Replacement heifer development is a critically important area for veterinarians to offer production medicine advice to their beef-producing clients. Productivity for beef cattle herds has been shown to increase when a high percentage of heifers become pregnant early in the first breeding season, and economic return is enhanced when more primiparous heifers conceive for a second pregnancy as 2-year-olds [1,2]. Heifer development should result in most heifers in the replacement pool reaching puberty at least 42 days before the start of breeding because the percentage conceiving at first service is lower on the puberal estrus compared with the third estrus [3,4]. Putting additional pressure on heifers to reach puberty at a young age is the fact that many producers breed heifers 3 to 4 weeks earlier than the mature cow herd. The risk of calving difficulty is greater with heifers than with older cows; thus, breeding replacement heifers essentially one heat cycle earlier than the mature cows allows the producer to concentrate available labor on heifers at calving. In addition, the length of time from calving to the resumption of cycling is longer in heifers than in cows [5]. Therefore, calving heifers earlier than mature cows gives the heifers the extra time they need to return to estrus and be cycling at the start of the subsequent breeding season.

To calve at approximately 24 months of age and to reach puberty the equivalent of three heat cycles before the start of the mature cow breeding season, heifers must become puberal by 11 to 13 months of age. Once puberty is attained, nutrition must be at a level that allows the heifer to continue cycling, ovulate a viable oocyte, and establish pregnancy. Nutritional demands of heifers during pregnancy exceed that of mature cows because the heifer is partitioning nutrients for her own growth and fetal growth and development. This increased demand for nutrients continues through early lactation, when the beef female has her highest nutritional...
requirements. Deficiency of energy or protein for extended periods of time during any production phase during the first 2.5 years of life will have a negative impact on fetal development, calf viability, milk production, or re-breeding for the next pregnancy.

**Birth to weaning**

During the early preweaning phase (first 90 days of life), the heifer calf’s requirements are met primarily by her dam’s milk production, but starting early in life, forage plays a role in supplying nutrients for the calf. By the time a calf is 60 days of age, she is consuming 1.5% of her bodyweight as forage dry matter [6]. As the preweaning phase progresses, forage becomes an increasingly important nutrient source. As long as nutrient intake (milk and forage) is adequate for growth, no additional energy is needed in most heifer development systems. However, some investigators speculate that the nutritional plane during the first 2 to 3 months of life influences the timing of puberty and the effectiveness of later dietary manipulations to affect age at puberty [7]. Increased plane of nutrition early in life can be caused by superior forage quantity and quality or high dam milk production [7,8]. The use of creep feeding in replacement heifers should be avoided if the additional energy is used for fat deposition, most importantly into the udder parenchyma. Fat deposition in the udder of immature heifers has been shown to decrease lifetime milk production and offsprings’ weaning weights [9–14].

**Puberty**

Puberty in the beef heifer is reached when she is able to express estrous behavior and ovulate a fertile oocyte [15]. The maturing of the neuroendocrine system that induces maturation and ovulation of the first oocyte, and the hormonal changes that induce the first expression of behavioral estrus, are the result of a gradual increase in gonadotropic (luteinizing hormone [LH] and follicle stimulating hormone) activity. This increased gonadotropic activity near the time of puberty is caused by a decreased negative feedback of estradiol on the hypothalamic secretion of gonadotropin-releasing hormone [16–18]. As puberty approaches, the gradually increased frequency of LH pulses results in increased secretion of LH, which enhances development of ovarian follicles that produce enough estradiol to induce behavioral estrus and a preovulatory surge of gonadotropins [18]. Wave-like patterns of follicular development can be detected as early as 2 weeks of age in heifer calves, and the duration of follicular waves and the maximum diameter of dominant follicles increase with age through puberty [7,19,20].

