters can be used to evaluate the effects of body reserves on reproductive performance of cows. Based on regression analysis of multiparous cows from several studies, 91% of cows that had no prepartum weight loss exhibited estrus by 60 days post partum (Dunn and Kaltenbach, 1980). For each kilogram weight loss prepartum, the percentage of cows that exhibited estrus by 60 days post partum decreases by .5%. The responses to prepartum weight change may depend upon the body condition of cows at parturition. Cows in good body condition at calving are affected little by either pre or postpartum weight changes (Corah, 1975; Whitman, 1975). Postpartum weight gains shorten the period to first estrous cycles for thin cows especially if they lost weight before calving (Dunn and Kaltenbach, 1980).

Body weight change during pregnancy is confounded with conceptus growth. Therefore, estimations of body fat, such as with body condition scores, should be useful in quantifying the energy status of beef cows prior to, or at parturition. Also, very few cow-calf producers routinely weigh cows, therefore, the usefulness of weight changes as indicators of the energy status of commercial beef cows is limited. In contrast, body condition scores may be assigned visually at times of normal management procedures, allowing even small herd owners to assess the energy status of the cows.

The specific purposes of this experiment were 1) to evaluate the relationships of prepartum supplementation, changes in body weight, body condition score, and reproductive performance in beef cows, and 2) to compare the relative importance of weight changes, condition score changes, and peripartum body condition score as factors influencing reproduction.

Materials and Methods

A total of 284 pregnant multiparous Hereford range cows were allocated by age, weight and body condition into one of four treatment groups during November of four successive years: 1979, (n = 78); 1980, (n = 66); 1981, (n = 69); and 1982, (n = 71). Another 45 pregnant first or second calf Hereford heifers were similarly assigned to treatments in November, 1983. Over the five years of the study, records

from 329 cows were analyzed. Group 1 (Mod) cows were supplemented to maintain their November weights until calving in March and April. Groups 2, 3, and 4 were restricted in supplementation so as to lose 5 percent of their November weights by approximately 60 days prior to average expected calving date (circa January 20). After January 20, Group 2 (Low-Low) cows were continued on the restricted diet so they would lose another 5% of their weight before calving. Group 3 (Low-Mod) cows were supplemented the same as Group 1 cows the last 60 days prior to calving. Cows in Group 4 (Low-High) were given 140 percent the supplemental feed given to Group 1 cows during the last 60 d of gestation. After calving, cows were placed in a common pasture and fed 1.8 kg of cottonseed meal (csm) per cow per day plus grass hay ad libitum, when dry standing forage was limited, until sufficient green forage was available. Table 1 (Chapter III) summarizes the treatments. Tables 19, 20, and 21 (Chapter IV), and 2, and 3 (Chapter III) outline the supplementation programs for cows calving in 1980, 1981, 1982, 1983, and 1984, respectively. In 1979-1980 body weights were obtained on November 19, December 20, January 10, January 24, February 7, February 21, March 6 and March 20. Body condition scores were assigned at the initiation of treatment, (November 19), at the time of nutrition change, (January 21), and before calving (March 6). During each of the subsequent four years, cows were weighed and assigned body condition scores biweekly from November until calving. One

postpartum weight was obtained in 1980 (March 20) and body condition scores were assigned on June 19. In 1981 one postpartum weight (April 23) and no postpartum body condition scores were recorded. Three postpartum weights and body condition scores were obtained in 1982 (April 1, 15, 29). Until 85 d postpartum, biweekly weights and body condition scores were obtained for cows in 1983 and 1984. Body weights were obtained after cows were removed from feed and water for 16 h.

Two or more fertile bulls were in breeding pastures (1 bull/20 cows) on or near May 1 of each year and were removed about August 1.

The date of onset of ovarian luteal activity was estimated by concentrations of progesterone in plasma obtained weekly during the first 85 d post partum (Lusby et al., 1981). The onset of ovarian luteal activity was considered to occur at the first of two successive weekly bleeding dates when concentrations of progesterone were equal to or greater than 1 ng/ml. Conception dates were estimated from the subsequent calving date minus 281 d. Pregnancy was determined by rectal palpation at least 60 d after the end of the breeding season.

Statistical Analyses

Regression analyses of variance for pregnancy rate, percentage of cows with ovarian luteal activity by 85 d post partum, days from calving to ovarian luteal activity, and

days from calving to conception, was performed with year, treatment, and calving date, as well as all interactions in the model. The models were reduced by omitting all non-significant interactions (P > .2), and the variation and degrees of freedom were included in the residual component (Table 28). Linear regression analysis was used to examine the relationships of mid-gestation and late-gestation changes in body weight and body condition score on pregnancy rate, days from calving to onset of ovarian luteal activity, percentage of cows with ovarian luteal activity by 85 d post partum, and days from calving to conception. Year and calving date (expressed as days from January 1 of the calving year) were used as linear covariates. Multivariate regression analyses were used to examine curvilinear relationships between precalving body condition scores with reproductive parameters. Precalving body condition scores and body weights that were analyzed were the predicted values at calving. Linear models were developed for each cow using the measurements after the treatment change in January to parturition. The intercept was considered to be the predicted weight or condition score at calving. Correlation coefficients between the last recorded weight or condition score and the predicted values were large (r = .96 and .98, respectively).

Discriminant analyses (Morrison, 1976) were employed to compare weights, condition scores, and changes in these parameters as predictors of pregnancy rate or the presence

of ovarian luteal activity by 85 d. Prepartum weight changes were calculated as a percent of the fall body weight. Postpartum weight changes were calculated as a percentage of the precalving body weight. Body condition score changes were expressed as the actual units or the appropriate fraction thereof, but not as percent changes.

Results and Discussion

The body weights for cows each year at the fall, at treatment change, precalving, and within 1 week of the start of the breeding season (May 1) are presented in Table 22. Fall body weights were similar among treatment groups, however, Mod cows had greater (P<.05) body weights in January at the time of the treatment change (approximately January 20 each year). The least squares means for body weights for the four nutritional treatment groups averaged over the five years are given in Table 23. The body condition scores at fall, treatment change, precalving and start of breeding season for each year are presented in Table 24. Similar to body weight, body condition scores were similar among treatment groups in the fall and Mod cows had a greater (P<.05) body condition in January. The least squares means for body condition scores for the four nutritional treatment groups are listed in Table 25. At the start of the breeding season, body condition was similar for Mod and LH cows, but body condition scores for these two groups were greater (P<.05) than both LL and LM cows. Similarly, body weights

for Mod and LH cows were greater (P<.05) than the weights for LL and LM cows at the beginning of the breeding season (approximately May 1). Body weights and body condition scores at calving could not be compared across years since there was a (P<.01) treatment x year interaction. Body weight and condition for the individual years have been discussed by Mobley (1982), Rasby (1983), and Garmendia (1984), and data from the latter two years were discussed in Chapter III of this dissertation. Likewise, significant treatment x year interactions (P<.01) for weight and condition score changes allow only the presentation of yearly least squares means for the changes in those measurements (Table 26).

