

# Impact of Nutrition on Dairy Cattle Reproduction

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## ABSTRACT

Nutrition has an important impact on the reproductive performance of dairy cattle. Energy is the major nutrient required by adult cattle and inadequate energy intake has a detrimental impact on reproductive activity of the female bovine. Cows under negative energy balance have extended periods of anovulation. Postpartum anestrus, as well as infertility, is magnified by losses of body condition during the early postpartum period. Resumption of ovulatory cycles is associated with energy balance, but seems to be mediated by a rise in plasma IGF-I; which is linked to nutritional status and concentrations of insulin in blood. Feeding diets that promote higher plasma glucose and insulin may improve the metabolic and endocrine status of cows. Feeding behavior of dairy cows during the transition period, particularly a decline in feed intake prior to calving, is associated with risk of postpartum uterine disease, such as metritis. Because metritis has a profound negative effect on risk of pregnancy in dairy cows, providing adequate bunk space and environment to maximize feed intake is expected to minimize the risk of uterine diseases and improve fertility. Addition of supplemental fat to the diet improves energy intake, modulates  $\text{PGF}_{2\alpha}$  secretion by the uterus, affects ovarian dynamics, enhances luteal function, and improves fertility. More specifically, some fatty acids (**FA**) might impact fertilization rate and embryo quality in dairy cows. Although gossypol intake seems to not affect lactation performance of dairy cows, it may affect fertility when the resulting plasma gossypol concentrations are excessive.

## INTRODUCTION

Selection of dairy cattle for milk yield has linked the endocrine and metabolic controls of nutrient balance and reproductive events so that reproduction in dairy cattle is compromised during periods of nutrient shortage, such as in early lactation. The energy costs to synthesize and secrete hormones, ovulate a follicle, and sustain an early developing embryo are probably minimal compared to the energy needs for maintenance and lactation. However, the metabolic and endocrine cues associated with negative energy balance (**NEB**) impair resumption of ovulatory cycles, oocyte and embryo quality, and establishment and maintenance of pregnancy in dairy cattle.

As the demands for milk synthesis increase, reproductive functions may be depressed when no compensatory intake of nutrients is achieved. Numerous recent studies have reported that reproductive performance is compromised by the nutrient demands associated with high levels of production. Milk yield increases at a faster rate in the first 4 to 6 wk after parturition than energy intake, consequently high yielding cows will experience some degree of negative balance of energy and other nutrients during the early postpartum period. When cows experience a period of NEB, the blood concentrations of nonesterified fatty acids (**NEFA**) increase, at the same time that 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. It has also been reported that energy balance and dry matter intake (**DMI**) might affect plasma concentrations of progesterone (Vasconcelos et al., 2003; Villa-Godoy et al., 1988), which may interfere with follicle development and maintenance of pregnancy.

During the last decades, genetic selection and improved management of herds have dramatically increased milk production of dairy cows, at the same time that fertility has decreased (Butler, 2003). Selection for higher milk production in dairy cattle has changed endocrine profiles of cows so that blood concentrations of bovine somatotropin and prolactin have increased; whereas insulin has decreased (Bonczek et al., 1988). These hormonal changes and the increased nutrient demands for production might negatively impact reproduction of dairy cows. However, adequate nutrition and sound management have been shown to offset depression of fertility in herds with average milk production exceeding 12,000 kg/cow/yr (Nebel and McGilliard, 1993; Jordan and Fourdraine, 1993).

Several nutritional strategies have been proposed to improve reproduction of dairy cattle with no detrimental effect on lactational performance. Maximizing DMI during the transition period, minimizing the incidence of periparturient problems, adding supplemental fat to diets, and manipulating the FA content of fat sources are expected to benefit reproduction in dairy cattle. However, factors such as high incidence of metabolic diseases early postpartum, poor body condition score (**BCS**) at first insemination, and excessive gossypol concentrations in plasma are detrimental to fertility of dairy cattle.

## **NUTRITION AND POSTPARTUM UTERINE HEALTH AND FERTILITY**

Epidemiological studies have clearly demonstrated strong relationships between postparturient diseases and subsequent reproductive performance in dairy cattle. Cows diagnosed with clinical hypocalcemia were 3.2 times more likely to experience retained placenta (**RP**) than cows that did not have clinical hypocalcemia (Curtis et al., 1983). Whiteford and Sheldon (2005) also found that hypocalcemia was associated with occurrence of uterine disease in lactating dairy cows. Markusfeld (1985) reported that 80 % of cows with ketonuria developed metritis.

