JOURNAL OF ANIMAL SCIENCE
The Premier Journal and Leading Source of New Knowledge and Perspective in Animal Science

PHYSIOLOGY AND ENDOCRINOLOGY SYMPOSIUM: Nutritional aspects of developing replacement heifers

R. N. Funston, J. L. Martin, D. M. Larson and A. J. Roberts

J ANIM SCI 2012, 90:1166-1171.
doi: 10.2527/jas.2011-4569 originally published online September 30, 2011

PHYSIOLOGY AND ENDOCRINOLOGY SYMPOSIUM: Nutritional aspects of developing replacement heifers[1]

R. N. Funston,*[2] J. L. Martin,* D. M. Larson,* and A. J. Roberts†

*University of Nebraska West Central Research and Extension Center, North Platte 69101; and †USDA, ARS, Fort Keogh Livestock and Range Research Laboratory, Miles City, MT 59301

ABSTRACT: Studies in numerous species provide evidence that diet during development can mediate physiological changes necessary for puberty. In cattle, several studies have reported inverse correlations between postweaning growth rate and age at puberty and heifer pregnancy rates. Thus, postweaning growth rate was determined to be an important factor affecting age of puberty, which in turn influences pregnancy rates. This and other research conducted during the late 1960s through the early 1980s indicated puberty occurs at a genetically predetermined size, and only when heifers reach their target BW can increased pregnancy rates be obtained. Guidelines were established indicating replacement heifers should achieve 60 to 65% of their expected mature BW by breeding. Traditional approaches for postweaning development of replacement heifers used during the last several decades have primarily focused on feeding heifers to achieve or exceed an appropriate target BW and thereby maximize heifer pregnancy rates. Intensive heifer development systems may maximize pregnancy rates, but not necessarily optimize profit or sustainability. Since inception of target BW guidelines, subsequent research demonstrated that the growth pattern heifers experience before achieving a critical target BW could be varied. Altering rate and timing of BW gain can result in compensatory growth periods, providing an opportunity to decrease feed costs. Recent research has demonstrated that feeding replacement heifers to traditional target BW increased development costs without improving reproduction or subsequent calf production relative to development systems in which heifers were developed to lighter target BW ranging from 50 to 57% of mature BW.

Key words: beef cattle, heifer development, target body weight

J. Anim. Sci. 2012. 90:1166–1171
http://dx.doi.org/10.2527/jas.2011-4569

INTRODUCTION

Studies in numerous species provide evidence that diet during development can partially control physiological changes necessary for puberty (Frisch, 1984). Energy balance or plane of nutrition influences reproductive performance in heifers and cows (Short and Adams, 1988; Butler and Smith, 1989; Swanson, 1989; Randel, 1990; Robinson, 1990). Numerous studies have reported inverse correlations between postweaning growth rate and age at puberty (Wiltbank et al., 1966, 1969, 1985; Arije and Wiltbank, 1971; Short and Bellows, 1971; Ferrell, 1982) and pregnancy rates in heifers were shown to be dependent upon the number displaying estrus before or early in the breeding season (Short and Bellows, 1971; Byerley et al., 1987). Thus, postweaning growth rate was determined to be an important factor affecting age at puberty, which influences pregnancy rates. This and other research conducted during the late 1960s through the early 1980s indicated puberty occurs at a genetically predetermined size, and only when heifers reach their target BW can increased pregnancy rates be obtained (reviewed by Patterson et al., 1992). Guidelines were established indicating replacement heifers should achieve 60 to 65% of their expected mature BW by breeding (Patterson et al., 1992). Traditional approaches for postweaning development of replacement heifers used during the last several decades have primarily focused on feeding heifers to achieve or exceed an appropriate target BW and thereby maximize heifer pregnancy rates. Substantial changes in cattle genetics and the economy have occurred over this time, indicating that traditional approaches should be reevaluated. Intensive heifer development systems may maximize pregnancy rates, but

[1]Based on a presentation at the Physiology and Endocrinology Symposium titled "Factors Controlling Puberty in Beef Heifers" at the Joint Annual Meeting, July 10 to 14, 2011, New Orleans, Louisiana, with publication sponsored by the American Society of Animal Science and the *Journal of Animal Science*.

