Applied Animal Science 36:70–77
https://doi.org/10.15232/aas.2019-01883

PRODUCTION AND MANAGEMENT: *Invited Review*

INVITED REVIEW: Effects of selection for milk production on cow-calf productivity and profitability in beef production systems

J. T. Mulliniks,* PAS, J. K. Beard, and T. M. King, PAS
West Central Research and Extension Center, University of Nebraska, North Platte 69101

ABSTRACT

Purpose: The objective of this review was to discuss the effects of selection for milk production in beef production systems on productivity and profitability.

Sources: The sources of data in this review were peer-reviewed literature, experiment station reports, and PhD dissertations.

Synthesis: In an effort to maximize output, selection for growth-oriented maternal traits has been a focus in the beef industry. Although emphasis is placed on output traits, optimizing cowherd production costs (i.e., feed costs) and reproductive performance are drivers of cow-calf profitability. With increased milk production potential in beef cows, cow maintenance requirements have increased, thus increasing production costs. Increased selection for milk production can result in beef cows undergoing greater nutritional stress during early lactation, which ultimately reduces cowherd reproduction and efficiency. In addition, the influence of milk production on calf weaning weight has been shown to be highly variable. This may be due to the value of the added milk production not being fully captured due to environmental conditions. Previous research has shown offspring from high-milking cows have decreased postweaning growth and feed efficiency, due to increased maintenance requirements.

Conclusions and Applications: Selection for milk production can led to a decrease in reproduction, resource use efficiency, cowherd retention rate, and offspring postweaning feed efficiency. Matching cow type or genetic potential to the production environment is important to optimize productivity and costs within the particular beef production system. Priority for commercial beef producers should be focused on economically relevant traits such as fertility and resource use efficiency.

Key words: beef cow, calf weaning weight, genetic selection, milk production, reproduction

INTRODUCTION

Calf BW at weaning can be an important driver for cow-calf profitability. Cow-calf producers have focused selection efforts on increased milk production and greater calf gains to improve output-related growth traits. In the last 40 yr, national cattle evaluation genetic trends have suggested a steady increase in selection for increased calf BW at weaning in most breeds (Kuehn and Thallman, 2016). However, during that same time period, Lalman et al. (2019) indicated calf BW at weaning may have plateaued in many regions of the United States. This may indicate environmental constraints on growth traits within forage-based production systems.

In selecting for growth with maternal milk, Edwards et al. (2017) reported no difference in calf weaning weight but observed a decrease in reproductive performance in high-milking beef cows. With the economic value of reproduction being reported to be 5 times greater than growth or milk traits in beef cattle (Trenkle and Willham, 1977), more emphasis may need to be placed on reproductive efficiency than growth traits. As cost of production increases, total inputs and input costs need to be considered when selecting production traits. This is even more important because the financial costs associated with feed inputs are the greatest factors influencing profitability of cow-calf operations, with feed input accounting for over 63% of variation in total cow costs (Miller et al., 2001). Thus, it is becoming increasingly important for livestock producers to match cow type to their given production environment to achieve optimal efficiency and profitability. This review will focus on the effect of selecting for increased milk potential in the cowherd on cow-calf production and profitability.

MILK PRODUCTION ON NUTRIENT REQUIREMENTS AND INTAKE

The beef cow uses 70 to 75% of dietary energy for maintenance (Ferrell and Jenkins, 1985), and the residual is used for pregnancy, lactation, activity, and adaptation to the environment. As milk production potential increases in beef cows, cow maintenance requirements during ges-

---

The authors have not stated any conflicts of interest.

*Corresponding author: travis.mulliniks@unl.edu

tation and lactation increase (Ferrell and Jenkins, 1984; Taylor et al., 1986; Montaño-Bermudez et al., 1990). For instance, Montaño-Bermudez et al. (1990) reported that cows with high (10.5 ± 0.3 kg) and medium (9.6 ± 0.2 kg) milk production required 11% more energy to support the increased milk production compared with low (8.5 ± 0.3 kg) milk-production cows. This variation of maintenance requirements is made up largely with differences in energy expenditure of the visceral organs (Ferrell and Jenkins, 1985). Although making up less than 10% of body mass, digestive tract tissue and liver use approximately 40 to 50% of total energy expenditure in a beef cow (Ferrell, 1988). Selection for increased milk potential is accompanied by an increased visceral organ mass relative to BW, which increases cow maintenance requirements.

In addition to increased maintenance requirements, selection for increased milk potential results in greater feed intake. Hatfield et al. (1989) evaluated forage intake by range beef cows from 3 different sire breed types (Hereford, Red Poll, and Milking Shorthorn) by Angus dams that differed in milk production potential. The authors reported positive linear ($P < 0.05$) and quadratic ($P < 0.01$) responses in DMI with increasing milk production during early and late lactation. Johnson et al. (2003) reported high milk EPD cows consumed 8% more forage than low milk EPD cows. With each kilogram increase in milk yield, forage DMI increased 0.33 and 0.37 kg in early and late lactation, respectively. Furthermore, the increase in forage DMI during late lactation occurred with no difference in milk production between the high and low milk EPD cows. In contrast, the National Academies of Sciences, Engineering, and Medicine (2016) estimates an increase in forage intake with each kilogram of milk production of 0.20 and 0.11 kg during early and late lactation, respectively. Thus, the increased forage intake with increasing milk potential during early lactation may be due to increased maintenance energy requirements and increased production energy requirements to support the increase in lactational demands.