The onset of puberty is influenced primarily by age and weight within breed [21–24]. Other factors that can also have some influence on the onset of puberty include exposure to bulls [25,26], time of year [27], and exposure to progestogens [28–31]. Age of puberty in other species such as humans and...
The latest edition of the National Research Council (NRC) *Nutrient Requirements of Beef Cattle* expresses protein requirements as absorbed protein, also known as metabolizable protein (MP) [53]. MP replaces the earlier use of crude protein (CP), and is defined as the true protein absorbed by the intestine, supplied by microbial cell protein and undegraded intake protein (UIP) [53]. The MP system accounts for the two components of protein nutrition of importance to the animal: the needs of ruminal
microorganisms and the needs of the beef animal. Lalman and colleagues [44] showed that feeding UIP in excess of NRC requirements may improve energy use of heifers fed mature forage, but may delay the onset of puberty compared with heifers fed monensin. Kane and colleagues [54] found that in cycling beef heifers supplemented with high levels of UIP, anterior pituitary gland synthesis, storage, and secretion of gonadotropins was decreased, and they suggested that these changes may impair follicular growth and development.

Fat supplementation of heifer diets is generally restricted to less than 5% of the total dry matter intake (DMI) because of potentially negative effects on fiber digestibility and DMI [55]. In a review of fat supplementation and its effect on beef female reproduction, Funston [56] reported that nutritionally challenged replacement heifers may experience reproductive benefits from fat supplementation, but there is limited benefit to fat supplementation in well-developed heifers.

Some researchers have reported that supplemental fatty acids had positive effects on ovarian function and reproductive performance that were independent of energy source [57,58]. In contrast, Howlett and colleagues [59] reported that adding oilseeds or soybean hulls to corn silage–based diets did not affect the reproductive performance of heifers. Lammoglia and colleagues [60] found that a high-fat diet fed for 162 days to beef heifers did not affect age at puberty, artificial insemination (AI) services per pregnancy, or final pregnancy percentage.

The fatty acid makeup of available fat sources varies. Linoleic acid is the primary fatty acid in grains and forages [58,61], whereas oleic acid is the primary fatty acid in rendered fats such as tallow and yellow grease [55,61]. The saturated fats palmitic and stearic acid are the primary fatty acids in calcium soaps and prilled fats [61]. Fishmeal contains a high percentage of the omega-3 fatty acids eicosapentaenoic acid and docosahexaenoic acid [62,63]. Regardless of the fatty acid makeup of dietary fats, once in the rumen a process called biohydrogenation changes the isomer orientation and reduces some double bonds of unsaturated fatty acids, so that the fatty acids leaving the rumen are substantially different than those consumed [62].

Fat supplementation will change the proportion of volatile fatty acids and some circulating hormone concentrations. The proportion of propionic acid and the propionate/acetate ratio is increased with fat supplementation [59,64]. Moreover, circulating concentrations of cholesterol and progesterone are increased with fat supplementation [61,64]. The effect of fat supplementation on prostaglandin F$_{2\alpha}$ (PGF$_{2\alpha}$) synthesis is not clear. The amount and type of fatty acids reaching target tissues likely influence whether PGF$_{2\alpha}$ synthesis is stimulated or inhibited [65]. Mattos and colleagues [62] concluded that although energy intake clearly influences LH secretion, a mechanism by which fatty acids per se affect LH secretion has not been established. A potentially negative consideration for feeding oilseed-based sources of fat is that phytoestrogens, which have been shown to affect reproduction in cattle negatively, can be present [66].
Typically, the major minerals that need to be supplemented in heifer diets are sodium, calcium, and phosphorus. Magnesium and potassium may also require supplementation under certain circumstances. Because salt is deficient in most natural feeds, it should be supplemented by including it with the concentrate portion of the diet or by feeding it free-choice. The level of salt needed in the diet can vary depending on the diet, type of cattle, and environmental conditions, but a general rule is to supply 0.25% to 0.5% of the diet on an as-fed basis (1–2 oz) per day.

Calcium metabolism and phosphorus metabolism are interrelated and complex. Controlling factors include vitamin D, parathyroid hormone, thyrocalcitonin, and the dietary levels of calcium and phosphorus. The absorption of calcium is regulated to a large extent by calcium intake: the higher the intake of calcium, the less that is absorbed [53]. The published dietary requirements for calcium are converted from the absolute requirements by an assumed absorption of 50% for the 1996 NRC and 68% for the Agricultural and Food Research Council [67]. The extent of dietary phosphorus absorption depends on phosphorus source, vitamin D intake, and intake of other minerals such as aluminum, manganese, and potassium in the diet. For calculating dietary requirements, NRC assumes 68% of ingested phosphorous is absorbed. Other researchers agree with this figure [68–71].