[2]Corresponding author: rfunston2@unl.edu

Received August 8, 2011.
Accepted September 25, 2011.

not necessarily optimize profit or sustainability. These systems require significant use of fossil fuels and cereal grains, and increased capital investment in equipment and facilities. Cereal grains, often used as an energy source in heifer diets, detract from the sustainability of the system due to growing demand for human food and ethanol production. Furthermore, almost all heifer development studies conducted over the last half century have focused on production to first calving with little information concerning effects of heifer development systems on lifetime productivity.

Since inception of target BW guidelines, subsequent research demonstrated the growth pattern heifers experience before achieving a critical target BW could be varied. Altering rate and timing of BW gain can result in compensatory growth periods and allow producers to limit supplementation, providing an opportunity to decrease feed costs (Clanton et al., 1983; Lynch et al., 1997; Freetly et al., 2001). For example, minimizing heifer BW gain until 47 or 56 d before the breeding season did not negatively influence reproductive performance, but reduced the amount of feed needed (Lynch et al., 1997). Similarly, Freetly et al. (2001) found that minimizing BW gain until later in the postweaning period reduced total energy intake, but calving rate, age at calving, postpartum interval, and second-year pregnancy rate were not affected. These studies indicate that total energy intake, and possibly heifer development costs, may be reduced by limiting heifer gain early in the postweaning period followed by accelerated gains before the breeding season.

REVIEW OF TARGET BW

Substantial research contributed to the guidelines of developing heifers to 60 to 65% of mature BW at the time of breeding. Studies evaluating different postweaning rates of BW gain or target BW have used either different feed amounts or different feedstuffs varying in energy or protein content or both to obtain growth rate differences and thus achieve different target BW at a given point in time. A review of studies conducted over the last several decades along with new research discussed later indicates that associations among BW, puberty, and heifer pregnancy rate appear to have changed over time. Research reports published through the late 1980s demonstrated much greater negative effects of limited postweaning growth on age of puberty and subsequent pregnancy rates (Short and Bellows, 1971; Wiltbank et al., 1985; Patterson et al., 1989), whereas more recent studies indicate less of a negative impact of delayed puberty on pregnancy response (Buskirk et al., 1995; Freetly and Cundiff, 1997; Lynch et al., 1997). Several factors likely contribute to this change over time. Initial research corresponds to the industry shift from calving heifers at 3 yr of age to calving at 2 yr of age. Thus, selection pressure for age of puberty was probably minimal in animals in the early studies. Whereas selection intensity would have increased with the reduction in calving age of heifers, genetic progress would take time due to the long generation interval in cattle. In 1978, researchers identified the association between scrotal circumference in bulls and age at puberty in their daughters (Brinks et al., 1978). Since then, scrotal circumference has been used as an indicator trait for puberty. Breed association web sites show substantial scrotal circumference increases occurring from 1985 to the present, indicating progress in changing this trait; a similar response in age at puberty would be expected. Increases in scrotal circumference and decreases in age at puberty are also expected responses to genetic selection for BW increases at weaning and year of age. Indeed, inability of heifers to attain puberty before breeding may not be as problematic as heifers reaching puberty before weaning (Gasser et al., 2006a,b).

Association between timing of puberty and subsequent pregnancy rate also seems to have changed over time. Early research indicated heifers should experience 2 or 3 estrous cycles before onset of breeding season because first estrus fertility was less than subsequent estrous cycles (Byerley et al., 1987). Thus, delayed onset of puberty was expected to be associated with reduced pregnancy rates. However, several studies have not shown strong associations between nutritionally related changes in age at puberty and final pregnancy rates (Ferrell, 1982; Buskirk et al., 1995; Freetly and Cundiff, 1997; Lynch et al., 1997). Evidence for a genetic basis for these differences is provided by Freetly and Cundiff (1997), who reported that pregnancy rates, but not age and BW at puberty, were greater in heifers AI-sired by bulls born after 1988 than bulls born between 1982 and 1984. These changes, combined with continued increases in harvested feedstuff costs, indicate the need for alternative heifer development systems to optimize opportunity for early conception at reduced cost.