Within a specific environment and production system, calving season is a major factor in the optimal milk production potential. Grings et al. (2008) indicated season of calving influences timing of peak lactation and amount of milk produced. In agreement, Brown et al. (2005) reported increased genetic potential for milk production may be suppressed by the nutritional environments. Mulliniks and Adams (2019) modeled the effects of milk production level on nutrient balances in March- and May-calving herds grazing upland native range. In March-calving cows, MP and ME were deficient within the first 30 d of the breeding season when milk production was over 11 kg/d. Within the May-calving herd, cows with milk production from 9 to 14 kg/d were deficient in both MP and ME for maintenance for the entirety of the breeding season. With the dynamics of forage quality within forage-based systems, selection for moderation in milk production may be important in optimizing reproductive performance within these systems. Matching cow type or genetic potential to the production environment is important to optimize productivity and costs within a production environment. In doing so, producers can match milk production potential to forage resources to optimize forage utilization and reproductive efficiency.

MILK PRODUCTION ON COW PERFORMANCE

Selection for increased milk production can result in beef cows under a greater nutritional stress in critical physiological periods and ultimately reduce reproductive performance (Dillon et al., 2006; Mulliniks et al., 2011a). Grazing dairy cows in New Zealand provide a good illustration of the effect of selection for milk production when exceeding the nutrient environment on cow performance. For instance, Macdonald et al. (2008) used 3 genetics strains consisting of (1) a 1970s strain of New Zealand Friesian with, at the time, high genetic potential for combined yield of fat and protein for 1975; (2) a 1990s strain of New Zealand origin and selected for high genetic potential of combined fat and protein yield; or (3) a conventional North American dairy system strain selected for high genetic potential of combined fat and protein. Across the 3 strains, feed allowances ranged from moderate feed restriction up to generous feeding (4.5 to 7.0 t of DM/cow per year) to determine the interaction of nutrient input and increasing genetic potential for milk. Cows from the North American dairy system strain, even at the greatest feed allowance, had shorter lactation lengths and reduced pregnancy rates, leading to decreased farm profitability, indicating the need to select for milking potential within a given environment.

With an increase in nutrient demand during lactation, cows often experience extended periods of negative energy balance after calving, which can have a deleterious effect on reproductive performance. Inadequate nutrient intake to meet production energy requirements can result in reduced reproductive performance (Randel, 1990). In a study conducted at the University of Tennessee (Edwards et al., 2017), 237 Angus-bred beef cows were milked with a milking machine at d 58 and 129 postpartum to determine the influence of milk production on cow-calf performance. Timed-AI pregnancy rates were the lowest in the high-milk-producing cows, with no difference between low- and moderate-milking cows. The decreased pregnancy rate after AI in high-milking cows continued through the breeding season, with high-milking cows having the lowest overall pregnancy rates. Even in environments where energy intake levels meet or exceed requirements, increased milk production can decrease reproductive efficiency in beef cattle. In agreement, Butler (2000) reported an inverse relationship between milk yield and fertility in dairy cows. This inverse relationship is due to increased demand of energy competing with nutrient demands for reproduction. The inverse relationship between milk and reproduction may be partially due to timing of peak lactation (~60 d postpartum) and start of the breeding season. However, Fiss and Wilton (1992) and Beal et al. (1990) reported no effect of milk production levels on reproductive performance in beef cows.

In limited nutrient environments, milk production potential may have a larger effect on reproductive performance than in more humid environments, due to increased periods of low-quality forage conditions. In the 1960s and 1970s, crossbreeding beef breeds and dairy breeds was used as a breeding strategy to increase productivity and weaning weight of offspring (Deutscher and Whiteman, 1971; Holloway et al., 1975; Wyatt et al., 1977). Holloway et al. (1975) and Wyatt et al. (1977) both indicated reproductive performance in Holstein and Holstein × Hereford cows decreased during periods of nutrient restrictions. However, high levels of supplementation to Holstein crossbreds and Holstein cows did result in adequate reproductive performance. In addition, the crossbred Holstein and purebred Holstein cows in the studies above with decreased reproductive performance had lower or similar milk production as reported by Edwards et al. (2017). These studies indicate continued selection for high genetic milk potential would require increased nutrient supply and may be more severely affected in nutrient-restricted environments.

Influence of milk production on young beef cows may have a larger effect on reproductive performance. Young beef cows are calving for the first or second time, supporting calf growth, and require additional nutrients for growth to reach their mature BW. These factors contribute to increased nutrient demand, resulting in young beef cows having extended days to resumption of estrus after calving (Bellows and Short, 1978) and lower pregnancy rates (Meek et al., 1999) compared with mature cows. With that in mind, the challenge to get young beef cows rebred is often the length of the postpartum interval (Wiltbank, 1970). In addition, young beef cows are more prone to decreased reproductive efficiency and metabolic disorders caused by the metabolic load of lactation (Mulliniks et al., 2013; Hobbs et al., 2017). Using milk production and resumption of estrus data from Mulliniks et al. (2011a), postpartum interval increased 5.5 d/kg of milk produced in 2- and 3-yr-old range cows ($P < 0.01$; $R^2 = 0.29$; Figure 1). In agreement, Boggs et al. (1980) and Bartle et al. (1984) illustrated resumption of estrus after calving increased 1.4 and 3.3 d/kg of milk produced, respectively. Increasing milk potential in the cow herd may not only affect timing of conception, as shown by Edwards et al. (2017), but also calf BW at weaning the following year due to a later calving date. Although not statistically significant, Mulliniks et al. (2013) showed a numerical decrease in milk production by 0.5 kg at peak lactation in young cows conceiving earlier in the breeding season compared with late breeding cows. Supplementation strategies during early lactation that allow for partitioning of nutrients away from milk production and toward reproduction could potentially increase cow longevity and ranch sustainability. For instance, Hunter and Magner (1988) found that supplementing formaldehyde-treated casein to 2-yr-old Brahman × Hereford cows resulted in decreased milk production, increased postpartum BW gain, and decreased postpartum interval after calving. Partitioning nutrients away from lactation or selecting beef cows with moderate milk potential may increase reproductive performance and longevity in the cowherd.