Cattle require 15 trace minerals. Of these, six (copper, cobalt, iodine, selenium, zinc, and manganese) are commonly deficient in forage-based diets [72]. Some researchers have reported positive reproductive effects associated with trace mineral supplementation, and others have not. Saxena and colleagues [73] found a correlation between serum copper and zinc concentrations and age at puberty in heifers. DiCostanzo and colleagues [74] reported improved first-service conception by heifers fed corn-silage diets supplemented with either manganese, or with a combination of manganese, copper, and zinc, compared with unsupplemented heifers. In contrast, others have failed to observe a response to trace mineral supplementation on reproductive performance in cattle [75–78].

Originally, ionophores were cleared for use to improve the feed efficiency of feedlot cattle on high-concentrate diets and to improve pasture cattle gains [79–81]. Inclusion of ionophores in heifer diets has been shown to increase the number of heifers that reach puberty by the start of the breeding season [82], decrease age at puberty [83–85], decrease weight at puberty [83], increase corpora luteal weight, and increase the amount of progesterone produced [86]. The decrease in age at puberty was independent of improved average daily gain and increased body weight.

Weaning to breeding

The 1996 NRC estimations of net energy and MP requirements for British-type heifers from weaning through early pregnancy should be used as a guideline in formulating rations for developing heifers. Adjustments
may need to be made to achieve the desired gains. Factors such as amount of activity required for grazing [53], environmental temperature [87], breed [88–90], and nutritional history [91,92] may decrease or increase requirements, when compared with the NRC estimates. Using NRC estimates of nutrient requirements with appropriate adjustment factors allows diets to be formulated to meet a desired target weight at specified intervals during development. If the target weight at a particular interval is not met, adjustments can be made so that the ultimate goal of a specified prebreeding target weight is achieved.

The target-weight concept is based on reports that *Bos taurus* heifers, such as Angus, Hereford, Charolais, or Limousin, are expected to reach puberty at about 60% of mature weight [93,94]. Dual-purpose breed heifers, such as Braunvieh, Gelbvieh, or Red Poll, tend to reach puberty at about 55% of mature weight, whereas *Bos indicus* heifers, most commonly Brahma or Brahman-cross, reach puberty at about 65% of mature weight [95–99]. In well-managed herds, opportunities may exist to lower heifer development costs by decreasing these traditional target breeding weights. Funston and Deutscher [100] found that spring-born composite heifers (MARC II: 25% Gelbvieh, 25% Simmental, 25% Angus, 25% Hereford) reaching 53% or 58% of mature body weight at breeding had similar reproduction and first-calf production traits. Similarly, Clark and colleagues [101] showed that MARC II heifers that were targeted to achieve 50% to 55% of mature body weight at first breeding had equal reproductive performance and superior economic performance, when compared with heifers targeted to achieve 65% of mature body weight.

Meeting, but not grossly exceeding, the target weight is important for heifer fertility and production. Developing heifers on a high plane of nutrition (both energy and protein) from weaning to breeding results in earlier puberty [21,23], improved udder development [102], and increased conception rates [43,103], compared with a low plane of nutrition. Short and Bellows [43] showed that the pregnancy percentage of heifers fed to gain 0.27 kg per day (0.6 lbs/day), 0.45 kg per day (1 lb/day), or 0.68 kg per day (1.5 lbs/day) from weaning to breeding was 50%, 86%, and 87% respectively, during a 60-day breeding season. Differences in pregnancy percentage were caused partially by differences in the pituitary function of heifers fed a low-energy versus a high-energy diet. Day and colleagues [46] found that heifers developed on a low-energy diet failed to exhibit increased LH pulse frequency at a time when heifers fed an adequate-energy diet exhibited normal LH pulse frequency and attained puberty.

