Nutrition and reproduction interactions

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Introduction

Direct reproductive traits as they are currently measured tend to be low in heritability, making the beef female's environment key to reproductive success. Large cow size and high milk production translate into increased energy and protein requirements for the cow, even when not lactating. The increased nutrient requirements can significantly limit the carrying capacity of any farm or ranch. A cow's nutrient requirements must match feed resources or reproduction will be compromised.

Body Condition Score

Body condition score (BCS) is correlated with several reproductive events, such as postpartum interval, services per conception, calving interval, milk production, weaning weight, calving difficulty, and calf survival; which greatly affect net income in a cow-calf operation (Table 1).[25] The most important factor influencing pregnancy rate in beef cattle is body energy reserves at calving.[45] Body condition at calving is the single most important factor determining when beef heifers and cows will resume cycling after calving. Body condition score at calving also influences response to postpartum nutrient intake. Spitzer et al[41] fed primiparous cows differing in body condition (BCS 6 vs 4; 1 = emaciated, 9 = obese) to gain either 1.87 or 0.97 lb (0.85 or 0.44 kg)/day. The percentage of BCS 6 cows in estrus during the first 20 days postpartum increased from 40 to 85% when fed to the higher rate of gain, while the cows in BCS 4 only increased estrous response from 33 to 50% during the first 20 days postpartum when fed to gain at the higher rate. Cattle should have an optimum BCS of 5 to 6 at calving through breeding to assure optimal reproductive performance. Body condition score is generally a reflection of nutritional management; however, disease and parasitism can contribute to lower BCS even if apparent nutrient requirements are met.

Specific Nutrients and Reproduction

Feeding a balanced diet to beef females in the last trimester of pregnancy through the breeding season is critical. Nutritional demands increase greatly in late gestation, and even more in early lactation. Reproduction has low priority among partitioning of nutrients and consequently, cows in thin body condition often don't rebreed. Plane of nutrition the last 50 to 60 days before calving has a profound effect on postpartum interval (Table 2).[36] The importance of pre- and postpartum protein and energy level on reproductive performance has been consistently demonstrated (Table 2). Positive energy balance postpartum is essential for prompt rebreeding of heifers calving in thin condition (Table 3).[26]

Bearden and Fuquay summarized the effects of inadequate and excessive nutrients on reproductive efficiency (Table 4).

Protein and Energy

Inadequate daily energy intake is a primary cause of reduced cattle performance on forage diets. In many instances with warm-season perennial forages (and possibly with cool-season perennial forages at advanced stages of maturity), there is an inadequate supply of crude protein, which will limit energy intake.[33,35] An example of the relationship between crude protein content of forages and forage intake is presented in Figure 1. Dry matter intake declined rapidly as forage crude protein fell below 7%, a result attributed to a deficiency of nitrogen (protein) in the rumen, which decreased microbial activity. If forage contains less than approximately 7% crude protein, feeding a protein supplement generally improves the energy and protein status of cattle by improving forage intake and digestibility. For example (Figure 1), forage intake was about 1.6% of body weight when crude protein was 5%, while at 7% crude protein, forage intake was 44% higher and consumption was 2.3% of body weight.

Improved forage intake increases total dietary energy intake, and explains why a protein deficiency is usually corrected first when formulating a supplementation program for animals grazing poor quality forage. As suggested, when the crude protein content of forages drops below about 7%, forage intake declines. However, intake of other forages may decline when forage crude protein drops below 10%. Part of the variation is attributed to differences in nutrient requirements of the cattle, with the remainder of the variation attributed to inherent differences among forages presenting different proportions of nutrients to rumen microbes. Intake response to a single nutrient such as crude protein is not expected to be similar among all forages.[33]

Livestock producers are often concerned excessive dietary nutrients during the last trimester of pregnancy may negatively influence calf birth weights and dystocia. Selk summarized the effects of providing either

Table 1. Relationship of body condition score (BCS) to beef cow performance and income.[a]

BCS	Pregnancy rate, %	Calving interval, days	Calf ADG, lb	Calf WW, lb	Calf price, $/100 lb	$/cow exposed[b]
3	43	414	1.60	374	96	154
4	61	381	1.75	460	86	241
5	86	364	1.85	514	81	358
6	93	364	1.85	514	81	387

[a]Kunkle WE, Sands RS, Rae DO. Effect of body condition on productivity in beef cattle. In: Fields M, Sands R, eds. *Factors affecting calf crop*. Boca Raton: CRC Press, 1994;167-178.
[b]Income per calf x pregnancy rate.