MILK PRODUCTION ON PROGENY PRE- AND POSTWEANING PERFORMANCE

Preweaning Calf Performance

Milk production has been shown to be an important trait affecting calf growth and profitability of a cow-calf enterprise. The effect of milk and calf gain has been shown to be greatest at peak lactation and to decline as DIM increases (Clutter and Nielsen, 1987). For instance, Bailey and Lawson (1981) estimated milk intake provided 86% of dietary energy for growth at 44 d of age and declined to 19% of the dietary energy by weaning. Ansotegui et al. (1991) reported milk production influenced calf growth up to 60 d postpartum, with no differences in calf ADG after peak lactation. In agreement, Edwards et al. (2017) reported calf d-58 BW was greater in calves from moderate- and high-milking cows compared with low-milking cows; however, calf BW at weaning was similar among milk production groups. The lack of increased calf growth with additional milk after d 60 in the studies by Edwards et al. (2017) and Hatfield et al. (1989) may be explained by differences in milk and forage intake and decreased efficiency of converting milk to calf gain in calves (Montano-Bermudez et al., 1990). In agreement, van Oijen et al. (1993) reported efficiency of converting nutrient intake to gain of progeny from moderate- or high-milk-production beef cows was approximately 3 to 4% lower at weaning than the offspring from low-milk-production cows.

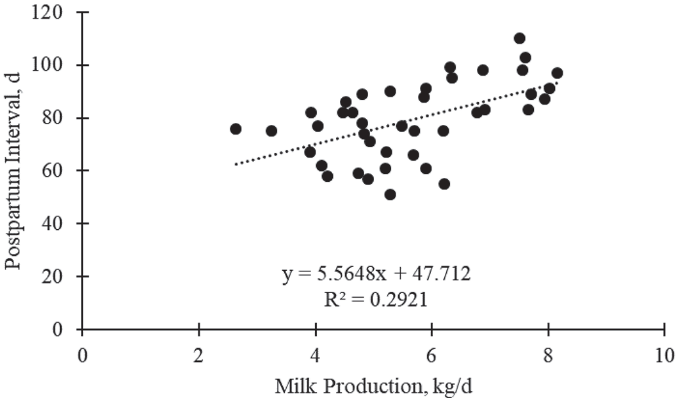

Figure 1. Influence of milk production on postpartum interval in young range cows grazing native range. Data taken from Mulliniks et al. (2011b). The linear slope ($P < 0.01$) and regression equation are shown.

Calf milk intake may influence forage utilization and rumen development. For instance, Lusby et al. (1976) reported milk consumption amount was negatively correlated with cellulose digestibility. In agreement, increased hay consumption has been associated with greater ruminal development in calves compared with calves consuming little to no hay (Otterby and Rust, 1965; Stobo et al., 1966). Forage or hay consumption stimulates rumen muscular development (Hamada et al., 1976), which insufficient rumen development can negatively affect nutrient digestion and absorption (Baldwin et al., 2004). Because the effect of milk consumption on calf growth declines as lactation progresses (Clutter and Nielsen, 1987), rumen development and forage digestibility may become more important for late-lactation and postweaning growth.

Influence of milk production on calf weaning weight has been shown to be highly variable, ranging from 20 to 60% (Robison et al., 1978). Lewis et al. (1990) reported the correlation between milk production and calf gain varied from 0 to 0.51. Using meta-analysis from 14 peer-reviewed papers, milk production had a positive linear effect ($P = 0.03$; $R^2 = 0.19$; Figure 2) on calf growth and weaning BW. Most the studies fall into 10 kg/d or less of milk production at peak lactation. If data points greater than 10.5 kg/d of milk production were excluded from the data set; the effect of milk production on calf weaning weight would not be significant ($P = 0.12$; $r^2 = 0.06$), illustrating the variation in response to milk production and the effect nonmilk influences have on calf growth and weaning BW. Minick et al. (2001) reported calf BW at weaning increased as age of dam increased; however, milk production was not different between 3-, 4-, and 5-yr-old cows. These authors concluded older cows provided something other than milk production to increase calf gain. Marshall and Long (1993) reported a low, positive residual correlation coefficient between milk yield and calf BW at weaning. However, the correlation between milk production and calf weaning weight decreases as nonmilk nutrient supply improves (Neville and McCullough, 1969). In nutrient-restricted environments, selection for increased milk potential may not be fully expressed due to limited nutrient supply by the forage system (Brown et al., 2005; Brown and Lalman, 2010). The dynamic changes in quantity and quality of forage produced in forage-based production systems can affect calf growth (Grings et al., 2008), which may explain the variation in responses of calf growth to increased dam milk production.

Postweaning Steer Performance

The majority of research on dam milk potential has been focused on the preweaning segment of the beef production system. However, due to different growth rates, potential compensatory gain, and maintenance requirements, selection of milk production may affect subsequent calf postweaning performance and feed efficiency. Davis et al. (1985) suggested increasing milk production would improve the efficiency of slaughter weight of progeny from low-milk-producing dams. In a simulated model, Bourdon and Brinks (1987) suggested high-milking cows were more favorable when feedlot costs were high but not during periods of high cow-calf production costs.