Adequate gains during the weaning to breeding phase are also necessary for proper udder development and future milking ability. For heifers fed to gain 0.5 kg per day (1.1 lbs/day), 0.59 kg per day (1.3 lbs/day), or 0.64 kg per day (1.4 lbs/day) post-weaning, milk production increased with the rate of postweaning weight gain [8,104,105]. Conversely, overfeeding heifers before breeding has detrimental effects on pregnancy percentages [8,43,106]. Heifers that gained 0.45 kg to 0.68 kg per day (1–1.5 lbs/day) had higher
pregnancy percentages during a 45-day breeding season than heifers with gains above or below this range [107]. Likewise, first-service conception rates improved as body condition increased up to a score of 6. At body condition scores greater than 6, first-service conception rates decreased [107]. In addition, excessive supplemental feeding of beef heifers before puberty (ie, creep feeding) reduces lifetime milk production and lifetime calf weaning weights [14,108]. The impairment in milk production appears to occur in heifers that exceed energy intake needed for optimal preweaning gain and subsequently deposit fat in the udder.

Although hitting the target weight at the start of the breeding season is important for fertility and future productivity, weight gains do not need to be consistent throughout the weaning-to-breeding period. The timing of gain is not critical, as long as heifers reach the prebreeding body weight target [109,110]. Heifers may be fed to gain at a slow rate (ie, less than 1.25 lbs/day) for 100 to 115 days immediately following weaning, and subsequently fed to gain at a rapid rate (ie, greater than 2.5 lbs/day) for 45 to 60 days before breeding. Heifers fed in this manner reached the same body weight target at the same point in time as heifers fed to gain at a consistent rate (ie, 1.8 lbs/day) for the entire period (ie, 160 days) between weaning and breeding. When heifer weight gains are restricted for a time postweaning, maintenance energy costs are reduced. The net effect may be that less feed and less expense are required to bring the heifer to the prebreeding target weight [109,111]; however, the likelihood of such a savings probably depends on the length of the period of restricted gain [112,113].

**Breeding through midgestation**

The target-weight concept can also be used to plan nutritional requirements through pregnancy. Heifers should reach 80% to 85% of their mature weight by the time they first calve as 2-year-olds. Overfeeding protein (ie, CP > 18% of dietary dry matter [DM]) during the breeding season and during early gestation, particularly if ruminal energy supply is limited, has been associated with decreased fertility [114]. Abnormally low uterine pH can result when cows and heifers are fed high levels of degradable intake protein. When this occurs during the luteal phase of the estrus cycle, conception rates may decrease [114]. Occasionally, the reproductive performance of cows and heifers maintained on lush, cool-season pasture is below expectations. The combination of readily degradable protein and the low energy contents of early-growth, cool-season grasses may explain this phenomenon.

**Last 60 days of gestation**

The nutritional demands of pregnancy increase as gestation progresses. Nutritional requirements attributable to pregnancy per se include fetal
growth, uterine changes, and placental development. These requirements do not increase linearly as pregnancy progresses; rather, requirements increase logarithmically during the last trimester of gestation. Roughly 50% of fetal growth occurs during the last 35 days of pregnancy [115].

Calf birth weight increased progressively as the body condition score of heifers increased from four to six; however, dystocia score was not influenced by BCS at calving [116]. Greater body condition score (BCS) at calving resulted in more heifers in estrus and more heifers pregnant by 40 and 60 days of the subsequent breeding season; moreover, the rate of prepartum weight gain of heifers was positively associated with calf weaning weights [116]. Thin females should be fed to achieve a targeted body condition score of at least six at calving, whereas those in moderate-high to high-body condition should be fed levels to maintain body reserves.

When body weight or body condition loss occurred during the middle third of pregnancy, increased nutrient intake during the final third of pregnancy substantially improved subsequent pregnancy rate compared with cows that continued to lose weight and condition during the final third of pregnancy. In the same study, cows that maintained weight throughout the second half of pregnancy had higher pregnancy rates than those that lost weight, even though precalving BCS were similar between the two groups [117].

Most research clearly demonstrates that body condition at calving is a critical factor in postpartum fertility. Greater body condition scores or greater levels of supplemental energy during late gestation improved the percentage of cows showing estrus by 60 days postpartum and subsequent pregnancy rates [117,118]. Heifers that calved in poor body condition had lighter birthweight calves, a longer postpartum interval to return to estrus, and lower pregnancy rates during the following breeding season [116,117].

