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Effects of nutrition on reproduction- A review

Yugal Raj Bindari[1], Sulochana Shrestha[1], Nabaraj Shrestha[1] and Tara Nath Gaire[2]

[1]*Himalayan College of Agricultural Sciences and Technology (HICAST), Gatthaghar-15, Bhaktapur, Nepal*
[2]*Veterinary Officer, DLSO (Parbat), Nepal*

ABSTRACT

Nutrition plays a major role on enhancing reproductive efficiency in all animals. Energy and protein are the major nutrients required in the greatest amounts and should be in the topmost priority in order to optimize reproduction in dairy cattle. Minerals and vitamins also cannot be neglected and must be balanced in the diet. In the other hand, the nutrient should not be over-fed as this may also impairs the reproduction. This article generally focused on the effect of various nutrients on reproductive efficiency of dairy cattle. Furthermore, article also describes the negative effects of nutrition when they are over fed.

Keywords: Nutrition, Reproduction

INTRODUCTION

The relationship between nutrition and reproduction is a topic of increasing importance and concern among dairy producers, veterinarians, feed dealers and extension workers. The interaction between nutrition and reproduction has long been known to have important implications for the reproductive performance [45]. Under nutrition results in the loss of body weight and body condition, delays the onset of puberty, increases the post-partum interval to conception, interferes with normal ovarian cyclicity by decreasing gonadotropin secretion and increases infertility [6,5]. A more complete understanding of how and when nutrition affects reproduction may provide an alternative approach to managing reproduction in commercial systems that do not depend on the use of exogenous hormones [35].

NUTRITIONAL FACTORS AFFECTING REPRODUCTION

Energy

Insufficient intake of energy, protein, vitamins, and micro- and/or macro-minerals has all been associated with sub-optimal reproductive performance. Of these nutritional effects on reproduction, energy balance is probably the single most important nutritional factor related to poor reproductive function in animals [36, 37]. Short and Adams prioritized the metabolic use of available energy in ruminants ranking each physiological state in order of importance, as follows: 1) basal metabolism, 2) activity, 3) growth, 4) energy reserves, 5) pregnancy, 6) lactation, 7) additional energy reserves, 8) estrous cycles and initiation of pregnancy, and 9) excess energy reserves [40]. Based on this list of metabolic priorities for energy, reproductive function is compromised because available energy is directed towards meeting minimum energy reserves and milk production. Restricting energy intake during late gestation increases the length of postpartum anestrous [3] and reduces subsequent pregnancy rate. The impact of insufficient energy intake during late gestation cannot be overcome by increasing energy intake postpartum [38].

The impact of a short-term increase in energy intake (flushing) on the numbers of cows cycling or pregnancy rate may be dependent on the previous nutritional status of the cow. Reduction of energy demands by short-term (48 hour) calf removal combined with flushing can reduce days to estrus and improve conception rates [31].

Excessive energy intake during late lactation and the dry period can cause "fat cow" problems which lower reproductive efficiency in the next lactation. When heifers are fed inadequate amounts of energy, they reach sexual maturity later [22,26]. If energy deficient rations are fed to heifers that have begun to have normal estrous cycles, they may stop cycling. An example is heifers fed diets composed mainly of poor quality hay. They often will not show signs of estrus during late winter. If grain is provided, or they are put on good pasture, normal estrous cycle activity will resume as they begin to consume adequate amounts of energy [41]. Caution should be used with feeding excessive amounts of nutrients before or after calving. Not only is it costly, but animals with excess body condition (BCS >7) have lower reproductive performance and more calving difficulty than animals in moderate body condition (BCS 5-6) [13]. Excessive energy intakes during the late lactation and dry periods can lead to "fat cow" problems. Cows that are over-conditioned when they calve have a higher incidence of retained placenta, more uterine infections and more cystic ovaries. They also have a higher incidence of metabolic disorders and have a greater tendency to go off feed. All of these problems can result in poor reproductive performance [13].

