Artykuł przeglądowy ***Review***

Effect of nutrition on reproductive efficiency of dairy animals

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Summary

Nutrition plays a key role in the maintenance of animal reproductive performance. Reduced reproductive efficiency can decrease the profitability of dairy production by increasing days open, calving interval, the number of services per conception, culling rate, and veterinary services. Nutritional requirements increase rapidly with milk production after calving, but an improper diet plan could result in a negative energy balance (NEB). NEB delays the time of first ovulation through uncoupled hormones production. A diet high in fat could prevent the NEB state by increasing the energy status of animals. Protein supplementation supports high production but can also have severe effects on the reproductive performance of the animal. Deficiency of minerals can also alter the reproductive performance of the animal. This article has generally focused on the effects of various nutrients on reproductive efficiency of dairy cattle.

Keywords: dairy animals, nutrition, negative energy balance, reproductive efficiency

Milk and milk products are an important source of food. Milk consumption is predicted to increase globally in the coming years in synchrony with the increasing world population. Although genetic improvement has increased animal production (17), at the same time decreased fertility also has been observed in dairy animals. Decreased fertility in high-producing cows is one of the greatest concerns in modern dairies. The fertility of dairy animals is affected mainly by a network of genetic, environmental and managerial factors, and their complex interactions make it more difficult to determine the exact reason for this decline.

The relationship between nutrition and reproduction is a topic of increasing importance, and their interaction has long been known to have important implications for reproductive performance. Nutrition plays a pivotal role in maintaining the body condition and reproductive efficiency of dairy animals (15). Nutrition consists of different nutrients, but mainly includes protein, fat, carbohydrates and micro-elements. Carbohydrates and proteins provide substrates for rumen fermentation, which results in the production of volatile fatty acids (VFA). Animals utilize these volatile fatty acids (VFA's) as their main source of energy for maintenance, milk production and reproductive performance (Fig. 1).

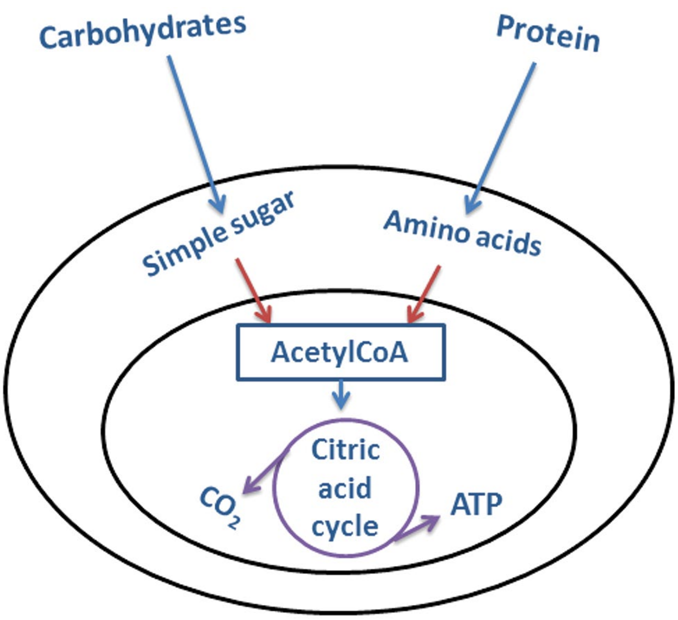

Fig. 1. Outline of the catabolism of dietary carbohydrates and proteins

Malnutrition 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 the chances of infertility (31). One of the major problems related to nutritional management in periparturient dairy cows is negative energy balance (NEB), which is an inevitable phenomenon. It results from the fact that post parturition stress decreases dairy animals feed intake but at the same time they have high production, and in order to compensate the energy for lactation cows utilizes their own body fat to meet the energy requirements and so experience NEB. When cows experience a period of NEB, the blood concentrations of non-esterified fatty acids (NEFA) increases and at the same time levels of insulin-like growth factor-I (IGF-I), glucose, and insulin are low. These shifts in blood metabolites and hormones might compromise ovarian function and fertility (13). Evidence exists that dairy cows with a post-partum NEB had poor fertility in the next reproductive cycle (18).