Reductions in preweaning gain by offspring from lower milking dams has been shown to capture efficiency through compensatory gain after weaning. Clutter and Nielsen (1987) reported the preweaning growth rate advantage for offspring of high-milking cows was decreased after weaning compared with offspring of low-milking cows. Mulliniks et al. (2018) reported offspring from low- and moderate-milking cows had increased BW gain and ADG during a 75-d preconditioning period compared with offspring of high-milking cows. Lewis et al. (1990) reported the increased steer BW advantage at weaning for offspring of high-milking cows was lost due to compensatory postweaning gain of the steers from low-milking cows. When estimated as output per unit of cow energy intake, offspring from lower-milking cows have been reported to be more efficient to weaning and through the feedlot (Montano-Bermudez and Nielsen, 1990). Similarly, this increased energy intake efficiency advantage to weaning has been reported to remain throughout the lifetime production of lower-milking cows (Davis et al., 1983a,b). In agreement, van Oijen et al. (1993) illustrated offspring from low-milk-yielding beef cows were approximately 7% greater in biological efficiency at slaughter than offspring from moderate- and high-milk-yield cows. Wang et al. (2009) reported increased milk production was associated with decreased backgrounding ADG. However, results from this study indicate the effect of milk production on calf postweaning performance may be dependent on both breed of sire and postweaning management of either drylot rations or grazing wheat pasture.

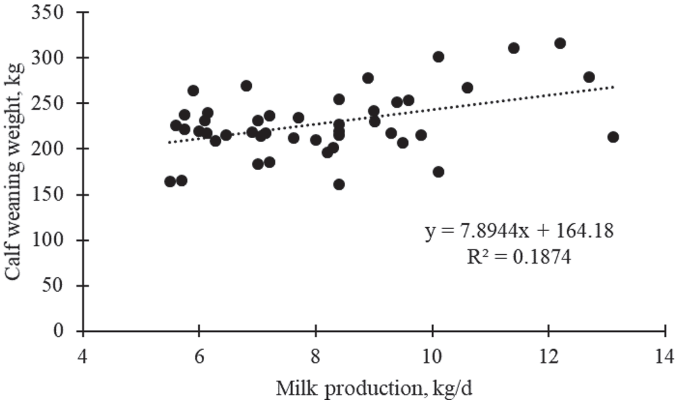

Figure 2. Influence of milk production on calf BW at weaning in 14 studies (Rutledge et al., 1971; Totusek et al., 1973; Wyatt et al., 1977; Hatfield et al., 1989; Lewis et al., 1990; Marston et al., 1992; Minick et al., 2001; Baker and Boyd, 2003; Grings et al., 2008; Mulliniks et al., 2011a; Harrelson, 2010; Rodrigues et al., 2014; Edwards et al., 2017; Springman et al., 2018). The linear slope ($P = 0.03$) and regression equation are shown.

With increased dam milk production, Lewis et al. (1990) reported a linear increase in daily feed intake and a decrease in feed efficiency during the feedlot finishing phase. In agreement, Mulliniks et al. (2018) reported increased DMI and decreased feed efficiency in steers from high-milk-producing dams during a 75-d backgrounding period. This increase in DMI and decrease in feed efficiency may be due to increased maintenance requirements (Ferrell and Jenkins, 1985). In contrast, Miller et al. (1999) reported no differences in postweaning DMI of progeny from different levels of milk production dams. With a lack of difference in DMI, Miller et al. (1999) concluded offspring from high-milk-producing cows were more energetically efficient than offspring from lower-milk-yielding cows.

Postweaning Heifer Progeny

Dam age and preweaning growth rate may play a significant role in the effect milk production has on future productivity of the suckling heifer calf. In general, milk production tends to peak at 5 yr of age and then decline after 8 yr of age (Robison et al., 1978). With that in mind, age of dam during lactation had been reported to affect suckling female progeny performance. Lubritz et al. (1989) indicated age of dam had subsequent effects on the milk production of heifer progeny. Cows born and reared by young cows had greater milk production and increased calf BW at weaning. These authors concluded mature, higher milking dams may be unfavorable for future cow performance of their female offspring due to increased preweaning growth and decreased subsequent milking ability. Increased preweaning growth in offspring of high-milk-producing cows can influence fat deposition in the udder and decrease subsequent milk production. Rapid growth rates of dairy and beef heifer calves have been shown to increase fat deposition within the udder and ultimately reduce milk production (Sejrsen et al., 1982). In addition, Mangus and Brinks (1971) suggested high preweaning nutrition levels would result in decreased subsequent cow productivity of the growing heifer. For instance, creep-fed beef heifers tended to produce less milk (Holloway and Totusek, 1973; Hixon et al., 1982). Similarly, creep feeding heifers had a negative effect on future productivity as a cow by decreasing number of calves weaned, calf birth weight, 120-d calf weight, 210-d calf weight, and lifetime productivity (Martin et al., 1981), which may have been due to increased fat deposition in the udder. In contrast, Buskirk et al. (1995) illustrated an increase in postweaning BW gain resulted in increased subsequent milk production as a first-calf heifer. Therefore, selection for increased genetic potential for milk production may result in offspring with high genetic potential but lower actual milking ability due to increased fat deposition in the udder.

Economics of Milk Production

As selection for milk production potential increases in beef cows, cow maintenance requirements during gestation and lactation have increased (Ferrell and Jenkins, 1984; Taylor et al., 1986; Montano-Bermudez et al., 1990), thus increasing production costs. Decreasing production costs has been shown to have a larger effect on cow-calf profitability than increasing production output through increased calf BW at weaning (Pendell and Herbel, 2018). Miller et al. (2001) analyzed financial and production information from standardized performance analysis cow-calf data from Illinois and Iowa. Selection for growth traits does play a role in profitability for cow-calf producers; however, calf BW at weaning only accounts for 5% of the variation in profitability for the cow-calf producers in a profit model (Miller et al., 2001). With feed costs accounting for 63% of the variation of annual cow cost, management and genetic selection strategies should be focused on decreasing high-input costs associated with high-maintenance-requirement beef cows.