High feed intake

↓

High blood flow to digestive tract

↓

High blood flow to the liver

↓

Estrogen and progesterone removed from liver

↓

Low estrogen and progesterone level in the blood

↓

Changes in reproduction

- Decreased duration of estrus (Standing heat)
- Increased double ovulation rate (Increased twining)
- Decreased conception rate
- Increased Pregnancy loss

Figure 1 Schematic representation of the potential physiological pathway that may produce the changes observed in high-producing lactating dairy cows [51].

Protein

The effect of dietary protein on reproduction is complex [48]. Prolonged inadequate protein intake has been reported to reduce reproductive performance. More recently it has been found that reproductive performance may be impaired if protein is fed in amounts that greatly exceed the cow's requirements.

Over-feeding of DIP either as protein or urea has been associated with decreased pregnancy rates in female dairy and beef cattle [4,45]. It appears that exposure to high levels of ammonia or urea may impair maturation of oocyte and subsequent fertilization or maturation of developing embryos. However, supplying adequate energy for excretion of excess ammonia or urea may prevent decreases in fertility in dry cows or heifers [14]. In addition, not all studies have observed negative effects of elevated BUN concentrations on embryo quality or pregnancy rates [24]. 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 [12]. 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.

Research at Oregon State University and in Israel indicated that cows fed excess protein (more than 10-15% above requirements) required more services per conception and had longer calving intervals. Other research has not indicated a harmful effect of feeding high levels of protein. Thus, it appears that excessive protein might be harmful in some situations, but not in others. Some of the following effects have been demonstrated to explain the poor reproduction sometimes observed with excessive levels of protein in the diet:

- High levels of blood urea may occur, which has a toxic effect on the sperm, the ova, and the developing embryo.
- The balance of hormones may be altered—progesterone levels are low when the blood contains high levels of urea.
- In the early lactating cow, high levels of protein may exacerbate the negative energy balance and delay the return of normal ovarian function [48].

Because forages, especially pasture, contain mostly DIP, there has been interest in the use of undegradable intake protein (UIP) or rumen by-pass protein to enhance beef production. Missouri researchers reported that addition of 0.2 lbs. of blood meal increased average daily gains in stocker steers. Work with gestating or early lactating cows indicates that addition of rumen by-pass protein usually decreases weight loss, slightly increases weight gain, enhances milk production, and alters blood metabolites. Lactation and body weight effects of UIP in postpartum cows may be dependent on amount of UIP added to the diet, parity, and/or protein content of the forage [32].

However, regardless of a possible effect on reproductive performance, overfeeding protein should be discouraged simply on an economic basis. It is costly and wasteful. Urea is added to some dairy rations as a source of nitrogen which the rumen bacteria can convert into protein. Feeding protein and urea, such that early lactating cows have a diet containing 16% protein and late lactating cows have a diet containing 12% protein, should optimize the fertility of the cows [48]. Extensive research has shown that reproduction is not affected when urea is fed at recommended levels [41].

Fats

The impact of fats on reproduction in cattle is a focus of considerable research [13, 19]. Because fatty acids and cholesterol are substrates for hormone synthesis, increasing fat in the diet may increase levels of reproductive hormones (progesterone, prostaglandins) or fats may act directly on the reproductive axis. Therefore, the effects of fat may be independent of or additive to those of increased energy availability. Cattle diets usually contain less than 2 or 3% fat. Supplementing fat to improve reproduction was initially attempted to increase the energy density in the diet. High fat diets for cattle contain 5% to 8 % fat. Exceeding these dietary fat levels impairs rumen function. Lactating cows are the primary animals to be supplemented because of their increased energy requirements, and the difficulty involved with getting these cows rebred. It is important to note that in all the studies discussed in this section, fat –fed animals and control animals were receiving the same amount of energy. Early studies [45, 50] indicated that feeding high fat diets to cycling heifers and postpartum cows increased progesterone production and the lifespan of the corpus luteum (CL). Higher progesterone levels during the luteal phase generally result in improved fertility. Increasing dietary fat also results in increased follicular growth. More small and medium follicles are present in cows and heifers fed high fat diets [47,37,26]. In addition, this increased follicular growth is often accompanied by increased estrogen and/or progesterone production. These changes in follicular growth and hormone production may enhance reproduction[19,47,52].