Table 2. Effect of pre- or postpartum dietary energy or protein on pregnancy rates in cows and heifers.[a]

Nutrient and time	Adequate	Inadequate	
	Pregnant, %		Difference, %
Energy level pre-calving[b]	73	60	13
Energy level post-calving[c]	92	66	26
Protein level pre-calving[d]	80	55	25
Protein level post-calving[e]	90	69	21

[a]Randel RD. Nutrition and postpartum rebreeding in cattle. *J Anim Sci* 1990;68:853-862.
[b,c,d,e]Combined data from 2, 4, 9, and 10 studies, respectively.

Table 3. Influence of postpartum diet on weight change, body condition score (BCS) change, and postpartum interval (PPI).[a]

	Diet			
Item	Low	Maintenance	Maint/high	High
Post-calving weight, lb	835	822	826	821
BCS at calving	4.27	4.26	4.18	4.10
PPI, days	134	120	115	114
PPI wt change, lb	12	40	70	77
PPI BCS change	-.32	.37	1.24	1.50

[a]Lalman DL, Keisler DH, Williams JE, Scholljegerdes EJ, Mallett DM. Influence of postpartum weight and body condition change on duration of anestrus by undernourished suckled beef heifers. *J Anim Sci* 1997;75:2003-2008.

Table 4. Influence of inadequate and excessive dietary nutrient intake on reproduction in beef cattle.[a]

Nutrient consumption	Reproductive consequence
Excessive energy intake	Low conception, abortion, dystocia, retained placenta, reduced libido
Inadequate energy intake	Delayed puberty, suppressed estrus and ovulation, suppressed libido and spermatozoa production
Excessive protein intake	Low conception rate
Inadequate protein intake	Suppressed estrus, low conception, fetal reabsorption, premature parturition, weak offspring
Vitamin A deficiency	Impaired spermatogenesis, anestrus, low conception, abortion, weak offspring, retained placenta
Phosphorus deficiency	Anestrus, irregular estrus
Selenium deficiency	Retained placenta
Copper deficiency	Depressed reproduction, impaired immune system, impaired ovarian function
Zinc deficiency	Reduced spermatogenesis

[a]Bearden HJ, Fuquay JW. Nutritional management. In: Applied Animal Reproduction. Englewood Cliffs, NJ: Prentice Hall, 1992; 283-292.