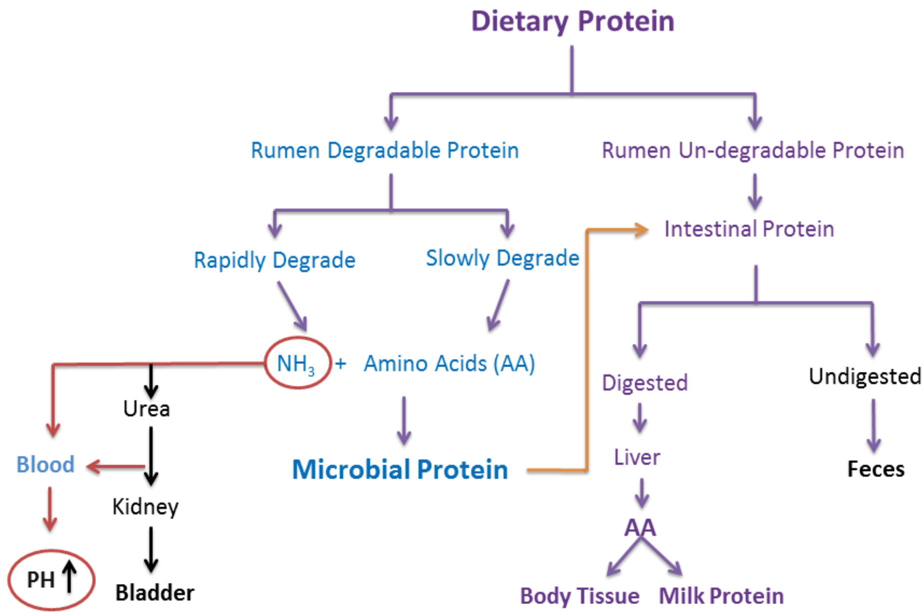

Fig. 2. Schematic summary of protein metabolism and digestion in dairy animals

Therefore high-yielding cows must be nutritionally managed to improve their general, productive and reproductive health (35). A more complete understanding of how and when nutrition affects reproduction may provide an alternative approach to manage the reproductive performance of cows in the commercial systems that do not depend on the use of exogenous reproductive hormones for improving the reproduction of their herd. This review attempts to summarize nutritional factors influencing reproductive performance of dairy animals.

Effect of dietary protein

Dietary strategies for meeting the nutritional requirements of high-producing dairy cows have been adjusted in response to genetic gains in milk yield. Nutritional management during pre-parturient and early lactation is most important. Milk yield increases at a faster rate than energy intake in the first 4 to 6 weeks after parturition. Consequently, high yielding cows will experience some degree of NEB during the early postpartum period (25). NEB induces excessive tissue mobilization, primarily of fat but also of protein, leading to subclinical and clinical ketosis and fatty liver (20).

Additionally, the low feed intake in early lactation reduces microbial protein synthesis limiting the supply of essential amino acids for optimum production. This is important during the transition period when amino acids make up a large proportion of the precursors needed for gluconeogenesis (24).

Research suggests that 17% to 19% dietary crude protein (on a dry matter basis) should be provided to the lactating cows to meet the nutritional requirements. Protein sources provide specific amino acids that animals needs for milk synthesis, reproduction and for body maintenance (Fig. 2). Short-term protein deficiencies can be met by body reserves, while prolonged inadequate protein intake can compromise the reproductive efficiency. Adequate dietary protein is required by dairy cattle during all stages of the life cycle. Heifers fed a diet deficient in protein may show a delayed onset of puberty while cows with protein deficient diets may have an increase in the number of days open. Adequate protein is necessary for the proper functioning of the reproductive organs and normal development of the fetus. In lactating cows protein deficiency may result in low milk production, decreased appetite and hence a low body condition.

Moreover, recently it has also been determined that reproductive performance may be impaired if the protein fed exceeds the cow's requirements. Excess protein is converted into ammonia, which is not utilized in the rumen and is absorbed in the blood (Fig. 2). This ammonia in the blood is converted into urea. Elevated levels of urea have been associated with decreased pregnancy rates in dairy cows through a poorly understood mechanism (7). It appears that exposure to high levels of ammonia or urea may impair the maturation of oocytes and subsequent fertilization or maturation of developing embryos. Successful embryo development depends upon the nature of the uterine environment, while increased urea level can decrease the uterine pH that would negatively affect the implantation (2) and development of embryos, mostly at the cleavage and blastocyst formation stage (16). However, supplying adequate energy for excretion of excess ammonia or urea may prevent these negative effects on reproductive performance of cows.