Minerals

Minerals are important for all physiological processes in animals including reproduction [13]. Mineral deficiencies and imbalances are often cited as causes of poor reproduction. It is clear that adequate amounts of minerals must be provided, but little is known about the effects of marginal deficiencies and imbalances. The same is true of excessive intakes of minerals which may indeed be harmful. Producers should avoid overfeeding minerals. If a little bit is enough, twice as much will not be better and may in fact cause problems [41].

An important concept surrounding macromineral balance is dietary cation-anion difference (DCAD). DCAD measures the level of four macrominerals: sodium and potassium, which are cations and carry a positive charge, and chloride and sulfur, which are anions and carry a negative charge. The equation for calculating DCAD balance is:

(Sodium + potassium) – (chloride + sulfur) = DCAD in mEq/100g of ration dry matter

Research shows that a negative DCAD prior to calving helps cows successfully join the milking string, decreasing the incidence of metabolic disorders postpartum and increasing early lactation production. By helping cows mitigate the challenges of the transition period, a negative DCAD helps maintain reproductive integrity for future lactations [8].

- *Phosphorus (P)*

There has been much debate and research conducted on phosphorus supplementation effects on reproductive function [13]. Decreased fertility rate, feed intake, milk production, decreased ovarian activity, irregular estrous cycles, increased occurrence of cystic ovaries, delayed sexual maturity and low conception rates have been reported when phosphorus intakes are low [8]. In a field study when heifers received only 70-80% of their phosphorus requirements and serum phosphorus levels were low, fertility was impaired (3.7 services per conception). Services per conception were reduced to 1.3 after adequate phosphorus was supplemented. In another experiment, increasing phosphorus supplementation from 0.4% to 0.6% of the ration had no effect on days to first estrus or services per conception. However, in some instances, responses have been reported in the field when phosphorus supplementation was increased to 0.5% or 0.6%. The reason for these differences in response is unclear, but may be related to the availability of the phosphorus that is added to the ration or the actual amount of phosphorus consumed. Caution should be used to not overfeed phosphorus - it is costly, of potential environmental concern, and does not positively influence reproduction in beef [11] or dairy cattle [27]. The ration containing 0.45 to 0.50 percent phosphorus on dry matter basis should be provided to high producing cows [41].

- *Calcium (Ca)*

Most experimental work relating calcium to reproduction has centered on the effect of the calcium: phosphorus ratio. Controlled experiments demonstrated no effect of altered ratios on reproduction in heifers or lactating cows. Ratios (Ca:P) between 1.5:1 and 2.5:1 for lactating cows should not result in problems. Milking cows should always be provided adequate amounts of calcium to maximize production and minimize health problems. One of the functions of calcium is to allow the muscle contraction. Clearly a reduction in muscle contractility will lead to a decrease in dry matter intake (DMI) as rumen function decreases, leading to severe Negative energy balance (NEB). As consequences, there is an increase in fat mobilization that may result in fatty liver syndrome and ketosis. An excess of ketone bodies can further suppress appetite [5], it has been shown that plasma calcium concentration of 5mg/ml reduce abomasal motility by 70% and the strength of the contraction by 50% [9]. Low calcium concentrations also prevent insulin production, further exacerbating this situation [16]. Ultimately, milk yield will be reduced and fertility will suffer. Muscle tone in the uterus will also be adversely affected with cows experiencing prolonged calving and retained placenta. Uterine involution may also be impaired giving rise to fertility problems. A major concern in the mineral feeding of dry cows relates to providing optimum levels of calcium and phosphorus in order to decrease the occurrence of milk fever. The ration containing 0.75 to 0.80 percent calcium on dry matter basis should be provided to high producing cows. Increase calcium to 0.9 to 1.0 percent and magnesium from 0.25 to 0.30 percent when feeding supplemental fat [41].

- *Selenium (Se)*

Selenium is important for normal spermatogenesis and largely as a component of seleno-proteins phospholipid hydroperoxide glutathione peroxidase (PHGPx/GPX4) and Seleno-protein V. Most of the selenium found in the testis is associated with PHGPx/GPX4. It serves as a powerful antioxidant protecting cells from oxidative stress. PHGPx also appears to be involved as a structural protein to provide normal sperm motility[19]. It has also been shown that a variant to this protein is necessary for normal chromatin condensation and subsequent normal spermatozoa head formation. Both deficiency and excessive selenium have been demonstrated to be detrimental to normal spermatogenesis [55].