A major risk factor for uterine disease is RP. Generally, cows with RP have increased risk of developing metritis compared with cows not experiencing RP. Both metritis and RP double the risk of cows remaining with uterine inflammation at the time of first postpartum insemination (Rutigliano, 2006). In the US, a recent USDA study (NAHMS, 1996) indicated that the incidence of RP in dairy cows was  $7.8 \pm 0.2$  %. A 2006 study on 5 dairy farms in Israel observed that RP was diagnosed in 13.1 % (9.4 to 18.1 %) and 9.2 % (3.6 to 13.8 %) of multiparous and primiparous cows, respectively (Goshen and Shpiegel, 2006). In the same study, metritis affected 18.6 % (15.2 to 23.5 %) and 30 % (19.4 to 42.3 %) of the multiparous and primiparous cows, respectively. Both RP and metritis can have devastating effects on reproductive efficiency in lactating dairy cows, with reduced conception rates and extended intervals to pregnancy (Goshen and Shpiegel, 2006). In fact, not only does the clinical disease negatively affect fertility of dairy cows; but subclinical endometritis, a disease characterized by increased proportion of neutrophils in uterine cytology without the presence of clinical signs of

inflammation of the uterus, has major deleterious effects on conception rates of lactating dairy cows at first postpartum insemination.

A rising story suggests that feed intake and feeding behavior around parturition might mediate some of the increased risk for uterine diseases in dairy cattle (Hammon et al., 2006; Huzzey et al., 2007; Urton et al., 2005). Hammon et al. (2006) observed that cows developing uterine disease postpartum experienced reduced DMI beginning 1 wk before calving. Similarly, cows diagnosed with severe metritis after calving were already consuming less dry matter 2 wk prior to calving (Huzzey et al., 2007). In the same study, even cows that subsequently developed mild metritis had reduced DMI 1 wk before calving compared with cows with healthy uteri. The same group (Urton et al., 2005) observed that cows subsequently developing metritis spent significantly less time eating before and after calving than cows that did not develop metritis. These data indicate that suppressed intake of nutrients or alterations in feeding behavior prior to calving are major risk factors for development of metritis postpartum.

A potential link between nutrient intake and development of uterine diseases may be the immune status of the cow. Kimura et al. (2002) evaluated neutrophil function in 142 periparturient dairy cows from 2 herds by evaluating chemotactic and killing activity of those cells. The authors observed that 14.1 % of the cows developed RP. Neutrophils isolated from blood of cows with RP had reduced ability to migrate to placental tissue and reduced myeloperoxidase activity, a marker for oxidative burst and killing activity of neutrophils. Interestingly, the reduced neutrophil function was observed between 1 and 2 wk prior to calving, which suggests

that the reduced innate immune function may be part of the cause of RP rather than a consequence of the disease. In fact, cows that developed uterine disease, either clinical metritis or subclinical endometritis, experienced reduced DMI and neutrophil function prior to calving (Hammon et al., 2006). These data strongly suggest that inadequate nutrient intake before calving might predispose cows to impaired immune function; and, subsequently, increased risk for uterine diseases that negatively affect reproduction.

Because intake of nutrients seems to influence energy status and immune function of dairy cows, both of which seem to be related to risk of uterine diseases; it is prudent to suggest that nutritional and management strategies that optimize nutrient intake around parturition should improve uterine health and subsequent fertility of dairy cows. Perhaps, of equal or greater importance than the diet composition is the environment to which the preparturient cow is subjected. Inadequate cow comfort, competition for space, and hierarchical status can influence the ability of the cow to consume nutrients; which can consequently predispose her to uterine disease (Hammon et al., 2006; Huzzey et al., 2007; Urton et al., 2005).

## **RESUMPTION OF POSTPARTUM CYCLICITY**

The onset of lactation creates an enormous drain of nutrients in high producing dairy cows; which, in many cases, antagonizes the resumption of ovulatory cycles. During early postpartum, reproduction is deferred in favor of individual survival. Therefore, in the case of the dairy cow, lactation becomes a priority to the detriment of reproductive functions.