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 (7). This decrease in fertility may result from decreased uterine pH during the luteal phase of the oestrous cycle in cattle fed high levels of degradable protein. However, regardless of a possible effect on reproductive performance, overfeeding protein should be discouraged simply on an economic basis. It is costly and wasteful.

Effect of minerals

Minerals are structural components of the body and play a significant role in activities of enzymes and hormones as constituents of body fluids and tissues. They also act as regulators of cell replication and differentiation. Deficiencies, imbalances and toxicities of certain mineral elements may cause reproductive disorders, as minerals play an important role in the health and reproduction of livestock. After energy and protein, minerals are the most important nutrients required by the animals. Minerals should be given priority while optimizing the reproductive performance in dairy cattle.

Mineral deficiency can cause conditions like hypocalcaemia, mastitis, lameness and retained placenta (RP) in dairy animals (29). As per their requirement, minerals are divided into two categories, i.e. macro and micro minerals. Macro minerals are required in more than 100 ppm in a diet including calcium, phosphorus, magnesium, potassium, sulphur, sodium and chloride. Micro minerals, also called trace minerals, are required in lower quantities (less than 100 ppm) but are equally important, these includes cobalt, copper, iodine, iron, manganese, selenium and zinc. Mineral requirements of animals are met by consuming natural feeds, fodders and supplementation of inorganic salts in a ration.

Zinc is a very important macro mineral required by animals. It is essential for over 300 enzyme systems, which helps in carbohydrate and protein metabolism, protein synthesis and DNA and RNA synthesis. Zinc has a critical role in the repair and maintenance of the uterine lining following parturition, speeding the return of the uterus to normal reproductive functioning and oestrus (26). A good Zn status also improves fertility by reducing lameness; cows are more willing to show signs of heat and improved mobility, and the performance of bulls. In addition, zinc also plays a major role in certain reproductive hormones and the immune system (26). A severe Zn deficiency in cattle could result in slow growth, reduced feed intake, loss of hair, skin lesions that are most severe on the legs, neck, head and around the nostrils, excessive salivation, swollen feed with open-scaly lesions, and impaired reproduction (32). The recommended dietary requirement of Zn for dairy cattle is typically between 18 to 73 ppm depending upon the stage of the life cycle and dry matter intake (5).

Selenium is regarded as an important trace element. It plays an important role in the health and performance of animals. In dairy animal selenium deficiency can reduce fertility and increase the chances of placental retentions, mastitis and metritis (23). It also plays a vital role in protecting both the intra- and extracellular lipid membranes against oxidative damage and protects milk lipids from oxidation. A low level of Se in the diet has negative effects on the antioxidant system with subsequent detrimental consequences in terms of animal health. Se supplementation reduces the incidences of retained placentas, improves uterine involution and silent heats (23). Selenium can reduce embryonic death, especially if it is supplemented during the first month of gestation (28). The recommended dietary requirement of Se is at least 0.1 ppm on a dry matter basis (5).

Cobalt is needed for the synthesis of vitamin B12 in the rumen, thus maintaining vitamin the B12 status of the cow, which is important because it benefits both the dam and offspring (27). A depletion of Co and vitamin B12 during parturition can causes decreased milk production and colostrum quantity and quality (1). Co deficiency is associated with an increased incidence of silent heats, a delayed onset of puberty, non-functional ovaries, and abortion. Inadequate cobalt levels in the diet have been correlated with increased early calf mortality. The recommended dietary requirement of cobalt for dairy cattle is 0.11 ppm (5).

Manganese is a trace element and functions as an activator of enzyme systems in the metabolism of carbohydrates, fats, protein and nucleic acids. Manganese has a vital role in reproduction, as it is involved in the synthesis of cholesterol which is required for synthesis of the sex hormones including steroids, oestrogen, progesterone and testosterone (30). Insufficient steroid production results in decreased circulating concentrations of reproductive hormones, resulting in abnormal sperm in males and irregular oestrus cycles in females. The corpus luteum has a high Mn content and thus may be influenced by an Mn deficient diet. A deficiency of Mn may be associated with suppression of oestrus cyclic, ovaries and reduced conception rate.