Least squares means for reproductive performance traits for cows in each treatment, by year, are presented in Table 27. In the absence of treatment x year interactions, least squares treatment means are compared in Table 29. Treatment influenced pregnancy rate (P<.01). Moderate cows had a much greater pregnancy rate (71.3%) than did any of the other groups (P<.05). The LL cows had a lesser pregnancy rate (41.8%) than did the LM (51.3%) or LH (58.3%) cows (P<.05). Cows on LM and LH treatments cows had similar pregnancy rates. This suggests that cows fed to maintain weight during the last 2/3 of pregnancy (Mod) will have a greater pregnancy rate than cows that had an opportunity to regain weight and condition during the last 6 weeks of gestation (LH cows). Furthermore, when weight or condition loss occurred during the middle third of pregnancy, improving the

nutrient intake of the cows during the last 6 weeks prior to calving (LM and LH cows) resulted in substantial improvement (P<.05) in pregnancy rate compared to cows that continue on a restricted diet (LL cows) until parturition.

Both year (P<.001) and calving date (P<.001) influenced pregnancy rate. During 1980-1981 and 1983-1984 the winters were milder with greater forage available than during the other years. The reduced environmental stress and greater forage availability undoubtedly were factors contributing to the greater pregnancy rates during those two years. In addition, the earlier calving cows had a greater opportunity to return to estrus and conceive during the breeding season than did their later calving counterparts.

Analysis of variance for prepartum body condition score, body weight and condition score changes with calving date and year as linear covariates revealed that the pre-calving body condition score and body weight change from fall to Jan. were important factors influencing pregnancy rate (P<.001). These findings support those of Wiltbank et al. (1964), Whitman (1975), and Richards et al. (1985). The influence of percentage weight change from fall to 60 d prepartum also is in agreement with previous findings (Dunn and Kaltenbach, 1980).

The results of the discriminant analysis of pregnancy rate are presented graphically in Figure 15. Of the total of 329 cows used the analysis, 55.67% were pregnant. There-fore, when a continuous variable such as precalving body

condition score is used in the analysis it must correctly classify substantially more than 50% of the cows correctly in order for it to be expected to be a factor influencing pregnancy rate. Precalving body condition score (PBCS) and breeding season body condition score (BSBCS) were the most accurate predictors of pregnancy. The weight change from fall to treatment change (BWC1) also improves the predictability of potential pregnancy beyond that of random chance. Body weight change from Jan. to calving is not as useful as a predictor for potential pregnancy. Weight change during the last 60 d of gestation is greatly confounded by conceptus growth and, especially in cows on a negative nutritional plane, does not reflect the energy status of cows. However, body condition score change during this same time period is a more accurate predictor of potential pregnancy status. By using all of the body weight and score measurements depicted in Figure 15 in a discriminant analysis, 72% of 291 cows were classified correctly as to their potential pregnancy.

Discriminant analysis identifies those variables most closely associated with potential pregnancy and also points out that 28% of the cows would be misclassified using the variables stated. Therefore other sources of variation account for some of the differences seen in pregnancy rate. The discriminant analysis finds two mathematical planes through the data and assigns each observation to the plane that is the least distant from that data point. In the

analysis of precalving body condition score and pregnancy,

analysis of precalving body condition score and pregnancy, data are split along a general line of a body condition score of 5.3. Those cows with greater than a body condition score of 5.3 at calving are assigned to the pregnant class whereas cows with less than a BCS of 5.3 are assigned to the nonpregnant class. This mathematical division may have biological implications. A BCS of 5.3 may represent the threshold that the "average" cow needs to reach to be expected to become pregnant under the environmental and pasture conditions of this study.

Body condition score at calving to the third power best described the relationship between precalving BCS and pregnancy rate (Figure 16). The rate of change in pregnancy rate decreased as cows approached a body condition score seven. This suggests that the effect of increasing the condition score of a cow by one unit at 5 has a greater impact on pregnancy rate than increasing the condition score of a cow that has a score of 6.5

Prepartum nutritional treatments did not influence (P>.05) days from calving to ovarian luteal activity (DTOOA), percentage of cows with ovarian luteal activity by 85 d (OLA), or days from calving to conception (DTC; Table 29). The means for days from calving to conception indicate that, for many of the cows, the first estrus occurred after the weekly bleedings were ceased at 85 d postpartum. Less than 50% of the cows in any of the treatment groups had ovarian luteal activity by 85 d postpartum. Therefore, less

than half of the cows in the study maintained a 12 month calving interval. Of those cows that were found to have OLA by 85 d, the average days from calving to the onset of luteal activity was quite similar among treatment groups. Analysis of variance for OLA revealed a year x calving date interaction (P<.001) which implied that early calving cows were less likely to have OLA in some years than in others. The tremendous year to year variation in weather and pasture conditions is a contributing factor to this and other influences of year.

The discriminant analysis for the prediction of the presence of OLA (Figure 17) illustrates the importance of weight changes during the fall to Jan. period (BWC1) and from precalving to the start of the breeding season (BWC3). Body condition score at calving or at the start of the breeding season were not important predictors of the presence of OLA by 85 d. These results, when compared to the pregnancy rate information, imply that a minimum body condition at parturition is necessary for pregnancy to occur during a 90 d breeding season, and weight changes influence the time that OLA begin.

Within class partial correlation coefficients (adjusted for calving date and year) are presented for days to conception (DTC) and the days from parturition to the onset of ovarian luteal activity (DTOOA) in Table 30. Also included as correlated variables are pre and postpartum body condition and changes in body condition score and weight. Days

to conception (DTC) was negatively correlated (r = -.17; P<.05) with percentage weight change from fall to Jan., indicating that the smaller the weight loss, the shorter the time to conception. Also, the negative correlation (r = -.25; P<.01) between body condition score change during the fall to Jan. period and DTC indicates that decreases in body condition were associated with increases in DTC. Significant correlations were not found between most traits and DTOOA, however precalving body condition score was negatively correlated with DTOOA (r = -.18; P<.05). Greater body condition scores at parturition were associated with fewer days to ovarian luteal activity. Several of the body condition score changes were associated with the corresponding change in body weight. An example is the relationship between body condition change and body weight change from fall to Jan. The partial correlation coefficient (r = .51) is similar to the association found in postpartum weight and score changes reported in chapter three of this dissertation.

Many factors influence reproductive performance of beef cows. Some of these factors have been explored in this study. However, the amount of unaccounted variation for all of the reproductive traits studied leaves room for continued research into this complex segment of beef cattle science.

Body condition as it reflects the energy status of beef cows is related to reproductive performance. Cows with body condition scores at or near 6 have greater pregnancy rates

than do cows with lower scores. Weight change during the last the half of gestation is also related to potential pregnancy. Under Oklahoma range conditions, allowing spring-calving cows to lose substantial weight during mid-winter and then have them regain this weight before parturition may result in reduced pregnancy rate when compared to cows that have been fed to maintain the fall weight to calving.