The economic benefit of increased calf weaning BW due to increased milk production only holds true if the marginal cost to achieve the increased BW is less than the marginal revenue received from the increased BW. However, van Oijen et al. (1993) reported variation in energy input had greater contribution to differences in economic and biological efficiency outweighed differences in calf output. Biological and economic efficiency depends on the interaction between genetic potential and the environment, which would consist of availability and cost of feed resources. In a review paper, Mulliniks et al. (2015) illustrated the economic and production efficiency of milk production in 2 distinct environments and management goals in New Mexico and Tennessee. In the Tennessee data, selection for increased growth and milk production resulted a 5 kg/d increase in milk production at peak lactation and 18-kg increase in calf BW at weaning; however, the increase in production resulted in a $360/cow increase in annual cost of production and a decrease in pregnancy rates by 8 percentage points. Taking into account the cost of production difference and reproduction, increasing calf weaning weight with increased milk production in Tennessee decreased the economic and production efficiency of the production system. Therefore, the effect of increasing milk potential in beef herds is dependent on the cost and availability of high-quality feed resources while maintaining adequate reproductive performance within that management system.

APPLICATIONS

In forage-based beef systems, balancing environmental factors (e.g., forage quality and quantity) and cow requirements is the foundation for economic efficiency. Pinpointing the optimal level of milk production is challenging in livestock production due to differences in environment, management, annual cost of production, and market end point. However, the need for beef producers to match cow size and milk production potential to forage resources to optimize forage utilization and reproductive efficiency is still critical. In general, selecting for increased milk production does increase calf weaning weight; however, the response is highly variable across differing environments and environmental conditions. Continual increase in selection for milk production in beef cows in pursuit of increased calf weaning weight increases the nutritional stress in critical physiological periods, such as early lactation, and will ultimately reduce reproduction, increase production costs to maintain performance, or both. In addition, selection for high milk production may have a long-term negative effect on the milking ability and decreased postweaning feed efficiency of subsequent offspring.

ACKNOWLEDGMENTS

The authors thank Robert Ziegler (West Central Research and Extension Center, University of Nebraska–Lincoln) for editing this manuscript.

LITERATURE CITED

Ansotegui, R. P., K. M. Havstad, J. D. Wallace, and D. M. Hallford. 1991. Effects of milk intake on forage intake and performance of suckling range calves. J. Anim. Sci. 69:899–904. https://doi.org/10.2527/1991.693899x.

Bailey, C. B., and J. E. Lawson. 1981. Estimated water and forage intake in nursing beef calves. Can. J. Anim. Sci. 61:415–421. https://doi.org/10.4141/cjas81-049.

Baker, J. F., and M. E. Boyd. 2003. Evaluation of age of dam effects on maternal performance of multilactation daughters from high- and low-milk EPD sires at three locations in the southern United States. J. Anim. Sci. 81:1693–1699. https://doi.org/10.2527/2003.8171693x.

Baldwin, R. L., K. R. Mcleod, J. L. Klotz, and R. N. Heitmann. 2004. Rumen development, intestinal growth and hepatic metabolism in the pre- and postweaning ruminant. J. Dairy Sci. 87:E55–E65. https://doi.org/10.3168/jds.S0022-0302(04)70061-2.

Bartle, S. J., J. R. Males, and R. L. Preston. 1984. Effect of energy intake on the postpartum interval in beef cows and the adequacy of the cow's milk production for calf growth. J. Anim. Sci. 58:1068–1074. https://doi.org/10.2527/jas1984.5851068x.

Beal, W. E., D. R. Notter, and R. M. Akers. 1990. Techniques for estimation of milk yield in beef cows and relationships of milk yield to calf weight gain and postpartum reproduction. J. Anim. Sci. 68:937–943. https://doi.org/10.2527/1990.684937x.

Bellows, R. A., and R. E. Short. 1978. Effects of precalving feed level on birth weight, calving difficulty and subsequent fertility. J. Anim. Sci. 46:1522–1528. https://doi.org/10.2527/jas1978.4661522x.

Boggs, D. L., E. F. Smith, R. R. Schalles, B. E. Brent, L. R. Corah, and R. J. Pruitt. 1980. Effects of milk and forage intake on calf performance. J. Anim. Sci. 51:550–553. https://doi.org/10.2527/jas1980.513550x.

Bourdon, R. M., and J. S. Brinks. 1987. Simulated efficiency of range beef production. I. Growth and milk production. J. Anim. Sci. 65:943–955. https://doi.org/10.2527/jas1987.654943x.

Brown, M. A., S. W. Coleman, and D. L. Lalman. 2005. Relationship of sire expected progeny differences to milk yield in Brangus cows. J. Anim. Sci. 83:1194–1201. https://doi.org/10.2527/2005.8351194x.

Brown, M. A., and D. L. Lalman. 2010. Milk yield and quality in cows sired by different beef breeds. Prof. Anim. Sci. 26:393–397. https://doi.org/10.15232/S1080-7446(15)30620-3.

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. https://doi.org/10.2527/1995.734937x.

Butler, W. R. 2000. Nutritional interactions with reproductive performance in dairy cattle. Anim. Reprod. Sci. 60-61:449–457. https://doi.org/10.1016/S0378-4320(00)00076-2.

Clutter, A. C., and M. K. Nielsen. 1987. Effect of level of beef cow milk production on pre- and postweaning calf growth. J. Anim. Sci. 64:1313–1322. https://doi.org/10.2527/jas1987.6451313x.