Calcium plays a very important role in structural and physiological functions. Lactating cows must be provided with adequate amounts of Ca to maximize production and minimize health problems. Calcium related disorders are mostly very common during parturition or within a few days following parturition. The Ca : P ratio alteration may affect reproductive enzyme secretion. This results in prolongation of the first oestrus and ovulation, delayed uterine involution, increased incidence of dystocia, retention of the placenta and prolapse of the uterus (3). Moreover excess of calcium can also affect the reproductive status of animals by impairing absorption of phosphorus, manganese, zinc, copper and other elements from the gastro intestinal tract (12). The exact amount of calcium required is still under debate, but practical experience has shown that 120 g or more of calcium in the total diet (approximately 1% of dry matter intake) can avoid problems.

Copper is a vital component in many enzyme systems. Some of Cu linked enzymes are important for scavenging free radicals and preventing tissue susceptibility to infections. It also increases the structural strength of connective tissues and blood vessels, and strength of horns and hooves. Deficiencies of Cu have been associated with retained placenta, embryonic death and decreased conception rates and anoestrus (8). Copper deficiency is also associated with depressed oestrus, silent heats and reduced conception rate (21).

Preclusion of metabolic diseases is an important component for attaining high reproductive efficiency in dairy cows. This could be attained by nutritional management. Diets deficient in one or more trace minerals may induce mixed mineral deficiencies. Such conditions may cause long standing problems in the performance of the herd without showing clinical signs of deficiency but have a negative affect on the reproductive efficiency of the animals.

Fatty acid and fertility

Fats are classified as lipids, biological compounds that are soluble in organic solvents. Fatty acids and cholesterol are the substrates for reproductive hormone synthesis. Increasing fat in the diet may increase levels of reproductive hormones.

Reproduction in ruminants is associated closely with the availability of energy as the secretion of hormones depends on the energy status of animals (35). Fatty acids are an important source of energy, which is why an adequate amount (2-3%) of fatty acids could improve the reproductive functioning of dairy animal. Potential improvements in dairy cow's fertility with supplemental fat have generally been associated with increased dominant follicle diameter, improved oocyte and embryo quality (33). Supplemented animals showed greater progesterone (P4) concentrations and prostaglandins synthesis (19). Prostaglandins play an important role in regulation of parturition and initiate ovulatory process (4). According to the National Research Council (1989), in the postpartum period animal rations should contain 3% fat (on dry matter basis) to meet its energy requirements. In short, fat supplementation can increase the concentration of hormones in the blood and increase the size of ovulating follicles. The cumulative effect of all these effects is the improved fertility of animals (Fig. 3).

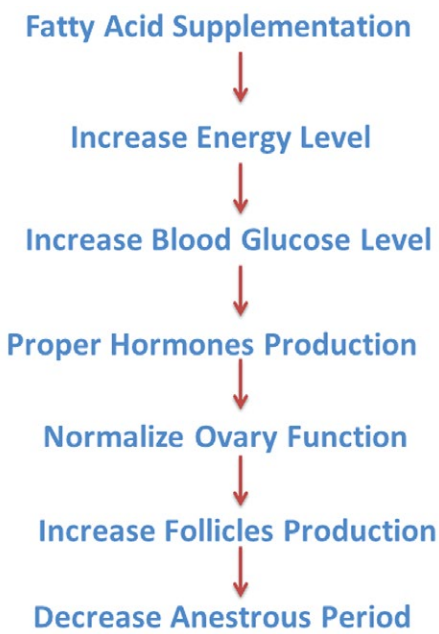

Fig. 3. Schematic representation of the potential pathway of Fatty acid to improve reproductive performance