Marginally selenium deficient animals will abort, or calves will be weak and unable to stand or suckle. Research indicates that selenium supplementation reduces the incidence of retained placentas, cystic ovaries, mastitis and metritis [34]. In addition, cattle that maintain adequate blood selenium levels have reduced incidence of abortions, still births and peri-parturient recumbency [29]. Compromised selenium status has also been associated with poor uterine involution, and weak or silent heats. In males, selenium supplementation has been shown to increase semen quality [34]. Symptoms of chronic selenium toxicity include lameness, sore feet, deformed claws and loss of hairs from tail. In pregnant animals, selenium toxicity will produce abortions, stillbirth and weak and lethargic calves as selenium accumulate in the fetus at the expense of the cow [34].

Diets should contain at least 0.1 ppm selenium on a dry matter basis [30]. In some herds, feed sources must be supplemented with selenium injections to maintain blood levels above the recommended 8-10 mg/100 ml. In herds where selenium levels are extremely low, injections are often required to rapidly return blood selenium levels to normal. After injection, feed supplements may provide enough selenium to maintain adequate blood levels in the cow. Blood tests are recommended to confirm selenium status when questions arise.

- *Zinc (Zn)*

Zinc is an essential component of over 200 enzyme systems of which the metabolic action include carbohydrate and protein metabolism, protein synthesis, nucleic acid metabolism, epithelial tissue integrity, cell repair and division, and vitamin A and E transport and utilization [50]. In addition, zinc plays a major role in the immune system and certain reproductive hormones [6]. Zinc is known to be essential for proper sexual maturity, reproductive capacity, and more specifically, onset of estrus. Zinc has a critical role in the repair and maintenance of the uterine lining following parturition, speeding return to normal reproductive function and estrus [16]. In bulls, a zinc deficiency results in poor semen quality and reduced testicular size and libido [10]. Zinc has also been shown to increase plasma beta carotene levels. Increased plasma beta carotene has been directly correlated to improved conception rates and embryonic development [46]. Improved zinc status also improves fertility by reducing lameness, resulting in cows more willing to show heat and improved mobility and performance of bulls. Inadequate zinc supplementation results in mild to severe claw (hoof) disorders, including weak claws that are more susceptible to inter-digital and digital dermatitis and foot rot [34]. The recommended dietary content of zinc for dairy cattle is typically between 18 and 73ppm depending upon the stage of lifecycle and dry matter intake [31]. Copper, Cadmium, Calcium and iron reduce zinc absorption and interfere with zinc metabolism [34].

A recent study investigating level and source of zinc on a limited number of crossbred bulls (n=16) demonstrated that zinc supplementation increased mean ejaculate volume, sperm concentration, percent live and percent motility. Studying fertile and infertile male, it was observed that seminal zinc levels were lower for infertile male than fertile male and researchers suggested that poor zinc nutrition may be a risk factor for infertility in male. Zinc supplementation was shown to reduce asthenozoospermia in male by reducing oxidative stress, DNA fragmentation and apoptosis. However, there is conflicting evidence as to the importance of zinc concentrations in the semen and infertility of male.

- *Copper (Cu)*

Copper is a necessary component of number of enzymes including superoxide dismutase, lysyl oxidase and thiol oxidase [7]. These enzymes function to eliminate free radicals that increase tissue susceptibility to bacterial infections, increase structural strength and elasticity of connective tissues and blood vessels and increase strength of horn such as in the claw (Hoof), minimizing lameness [7,32]. Reproductive problems that relate to copper deficiency manifest themselves in inhibited conception rate even though estrus may be normal. Symptoms of a copper deficiency include early embryonic death, resorption of embryo, increased retained placentas and necrosis of the placenta [34, 29]. Weak and silent heats have been reported. Dairy cows with higher serum copper levels had significantly less days to first service, fewer services per conception and fewer days to open [23]. Proper copper supplementation of the sire is needed for production of quality semen [34].