Davis, M. E., J. J. Rutledge, L. V. Cundiff, and E. R. Hauser. 1983a. Life cycle efficiency of beef production: I. Cow efficiency ratios for progeny weaned. J. Anim. Sci. 57:832–851. https://doi.org/10.2527/jas1983.574832x.

Davis, M. E., J. J. Rutledge, L. V. Cundiff, and E. R. Hauser. 1983b. Life cycle efficiency of beef production: II. Relationship of cow efficiency ratios to traits of the dam and progeny weaned. J. Anim. Sci. 57:852–866. https://doi.org/10.2527/jas1983.574852x.

Davis, M. E., J. J. Rutledge, L. V. Cundiff, and E. R. Hauser. 1985. Life cycle efficiency of beef production. VI. Relationship of cow efficiency ratios for progeny slaughtered to growth, condition, fertility and milk production of the dam. J. Anim. Sci. 60:69–81. https://doi.org/10.2527/jas1985.60169x.

Deutscher, G. H., and J. V. Whiteman. 1971. Productivity as two-year-olds of Angus-Holstein crossbreds compared to Angus heifers under range conditions. J. Anim. Sci. 33:337–342. https://doi.org/10.2527/jas1971.332337x.

Dillon, P., D. P. Berry, R. D. Evans, F. Buckley, and B. Horan. 2006. Consequences of genetic selection for increased milk production in European seasonal pasture based systems of milk production. Livest. Sci. 99:141–158. https://doi.org/10.1016/j.livprodsci.2005.06.011.

Edwards, S. R., J. D. Hobbs, and J. T. Mulliniks. 2017. High milk production decreases cow-calf productivity within a highly available feed resource environment. Transl. Anim. Sci. 1:54–59. https://doi.org/10.2527/tas2016.0006.

Ferrell, C. L. 1988. Contribution of visceral organs to animal energy expenditures. J. Anim. Sci. 66(Suppl. 3):23–34.

Ferrell, C. L., and T. G. Jenkins. 1984. Energy utilization by mature, nonpregnant, nonlactating cows of different types. J. Anim. Sci. 58:234–243. https://doi.org/10.2527/jas1984.581234x.

Ferrell, C. L., and T. G. Jenkins. 1985. Cow type and the nutritional environment: Nutritional aspects. J. Anim. Sci. 61:725–741. https://doi.org/10.2527/jas1985.613725x.

Fiss, C. F., and J. W. Wilton. 1992. Contribution of breed, cow weight, and milk yield to the traits of heifers and cows in four beef breeding systems. J. Anim. Sci. 70:3686–3696. https://doi.org/10.2527/1992.70123686x.

Grings, E. E., A. J. Roberts, T. W. Geary, and M. D. MacNeil. 2008. Milk yield of primiparous beef cows from three calving systems and varied weaning ages. J. Anim. Sci. 86:768–779. https://doi.org/10.2527/jas.2007-0389.

Hamada, T., S. Maeda, and K. Kameoka. 1976. Factors influencing growth of rumen, liver, and other organs in kids weaned from milk replacers to solid foods. J. Dairy Sci. 59:1110–1118. https://doi.org/10.3168/jds.S0022-0302(76)84330-5.

Harrelson, F. W. 2010. Effects of winter supplementation strategy on beef cattle performance and metabolism as well as calf health and performance. PhD Diss. New Mexico State Univ., Las Cruces.

Hatfield, P. G., D. C. Clanton, K. M. Eskridge, and D. W. Sanson. 1989. Forage intake by lactating beef cows differing in potential for milk production. J. Anim. Sci. 67:3018–3027. https://doi.org/10.2527/jas1989.67113018x.

Hixon, D. L., G. C. Fahey Jr., D. J. Kesler, and A. L. Neumann. 1982. Effects of creep feeding and monensin on reproductive performance and lactation of beef heifers. J. Anim. Sci. 55:467–474. https://doi.org/10.2527/jas1982.553467x.

Hobbs, J. D., S. R. Edwards, E. R. Cope, Z. D. McFarlane, K. G. Pohler, and J. T. Mulliniks. 2017. Circulating beta-hydroxybutyrate concentration may be a predictive measurement for young cows that have a greater probability to conceive at a fixed-time artificial insemination. J. Anim. Sci. 95:1545–1552. https://doi.org/10.2527/jas.2016.1247.

Holloway, J. W., D. F. Stephens, J. V. Whiteman, and R. Totusek. 1975. Performance of 3-year-old Hereford, Hereford × Holstein and Holstein cows on range and in drylot. J. Anim. Sci. 40:114–125. https://doi.org/10.2527/jas1975.401114x.

Holloway, J. W., and R. Totusek. 1973. Relationship between preweaning nutritional management and subsequent performance of Angus and Hereford females through three calf crops. J. Anim. Sci. 37:807–812. https://doi.org/10.2527/jas1973.373807x.

Hunter, R. A., and T. Magner. 1988. The effect of supplements of formaldehyde-treated casein on the partitioning of nutrients between cow and calf in lactating *Bos indicus* × *Bos taurus* heifers fed a roughage diet. Aust. J. Agric. Res. 39:1151–1162. https://doi.org/10.1071/AR9881151.

Johnson, C. R., D. L. Lalman, M. A. Brown, L. A. Appeddu, D. S. Buchanan, and R. P. Wettemann. 2003. Influence of milk production potential on forage dry matter intake by multiparous and primiparous Brangus females. J. Anim. Sci. 81:1837–1846. https://doi.org/10.2527/2003.8171837x.