During periods of energy restriction, oxidizable fuels consumed in the diet are prioritized toward essential processes such as cell maintenance, circulation, and neural activity (Wade and Jones, 2004). Homeorhetic controls in early lactation assure that body tissue, primarily adipose stores, will be mobilized in support of milk production. Therefore, the early lactation dairy cow that is unable to consume enough energy-yielding nutrients to meet the needs of production and maintenance, will sustain high yields of milk and milk components at the expense of body tissues. This poses a problem to reproduction, as delayed ovulation has been linked repeatedly with energy status (Butler, 2003). Energy deprivation reduces the frequency of pulses of luteinizing hormone (LH); thereby impairing follicle maturation and ovulation. Furthermore, undernutrition inhibits estrous behavior by reducing responsiveness of the central nervous system to estradiol by reducing the estrogen receptor  $\alpha$  content in the brain (Hileman et al., 1999).

Generally, the first postpartum ovulation in dairy cattle occurs 10 to 14 d after the nadir of NEB (Butler, 2003). Severe weight and BCS losses caused by inadequate feeding or illnesses are associated with anovulation and anestrus in dairy cattle. In fact, cows with low BCS at 65 d postpartum are more likely to be anovular (Santos et al., 2008); which compromises reproductive performance at first postpartum insemination.

Prolonged postpartum anovulation or anestrus extends the period from calving to first AI and reduces fertility during the first postpartum service (Santos et al., 2008). In fact, anovular cows not only have reduced estrous detection and conception rates, but also have compromised embryo survival (Santos et al., 2004b). On the other hand, an

early return to cyclicity is important in regard to early conception. The timing of the first postpartum ovulation determines and limits the number of estrous cycles occurring prior to the beginning of the insemination period. Typically, in most dairy herds, fewer than 20 % of cows should be anovulatory by 60 d postpartum (Santos et al., 2008). Estrous expression, conception rate, and embryo survival improved when cows were cycling prior to an estrous synchronization program for first postpartum insemination (Santos et al., 2004 a,b).

Resumption of ovarian activity in high producing dairy cows is determined by energy status of the animal. Therefore, feeding management that minimizes loss of body condition during the early postpartum period and incidence of metabolic disorders during early lactation should increase the number of cows experiencing a first ovulation during the first 4 to 6 wk postpartum.

## **ENERGY AND REPRODUCTION**

Energy intake appears to have the greatest impact on energy status of lactating dairy cows. Villa-Godoy et al. (1988) reported that variation in energy balance in postpartum Holstein cows was influenced most strongly by DMI ( $r = 0.73$ ) and less by milk yield ( $r = -0.25$ ). Therefore, differences among cows in the severity of NEB are more related with how much energy they consume than with how much milk they produce. During periods of NEB, blood concentrations of glucose, insulin, and IGF-I are low; as well as the pulse frequency of GnRH and LH. Plasma progesterone concentrations are also affected by the energy balance of dairy cows. These metabolites and hormones have been shown to affect folliculogenesis, ovulation, and

steroid production *in vitro* and *in vivo*. The exact mechanism by which energy affects secretion of releasing hormones and gonadotropins is not well defined; but it is clear that lower levels of blood glucose, IGF-I, and insulin may mediate this process.

It has been suggested that NEB influences reproduction of dairy cows by impacting the quality and viability of the oocyte of the ovulatory follicle and the CL resultant of the ovulation of that follicle. Because there is substantial evidence that metabolic factors can influence early follicular development, it is conceivable that changes in metabolism during periods of NEB could influence preantral follicles destined to ovulate weeks later during the breeding period. To test this hypothesis, Kendrick et al. (1999) randomly assigned 20 dairy cows to 1 of 2 treatments formulated so that cows consumed either 3.6 % (high energy) or 3.2 % (low energy) of their body weight. Follicles were transvaginally aspirated twice weekly and oocytes were graded based upon cumulus density and ooplasm homogeneity. Cows in better energy balance (high energy) had greater intrafollicular IGF-I and plasma progesterone levels and tended to produce more oocytes graded as good. Therefore, NEB not only delays resumption of ovulatory cycles, but it might also influence the quality of oocytes once cows are inseminated.