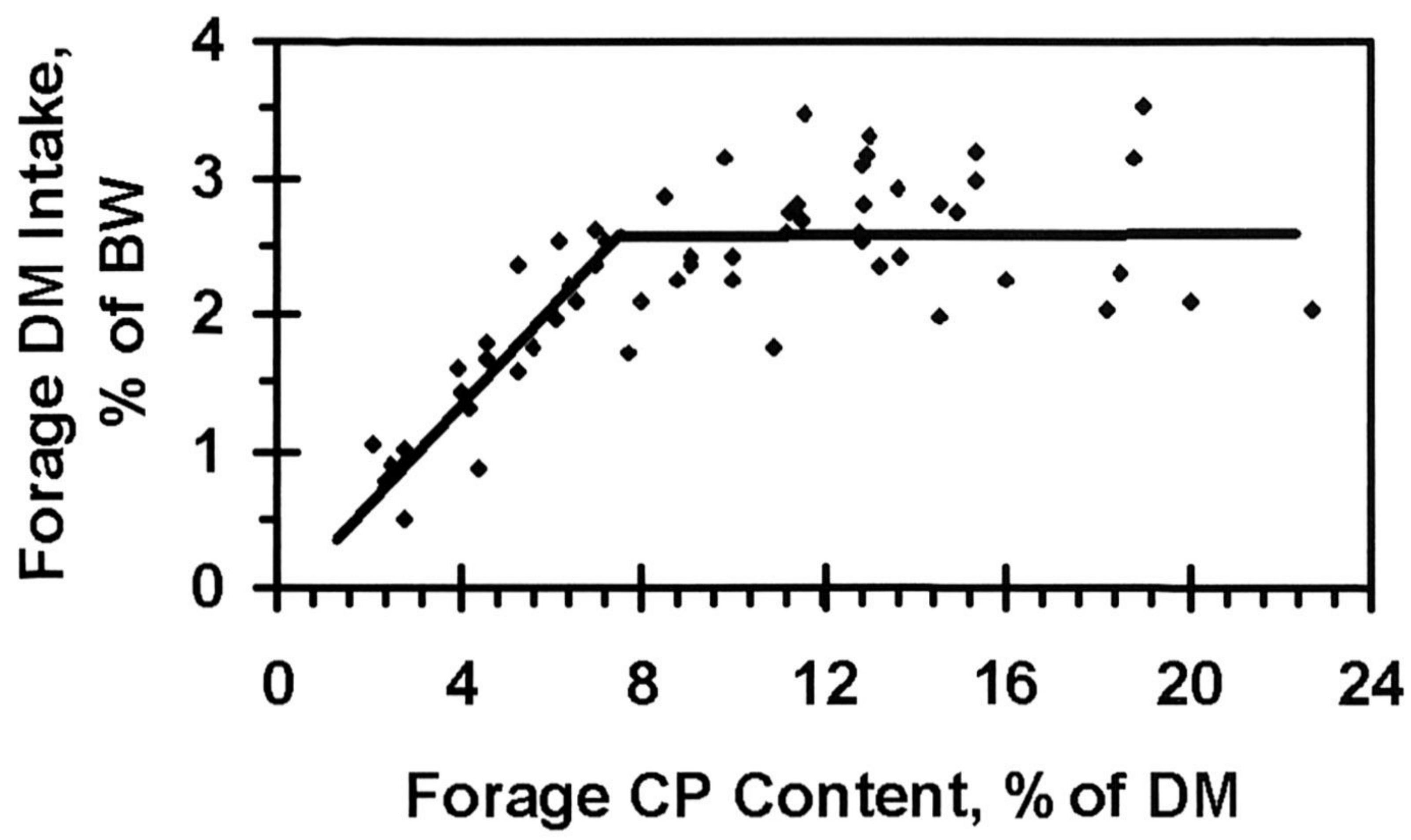

Figure 1. Effect of forage crude protein (CP) on dry matter (DM) intake.

adequate or inadequate amounts of dietary energy and protein on calving difficulty, reproductive performance, and calf growth. These summaries are presented in Tables 5 and 6.

Reducing energy pre-partum had virtually no effect on dystocia rates, even though birth weights were altered in some experiments. Of the 9 trials summarized, 7 indicated increased energy intakes during the last trimester of gestation did not increase calving difficulty.

In addition, producers are often concerned with levels of crude protein and possible effects on calf birth weight. Selk summarized studies conducted to specifically measure effects of varying protein intake to the prepartum beef female on calving difficulty (Table 6). Reducing dietary crude protein prepartum does not decrease calving difficulty and may compromise calf health and cow reproductive performance.

Excess Protein and Energy

Caution should be used with feeding excessive amounts of nutrients before or after calving. Not only is it costly, but animals with BCS >7 have lower reproductive performance and more calving difficulty than animals in moderate BCS 5 to 6. Excessive protein and energy can both have negative effects on reproduction. Overfeeding protein during the breeding season and early gestation, particularly if the rumen receives an inadequate supply of energy, may be associated with decreased fertility.[13] This decrease in fertility may result from decreased uterine pH during the luteal phase of the estrous cycle in cattle fed high levels of degradable protein. The combination of high levels of degradable protein and low energy concentrations in early-season grasses may contribute to lower fertility rates in females placed on such pastures near the time of breeding. Negative effects of excess rumen degradable intake protein on reproduction are well documented in dairy literature.[14]

Effects of supplementing feedstuffs high in undegradable intake protein (UIP) on reproduction are inconclusive and appear to be dependent on energy density of the diet.[20] Recent research[24] demonstrated negative effects on reproductive hormones when high (0.71 lb (0.32 kg)/day) levels of UIP were supplemented but not at low (0.25 lb (0.11 kg)/day) or moderate (0.48 lb (0.22 kg)/day) levels. Heifers fed additional UIP (0.55 lb (0.25 kg)/day) during development reached puberty at a later age and heavier weight, and had fewer serviced in the first 21 days of the breeding season. Fall pregnancy rate was not affected.[27] Further research is needed to elucidate potential mechanisms UIP may stimulate or inhibit reproductive processes and under what conditions.

Distillers grains are a co-product from the ethanol industry being utilized in beef cattle diets and are also high (65% of CP content) in UIP. A 2-year study was conducted at 2 locations to determine if supplementing beef heifers with dried distillers grains (DDG) as an energy source affected growth or reproduction.[31] Spring-born crossbred heifers (n = 316) were blocked by age or sire and age and assigned randomly to DDG or control (dried corn gluten feed, whole corn germ, urea) supplement. Heifers received prairie hay in amounts sufficient for ad libitum intake and 0.59% of BW DDG or 0.78% of BW control supplement (DM basis). Supplements were formulated to be isocaloric, but protein degradability differed. Supplemental UIP intake from DDG averaged 267 g/animal daily and reached 318 g/animal daily; control supplemental UIP intake averaged 90 g/animal daily and peaked at 107 g/animal daily. Initial pubertal status was determined by 2 blood samples collected 10 days apart, and monthly BW were collected from November through January; then biweekly BW and blood samples were collected from February until May yearly. Heifers were synchronized with 2 injections of $PGF_{2\alpha}$ 14 days apart; estrus was detected, and heifers were artificially inseminated for 5 days and placed with bulls 10 days later. Initial age, BW, and BCS did not differ for control and DDG heifers. Final BW, ADG, and final BCS also were not affected by supplementation. Estimated age and BW at puberty did not differ between treatments, and the proportions of pubertal heifers did not differ at the initiation of the experiment, at the beginning of the 14-day sampling intervals, or before synchronization. Estrus synchronization rate (75.9%), time of estrus, and overall pregnancy rate (89.5%) were not affected by treatment. However, a greater proportion of DDG than control heifers conceived to AI (75.0 vs 52.9%), resulting in greater AI pregnancy rates for DDG heifers (57.0 vs 40.1%). Body weight or BCS at pregnancy diagnosis did not differ between DDG and control heifers. Supplementing beef heifers with DDG during development did not affect age at puberty, but improved AI conception and