Kuehn, L. A., and M. Thallman. 2016. Across-breed EPD tables for the year 2016 adjusted to breed differences for birth year of 2014. Pages 127–154 in Beef Improve. Fed. Proc. Beef Improve. Fed., Verona, MS.

Lalman, D. L., C. E. Andresen, C. L. Goad, L. Kriese-Anderson, M. E. King, and K. G. Odde. 2019. Weaning weight trends in the US beef cattle industry. Appl. Anim. Sci. 35:57–65. https://doi.org/10.15232/aas.2018-01797.

Lewis, J. M., T. J. Klopfenstein, R. A. Stock, and M. K. Nielsen. 1990. Evaluation of intensive vs extensive systems of beef production and the effect of level of beef cow milk production on postweaning performance. J. Anim. Sci. 68:2517–2524. https://doi.org/10.2527/1990.6882517x.

Lubritz, D. L., K. Forrest, and O. W. Robison. 1989. Age of cow and age of dam effects on milk production of Hereford cows. J. Anim. Sci. 67:2544–2549. https://doi.org/10.2527/jas1989.67102544x.

Lusby, K. S., D. F. Stephens, and R. Totusek. 1976. Effects of milk intake by nursing calves on forage intake on range and creep intake and digestibility in drylot. J. Anim. Sci. 43:1066–1071. https://doi.org/10.2527/jas1976.4351066x.

Macdonald, K. A., G. A. Verkerk, B. S. Thorrold, J. E. Pryce, J. W. Penno, L. R. McNaughton, L. J. Burton, J. A. S. Lancaster, J. H. Williamson, and C. W. Holmes. 2008. A comparison of three strains of Holstein-Friesian grazed on pasture and managed under different feed allowances. J. Dairy Sci. 91:1693–1707. https://doi.org/10.3168/jds.2007-0441.

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. 32:17–25. https://doi.org/10.2527/jas1971.32117x.

Marshall, D. M., and M. B. Long. 1993. Relationship of beef sire expected progeny difference to maternal performance of cross-bred daughters. J. Anim. Sci. 71:2371–2374. https://doi.org/10.2527/1993.7192371x.

Marston, T. T., D. D. Simms, R. R. Schalles, K. O. Zoellner, L. C. Martin, and G. M. Fink. 1992. Relationship of milk production, milk expected progeny difference, and calf weaning weight in Angus and Simmental cow-calf pairs. J. Anim. Sci. 70:3304–3310. https://doi.org/10.2527/1992.70113304x.

Martin, T. G., R. P. Lemenager, G. Srinivasan, and R. Alenda. 1981. Creed feed as a factor influencing performance of cows and calves. J. Anim. Sci. 53:33–39. https://doi.org/10.2527/jas1981.53133x.

Meek, M. S., J. C. Whittier, N. L. Dalsted, F. A. Thrift, and T. L. Stanton. 1999. Estimation of net present value of beef females of various ages and the economic sensitivity of net present value to changes in production. Prof. Anim. Sci. 15:46–52. https://doi.org/10.15232/S1080-7446(15)31723-X.

Miller, A. J., D. B. Faulkner, R. K. Knipe, D. R. Strohbehn, D. F. Parrett, and L. L. Berger. 2001. Critical control points for profitability in the cow-calf enterprise. Prof. Anim. Sci. 17:295–302. https://doi.org/10.15232/S1080-7446(15)31643-0.

Miller, S. P., J. W. Wilton, and W. C. Pfeiffer. 1999. Effects of milk yield on biological efficiency and profit of beef production from birth to slaughter. J. Anim. Sci. 77:344–352. https://doi.org/10.2527/1999.772344x.

Minick, J. A., D. S. Buchanan, and S. D. Rupert. 2001. Milk production of crossbred daughters of high- and low-milk EPD Angus and Hereford bulls. J. Anim. Sci. 79:1386–1393. https://doi.org/10.2527/2001.7961386x.

Montaño-Bermudez, M., and M. K. Nielsen. 1990. Biological efficiency to weaning and to slaughter of crossbred beef cattle with different genetic potential for milk. J. Anim. Sci. 68:2297–2309. https://doi.org/10.2527/1990.6882297x.

Montaño-Bermudez, M., M. K. Nielsen, and G. H. Deutscher. 1990. Energy requirements for maintenance of crossbred beef cattle with different genetic potential for milk. J. Anim. Sci. 68:2279–2288. https://doi.org/10.2527/1990.6882279x.

Mulliniks, J. T., and D. C. Adams. 2019. Evaluation of lactation demands on nutrient balance in two calving seasons in range cows grazing Sandhills upland range. Pages 18–20in Univ. Nebraska Beef Report. Agric. Res. Dev., UNL Coop. Ext., Lincoln, NE.

Mulliniks, J. T., S. H. Cox, M. E. Kemp, R. L. Endecott, R. C. Waterman, D. M. VanLeeuwen, L. A. Torell, and M. K. Petersen. 2011a. Protein and glucogenic precursor supplementation: A nutritional strategy to increase reproductive and economic output. J. Anim. Sci. 89:3334–3343. https://doi.org/10.2527/jas.2010-3286.

Mulliniks, J. T., S. R. Edwards, J. D. Hobbs, Z. D. McFarlane, and E. R. Cope. 2018. Post-weaning feed efficiency decreased in progeny of higher milk yielding beef cows. Animal 12:275–279. https://doi.org/10.1017/S1751731117001458.

Mulliniks, J. T., M. E. Kemp, S. H. Cox, D. E. Hawkins, A. F. Cibils, D. M. VanLeeuwen, and M. K. Petersen. 2011b. The effect of increasing amount of glucogenic precursors on reproductive performance in young postpartum range cows. J. Anim. Sci. 89:2932–2943. https://doi.org/10.2527/jas.2010-3198.