### **NUTRITIONAL MANIPULATION TO INCREASE ENERGY INTAKE**

Nutritional efforts to minimize the extent and duration of NEB may improve reproductive performance. The first and most important factor that affects energy intake in dairy cows is feed availability (Grant and Albright, 1995). Therefore, dairy cows should have continual access to a high

quality, palatable diet to assure maximum DMI. However, DMI is limited during late gestation and early lactation, which can compromise total energy intake and reproductive performance. Several nutritional management strategies have been proposed to increase energy intake during early lactation. Feeding high quality forages, increasing the concentrate:forage ratio, or adding supplemental fat to diets are some of the most common ways to improve energy intake in cows.

A number of studies have demonstrated the importance of insulin as a signal mediating the effects of acute changes in nutrient intake on reproductive parameters in dairy cattle. In early postpartum dairy cattle under NEB, reduced expression of hepatic growth hormone receptor 1A (**GHR-1A**) is thought to be responsible for the lower concentrations of IGF-I in plasma of cows (Radcliff et al., 2003). Because IGF-I is an important hormonal signal that influences reproductive events such as stimulation of cell mitogenesis, hormonal production, and embryo development, among other functions; increasing concentrations of IGF-I early postpartum are important for early resumption of cyclicity and establishment of pregnancy. It is interesting to note that insulin mediates the expression of GHR-1A in dairy cows (Butler et al., 2003; Rhoads et al., 2004), which results in increased concentrations of IGF-I in plasma. Because IGF-I and insulin are important for reproduction in cattle, feeding diets that promote greater insulin concentrations should benefit fertility. Gong et al. (2002) fed cows of low- and high-genetic merit isocaloric diets, that differed in the ability to induce high or low insulin concentrations in plasma. The diets that induced high insulin reduced the interval to first postpartum ovulation and increased the

proportion of cows ovulating in the first 50 d postpartum.

### **FAT, FATTY ACIDS, AND REPRODUCTION**

Studies evaluating the effects of supplemental fat on reproductive performance of beef cattle are limited. To our knowledge, no controlled trials have been conducted with adequate number of animals to evaluate the potential for fat supplementation to impact establishment and maintenance of pregnancy of beef cows. De Fries et al. (1998) observed a tendency ( $P = 0.09$ ) for increased pregnancy in Brahman cows fed 5.2 % fat compared with cows fed 3.7 % fat in the diet; however, the number of cows used in this study was limited to only 20/treatment.

Feeding fat to dairy cattle usually improved the risk for pregnancy, although responses have not been consistent. When fat feeding improved production and increased body weight loss, primiparous cows experienced reduced pregnancy risk at first AI (Sklan et al., 1994); although pregnancy to AI was extremely high in the unsupplemented cows. However, Ferguson et al. (1990) observed a 2.2 fold increased risk of pregnancy at first AI and all AI in lactating cows fed 0.5 kg/d of fat, which tended ( $P = 0.08$ ) to enhance the proportion of pregnant cows at the end of the study (93 vs. 86.2 %).

In grazing cows, supplementation with 0.35 kg of FA improved the risk of pregnancy after the first postpartum AI; although a similar proportion of cows were pregnant at the end of the study (McNamara et al., 2003). Feeding calcium salts of long chain fatty acids (**Ca-LCFA**) of palm oil improved pregnancy of dairy cows (Schneider et al., 1988), although the

authors did not report statistical significance. On the other hand, others did not observe improvements in fertility of dairy cows supplemented with Ca-LCFA (Scott et al., 1995; Sklan et al., 1991) or oilseeds (Schingoethe and Casper, 1991); which might be attributed to increased milk yield and body weight losses (Sklan et al., 1991; Sklan et al., 1994).

Because the benefits of feeding fat may originate from specific FA (Staples et al., 1998; Staples and Thatcher, 2005), others have evaluated whether feeding FA differing in the degree of saturation might influence fertility of cows. The essential FA of the n-6 and n-3 families are available in much smaller supply to ruminants than nonruminants because of microbial biohydrogenation of FA in the rumen (Juchem, 2007), suggesting that their supplementation may benefit reproduction (Staples and Thatcher, 2005).