Once a minimum body condition at calving (according to the discriminant analyses, 5.3) is reached, the changes in body weight or condition become important. This is not contradictory with the reports of Corah (1975) and Whitman (1975) when they suggest that cows in good body condition at calving are affected little, if any, by either pre or post-partum weight changes. In those studies, "good" body condition referred to cows with condition equivalent to scores of 6 or 7 cows, as compared to most of the cattle in this study that calved in a body condition less than 6. Minimal prepartum body weight or condition losses were associated with shorter periods to the next conception, reconfirming the views of Dunn and Kaltenbach (1980), who compiled data from several studies and reported that little or no weight loss prepartum was associated with a great percent of cows exhibiting estrus early in a breeding season.

The importance of using body condition scores as a management tool for cow-calf producers cannot be underestimated. Cattlemen can learn to utilize this simple procedure

for estimating the energy status of the cows in their herds, and consequently can make nutritional and managerial decisions to prevent reproductive shortcomings due to cows calving in a thin and costly body condition.

TABLE 19.   SUPPLEMENTATION REGIMEN FOR COWS CALVING IN 1980

Treatment Group	Interval	Nutritional Program
Moderate	Nov. 19 - calving	1.4 kg csm[a]/d
Low-Low	Nov. 19 - Jan. 21	.4 kg csm/d
	Jan. 21 - calving	.8 kg csm/d
Low-Moderate	Nov. 19 - Jan. 21	Same as Low-Low
	Jan. 21 - calving	Same as Moderate
Low-High	Nov. 19 - Jan. 21	Same as Low-Low
	Jan. 21 - calving	2.3 kg csm/d

[a]Cottonseed meal cubes, 41% crude protein

TABLE 20.   SUPPLEMENTATION REGIMEN FOR COWS CALVING IN 1981

Treatment Group	Interval	Nutritional Program
Moderate	Nov. 19 - calving	1.4 kg csm[a]/d
Low-Low	Nov. 19 - Jan. 22	.3 kg csm/d
	Jan. 22 - calving	.3 kg csm/d
Low-Moderate	Nov. 19 - Jan. 22	Same as Low-Low
	Jan. 22 - calving	Same as Moderate
Low-High	Nov. 19 - Jan. 22	Same as Low-Low
	Jan. 22 - calving	1.9 kg csm/d

[a]Cottonseed meal, 41% crude protein

TABLE 21.   SUPPLEMENTATION REGIMEN FOR COWS CALVING IN 1982

Treatment Group	Interval	Nutritional Program
Moderate	Nov. 10 - calving	1.4 kg csm[a]/d
Low-Low	Nov. 10 - Jan. 20	.9 kg csm/d
	Jan. 20 - calving	.7 kg csm/d
Low-Moderate	Nov. 10 - Jan. 20	Same as Low-Low
	Jan. 20 - calving	Same as Moderate
Low-High	Nov. 10 - Jan. 20	Same as Low-Low
	Jan. 20 - calving	2.3 kg csm/d

[a]Cottonseed meal cubes, 41% crude protein

TABLE 22. LEAST SQUARES MEANS FOR BODY WEIGHTS (KG) OF COWS IN 1980, 1981, 1982, 1983, AND 1984 FOR FOUR TREATMENTS AT FALL, TREATMENT CHANGE IN JAN., PRECALVING, AND THE START OF THE BREEDING SEASON

Year	Treatment				
	Mod	LL	LM	LH	E.M.S.
1980					
Fall	414 (18)[a]	413 (19)	408 (17)	413 (21)	2169.6
Trt. change in Jan.	422 (19)	363 (19)	362 (18)	359 (22)	1906.6
Precalving	409 (18)	351 (19)	388 (18)	381 (20)	1829.4
Start of Breeding	342 (18)	316 (18)	332 (18)	334 (22)	1604.8
1981					
Fall	459 (11)	459 (17)	448 (19)	464 (19)	2169.6
Trt. change in Jan.	471 (11)	471 (17)	449 (19)	463 (19)	1906.6
Precalving	443 (11)	421 (17)	436 (19)	471 (19)	1829.4
Start of Breeding	404 (9)	389 (12)	386 (15)	423 (11)	1604.8
1982					
Fall	444 (19)	446 (16)	435 (18)	447 (16)	2169.6
Trt. change in Jan.	450 (19)	425 (16)	417 (18)	426 (16)	1906.6
Precalving	438 (19)	398 (16)	410 (18)	425 (16)	1829.4
Start of Breeding	418 (19)	388 (16)	377 (18)	402 (13)	1604.8
1983					
Fall	447 (17)	442 (17)	448 (17)	472 (20)	2169.6
Trt. change in Jan.	431 (17)	429 (17)	422 (17)	439 (20)	1906.6
Precalving	400 (17)	403 (17)	400 (17)	448 (20)	1829.4
Start of Breeding	364 (16)	364 (17)	356 (17)	389 (20)	1604.8
1984					
Fall	405 (12)	410 (10)	412 (10)	397 (13)	2169.6
Trt. change in Jan.	404 (12)	392 (10)	394 (10)	381 (13)	1906.6
Precalving	416 (12)	405 (10)	405 (10)	404 (13)	1829.4
Start of Breeding	350 (12)	342 (10)	353 (10)	343 (12)	1604.8

[a]Number of cows in parenthesis

TABLE 23. LEAST SQUARES MEANS FOR BODY WEIGHTS (KG) OF MOD, LL, LM, AND LH COWS ACROSS 5 YEARS AT FALL, TREATMENT CHANGE IN JAN., PRECALVING, AND AT THE START OF THE BREEDING SEASON

| Time | Mod | Treatment | | | E.M.S. |
		LL	LM	LH	
Nov. (Fall)	434 (77)[a]	434 (79)	431 (81)	439 (89)	2169.6
Jan. Nutritional Change)	436[b] (78)	416[c] (79)	409[c] (82)	413[c] (90)	1906.6
Precalving	421 (77)	396 (79)	408 (82)	426 (88)	1829.4
May 1 Start of Breeding)	376[b] (74)	360[c] (73)	361[c] (78)	378[b] (78)	1604.8

[a]Number of cows in parentheses
[bc]Means in the same row not having common superscripts are different (P<.05)

TABLE 24. LEAST SQUARES MEANS FOR BODY CONDITION SCORES OF COWS IN 1980, 1981, 1982, 1983, AND 1984 FOR FOUR TREATMENTS AT FALL, TREATMENT CHANGE IN JAN., PRECALVING, AND THE START OF THE BREEDING SEASON