Negative Energy Balance (NEB) and fertility

Energy status is generally considered to be the major nutritional factor that influences reproductive performance of the animals. Prolonged low energy intake can impair the reproductive performance of animals. A couple of weeks before parturition the feed intake of animals decreases due to stress and it remains up to the 4th week post parturition but, in contrast, energy requirements of animals increase to maintain body condition and milk production after parturition. If animals are unable to get enough energy from rations then they start to mobilise body fat reserves to meet its energy demand (11) and enter in a state of NEB. Cows under NEB have lower plasma glucose, insulin, insulin (like growth factor-I) (IGF I), reduced peak frequency of LH pulses, lower plasma progesterone, and impaired ovarian activity (14). Incidences of postpartum anovulation and anoestrous, as well as reduced fertility, are magnified by losses in the body condition during the early postpartum period (10). During NEB progesterone and LH secretion decrease and uncoupled hormones production leads to irregular cycles by increasing the interval to first service and reduced conception rates by decreasing the size and development of follicles (34). Subnormal progesterone levels in energy deficient cows are primarily a result of the decreased corpus luteum (CL) function. Energy-deficient cows with low progesterone levels are probably at a higher risk for premature luteolysis than cows with normal progesterone levels and a positive energy balance.

During the NEB period, dairy cows have to confront a high concentration of non-esterified fatty acids or NEFA. These fatty acids are transported to several organs, particularly to the liver, where these fatty acids are oxidized to generate energy, or to ketone bodies and are re-esterified to triacylglycerols. If the liver could not excrete triacylglycerols – a very low-density lipoprotein – to the blood then accumulation of triacylglycerols in the liver could result in a fatty liver. The NEB and its consequences lead the periparturient cows to be more susceptible to metabolic disorders, infections and infertility. High blood concentrations of NEFA impair postpartum ovarian functions. NEFA have been linked to greater incidences of ketosis, displaced abomasum, retained placenta and alter blood metabolite and hormone profile (9). During NEB, IGF-1 production is down regulated and the glucose requirement is met by catabolism of amino acids stored in skeletal muscles and other tissue protein, which result in increased urea production (22). This increased urea and decreased IGF-1 severely effects the development of early embryo by altering the oviduct and uterine environment as reviewed previously.

The general thinking is that calving interval must be short because short intervals are more profitable, but NEB has severe effects on the first ovulation, which results in an increased anoestrous period (Fig. 4). Good feeding management can help prevent the animal from NEB, which will improve the production and reproduction of the animals.

Nutrition and first ovulation

An animal needs energy for its maintenance, growth, reproduction, production and fetal growth. Normally during early lactation, animal milk production is greater but feed intake is lower. This combination creates NEB and the animal start to use body reserves to overcome the energy deficit. NEB during the first 3 weeks of lactation is highly correlated with the interval of the first ovulation. Reproductive hormone production depends on the energy status of animals. Thus, low energy in early lactation or NEB will result in decreased reproductive hormones, and so delayed first ovulation. Delayed first ovulation as a consequence of NEB in early lactation may be explained by a prolonged an-ovulatory phase in nearly 30% of cows (6). Ovulation of the dominant follicle is necessary for successful conception of the animal. First ovulation after parturition reflects the resumption and completion of pre-ovulatory ovarian follicular development. Ovulation of the first dominant follicle depends on the following: size of follicle, oestradiol production and concentration of LH and IGF-1 (22). During low energy availability the LH pulse decreases significantly, additionally, IGF-I is also directly related to energy status and is critical to ovarian follicular development (Fig. 4).

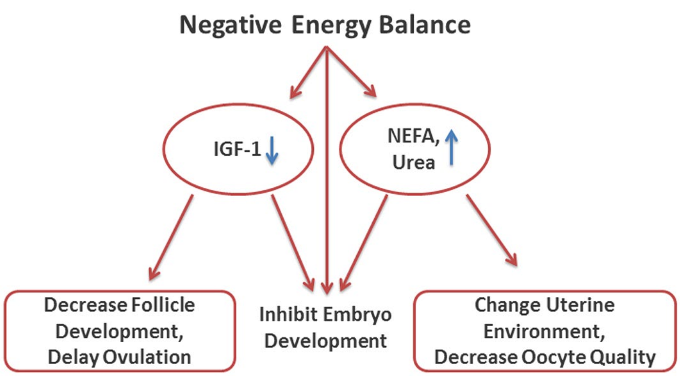

Fig. 4. Summary diagram showing the effect of NEB on reproduction of dairy animals

It is apparent that nutrition has a great effect on animal reproduction. Both cases of over or under feeding of nutrients has been shown to affect the reproductive performance of animals. The basic problem is that the level of the excess, deficiency or imbalance which can 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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