- *Manganese (Mn)*

Manganese is an activator of enzyme systems in the metabolism of carbohydrate, fats, protein and nucleic acids [34]. Manganese appears to have a vital role in reproduction. It is necessary for cholesterol synthesis [24], which in turn is required for synthesis of the steroids, estrogen, progesterone and testosterone. Insufficient steroid production results in decreased circulating concentrations of these reproductive hormones resulting in abnormal sperm in males and irregular estrus cycles in females. The corpus luteum has high manganese content and may be affected by level of manganese supplementation. Also, vaginal manganese concentration is higher in cycling than in anoestrous ruminants. A deficiency in manganese may be associated with suppression of estrus, cyclic ovaries and reduced conception rate [34].

- *Cobalt (Co)*

Cobalt is needed for proper vitamin B_{12} synthesis. Maintaining adequate vitamin B_{12} status benefits both the dam and offspring. When adequate, sufficient amounts of vitamin B_{12} cross the placenta and are present in colostrums [29]. Milk and colostrums in particular, contain high levels of vitamin B_{12} which is required for the conversion of propionate to glucose and for folic acid metabolism. Depletion of cobalt and vitamin B_{12} at parturition causes depressed milk production and colostrums yield and quality [34]. Reduced fertility and sub-optimal conditioning of the offspring are noted in a cobalt deficiency. Inadequate cobalt levels in the diet have been correlated with increased early calf mortality. A cobalt deficiency ultimately results in a vitamin B_{12} deficiency. Manganese, zinc, iodine and monensin may reduce cobalt deficiency [34]. The required dietary content of cobalt for dairy cattle is 0.11ppm [30].

- *Iodine (I)*

Iodine is required for synthesis of thyroid hormone, thyroxin, which regulates the rate of metabolism [31] . Prior to regulation of the feeding rate of Ethylenediamine dihydriodide (EDDI), many producer fed iodine compounds to cattle in excess of the nutritional requirement to prevent foot rot [28]. Reproduction is influenced through iodine's action on the thyroid gland. Inadequate thyroid function reduces conception rate and ovarian activity. Thus, iodine deficiency impairs reproduction and iodine supplementation has been recommended when necessary to insure that cows consume 15-20 mg of iodine each day. Recently, the effects of excessive iodine intakes have been recognized. Excessive iodine intakes have been associated with various health problems including abortion and decreased resistance to infection and disease. Signs of subclinical iodine deficiency in breeding females include suppressed estrus, abortions, still births, increased frequency of retained placentas and extended gestation periods [21]. Calves born to cows that are marginally deficient in iodine are weak and may be hairless [34]. Furthermore, animals that have a subclinical iodine deficiency will also have increased incidence of foot rot and respiratory disease due to suppressed immune responses. One notable characteristic of a clinical iodine deficiency is an enlargement of the thyroid gland, often termed as goiter [21].

- *Potassium (K)*

Limited research suggests that feeding high levels of potassium may delay the onset of puberty, delay ovulation, impair corpus luteum (yellow body) development and increase the incidence of anestrous in heifers. Smith and Chase [41] reports lower fertility in cows fed with high levels of potassium or diets in which the potassium-sodium ratio was too wide.

- *Chromium (Cr)*

Chromium potentiates insulin action, resulting in increased uptake of glucose and amino acids by cells in the body [43]. A chromium deficiency in lactating cows may result in increased incidence of ketosis and decreased milk production. Improved energy balance in early lactation may improve reproduction [34].

- *Salt (Sodium and Chloride)*

Salt deficiencies can affect the efficiency of digestion and indirectly the reproduction performance of cows [25]. Sodium and chloride normally do not appear in feedstuffs in adequate amounts to meet animal requirements and should be provided free choice at all times [13].

Vitamins

The vitamin requirements of dairy cows are met by a combination of rumen and tissue synthesis, natural feeds and feed supplementation [41,13]. Most commercial concentrates contain supplemental vitamins so the probability of infertility due to a vitamin deficiency is greatly reduced. When commercial concentrates are not fed, vitamin supplements should be provided. Proper vitamin and mineral balance must be provided in dry cow rations when feed intake is restricted and (or) low quality forage is fed to control or reduce body condition. To ensure adequate intake, vitamins and minerals should be fed in small amounts of low energy concentrates or mixed in a complete dry cow ration [41].