Year			Treatment		
	Mod	LL	LM	LH	E.M.S.
1980					
Fall	6.5 (19)[a]	6.3 (19)	6.4 (18)	6.4 (22)	.42
Trt. change in Jan.	6.0 (19)	5.0 (19)	5.1 (18)	4.9 (22)	.33
Precalving	5.5 (10)	3.9 (12)	5.1 (11)	4.8 (8)	.37
Start of Breeding	Not available				
1981					
Fall	6.6 (11)	6.5 (17)	6.4 (19)	6.5 (19)	.42
Trt. change in Jan.	6.2 (11)	6.2 (17)	5.8 (19)	5.6 (19)	.33
Precalving	6.6 (11)	5.8 (17)	6.3 (19)	6.7 (19)	.37
Start of Breeding	5.9 (9)	5.7 (11)	5.8 (15)	6.1 (11)	.22
1982					
Fall	6.0 (19)	6.0 (16)	5.7 (18)	6.2 (16)	.42
Trt. change in Jan.	5.8 (19)	4.8 (16)	4.8 (18)	5.2 (16)	.33
Precalving	5.4 (19)	4.4 (16)	5.0 (18)	5.3 (16)	.37
Start of Breeding	5.3 (19)	4.7 (15)	4.8 (18)	5.2 (13)	.22
1983					
Fall	5.6 (17)	5.4 (17)	5.6 (17)	5.8 (20)	.42
Trt. change in Jan.	5.5 (17)	5.1 (17)	5.2 (17)	5.2 (20)	.33
Precalving	4.9 (17)	4.6 (17)	4.7 (17)	5.3 (20)	.37
Start of Breeding	4.9 (16)	4.7 (17)	4.6 (17)	5.0 (20)	.22
1984					
Fall	6.1 (12)	6.2 (10)	6.1 (10)	6.2 (13)	.42
Trt. change in Jan.	5.4 (12)	5.1 (10)	5.0 (10)	5.1 (13)	.33
Precalving	5.4 (12)	5.3 (10)	5.0 (10)	5.4 (13)	.37
Start of Breeding	5.0 (12)	4.8 (10)	4.8 (10)	5.0 (12)	.22

[a]Number of cows in parenthesis

TABLE 25.   LEAST SQUARES MEANS FOR BODY CONDITION SCORES OF
MOD, LL, LM, AND LH COWS ACROSS 5 YEARS AT FALL, TREATMENT
CHANGE IN JAN., PRECALVING, AND AT THE START OF THE
BREEDING SEASON

Time	Mod	LL	Treatment LM	LH	E.M.S.
Nov. (Fall)	6.1 (78)[a]	6.1 (79)	6.0 (82)	6.2 (90)	.42
Jan. Nutritional Change)	5.8[b] (78)	5.2[c] (79)	5.2[c] (82)	5.2[c] (90)	.33
Precalving	5.6 (69)	4.8 (72)	5.2 (75)	5.5 (76)	.37
May 1 Start of Breeding)	5.3[b] (56)	5.0[c] (53)	5.0[c] (60)	5.3[b] (56)	.22

[a]Number of cows in parentheses
[bc]Means in the same row not having common superscripts are different
(P<.05)

TABLE 26.   LEAST SQUARES MEANS FOR CHANGES[a] IN BODY WEIGHTS (PERCENT) AND BODY CONDITION SCORES OF COWS IN 1980, 1981, 1982, 1983, AND 1984 FOR FOUR TREATMENTS

Year	Mod	LL	Treatment LM	LH	E.M.S.
1980					
BWC1	1.7 (18)[b]	-11.0 (19)	-11.4 (17)	-12.5 (21)	10.79
BWC2	-3.7 (18)	-2.7 (19)	6.2 (18)	5.1 (20)	20.06
BWC3	-16.1 (18)	-9.2 (19)	-14.6 (18)	-12.4 (20)	24.63
BCSC1	-.4 (18)	-1.4 (18)	-1.3 (18)	-1.5 (22)	.22
BCSC2	-.4 (10)	-.9 (12)	0 (11)	-.1 (8)	.44
BCSC3	Not Available				
1981					
BWC1	2.5 (11)	-1.5 (17)	2.6 (19)	.3 (19)	10.79
BWC2	-5.8 (11)	-10.7 (17)	-2.9 (19)	2.0 (19)	20.06
BWC3	-10.5 (9)	-5.9 (12)	-11.9 (15)	-12.1 (11)	24.63
BCSC1	-.4 (11)	-.4 (17)	-.6 (19)	-.9 (19)	.22
BCSC2	.4 (11)	-.4 (17)	.5 (19)	1.1 (19)	.44
BCSC3	-.7 (9)	-.1 (12)	-.5 (15)	-.6 (11)	.31
1982					
BWC1	1.4 (19)	-4.4 (16)	-3.9 (18)	-4.6 (16)	10.79
BWC2	-2.7 (19)	-6.3 (16)	-1.6 (18)	-.1 (16)	20.06
BWC3	-4.7 (19)	-2.2 (16)	-8.2 (18)	-5.3 (13)	24.63
BCSC1	-.2 (19)	-1.2 (16)	-.9 (18)	-.9 (16)	.22
BCSC2	-.4 (19)	-.4 (16)	.3 (18)	.1 (16)	.44
BCSC3	-.1 (19)	.4 (15)	-.2 (18)	-.1 (13)	.31

TABLE 26 (Continued)

<u>1983</u>

BWC1	-3.6	-2.9	-5.6	-6.7	10.79
	(17)	(17)	(17)	(20)	
BWC2	-6.7	-5.9	-5.0	1.81	20.06
	(17)	(17)	(17)	(20)	
BWC3	-9.6	-9.5	-10.7	-13.4	24.63
	(17)	(17)	(17)	(20)	
BCSC1	-.1	-.3	-.4	-.7	.22
	(17)	(17)	(17)	(20)	
BCSC2	-.6	-.5	-.4	.2	.44
	(17)	(17)	(17)	(20)	
BCSC3	0	.1	-.1	-.3	.31
	(17)	(17)	(17)	(20)	

<u>1984</u>

BWC1	-.17	-4.37	-4.46	-4.05	10.79
	(12)	(10)	(10)	(13)	
BWC2	3.0	3.4	3.0	6.2	20.06
	(12)	(10)	(10)	(13)	
BWC3	-16.0	-15.9	-12.9	-15.6	24.63
	(12)	(10)	(10)	(13)	
BCSC1	-.7	1.0	-1.1	-1.0	.22
	(12)	(10)	(10)	(13)	
BCSC2	0	.1	0	.3	.44
	(12)	(10)	(10)	(13)	
BCSC3	-.4	-.4	-.2	-.4	.31
	(12)	(10)	(10)	(12)	

[a]BWC1=percentage weight change from fall to Jan; BWC2=percentage weight change from Jan. to precalving; BWC3=percentage body weight from precalving to start of breeding; BCSC1=body condition score change from fall to Jan.; BCSC2=body condition score change from Jan. to precalving; BCSC3=body condition score change from precalving to breeding season