RECENT RESEARCH

Feeding replacement heifers to traditional target BW increased development costs relative to more extensive heifer development systems where heifers were developed to decreased target BW ranging from 51 to 57% of mature BW (Funston and Deutscher, 2004; Roberts et al., 2007, 2009a; Martin et al., 2008; Larson et al., 2011). Feeding to a prebreeding BW as little as 51% of mature BW was shown to be more cost effective than development to 57% of mature BW, even though lighter heifers were allowed a 15 d longer (45 vs. 60 d) breeding season (Martin et al., 2008). Extending the breeding season by 15 d for lighter heifers resulted in similar conception rates between systems, and a similar ($P = 0.23$) proportion of heifers calved within the initial 45 d of the calving season, 87.4 and 76.1% for heifers fed to 57 or 51% of mature BW, respectively. Further characterization of each system revealed that only 21.1% of open heifers developed to 51% of mature BW reached puberty before the start of the breeding season, whereas 55% of open heifers developed to 57% of mature BW were pubertal at the start of breeding. This lends support to the hypothesis that one of the major determinants of the ability of a heifer to conceive during her first breeding season is the age when she reaches puberty. Heifers calving early during their first calving season have greater lifetime calf production than those calving late and are more likely to become pregnant sooner at 2 yr of age (Lesmeister et al., 1973). However, second-calf conception rates or calf production between cows developed to 51 or 57% of mature BW before breeding as yearlings were not different (Martin et al., 2008). This indicates that lighter heifers becoming pregnant during the 15-d extension of the first breeding season rebred with similar efficiency as those pregnant within the initial 45 d. Therefore, the proportion of heifers retained as pregnant 2-yr-olds was similar between systems. Thus, heifers may be developed to lighter than traditional target BW without negative effects on profitability or future productivity.

Research at Fort Keogh Livestock and Range Research Laboratory evaluating lifetime productivity of heifers developed with either unlimited or restricted (i.e., 27% less) feed during the postweaning period supports the potential to reduce target BW and costs during heifer development (Roberts et al., 2007, 2009a). Analysis of data from the first 3 yr of this study revealed that year of replication was a greater source of variation in the proportion of heifers achieving puberty before breeding (range of 46 to 92%) than feeding during the postweaning period (7 to 13% difference between feeding treatments). Restricted feeding resulted in a slightly older age at puberty (~12 d), but mean BW of heifers achieving puberty was lighter for restricted heifers. Furthermore, growth rate from birth to weaning accounted for more variation in puberty and AI pregnancy rate than postweaning ADG. Neither age nor ADG before postweaning period influenced final pregnancy rate. Thus, age and early growth rate (up to approximately 8 mo of age) influenced time of puberty and conception, but did not alter overall pregnancy rate in a 48- to 60-d breeding season.

When summarized over the last 7 yr, heifer pregnancy rate was 3.5% less in heifers developed under restricted feeding at Fort Keogh. Restricted feeding during the 140-d postweaning period increased efficiency of BW gain and reduced harvested feed inputs by 22% to achieve the same number of pregnant heifers. After ending the restriction, restricted heifers remained lighter but had greater ADG while grazing native range. However, restricted heifers still had lighter BW going into the winter than heifers not restricted. This lighter BW is expected to result in decreased maintenance requirements for restricted heifers. Heifers developed under restricted feeding had improved biological (i.e., reduced maintenance requirements) and economic efficiency (i.e., reduced cost of feed inputs per pregnant heifer).

Pregnant heifers resulting from the 2 postweaning treatments were also fed at different levels throughout each subsequent winter. Heifers developed without restriction were provided adequate harvested feed, primarily as a protein supplement, from early December through calving, whereas heifers developed on restricted feeding were fed 20 to 45% less harvested feed during this period. Restriction resulted in decreased BW through 5 yr of age (Roberts et al., 2009b), which is expected to result in decreased maintenance requirements.