Table 5. Summary of studies on supplemental prepartum energy intake on calving difficulty, subsequent reproductive performance, and calf growth.[a]

Researcher	Supplementation[b]	Summary of effects
Christenson et al, 1967	HE vs LE for 140 d prepartum	HE increased birth wt, dystocia, milk, and estrus activity
Dunn et al, 1969	ME vs LE for 120 d prepartum	ME increased birth wt and dystocia
Bellows et al, 1972	HE vs LE for 82 d prepartum	HE increased birth wt but had no effect on dystocia or weaning wt
Laster & Gregory, 1973	HE vs ME vs LE for 90 d prepartum	HE increased birth wt but had no effect on dystocia
Laster, 1974	HE vs ME vs LE for 90 d prepartum	HE increased birth wt but had no effect on dystocia
Corah et al, 1975	ME vs LE for 100 d prepartum	ME increased birth wt, estrus activity, calf vigor and weaning wt but had no effect on dystocia
Bellows and Short, 1978	HE vs LE for 90 d prepartum	HE increased birth wt, estrus activity, pregnancy rate and decreased postpartum interval but had no effect on dystocia
Anderson et al, 1981	HE vs LE for 90 d prepartum	HE had no effect on birth wt, milk or weaning wt
Houghton et al, 1986	ME vs LE for 100 d prepartum	ME increased birth wt and weaning wt but had no effect on dystocia

[a]Selk GE. Nutrition and its' role in calving difficulty. 2000. Available at: www.ansi.okstate.edu/exten/cc-corner/nutritionanddystocia.html
[b]HE = high energy (over 100% NRC or National Research Council's recommended dietary need); ME = moderate energy (approximately 100% NRC); LE = low energy (under 100% NRC)

Table 6. Summary of studies on feeding supplemental protein during gestation on calving difficulty, subsequent reproductive performance and calf growth.[a]

Researcher	Supplementation[b]	Summary of effects
Wallace & Raleigh, 1967	HP[a] vs LP for 104 - 137 d prepartum	HP increased cow wt, birth wt and conception rate but decreased dystocia
Bond & Wiltbank, 1970	HP vs MP throughout gestation	HP had no effect on birth wt or calf survivability
Bellows et al, 1978	HP vs LP for 82 d prepartum	HP increased cow wt, cow ADG, birth wt, dystocia, weaning wt and decreased conception rate
Anthony et al, 1982	HP vs LP for 67 d prepartum	HP had no effect on birth wt, dystocia or postpartum interval
Bolze et al,1985	HP vs MP vs. LP for 112 d prepartum	HP had no effect on birth wt, dystocia, weaning wt, milk or conception rate but decreased the postpartum interval

[a]Selk GE. Nutrition and its' role in calving difficulty. 2000. Available at: www.ansi.okstate.edu/exten/cc-corner/nutritionanddystocia.html
[b]HP = high protein (over 100% NRC); MP = moderate protein (approximately 100% NRC); LP = low protein (under 100% NRC)

pregnancy rates compared with an isocaloric control supplement.

Shike et al[40] (and personal communication) also did not observe a negative effect on reproduction when distillers grains were fed to postpartum Simmental cows. One-hundred cows were fed postpartum diets containing either 13 lb (5.9 kg) corn gluten feed and 10 lb (4.5 kg) alfalfa or 12.26 lb (5.56 kg) dried distillers grains and 10 lb (4.5 kg) alfalfa (DM basis) until the beginning of the breeding season (approximately 74 d). Pregnancy rate to AI (60 vs 60.5% for corn gluten and distillers, respectively) and after a 45 day bull breeding (97.1 vs 90.7 for corn gluten feed and distillers, respectively; $P = 0.13$) period did not differ. Cows fed corn gluten feed lost more weight, had greater milk production, and greater calf average daily gain during the postpartum period. Milk urea nitrogen levels were above levels reported to negatively influence reproduction in other studies.[8] Differences may be due to energy balance and lactation potential.

Minerals

Minerals are important for all physiological processes in the beef animal including reproduction, so it is simply a matter of determining when they have to be supplemented in the basal diet.