[b]Number of cows in parentheses

TABLE 27. LEAST SQUARES MEANS FOR PREGNANCY RATE, DAYS FROM CALVING TO CONCEPTION (DTC), DAYS FROM CALVING TO OVARIAN LUTEAL ACTIVITY (DTOOA), AND PERCENTAGE WITH LUTEAL ACTIVITY (OLA) BY 85 D IN 1980, 1981, 1982, 1983, AND 1984 FOR FOUR TREATMENTS

Year			Treatment		
	Mod	LL	LM	LH	E.M.S.
1980					
Pregnant(%)	49.8	15.3	31.4	45.8	
	(19)[a]	(19)	(18)	(22)	
DTC	114.0	128.1	91.3	111.8	493.25
	(8)	(3)	(4)	(7)	
DTOOA	67.9	NA	56.2	56.6	294.30
	(3)	(0)	(3)	(2)	
OLA	10.7	0.0	16.8	9.3	
by 85 d(%)	(19)	(19)	(18)	(22)	
1981					
Pregnant(%)	90.7	79.0	98.0	92.3	
	(11)	(17)	(19)	(19)	
DTC	79.4	88.4	96.4	98.7	493.25
	(9)	(13)	(16)	(15)	
DTOOA	71.5	70.4	59.8	64.3	294.30
	(6)	(10)	(18)	(13)	
OLA	54.6	58.7	52.5	68.3	
by 85 d(%)	(11)	(17)	(19)	(19)	
1982					
Pregnant(%)	84.9	26.1	42.1	46.9	
	(19)	(16)	(18)	(16)	
DTC	81.3	90.3	98.2	94.8	493.25
	(16)	(4)	(7)	(7)	
DTOOA	55.7	72.1	72.1	81.6	294.30
	(18)	(16)	(18)	(13)	
OLA	94.7	93.7	99.8	81.1	
by 85 d(%)	(19)	(16)	(18)	(16)	
1983					
Pregnant(%)	41.8	12.9	30.4	41.4	
	(17)	(17)	(17)	(20)	
DTC	107.7	81.9	103.7	83.7	493.25
	(6)	(2)	(3)	(5)	
DTOOA	70.4	77.4	78.5	69.6	294.30
	(4)	(5)	(5)	(9)	
OLA	23.5	29.3	29.4	44.9	
by 85 d(%)	(17)	(17)	(17)	(20)	
1984					
Pregnant(%)	89.3	75.6	54.5	65.2	
	(12)	(10)	(10)	(13)	
DTC	95.2	97.6	102.7	101.5	493.25
	(10)	(6)	(6)	(7)	
DTOOA	64.1	77.3	67.7	63.6	294.30
	(6)	(4)	(3)	(4)	
OLA	50.1	40.2	30.3	31.0	
by 85 d(%)	(12)	(10)	(10)	(13)	

[a]Number of cows in parentheses

TABLE 28. REDUCED ANALYSES OF VARIANCE TABLES FOR DAYS FROM
CALVING TO OVARIAN LUTEAL ACTIVITY (DTOOA), DAYS FROM
CALVING TO CONCEPTION (DTC), PRESENCE OF OVARIAN
LUTEAL ACTIVITY BY 85 D POSTPARTUM (OLA),
AND PREGNANCY RATE

Source	D. F.	M.S.

ANALYSIS OF VARIANCE FOR DAYS TO OVARIAN LUTEAL ACTIVITY (DTOOA)

Source	D. F.	M.S.
Treatment	3	246.3
Year	4	316.1
TreatmentxYear	11	480.7
Calving date	1	51.0
Residual	132	294.3

ANALYSIS OF VARIANCE FOR DAYS FROM CALVING TO CONCEPTION (DTC)

Source	D. F.	M.S.
Treatment	3	65.4
Year	4	1554.4**
TreatmentxYear	11	726.7
Calving date	1	18581.0***
Residual	133	493.26

ANALYSIS OF VARIANCE FOR PRESENCE OF OVARIAN LUTEAL ACTIVITY BY 85 D (OLA)

Source	D. F.	M.S.
Treatment	3	.025
Year	4	1.25***
Calving date	1	.11
Calving datexYear	4	1.03***
Residual	316	.15

ANALYSIS OF VARIANCE FOR PREGNANCY RATE

Source	D. F.	M.S.
Treatment	3	1.46***
Year	4	4.16***
Calving date	1	2.05***
Residual	320	.19

**(P<.05)
***(P<.01)

TABLE 29. LEAST SQUARES MEANS OVER FIVE YEARS FOR PREGNANCY
RATE, DAYS TO CONCEPTION (DTC), DAYS TO OVARIAN LUTEAL
ACTIVITY (DTOOA), AND PERCENTAGE OF COWS WITH LUTEAL
ACTIVITY (OLA) BY 85 D

| Year | Treatment | | | | |
	Mod	LL	LM	LH	E.M.S.
% pregnant	71.3a	41.8b	51.3bc	58.3c	
	(78)d	(79)	(82)	(90)	
DTC	95.5	97.3	98.5	98.1	493.25
	(49)	(28)	(36)	(41)	
DTOOA	66.5	72.9	66.9	67.1	294.30
	(37)	(35)	(39)	(41)	
OLA	46.7	44.4	45.7	46.9	
by 85 d	(78)	(79)	(82)	(90)	

[a,b,c]Means not sharing common superscript are different (P<.05)
[d]Numbers of cows in parentheses

TABLE 30. PARTIAL CORRELATION COEFFICIENTS FOR DAYS TO
CONCEPTION (DTC), DAYS TO OVARIAN LUTEAL ACTIVITY
(DTOOA), BODY CONDITION SCORES, CHANGES IN BODY
CONDITION SCORES, AND CHANGES IN BODY WEIGHT[a]

	DTOOA	PBCS	BSBCS	BWC1	BWC2	BWC3	BCSC1	BCSC2	BCSC3
DTC	.18 (95)[b]	-.002 (141)	-.04 (114)	-.17* (141)	.06 (141)	-.03 (114)	-.25** (141)	.05 (141)	.10 (114)
DTOOA		-.18* (147)	-.14 (125)	-.13 (147)	-.08 (147)	.02 (125)	-.10 (147)	-.02 (147)	.08 (125)
PBCS			.64** (225)	.36** (291)	.19** (291)	-.40** (225)	.01 (291)	.67** (291)	-.72** (225)
BSBCS				.17* (225)	.21** (225)	-.06 (225)	.01 (225)	.14* (225)	.08 (225)
BWC1					-.32** (291)	-.02 (225)	.51** (291)	.10 (291)	.03 (225)
BWC2						.43** (225)	-.30** (291)	.42** (291)	-.32** (225)
BWC3							.04 (225)	-.24** (225)	.45** (225)
BCSC1								-.36** (291)	.22** (225)
BCSC2									-.69** (225)