Three recent studies explored the role of n-6 and n-3 FA supplementation to lactating dairy cows on risk of pregnancy after the first postpartum AI (Ambrose et al., 2006; Fuentes et al., 2008; Petit and Twagiramungu, 2006). When cows were fed 0.75 kg of fat from flaxseed, a source rich in C18:3 n-3, or sunflower seed, a source rich in C18:2 n-6; pregnancy tended ( $P = 0.07$ ) to be greater for cows fed n-3 FA. However, a similar response was not observed by others when cows were fed flaxseed as the source of n-3 FA (Fuentes et al., 2008; Petit and Twagiramungu, 2006). Similarly, feeding n-3 FA from fish oil as Ca-LCFA did not improve risk of pregnancy in high producing, lactating dairy cows when compared with a source rich in saturated FA (Juchem, 2007) or with Ca-LCFA of palm oil (Silvestre et al., 2008).

Juchem (2007) evaluated the effect of feeding cows pre- and postpartum Ca-LCFA of either mostly saturated and monounsaturated FA or a blend of C18:2 n-6 and trans-octadecenoic FA. He observed that cows fed unsaturated FA had 1.5 times greater risk of pregnancy either at 27 or 41 d after AI compared with cows fed mostly saturated FA. Improvements in pregnancy risk when cows were fed C18:2 n-6 and trans-octadecenoic FA were supported by improved fertilization and embryo quality in non-superovulated lactating dairy cows (Cerri et al., 2004).

Because n-3 FA can suppress uterine secretion of PGF<sub>2α</sub> (Mattos et al., 2002, 2003, 2004), it is thought that they have the potential to improve embryonic survival in cattle (Mattos et al., 2000). In 3 of 5 experiments, feeding n-3 FA either as flaxseed rich in C18:3 n-3 (Ambrose et al., 2003; Petit and Twagiramungu, 2006) or fish oil rich in eicosapentanoic acid (**EPA**) and docosahexanoic acid (**DHA**; Silvestre et al., 2008) reduced pregnancy losses in lactating dairy cows after the first postpartum AI. On the other hand, when n-6 FA were fed as Ca-LCFA, pregnancy losses were similar to those observed for cows fed Ca-LCFA of palm oil (Juchem, 2007; Silvestre et al., 2008).

Collectively, these data suggest that feeding fat to dairy cows generally improves fertility and responses are observed when the energy density of the ration increased with fat feeding. Also, these data suggest that fertility responses to fat feeding is altered according to the type of FA supplemented in the diet. Feeding n-3 FA from oilseeds has improved pregnancy risk in some, but not all studies; however feeding n-3 FA as Ca-LCFA containing fish oils does not seem to influence risk of pregnancy. On the other hand, feeding Ca-

LCFA rich in n-6 and trans-octadecenoic FA improved pregnancy in lactating dairy cows. Although feeding n-3 FA has not consistently improved pregnancy risk, it has reduced pregnancy losses in dairy cows.

## **SOURCE OF SE AND REPRODUCTION**

During the immediate postpartum period, the cow's immune system is challenged severely (Goff, 2006), and the innate and humoral defense systems are reduced. The incidence of diseases and disorders can be high during this time period and have a negative impact on reproductive performance. For example the *risk* of pregnancy (odds ratio) was reduced if cows had RP or lost one BCS unit (Goshen and Shpigel, 2006; Santos et al., 2008). Reduction in adaptive and innate immunity at parturition increases the risk of health disorders such as RP, metritis, and mastitis.

Selenium has long been associated with immunity. Cattle supplemented with Se-yeast had an 18 % increase of Se in plasma in comparison to sodium selenite in some studies (Weiss, 2003). Some regions of the US are deficient in Se, particularly the Southeast; whereas other states, such as California, are mostly adequate in Se.

We have conducted an experiment to evaluate a supplemental source of organic selenium on reproductive and immune responses by dairy cows in FL and CA (Silvestre et al., 2006a,b; Rutigliano, 2006). Objectives were to evaluate effects of organic Se on health and reproductive performance of dairy cows. Cows were assigned prepartum at approximately 25 d prior to expected day of calving to 1 of 2 sources of Se, organic Se (Se-yeast [**SY**; Sel-Plex<sup>®</sup>, Alltech) or inorganic sodium Se (sodium selenite, **SS**) fed at 0.3 ppm (DM

basis) until 80 d postpartum. In both sites, cows followed the same study protocol and health was monitored daily throughout the study. Rectal temperature was recorded each morning for 10 d postpartum. In FL, vaginoscopic evaluation of the reproductive tract was performed at 5 and 10 d postpartum. Cows were evaluated for incidence of RP, metritis, puerperal metritis, subclinical endometritis by uterine cytology, ketosis, displacement of abomasum, and mastitis. Cows had their ovulation synchronized for first postpartum AI.