Heifer offspring from cows managed under the 2 different winter feeding levels were randomly assigned to restricted or nonrestricted protocols resulting in 4 treatments: restricted cows from restricted dams, restricted cows from control dams, control cows from restricted dams, and control cows from control dams. Interestingly, cows from restricted dams were 15.9 to 22.7 kg heavier than cows from nonrestricted dams at 3 to 5 yr of age, due in part to greater BCS than cows from control dams (Roberts et al., 2009b). Thus, the method of developing and maintaining replacement heifers may influence offspring growth and development. Differences in BW and BCS may also affect longevity. Preliminary data analysis on retention to the sixth breeding season when culling was based primarily on reproductive performance indicates an interaction between dam and cow treatments. Retention to sixth breeding was least for restricted cows from nonrestricted dams (37%) compared with other cow × dam treatment classifications, which did not differ: 42 or 46% for nonrestricted cows from either restricted or nonrestricted dams, and 43% for restricted cows from restricted dams. Preliminary evaluation of third generation calf performance found that calves from restricted cows out of restricted dams were lighter at birth and weaning by 1.4 and 5.9 kg, respectively. Thus, restricted cows from restricted dams may partition nutrients more toward body reserves (i.e., greater fleshing ability) and less toward calf BW production, resulting in greater retention. Results from Rogers et al. (2004) support the possibility that retention may be increased in cows that conserve nutrients for fleshing at the expense of output for calf growth. These researchers observed an inverse association of breeding value of cow BW at weaning (i.e., reflection of BCS) with risk of being culled and a positive association of maternal breeding value for preweaning BW gain (i.e., milk production) with risk of culling. Current data indicate that the small decrease in calf output may be more than compensated for by increased longevity.

Several similarities exist between heifer development studies conducted at the University of Nebraska (Funston and Deutscher, 2004) and Fort Keogh. Both locations used similar types of cattle (i.e., composites with approximately one-half Red Angus and one-half continental breeding), and the treatments resulted in development to similar target BW at breeding (53 vs. 58 and

55 vs. 59% of expected mature BW). Growth rates during the development period were similar between locations for the 2 treatments imposed, and both locations observed approximately a 10% reduction in proportion of heifers pubertal at breeding in the reduced input groups. Magnitude of savings achieved by lighter target BW was also similar ($22 to $24/pregnant heifer). In contrast to the Nebraska research, a slight decrease in pregnancy rate (i.e., 3 to 5%) was observed in heifers under restricted feeding at Fort Keogh (Roberts et al., 2009a). Methods used for restricting development rate differed between Nebraska (i.e., reduced diet quality) and Fort Keogh (i.e., reduced quantity fed), which may contribute to pregnancy differences. These studies indicate an opportunity to improve efficiency and decrease production costs by decreasing amount or quality or both of harvested feeds used for heifer development.

Recent experiments (Funston and Larson, 2011; Larson et al., 2011) have been conducted grazing heifers on corn residue or winter range as an alternative to dry lot feeding. In each study, heifers grazing corn residue gained approximately 0.23 kg/d less than their more traditionally fed counterparts, whether on winter grass or a dry lot. It is important to note that heifers grazing winter range or corn residue were only supplemented with the equivalent of 0.14 kg of protein/d and gained between 0.23 to 0.45 kg/d during winter grazing. However, once placed on greater quality spring pasture, the heifers gained 1.13 to 1.36 kg/d before, during, and after the breeding season. Regardless of these compensatory BW gains, heifers developed grazing corn residue weighed 5 to 7% less before breeding than heifers developed in the dry lot, had achieved 55 to 60% of their mature BW, and had similar pregnancy rates at the end of the breeding season. They also had decreased BW before first calving.