Salt (NaCl) is the most important mineral a beef animal needs. Normally, sodium and chloride do not appear in feedstuffs in adequate amounts to meet animal requirements and should be provided free choice at all times.

Calcium is generally adequate in forage-based diets, but is often included in commercially available mineral supplements because many phosphorus sources also contain calcium. Much debate and research has been conducted on the effects of phosphorus supplementation on reproductive function. Phosphorus and crude protein content generally parallel each other in pasture or rangeland. Mature forages are generally deficient in phosphorus and impaired reproductive function has been associated with phosphorus deficient diets.[12,29] Diets should be evaluated for phosphorus content and supplemented accordingly. Caution should be used to not overfeed phosphorus–it is costly, of potential environmental concern, and does not positively influence reproduction in beef[12] or dairy[30] cattle.

Other macrominerals include magnesium, potassium, chlorine, and sulfur. Need for supplementation, as with the previously mentioned minerals, is dependent on content in the basal diet and water. Both deficiencies and excesses can contribute to suboptimal reproductive function.

Micro or trace minerals include copper, cobalt, iodine, iron, manganese, and zinc. Inadequate consumption of certain trace elements, combined with antagonistic effects of other elements, can reduce reproductive efficiency.[17]

Vitamins

Most of the vitamins (C, D, E, and B complex) are either synthesized by rumen microorganisms, synthesized by the body (vitamin C) or are available in common feeds and are not of concern under normal conditions. Vitamin A deficiency, however, does occur naturally in cattle grazing dry winter range or consuming low quality crop residues and forages.[29] The role of vitamin A in reproduction and embryo development has been reviewed by Clagett-Dame and Deluca.[9] Supplementation before and after calving can increase conception rates.[21]

Water

Water is more essential to life than any other nutrient. Feed intake is directly related to water intake. Water may also contribute significant macro and micronutrients that may benefit or impair production and reproduction. Contribution of these nutrients from water sources must be considered to accurately design a supplementation program.

Strategies to Enhance Reproduction

Ionophores

Lasalocid[a] and monensin[b] have been shown to influence reproductive performance during the postpartum period. Cows and heifers fed an ionophore exhibit a shorter postpartum interval provided adequate energy is supplied in the diet (Table 7). This effect appears to be more evident in less intensely managed herds with a moderate (60-85 d) or longer postpartum interval. Scientists have also demonstrated heifers fed an ionophore reach puberty at an earlier age and a lighter weight.[34]

Fat Supplementation

Inadequate dietary energy intake and poor body condition can negatively affect reproductive function. Supplemental lipids have been used to increase the energy density of the diet and avoid negative associative effects[10] sometimes experienced with cereal grains[6] in high roughage diets.

Supplemental lipids may also have direct positive effects on beef cattle reproduction independent of the energy contribution. Lipid supplementation has been shown to positively affect reproductive function in several important tissues including the hypothalamus, anterior pituitary, ovary, and uterus. The target tissue and reproductive response appears to be dependent upon the types of fatty acids contained in the fat source. Fat supplementation is a common practice in dairy cattle production, primarily to increase the energy density of the diet. Associated positive and negative effects on reproduction have been reported.[18,43]

Research with supplemental fat has been conducted on cows that have had 1 or more calves and replacement heifers. Fats have been fed before and after calving and during the breeding season. Several response variables have been examined, including body weight and BCS, age at puberty, postpartum interval, first service conception rates, pregnancy rates, calving interval, calving difficulty, and calf birth and weaning weight. To determine potential mechanisms of action, scientists have investigated changes in follicular and uterine development, hormonal profiles and changes, brain function, and embryonic development.

The effects of fat supplementation on reproduction in beef heifers and cows has recently been reviewed[15] and is summarized below.

Table 7. Effect of ionophore feeding on postpartum interval (PPI) in beef cows and heifers.[a]

Study	Ionophore (PPI, d)	Control (PPI, d)	Difference (d)
1	30	42	-12
2	59	69	-10
3	67	72	-5
4	65	86	-21
5	92	138	-46

[a]Randel RD. Nutrition and postpartum rebreeding in cattle. *J Anim Sci* 1990;68:853-862.

Fat Supplementation to Replacement Heifers. Studies are limited on the use of fat supplements in replacement heifer diets. In general, heifers in the studies cited were on a positive plane of nutrition and developed to optimum weight and age at breeding. There may have been a positive response to fat supplementation had heifers been nutritionally challenged. It appears from the studies cited that there is limited benefit of fat supplementation in well-developed replacement females, and is probably only warranted when supplements are priced comparable to other protein and energy sources.