Early lactation

During the first 80 to 100 days after parturition, a heifer must continue to grow at about 0.23 kg per day (0.5 lbs/day), support lactation for a suckling calf, resume estrous activity, and conceive for a second pregnancy. The maintenance requirement for lactating heifers is about 20% greater than that of nonlactating heifers. Likewise, nutrient requirements to support lactation are affected greatly by milk production potential. In beef cattle, peak lactation occurs at approximately 60 days postpartum and peak milk yield has been reported to range from 4.1 kg per day to 13.6 kg per day (9–30 lbs/day) [53].

It is clear that energy and protein requirements postcalving greatly exceed that of midgestation heifers and even late gestation heifers. Undoubtedly, postcalving condition score and energy balance influence ovulation. Condition scores of six or greater are required for high conception rates in heifers; therefore, both body condition at calving and level of nutrition postpartum are critical control points affecting pregnancy rates [119,120]. Ciccioli and colleagues [40] showed that primiparous cows fed to gain more weight for
the first 71 days postpartum had a shorter interval to first postpartum estrus and ovulation, a larger dominant follicle at first estrus, and higher pregnancy percentage at first estrus, compared with cows fed to gain less weight. Conversely, Marston and colleagues [121] illustrated that heifers with adequate body condition at calving did not respond to postpartum supplementation of energy or protein.

The period of time between calving and rebreeding (ie, 80 days) is fairly short, and during that time cows and heifers experience their greatest nutritional demand because of lactation. The combination of these two factors makes it difficult for heifers and cows to gain weight or body condition during early lactation. Lalman and colleagues [122] found that feeding high-energy diets postpartum to thin primiparous cows reduced the negative effects of prepartum nutrient restriction, but did not reverse them completely. In that study, increasing dietary energy intake was associated with a curvilinear increase in milk yield and percentage milk fat, and a linear increase in energy available for milk production. Consequently, a high-energy diet, rather than a moderate- or low-energy diet, was necessary to improve the energy status of thin heifers [122].

For postpartum diets deficient in protein, additional dietary protein will increase intake and apparent dietary energy yield [123]. In addition, Wiley and colleagues [124] reported that UIP fed to primiparous 2-year-old beef cows in early lactation increased postpartum weight gains and increased the reproductive efficiency of those cows, regardless of prepartum nutrition. Dhuyvetter and colleagues [125] concluded that when adequate protein is provided to lactating mature beef cows for optimal rumen function, the addition of UIP decreases weight loss; however, they also reported that cows fed less UIP had a shorter postpartum anestrus period than cows fed more UIP. Other studies have supported the use of UIP to meet MP requirements in primiparous beef heifers in early lactation. Patterson and colleagues [2,126] reported that dietary supplementation with UIP added little benefit to heifer performance during gestation; however, weight gain was improved during lactation and pregnancy percentage was greater, compared with heifers fed to meet CP requirements. In contrast, Strauch and colleagues [127] reported that UIP supplementation did not affect body weight, body condition score, calf weight, milk production, or postpartum interval, when MP was adequate.

**Ration formulation and delivery**

Social interaction within beef herds dictates a lower status to smaller, younger animals such as replacement heifers. If harvested forage or supplements are fed to groups that contain mature cows and replacement heifers, the intake of heifers is affected negatively by the dominance displayed by mature cows. In addition, mature cows are able to consume 27% more alfalfa and 50% more brome hay per unit of metabolic body weight than 10-month-old heifers [128]. Improved forage use in cows seems to be
partially due to increased digestive function. Cows have a faster rate of in situ neutral detergent fiber degradation and apparent total tract neutral detergent fiber digestibility than heifers [128]. These constraints illustrate the need for greater-quality diets for heifers, compared with cows, and the need to feed heifers separately from cows.

Summary

The nutritional development of heifers from birth to the time they become pregnant with their second calf is a critical component of cowherd management. Veterinarians can use targeted body weights and condition scores to monitor progress and gauge future reproductive success throughout heifer development. Meeting NRC recommendations for net energy and MP is the single most successful strategy for maximizing reproductive performance from birth through the second pregnancy. Supplementation with fat, minerals, and additional UIP has not been consistently reported to enhance the reproductive function of heifers.

References