Greatest BW gain should not be the major goal in heifer development programs. Producers should strive for a sound, functional, low-cost, and pregnant heifer. Previous research (Patterson et al., 1992) supported the concept that a heifer must reach 65% of her mature BW for maximal reproductive efficiency. More recent data (Funston and Larson, 2011) provide evidence that a lighter BW is sufficient for attainment of puberty and pregnancy success. Even though puberty was delayed by reduced prebreeding BW gain, final pregnancy rates were similar (92 to 94%) between development systems. Previous research (Byerley et al., 1987) indicated that heifers not reaching puberty before breeding may become pregnant later than pubertal heifers. This may partially explain recent results from Funston and Larson (2011). Heifers developed in the dry lot had approximately a 10% greater AI pregnancy rate than cornstalk-developed heifers even though overall pregnancy rates and subsequent calving dates were similar.

All of these data provide evidence that heifers can be successfully developed into productive cows using low-quality feedstuffs. Heifer development costs can be reduced by limiting forage quality or quantity without compromising productivity. Regardless of source, low-quality feedstuffs exist in every environment and can be fed to beef cattle depending on stage of production. Moving heifer development out of the dry lot, in favor of corn residue or winter range, reduced development cost by $45/pregnant heifer (Funston and Larson, 2011).

EXCESS NUTRIENTS

A young, growing heifer at approximately 272 kg will require approximately 0.60 kg of CP and 4.3 kg of TDN to gain approximately 0.70 kg of BW/d. The majority of heifer development continues to occur in the dry lot using harvested forages. This typically includes some type of dry hay, a grain source, and perhaps an ensiled feedstuff. Often, dry hay is at least 12% CP and even moderate provision of a grain source will meet energy demands. In contrast, if an ensiled feed is used, energy needs will be met by the silage. This will produce a BW gain of 0.68 kg/d, sufficient to produce a heifer of adequate size for breeding by spring. This is especially true when one considers compensatory gain. Compensatory gain is the type of BW gain experienced by a previously restricted animal when exposed to a more nutrient-dense environment, such as spring or early summer pasture.

Perhaps of greater concern in areas where weather necessitates extended dry lot feeding is creating heifers with excessive body condition. Older data in dairy-type heifers indicate that heifers weighing 30 to 35% more than lighter counterparts at calving produced 318 kg less milk during their first lactation (Swanson, 1960). In beef cows, females having lighter weaning BW, out of young or low-milk-production dams, tend to wean heavier calves than cows out of high-production mature dams (Mangus and Brinks, 1971). In addition, cows that were creep fed as calves tended to wean lighter calves (Martin et al., 1981). The biological basis behind these observations may be due in part to inhibited mammary development in fat or well-fed heifers. This observation is supported by Ferrell et al. (1976). Ferrell offered pregnant heifers a high or low level of nutrient intake. Heifers were slaughtered and those on increased intake had a greater udder weight and a larger proportion of that weight was fat. Arnett et al. (1971) studied sets of twin heifers developed at a rate of 0.34 kg/d or at a rate designed to induce a high degree of body fatness. The overdeveloped twins were 30% heavier than more appropriately developed twins at first mating and maintained this difference through their third calving season. Developing heifers to become obese increased the number of services required for a conception by 7% compared with leaner heifers. This difference persisted through the third breeding season. The obese cows consistently required more services per conception, but differences were not statistically significant.

More striking was the difference in calving difficulty persisting through the third calving season. Obese heifers required 86% more assistance for calving than lean heifers. Across 3 lactation periods, heifers developed to become obese produced less milk than lean counterparts did, and as a result, their calves tended to be lighter at weaning. The difference in milk production is further supported by data from Ferrell (1982). Heifers developed at 0.79 kg/d produced 0.55 kg/d less milk than heifers developed at 0.59 kg/d. Furthermore, the heavier developed heifers weaned 14 kg lighter calves. Patterson et al. (1992) cited numerous other studies providing additional support for the concept that developing obese heifers negatively affects reproduction and calf production. However, more important, developing heifers to excessive weights is expensive, increasing costs per developed heifer.

SUMMARY AND CONCLUSIONS

Postweaning management of heifers to achieve 60 to 65% of mature BW at breeding, particularly by feeding high-energy diets, is not supported by current research. However, heifers developed on dormant forage generally require additional protein supplementation to achieve even modest BW gains. One reason reproductive performance has not been drastically impaired by feeding to lighter target BW may relate to genetic changes in age at puberty. Although the systems presented herein are not directly applicable to all locations, the principles of reduced input development are applicable if used correctly. Regardless of the system, minimizing expensive feedstuffs will reduce development cost, a major determinant in lifetime cow profitability.