Fat Supplementation Prepartum. Results from feeding supplemental fat prepartum are inconclusive. However, response to supplementation appears to be dependent on postpartum diet. Beef animals apparently have the ability to store certain fatty acids, supported by studies in which fat supplementation was discontinued at calving but resulted in a positive effect on reproduction. Postpartum diets containing significant levels of fatty acids may mask any beneficial effect of fat supplementation. There appears to be no benefit and in some cases, a negative effect of feeding supplemental fat postpartum, particularly when supplemental fat was also fed prepartum. Fat supplementation has been reported to both suppress and increase $PGF_{2\alpha}$ synthesis. When dietary fat is fed at high levels for extended periods of time, $PGF_{2\alpha}$ synthesis may be increased and compromise early embryo survival. Hess et al summarized research on supplementing fat during late gestation and concluded feeding fat to beef cows for approximately 60 days before calving may result in a 6.4% improvement in pregnancy rate in the upcoming breeding season.

Fat Supplementation Postpartum. Supplementing fat postpartum appears to be of limited benefit from studies reported here. Many of the studies reported approximately 5% fat in the diet supplemented with fat. It is not known if more or less fat would have elicited a different response (either positive or negative). If supplementing fat can either increase or decrease $PGF_{2\alpha}$ production, it seems reasonable the amount of fat supplemented might affect which response is elicited. Recent research[21] demonstrated a decrease in first service conception rates (50 vs 29%) when young beef cows were fed high linoleate safflower seeds (5% DMI) postpartum. The same laboratory has also reported[16] an increase in $PGF_{2\alpha}$ metabolite (PGFM) when high linoleate safflower seeds are fed postpartum, and a decrease in several hormones important for normal reproductive function.[37,38]

Feeding Considerations. The amount of supplemental fat needed to elicit a positive or, in some cases, a negative effect on reproductive function is largely unknown and titration studies are needed in all situations in which supplemental fat has been fed. Dose response studies indicate the amount of added plant oil necessary to maximize positive ovarian effects is not less than 4%.[42,44] Staples et al[43] indicated 3% added dietary fat (DM basis) has often positively influenced the reproductive status of the dairy cow. Lower levels of added dietary fat (2%) have also been shown to elicit a positive reproductive response,[4] and studies with fishmeal with less than 1% added fat[7] produced a positive reproductive response. This indicates both amount and types of fatty acids are important. Feeding of large quantities of fat (> 5% of total DMI) has not been recommended due to potential negative effects on fiber digestibility and reduction in DMI.[10] The duration and time (pre- or postpartum) of supplement feeding needed to elicit a positive response is not precisely known; many of the studies have supplemented fat at least 30 days. The period of supplementation has varied from different times before breeding in heifer development, pre-calving, post-calving, and/or pre-breeding periods. The young, growing cow appears to be the most likely to respond to supplemental nutrients. An appropriate situation for fat supplementation may be when pasture or range conditions are limiting or are likely to be limiting before and during the breeding season. Feeding supplemental fat to well-developed heifers or cows in adequate body condition on adequate pasture or range resources may not provide any benefit beyond energy contribution to the diet.

The majority of fat supplementation in beef cattle diets has been in the form of oilseeds added to a total mixed diet or fed as a supplement. A challenge has been making a supplement high in fat that can be pelleted or blocked and fed on the ground. Levels above 8% fat have resulted in pellets and blocks of poor quality and soft (Bellows, personal communication). Whole soybeans, sunflower, and cottonseeds have been fed without processing; it appears safflower seeds need to be processed to improve digestibility. Seeds should be processed (rolled) with enough pressure to crack about 90% of the seed hulls without extracting the oil.[28]

Additional Compounds in Oilseeds. Gossypol levels may be a concern when high levels of whole cottonseed are fed. However, levels of gossypol present in typically fed quantities of whole cottonseed for protein or fat supplementation provide only a fraction of the amount of gossypol fed in studies in which gossypol toxicity has been reported.[46] Other factors, such as phytoestrogens, may be present in some oilseeds (legumes in particular) and have been shown to negatively affect reproduction in cattle.[1] The precise effect of these factors and possibly others on reproductive function has not been fully elucidated, and is probably dependent on level of inclusion, basal diet, and stage of physiological maturity of the female being supplemented.