- *Vitamin A*

Vitamin A is one of the fat soluble vitamins and is well known to regulate the development, cellular growth and differentiation, and tissue function. Its metabolites affect ovarian follicular growth, uterine environments and oocyte maturation [38]. Vitamin A is required for maintaining healthy tissue in the reproductive tract. In deficient cattle, delayed sexual maturity, abortion, the birth of dead or weak calves, retained placenta and metritis have been reported. A deficiency of vitamin A has a direct effect on the structure and function of pituitary gland, gonads and uterus. Livestock, particularly ruminants, consume vitamin A, mainly in inactive form, the carotenes or provitamin A, except when it is fed as a supplement in cereal based concentrates. Provitamin A is converted into active vitamin A in small intestine and together with preformed vitamin A stored in liver [33].

Supplementation before and after calving can increase conception rates [20]. The recommended daily supplementation for dairy cows is 30,000-50,000 units. Dry cows fed only poor quality hay for extended periods without additional supplementation may benefit from vitamin A injections. β-carotene is a substance found in many plants. The cow converts this into vitamin A. It is known to be in high concentrations in fresh green roughages while grains contain relatively low amounts. Silages, especially alfalfa, contain moderate levels while corn silage is a poor source. Dry hays, especially alfalfa, are excellent sources of carotene. Despite high levels at harvest, β-carotene levels decrease during storage, with the extent of destruction being dependent on storage conditions [41].

The interest in β-carotene deficiency as a cause of reproductive problems comes from research done in Germany. Their results suggested that dairy cows and heifers consuming diets deficient in β -carotene suffered the following reproductive problems:

- Delayed uterine involution
- Delayed first estrus after calving
- Delayed ovulation
- Increased incidence of cystic ovaries

- *Vitamin D*

Vitamin D is required for normal calcium and phosphorus metabolism. However, deficiencies are seldom encountered in commercial herds. Animals with vitamin D deficiency symptoms have a stiff gait, labored breathing, weakness and possibly convulsions. Swollen knees and hocks can also occur. Bones may be soft (rickets) or be re-absorbed in older animals. Calves may be born dead, weak or deformed. Cows may not show heat when exposed. Recent research has implicated Vitamin D with heart health, cancer and infectious diseases [25]. In areas where sunlight is limited or on operations where animals are housed indoors, supplemental vitamin D is required. If an animal is losing weight or has a poor body condition score, vitamin D can be deficient Cows receiving a normal amount of natural light manufacture their own Vitamin D. Most commercial concentrates contain supplemental vitamin D in amounts sufficient to meet the cow's requirement of 10,000 IU per day [41].

- *Vitamin E*

Vitamin E functions as an intra-cellular antioxidant scavenging for free reactive oxygen and lipid hydroperoxidases, and converting them to non-reactive forms, thus maintaining the integrity of membrane phospholipids against oxidative damage and peroxidation [44, 53]. The investigation for the role of vitamin E in reproduction continues. To date there is no documented evidence that vitamin E deficiency is a significant cause of reproductive failure in dairy herds [54]. Moreover, the vitamin E requirement of milking cows is not known with certainty. In one experiment, cows were fed low vitamin E rations for four generations. There were no measurable effects on reproduction [41]. In vitamin E and selenium deficiency condition, these free radicals accumulate and not only damage cell membranes, but also disrupt several processes linked to the synthesis of steroids [42], prostaglandins [18], sperm motility and the development of the embryo [16]. It is not surprising therefore that negative impacts of vitamin E and selenium deficiencies have been observed on various components of the reproductive events, including ovulation rate [17], uterine motility, sperm motility and transport [39], conception rate and post-partum activities [2], fetal membrane expulsion [49], embryo survival, milk production, post natal growth [1].

CONCLUSION

It is clear that nutrition is directly related to reproduction in the dairy cow. Nutrient either in deficient amount or in higher amount has been shown to be capable of altering reproduction. The basic problem is that the degree of the excess, deficiency or imbalance which is required to alter reproduction is still unclear. The best recommendation at present is to provide a feeding program for dairy cows which is balanced for all nutrients and meets all known nutrient requirements.

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