LITERATURE CITED

Arije, G. F., and J. N. Wiltbank. 1971. Age and weight at puberty in Hereford heifers. J. Anim. Sci. 33:401–406.

Arnett, D. W., G. L. Holland, and R. Totusek. 1971. Some effects of obesity in beef females. J. Anim. Sci. 33:1129–1136.

Brinks, J. S., M. J. McInerney, and P. J. Chenoweth. 1978. Relationship of age at puberty in heifers to reproductive traits in young bulls. Proc. West. Sect. Am. Soc. Anim. Sci. 29:28–30.

Buskirk, D. D., D. B. Faulkner, and F. A. Ireland. 1995. Increased postweaning gain of beef heifers enhances fertility and milk production. J. Anim. Sci. 73:937–946.

Butler, W. R., and R. D. Smith. 1989. Interrelationships between energy balance and postpartum reproductive function in dairy cows. J. Dairy Sci. 72:767–783.

Byerley, D. J., R. B. Staigmiller, J. G. Berardinelli, and R. E. Short. 1987. Pregnancy rates of beef heifers bred either on pubertal or third estrus. J. Anim. Sci. 65:645–650.

Clanton, D. C., L. E. Jones, and M. E. England. 1983. Effect of rate and time of gain after weaning on the development of replacement beef heifers. J. Anim. Sci. 56:280–285.

Ferrell, C. L. 1982. Effects of postweaning rate of gain on onset of puberty and productive performance of heifers of different breeds. J. Anim. Sci. 55:1272–1283.

Ferrell, C. L., W. N. Garrett, and N. Hinman. 1976. Growth, development and composition of the udder and gravid uterus of beef heifers during pregnancy. J. Anim. Sci. 42:1477–1489.

Freetly, H. C., and L. V. Cundiff. 1997. Postweaning growth and reproduction characteristics of heifers sired by bulls of seven breeds and raised on different levels of nutrition. J. Anim. Sci. 75:2841–2851.

Freetly, H. C., C. L. Ferrell, and T. G. Jenkins. 2001. Production performance of beef cows raised on three different nutritionally controlled heifer development programs. J. Anim. Sci. 79:819–826.

Frisch, R. E. 1984. Body fat, puberty and fertility. Biol. Rev. Camb. Philos. Soc. 59:161–188.

Funston, R. N., and G. H. Deutscher. 2004. Comparison of target breeding weight and breeding date for replacement beef heifers and effects on subsequent reproduction and calf performance. J. Anim. Sci. 82:3094–3099.

Funston, R. N., and D. M. Larson. 2011. Heifer development systems: Dry lot feeding compared with grazing dormant winter forage. J. Anim. Sci. 89:1595–1602.

Gasser, C. L., E. J. Behlke, D. E. Grum, and M. L. Day. 2006a. Effect of timing of feeding a high-concentrate diet on growth and attainment of puberty in early-weaned heifers. J. Anim. Sci. 84:3118–3122.

Gasser, C. L., G. A. Bridges, M. L. Mussard, D. E. Grum, J. E. Kinder, and M. L. Day. 2006b. Induction of precocious puberty in heifers III: Hastened reduction of estradiol negative feedback on secretion of luteinizing hormone. J. Anim. Sci. 84:2050–2056.

Larson, D. M., A. S. Cupp, and R. N. Funston. 2011. Heifer development systems: A comparison of grazing winter range or corn residue. J. Anim. Sci. 89:2365–2372.

Lesmeister, J. L., P. J. Burfening, and R. L. Blackwell. 1973. Date of first calving in beef cows and subsequent calf production. J. Anim. Sci. 36:1–6.

Lynch, J. M., G. C. Lamb, B. L. Miller, R. T. Brandt Jr., R. C. Cochran, and J. E. Minton. 1997. Influence of timing of gain on growth and reproductive performance of beef replacement heifers. J. Anim. Sci. 75:1715–1722.