Recent studies feeding soybeans. Whole raw soybeans (SB), wet corn gluten feed (WCGF), and corn dried distillers grains (DDG) are available high-energy sources of protein in heifer development rations. Three studies were conducted[19] to compare puberty status before synchronization of estrus, response to synchronization, and AI and final pregnancy rates in heifers developed on diets similar in energy and CP containing SB and either WCGF or DDG. These ingredients vary substantially in fat content which may affect reproductive performance. Rate of gain during the feeding period and post-AI performance were also compared. In a preliminary experiment, 104 crossbred heifers were fed diets containing either 2.76 lb (1.25 kg) SB/day or 4.4 lb (2.0 kg) WCGF/day for 110 days (DM basis), beginning at 10 mo of age. In Exp. 1, 100 crossbred heifers received either 2.76 lb (1.25 kg) SB/day or 5.5 lb (2.49 kg) WCGF/day from approximately 7 to 10 mo of age (91 days), then were fed 2.76 lb (1.25 kg) SB/day for an additional 114 days (4 pens/diet). In Exp. 2, 2.76 lb (1.25 kg) SB/day or 2.76 lb (1.25 kg) DDG/day was fed to 100 crossbred heifers for 226 days, beginning at 6 mo of age (4 pens/diet). At approximately 13 mo of age, heifers were fed melengestrol acetate for 14 days followed by an injection of $PGF_{2\alpha}$ 19 days later to synchronize estrus. Heifers (14 mo of age) were artificially inseminated for 5 days after $PGF_{2\alpha}$, at which time treatments were ended. Heifers were then combined on native pasture and exposed to bulls for approximately 60 days beginning 10 days after the last day of AI. Pregnancy to AI was determined by ultrasound 45 days after the last day of AI. Heifers fed SB in the preliminary experiment had a lower synchronization rate (81 vs 96%) and longer interval from $PGF_{2\alpha}$ to estrus (76.6 vs 69.2 hours) compared to heifers fed WCGF. In Exp. 1, the age heifers were started on SB diets did not alter synchronization rate (79%) or timing of estrus after $PGF_{2\alpha}$ (77.8 hours). In Exp. 2, synchronization rate (86%) and timing of estrus after $PGF_{2\alpha}$ (69.3 hours) did not differ due to diet. There were no differences due to diet for AI conception rates (overall mean for each experiment: 76.5, 60, and 68.5%), percent of all heifers becoming pregnant to AI (67, 46, and 59%), or final pregnancy rates (92, 90, and 90%) in the preliminary experiment, Exp. 1, or Exp. 2, respectively. In summary, SB, DDG and WCGF can be used as high energy sources of protein in heifer development diets at the inclusion rates used in these studies.

Howlett et al also fed whole soybeans, whole cottonseed, or pelleted soybean hulls for 112 days in a total mixed diet to replacement heifers. Soybeans and cottonseeds contributed approximately 2% added fat to the diet. Heifers were synchronized with MGA/$PGF_{2\alpha}$, and experimental diets were discontinued approximately 1 week before the first MGA feeding. Treatment did not affect the proportion of heifers pubertal before beginning MGA feeding. First service conception rates were also not affected by treatment. However, there was a 20% increase ($P = 0.27$) in first service conception rates in the soybean fed group (57%) compared to controls (37%). In this study, 96 heifers were split into 3 treatments and a control group. Neither estrous response nor time of estrus was reported.

Five hundred-sixty Angus x Simmental cows were utilized to evaluate the effects of supplemental fat on performance, lactation, and reproduction.[40] Cows were fed 1 of 4 dietary supplements: whole raw soybeans, flaxseed, tallow, and corn-soybean meal (control). Flaxseed and tallow were added to the control supplement to provide similar fat levels as supplied by whole soybeans. Supplements (4 lb (1.8 kg)/day) were fed for 105 days after calving and ended at breeding. Cows grazed endophyte infected tall fescue and red and white clover pastures. There were no differences in cow or calf ADG or milk production. Soybean supplemented cows had greater milk fat and milk urea nitrogen than flaxseed supplemented cows. There were no differences in AI conception rates. However, conception rates to bulls were lower in cows fed soybeans (65%) compared to flaxseed (79%) or tallow (76%). Overall pregnancy rates were lower in cows fed soybeans (83%), compared to cows fed flaxseed (91%) or tallow (89%). Flaxseed, tallow, and control supplements were isonitrogenous, but apparently not the soybean supplement. It is not clear why there would be a reduction in bull, but not AI, pregnancy rates. Apparently protein levels were higher in the soybean supplement as demonstrated by higher milk urea nitrogen levels. Overall dietary protein may have been in excess throughout the supplementation period, depending on forage quality. Artificial insemination pregnancy rates were also apparently quite low. Cessation of supplement feeding may have actually benefited reproduction. This also appears to be a high supplementation rate of soybeans. Compounding this apparent problem may have been endophyte from tall fescue and phytoestrogens from clover.[1]

Summary of Fat Supplementation. Currently, research is inconclusive on exactly how to supplement fat to improve reproductive performance beyond energy contribution. Most studies have tried to achieve isocaloric and isonitrogenous diets. However, this can be challenging. Some studies only have sufficient animal numbers to detect very large differences in reproductive parameters, such as conception and pregnancy rate. Research on feeding supplemental fat has resulted in varied and inconsistent results as it relates to reproductive efficiency including positive, negative, and no apparent effect.