Mulliniks, J. T., M. E. Kemp, R. L. Endecott, S. H. Cox, A. J. Roberts, R. C. Waterman, T. W. Geary, E. J. Scholljegerdes, and M. K. Petersen. 2013. Does β-hydroxybutyrate concentration influence conception date in young postpartum range beef cows? J. Anim. Sci. 91:2902–2909. https://doi.org/10.2527/jas.2012-6029.

Mulliniks, J. T., A. G. Rius, M. A. Edwards, S. R. Edwards, J. D. Hobbs, and R. L. G. Nave. 2015. Forages and Pasture Symposium: Improving efficiency of production in pasture- and range-based beef and dairy systems. J. Anim. Sci. 93:2609–2615. https://doi.org/10.2527/jas.2014-8595.

National Academies of Sciences, Engineering, and Medicine. 2016. Nutrient Requirements of Beef Cattle. 8th rev. ed. Natl. Acad. Press, Washington, DC. https://doi.org/10.17226/19014.

Neville, W. E., Jr., and M. E. McCullough. 1969. Calculated energy requirements of lactating and non-lactating Hereford cows. J. Anim. Sci. 29:823–829. https://doi.org/10.2527/jas1969.295823x.

Otterby, D. E., and J. W. Rust. 1965. Effects of age and diet on rumen and blood components of the young calf. J. Dairy Sci. 48:1716–1718. https://doi.org/10.3168/jds.S0022-0302(65)88560-5.

Pendell, D. L., and K. L. Herbel. 2018. Differences Between High-, Medium-, and Low-Profit Cow-Calf Producers: An Analysis of 2012–2016 Kansas Farm Management Association Cow-Calf Enterprise. Dept. Agric. Econ., Kansas State Univ., Manhattan.

Randel, R. D. 1990. Nutrition and postpartum rebreeding in cattle. J. Anim. Sci. 68:853–862. https://doi.org/10.2527/1990.683853x.

Robison, O. W., M. K. M. Yusuff, and E. U. Dillard. 1978. Milk production in Hereford cows I. means and correlations. J. Anim. Sci. 47:131–136. https://doi.org/10.2527/jas1978.471131x.

Rodrigues, P. F., L. M. Menezes, R. C. C. Azambuja, R. W. Suñé, I. D. Barbosa Silveira, and F. F. Cardoso. 2014. Milk yield and composition from Angus and Angus-cross beef cows raised in southern Brazil. J. Anim. Sci. 92:2668–2676. https://doi.org/10.2527/jas.2013-7055.

Rutledge, J. J., O. W. Robison, W. T. Ahlschwede, and J. E. Legates. 1971. Milk yield and its influence on 205-day weight of beef calves. J. Anim. Sci. 33:563–567. https://doi.org/10.2527/jas1971.333563x.

Sejrsen, K., J. T. Huber, H. A. Tucker, and R. M. Akers. 1982. Influence of nutrition on mammary development in pre- and postpubertal heifers. J. Dairy Sci. 65:793–800. https://doi.org/10.3168/jds.S0022-0302(82)82268-6.

Springman, S. A., D. C. Adams, J. D. Volesky, J. T. Mulliniks, and R. N. Funston. 2018. The Nebraska Ranch Practicum: An insight into cow and calf production from varying precipitation and two weaning dates. J. Anim. Sci. 96(Suppl. 2):205. https://doi.org/10.1093/jas/sky073.378. (Abstr.)

Stobo, I. J. F., J. H. B. Roy, and H. J. Gaston. 1966. Rumen development in the calf. 1. The effect of diets containing different proportions of concentrates to hay on rumen development. Br. J. Nutr. 20:171–188. https://doi.org/10.1079/BJN19660021.

Taylor, C. S., R. B. Thiessen, and J. Murray. 1986. Inter-breed relationship of maintenance efficiency to milk yield in cattle. Anim. Prod. 43:37–61. https://doi.org/10.1017/S0003356100018328.

Totusek, R., D. W. Arnett, G. L. Holland, and J. V. Whiteman. 1973. Relation of estimation method sampling interval and milk composition to milk yield of beef cows and calf gain. J. Anim. Sci. 37:153–158. https://doi.org/10.2527/jas1973.371153x.

Trenkle, A., and R. L. Willham. 1977. Beef production efficiency: The efficiency of beef production can be improved by applying knowledge of nutrition and breeding. Science 198:1009–1015. https://doi.org/10.1126/science.198.4321.1009.

van Oijen, M., M. Montaño-Bermudez, and M. K. Nielsen. 1993. Economical and biological efficiencies of beef cattle differing in level of milk production. J. Anim. Sci. 71:44–50. https://doi.org/10.2527/1993.71144x.

Wang, X. Z., M. A. Brown, F. Q. Gao, J. P. Wu, D. L. Lalman, and W. J. Liu. 2009. Relationships of milk production of beef cows to postweaning gain of the calves. Prof. Anim. Sci. 25:266–272. https://doi.org/10.15232/S1080-7446(15)30717-8.

Wiltbank, J. N. 1970. Research needs in beef cattle reproduction. J. Anim. Sci. 31:755–762. https://doi.org/10.2527/jas1970.314755x.

Wyatt, R. D., K. S. Lusby, J. V. Whiteman, M. B. Gould, and R. Totusek. 1977. Performance of 4- and 5-year-old Hereford, Hereford × Holstein and Holstein cows on range and in drylot. J. Anim. Sci. 45:1120–1130. https://doi.org/10.2527/jas1977.4551120x.