Mangus, W. L., and J. S. Brinks. 1971. Relationships between direct and maternal effects on growth in Herefords: I. Environmental factors during preweaning growth. J. Anim. Sci. 32:17–23.

Martin, J. L., K. W. Creighton, J. A. Musgrave, T. J. Klopfenstein, R. T. Clark, D. C. Adams, and R. N. Funston. 2008. Effect of pre-breeding body weight or progestin exposure before breeding on beef heifer performance through the second breeding season. J. Anim. Sci. 86:451–459.

Martin, T. G., R. P. Lemenager, G. Srinivasan, and R. Alenda. 1981. Creep feed as a factor influencing performance of cows and calves. J. Anim. Sci. 53:33–39.

Patterson, D. J., L. R. Corah, G. H. Kiracofe, J. S. Stevenson, and J. R. Brethour. 1989. Conception rate in *Bos taurus* and *Bos indicus* crossbred heifers after postweaning energy manipulation and synchronization of estrus with melengestrol acetate and fenprostalene. J. Anim. Sci. 67:1138–1147.

Patterson, D. J., R. C. Perry, G. H. Kiracofe, R. A. Bellows, R. B. Staigmiller, and L. R. Corah. 1992. Management considerations in heifer development and puberty. J. Anim. Sci. 70:4018–4035.

Randel, R. D. 1990. Nutrition and postpartum rebreeding in cattle. J. Anim. Sci. 68:853–862.

Roberts, A. J., T. W. Geary, E. E. Grings, R. C. Waterman, and M. D. MacNeil. 2009a. Reproductive performance of heifers offered ad libitum or restricted access to feed for a 140-d period after weaning. J. Anim. Sci. 87:3043–3052.

Roberts, A. J., E. E. Grings, M. D. MacNeil, R. C. Waterman, L. Alexander, and T. W. Geary. 2009b. Implications of going against the dogma of feed them to breed them. Proc. West. Sect. Am. Soc. Anim. Sci. 60:85–88.

Roberts, A. J., S. I. Paisley, T. W. Geary, E. E. Grings, R. C. Waterman, and M. D. MacNeil. 2007. Effects of restricted feeding of beef heifers during the postweaning period on growth, efficiency and ultrasound carcass characteristics. J. Anim. Sci. 85:2740–2745.

Robinson, J. J. 1990. Nutrition in the reproduction of farm animals. Nutr. Res. Rev. 3:253–276.

Rogers, P. L., C. T. Gaskins, K. A. Johnson, and M. D. MacNeil. 2004. Evaluating longevity of composite beef females using survival analysis techniques. J. Anim. Sci. 82:860–866.

Short, R. E., and D. C. Adams. 1988. Nutritional and hormonal interrelationships in beef cattle reproduction. Can. J. Anim. Sci. 68:29–40.

Short, R. E., and R. A. Bellows. 1971. Relationships among weight gains, age at puberty and reproductive performance in heifers. J. Anim. Sci. 32:127–131.

Swanson, E. W. 1960. Effect of rapid growth with fattening of dairy heifers on their lactational ability. J. Dairy Sci. 43:377–387.

Swanson, L. V. 1989. Discussion-interactions of nutrition and reproduction. J. Dairy Sci. 72:805–814.

Wiltbank, J. N., K. E. Gregory, L. A. Swiger, J. E. Ingalls, J. A. Rothlisberger, and R. M. Koch. 1966. Effects of heterosis on age and weight at puberty in beef heifers. J. Anim. Sci. 25:744–751.

Wiltbank, J. N., C. W. Kasson, and J. E. Ingalls. 1969. Puberty in crossbred and straightbred beef heifers. J. Anim. Sci. 29:602–605.

Wiltbank, J. N., S. Roberts, J. Nix, and L. Rowden. 1985. Reproductive performance and profitability of heifers fed to weigh 272 or 318 kg at the start of the first breeding season. J. Anim. Sci. 60:25–34.