Elucidating mechanisms of action of how supplemental fat can influence reproductive function has been a difficult process. Animal response appears to be dependent on body condition score, age (parity), nutrients available in the basal diet, and type of fat supplement. The complexity of the reproductive system and makeup of fat supplements are often confounded by management conditions and forage quality both in research and in commercial feeding situations. This has contributed to inconsistencies in research findings.

Improvements in reproduction reported in some studies may be a result of added energy in the diet or direct effects of specific fatty acids on reproductive processes. As is the case for any technology or management strategy that improves specific aspects of ovarian physiology and cyclic activity, actual improvements in pregnancy rates, weaned calf crop, or total weight of calf produced are dependent on an array of interactive management practices and environmental conditions. Until these interrelationships are better understood, producers are advised to strive for low cost and balanced rations. If a source of supplemental fat can be added with little or no change in the ration cost, producers would be advised to do so. Research investigating the role of fat supplementation on reproductive responses has been variable. Therefore, adding fat when significantly increasing ration cost would be advised when the risk of low reproduction is greatest. Postpartum fat supplementation appears to be of limited benefit, and adding a fat source high in linoleic acid postpartum may actually have a negative effect on reproduction.

Maternal nutrition and postnatal development. Fetal programming is the concept maternal stimuli during fetal development influence the physiology of the fetus and postnatal growth and health.[2] Limited data exists concerning the influence of late-gestation nutrition of ruminants on reproductive performance of their female progeny. Primiparous heifers restricted to 65% of the NRC recommended energy intake during the final 100 days of pregnancy had calves with lighter birth weights and a reduced weaning percentage compared with heifers fed at NRC recommendations. Age at puberty of heifer calves from energy restricted primiparous dams was increased by 19 days, but pregnancy rate of the heifer calves was not measured.[11] Energy restriction of ewes for 10 days during late gestation resulted in altered adrenal steroid production in adult female progeny.[5]

A 3-year study was conducted with heifers (n = 170) whose dams were used in a 2 × 2 factorial arrangement of treatments to determine the effects of late gestation (LG) or early lactation (EL) dam nutrition on subsequent heifer growth and reproduction.[32] In LG, cows received 1 lb (0.45 kg)/day of a 42% CP supplement (PS) or no supplement (NS) while grazing dormant Sandhills range. During EL, cows from each late gestational treatment were fed cool-season grass hay or grazed subirrigated meadow. Cows were managed as a single herd for the remainder of the year. Birth date and birth weight of heifer calves were not affected by dam nutrition. Meadow grazing and PS increased heifer 205-day BW vs feeding hay and NS, respectively. Weight at prebreeding and pregnancy diagnosis were greater for heifers from PS dams, but were unaffected by EL nutrition. There was no effect of LG or EL dam nutrition on age at puberty or the percentage of heifers cycling before breeding. There was no difference in pregnancy rates due to EL treatment. Pregnancy rates were greater for heifers from PS dams, and a greater proportion of heifers from PS dams calved in the first 21 days of the heifers' first calving season. Dam nutrition did not influence heifers' average calving date, calving difficulty, and calf birth weight during the initial calving season. Weight at the beginning of the second breeding season was greater for heifers from PS dams, but was not affected by maternal nutrition during EL. Dam nutrition did not affect heifer ADG or G:F ratio. Heifers from PS dams had greater DMI and residual feed intake than heifers from NS cows if their dams were fed hay during EL, but not if their dams grazed meadows. Heifers born to PS cows were heavier at weaning, prebreeding, first pregnancy diagnosis, and before their second breeding season. Heifers from cows grazing meadows during EL were heavier at weaning, but not postweaning. Despite similar ages at puberty and similar proportions of heifers cycling before the breeding season, a greater proportion of heifers from PS dams calved in the first 21 days of the heifers' first calving season, and pregnancy rates were greater compared with heifers from NS dams. Collectively, these results provide evidence of a fetal programming effect on heifer postweaning BW and fertility.

Conclusions

Nutrition has a profound effect on reproductive potential in all living species. Body condition is a useful indicator of nutritional status, and when used in conjunction with body weight change can provide a useful method to assess reproductive potential. Energy and protein are the nutrients required in the greatest amounts and should be first priority in developing nutritional programs to optimize reproduction. Minerals and vitamins must be balanced in the diet to optimize reproductive performance. Consider water quantity and quality when balancing diets. Caution should be taken not to overfeed nutrients or reproductive processes may be adversely affected. No magic feed ingredient exists that will compensate for a diet greatly deficient in any of the mentioned nutrients or poor BCS. Nutritional considerations and impacts on reproduction have primarily focused on postnatal development; however, prenatal nutrition appears to have potential effects on subsequent reproductive performance in beef cattle.

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