[a]PBCS=precalving body condition score; BSBCS=breeding season body condition score; BWC1=weight change from fall to Jan.; BWC2=weight change from Jan. to precalving; BWC3=weight change from precalving to breeding season; BCSC1=body condition score change from fall to Jan.; BCSC2=body condition score change from Jan. to precalving; BCSC3=body condition score change from precalving to breeding season

[b]Numbers of cows in parentheses
*P<.05
**P<.01

Figure 15. Percentage of cows predicted
correctly for potential pregnancy using
precalving body condition score (PBCS),
breeding season condition score (PBCS),
breeding season condition score (BSBCS),
weight or score change from fall to Jan.
(BWC1; BCSC1), weight or score change
from Jan. to precalving (BWC2; BCSC2),
weight change or score change from pre-
calving to start of breeding season
(BWC3; BCSC3)

Figure 16. Pregnancy rate (percent) predicted by a third order expression of precalving body condition: $Y + 1.28 - .986(PBS) + .248(PBCS^2) - .016(PBCS^3)$
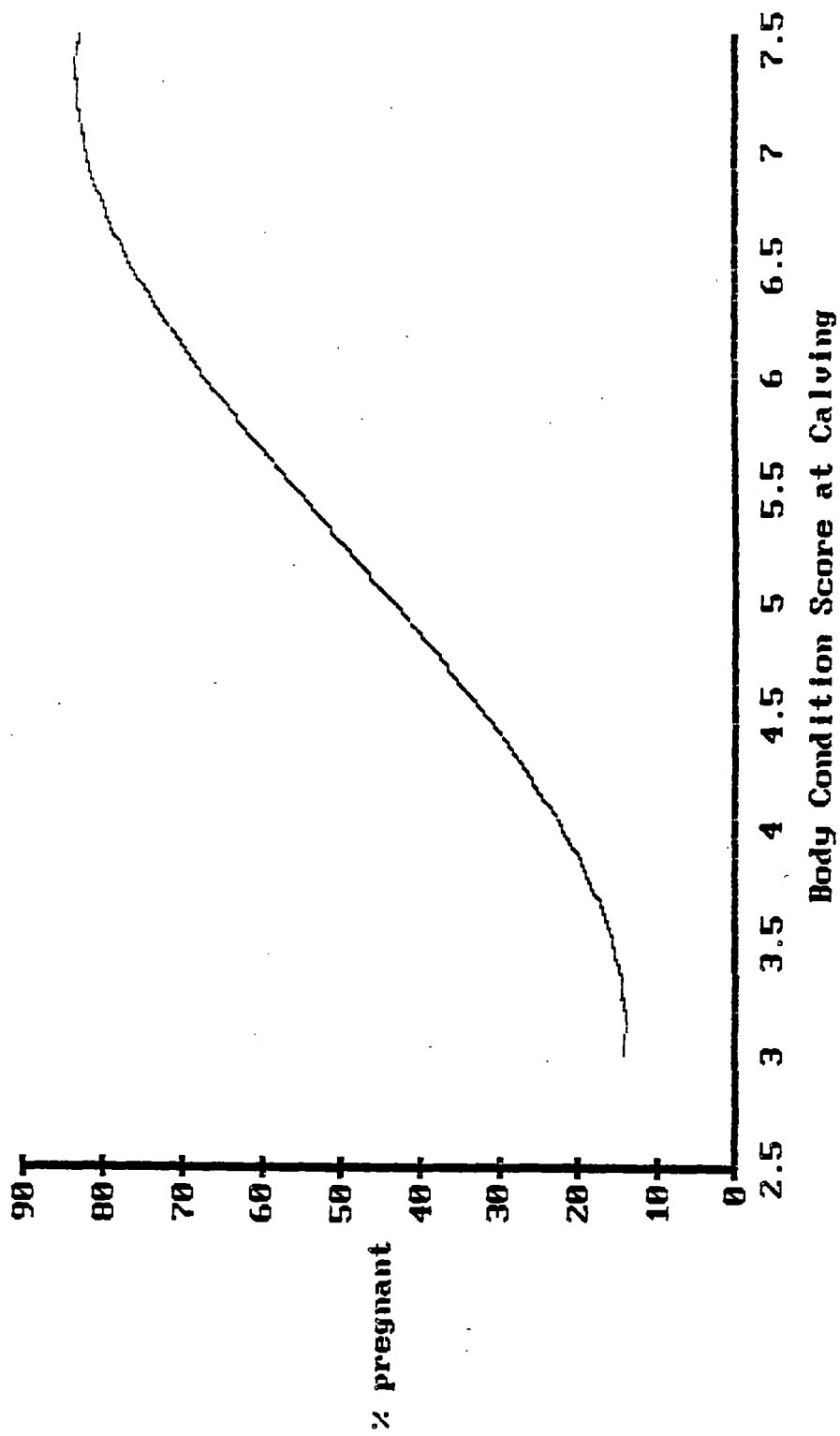
Figure 17.   Percentage of cows predicted
correctly for potential ovarian luteal
activity by 85 d using precalving body
condition   score   (PBCS),   breeding season
condition score (BSBCS), weight or score
change from fall to Jan. (BWC1; BCSC1),
weight   or   score   change   from   Jan.   to
precalving (BWC2; BCSC2), weight change
or score change from precalving to start
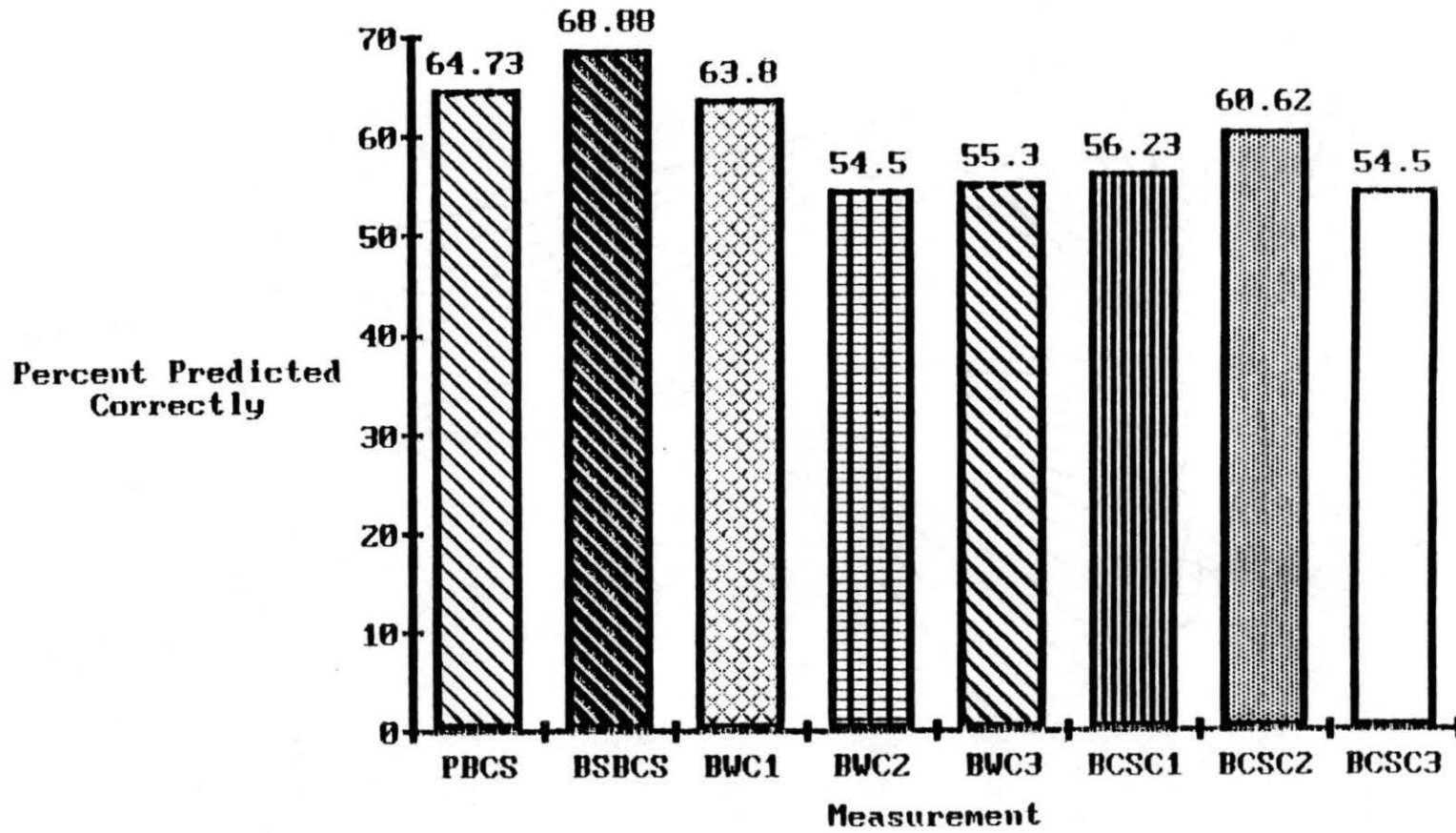of breeding season (BWC3; BCSC3)
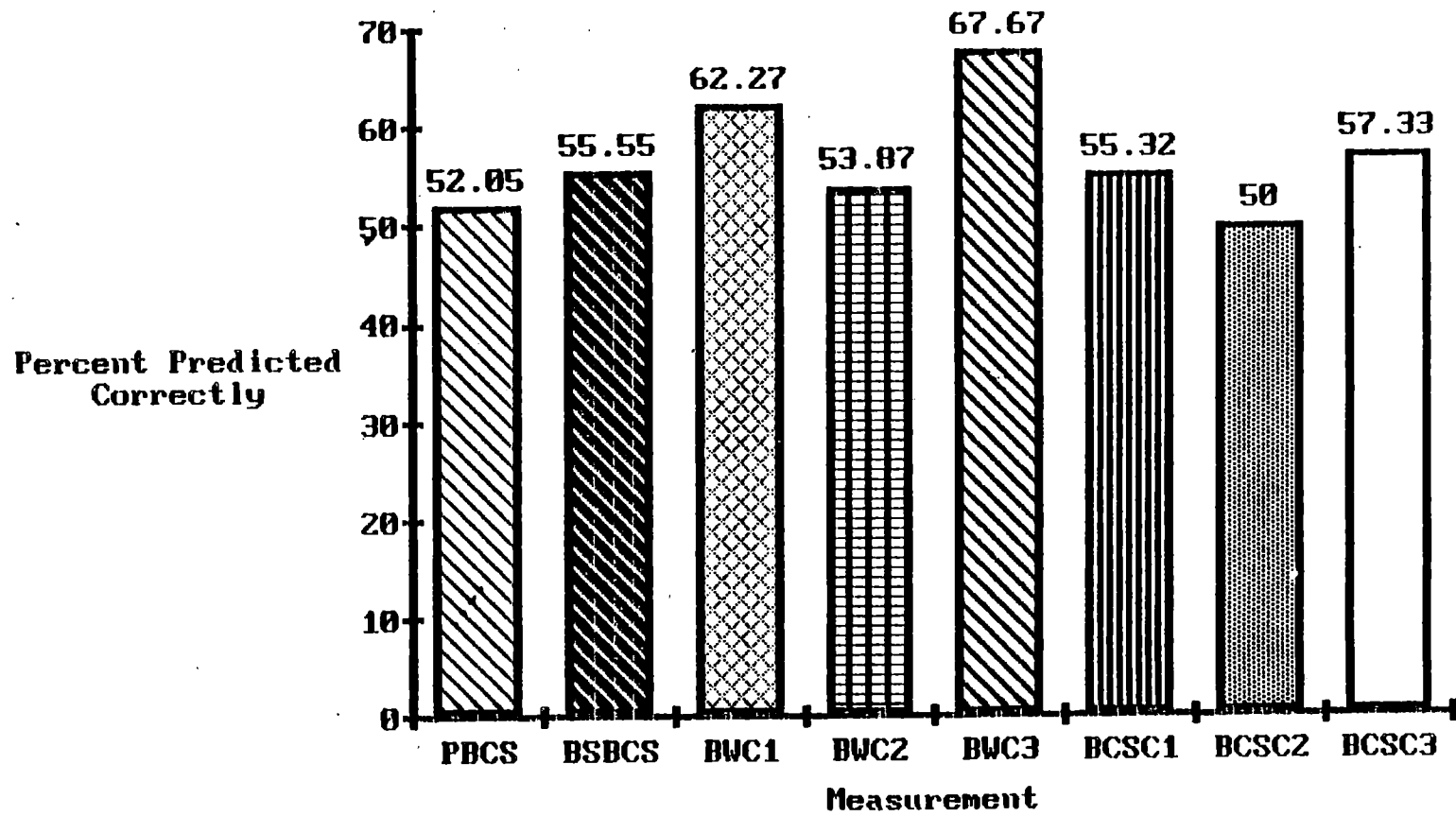
CHAPTER V

SUMMARY AND CONCLUSIONS

Summary: Experiment One

Prepartum nutrition influences reproductive performance in beef cows (Dunn and Kaltenbach, 1980). However, the physiological link between the nutritional status and reproductive function of cows remains unclear. Blood concentrations of glucose and insulin fluctuate with feed intake in ruminants (Rasby, 1983; Trenkle, 1978; Easdon, et al.,1985). Decreased concentrations of plasma glucose have been associated with reduced fertility in dairy and beef cows (Downie and Gelman, 1978; McClure, 1976; Kappel, et al. 1984). Diabetic laboratory animals, with reduced insulin concentrations, have impaired reproductive function.

To evaluate the relationships among concentrations of glucose and insulin in blood and reproductive performance, 71 spring-calving mature pregnant Hereford range cows and 45 spring-calving pregnant first and second calf Hereford heifers were blocked by age and body condition in the fall of 1982 and 1983, respectively. Each year the cows were placed in one of four nutritional treatment groups. Mod cows were fed to maintain the fall body weight until precalving. LL cows were fed to lose 10% of the fall weight by

precalving. LM cows were fed with the LL cows until (Jan 20), about 6 weeks prior to expected calving date, and then fed with the Mod cows. LH cows were supplemented the same as LL cows until Jan 20 then were given 140% the supplement received by Mod cows. The cows were weighed and body condition scores assigned twice monthly from early November to 85 days post partum. All cows were fed according to NRC protein requirements for lactating beef cows postpartum plus grass hay and standing pasture forages as they were available. Weekly blood samples were obtained for 85 d after calving. Plasma glucose and serum insulin concentrations were quantified both years, and serum luteinizing hormone (LH) concentrations were quantified the second year. For the purpose of statistical analysis, cows were designated as early or late calving within each calving season and were labeled pregnant or nonpregnant, depending upon the status of the cow at rectal palpation following the subsequent breeding season.

Plasma glucose concentrations were decreased in early-calving cows that failed to become pregnant in 1983. Late-calving, nonpregnant cows tended (P >.10) to have reduced concentrations for glucose compared to late-calving, pregnant cows. Concentrations of glucose in plasma were similar for pregnant and nonpregnant cows in 1984. Concentrations of insulin in serum were best fit by different response curves for pregnant vs. nonpregnant cows in the Mod and LL groups in 1983. In both of these treatment groups, nonpreg-

nant cows had increased insulin early postpartum, but decreased insulin from 6 weeks to 11 weeks postpartum compared to pregnant counterparts. Response curves for concentrations of insulin in serum were similar for pregnant and nonpregnant cows in 1984. Later-calving cows in both 1983 and 1984 had increased concentrations of insulin that may have coincided with the arrival of warmer ambient temperatures and warm season pastures. Luteinizing hormone concentrations were greater in cows that became pregnant than those that failed to conceive in 1984. Plasma glucose and serum insulin concentrations were correlated in cows that became pregnant (r=.20). Glucose and LH were correlated in cows that did not achieve pregnancy.

Summary: Experiment Two

Body weight change prepartum (Wiltbank, et al., 1964) and body condition at the time of calving (Corah, 1975; Whitman, 1975; Richards et al., 1985) have been associated with reproductive performance in beef cows. A five year study involving 329 pregnant Hereford range cows (approximately 70 per year the first four years and 45 young cows the fifth year) were used to evaluate relationships among prepartum nutrition, body condition scores, body weights and reproductive performance in beef cows.

The same four nutritional treatments as described in experiment one were imposed each of the five years. Cows were fed according to NRC requirements for supplemental pro-

tein and fed adequate amounts of grass hays postpartum.
Body weights and body condition scores were recorded at several times throughout each yearly trial. Body weights and condition scores were available for most cows in the fall, at the time of treatment change in January, precalving, and at the start of the breeding season. Linear regression analysis was conducted to examine treatment effects on body weight and body condition scores, pregnancy rate, days from parturition to conception (DTC), days from parturition to the onset of ovarian luteal activity (DTOLA), and the presence or absence of ovarian luteal activity by 85 d postpartum. Partial correlation coefficients were calculated for weights, condition scores and changes in these variables with DTC and DTOOA. A discriminant analysis was performed on pregnancy rate and percentage of cows with ovarian luteal activity by 85 d postpartum.

Mod cows had a greater pregnancy rate (71%) than any of the other treatment groups. LL cows had a reduced pregnancy rate (42%) compared to LM (51%) and LH (58%) cows. Prepartum nutritional treatment did not affect the days from parturition to conception, days from parturition to onset of ovarian luteal activity, or the presence of ovarian luteal activity by 85 d. Precalving body condition score and fall to January weight change influence pregnancy rate. A cubic response curve described the relationship between pregnancy rate and body condition score for cows between condition scores of 3 and 7. Changes in pregnancy rate were greater

when condition scores change from 4 to 5 or 5 to 6 than when scores change from 3 to 4 or from 6 to 7. The decrease in body condition score from fall to January was correlated ($r = -.25$) with the days to conception, whereas precalving body condition score was associated ($r = -.18$) with days from parturition to the onset of ovarian luteal activity.

Conclusions

Prepartum nutrition influences reproductive performance of spring-calving beef cows. Supplementation programs that maintain fall weight and condition will result in greater pregnancy rates than those that result in depletion of body energy stores during the winter. Body condition at calving influences pregnancy rate, and across the wide range of body condition scores in this study (3 to 7), does not interact with the condition or weight change (during gestation) leading to parturition. However, in those cows that had a sufficient body condition at calving to achieve pregnancy, the winter body condition score change did influence the length of the period from calving to conception.

Concentrations of glucose in plasma tended to be depressed in cows that failed to conceive. Cows that failed to conceive were also the cows with decreased body condition and depleted energy stores at calving. Gluconeogenesis, to maintain optimal concentrations of plasma glucose for all cells, will occur more readily in cows with energy stored as adipose tissue or glycogen. Serum concentrations of insulin

appear to be more readily influenced by the current diet than other factors related to reproduction. Serum concentrations of insulin vary more widely than the narrow range of postfasting concentrations found in the cows studied in this experiment. The relationships of insulin in the non-fasted state with reproductive performance of beef cows should be examined in future research.

Economic Considerations

All cows were fed similarly after calving each year. Therefore, the differences in pregnancy rate found among treatment groups were associated with prepartum supplementation programs. The Mod cows consumed 1.44 kg of cottonseed meal (csm; an overall five-year average) per cow per day during the prepartum treatment period. The LL, LM, and LH cows received .66, 1.0, and 1.34 kg, respectively. For the approximately 115 day prepartum supplementation season, the Mod, LL, LM and LH cows consumed csm valued at $32.76, $15.16, $22.77, and $30.51, respectively. Forage costs were quite variable due to the feeding of extra hay during times of inclement weather. Additional protein will stimulate ruminants to consume additional forage as digestibility and rate of passage increase. For the current example, an increase of 20% hay consumption for cows receiving the Mod supplementation regimes is assumed. If cows are fed 2% of their body weight in grass hay during 50 d with inclement weather, 400 kg cows would receive 8 kg per day or 400kg per

cow for the LL cows and 480 kg for Mod cows. An average hay price for the five year period would be $.09/kg. The additional hay consumed by cows with greater protein supplementation would cost $7.20 per cow. Therefore the additional feed cost for Mod cows above that of LL was $24.80 per cow. Cows supplemented at the Mod level, produced approximately .3 calves per cow more than the LL group. Assuming an average calf value of $260.00, and that nonpregnant cows are retained in the herd, a net return of $53.20 per cow would result from changing from the LL to Mod supplementation program. Using similar calculations, changing from the LM to Mod, or LH to Mod would result in a net return of $34.81, or $26.95 per cow, respectively.

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