Plasma Se concentrations increased with days postpartum, but source of Se did not influence Se concentrations in cows in CA. However, in FL, feeding SY improved plasma Se concentrations (0.087 vs 0.069 ± .004 µg/ml;  $P < 0.01$ ). Incidence of postpartum diseases did not differ between treatments in both sites, but cows fed SY had smaller incidence of purulent vaginal discharge than those fed SS in FL. Diet altered frequency of multiparous cows detected with > 1 event of fever (rectal temperature > 39.5 °C; SY, 13.3 % (25/188) vs SS, 25.5 % (46/181;  $P < 0.05$ ); but the SY effect was not observed in primiparous cows, which had a much higher frequency of fever (40.5 %). Vaginoscopy discharge scores at 5 and 10 d postpartum were better for the SY group; namely, 47.1 (217/460) vs 35.0 % (153/437) clear, 43.4 [200/460] vs 47.8 % [209/437] mucopurulent, and 9.3 (43/460) vs 17.1 % (75/437) purulent for SY and SS groups, respectively ( $P < 0.05$ ). Feeding organic Se (SY) improved uterine health and second service PR during summer.

Diet failed to alter first service pregnancy rates in CA and FL, and second service pregnancy rate in CA. However, second service pregnancy rate in FL was greater for cows fed SY than SS [SY, 17 %

(34/199) vs SS, 11.3 % (24/211);  $P < 0.05$ ]. The benefit of SY on second service pregnancy rate is intriguing. We hypothesize that cows of the SY group were better able to reestablish an embryo-trophic environment at second service following either early or late embryonic losses.

Measures of innate and humoral immune responses were unaltered by source of Se in CA, but cows fed SY in FL had improved neutrophil function and serum titers against ovalbumin. Our findings indicated that feeding SY improved measures of humoral and cellular immunity, uterine health, and second service pregnancy rate in cows in FL; which is known as a Se deficient state. However, in CA source of Se had no impact on health, measures of immune response, or reproductive performance.

## GOSSYPOL AND REPRODUCTION

Gossypol was first discovered by Chinese scientists after noticing that no children were born for more than a decade in a village where people cooked food with cottonseed oil. Since then, innumerable reports in the literature have confirmed the anti-fertility effect of gossypol in mammals. Gossypol disrupts cell membrane metabolism, affects glycolysis, influences mitochondrial and energy metabolism in the cell, and increases fragility of cell membranes, such as in red blood cells. In fact, erythrocyte fragility has been one of the indicators of potential gossypol toxicosis.

Risco et al. (1992) were one of the first to show that gossypol can be toxic and even kill growing cattle. They fed rations with 200, 400, or 800 mg/kg of free gossypol (FG) to bull calves for 120 d. The diets with 400 and 800 mg/kg of FG were considered to be toxic and could potentially cause the death of growing ruminants. Baby calves

have little ability to detoxify gossypol; therefore toxicity can be easily induced by feeding cotton products.

The negative effects of gossypol on fertility of ruminants are clear in males. Studies at University of Florida and Kansas State University have shown that as little as 8 g/d of FG fed to young bulls reduced sperm quality and sexual activity (Chenoweth et al., 2000; Velasquez-Pereira et al., 1998). However, the female ruminant seems to be relatively insensitive to the anti-fertility effect of gossypol because of rumen detoxification; but *in vitro* data indicate some inhibition of embryonic development and ovarian steroidogenesis (Randel et al., 1992).

More recently, a series of experiments by our group demonstrated that consumption of up to 40 mg of FG/kg of bodyweight did not influence follicle and luteal development in dairy heifers, but feeding a diet with 40 mg of FG/kg of body weight reduced embryo quality and development *in vivo* and *in vitro* (Coscioni et al., 2003a,b; Villasenor et al., 2008). These effects likely explain the reduced risk of pregnancy in dairy cows with high plasma gossypol concentrations (Santos et al., 2003), and compromised embryo survival after transfer (Galvão et al., 2006). Therefore, it is prudent to feed lactating dairy cows amounts of cottonseed that result in low plasma gossypol concentrations.

## IMPLICATIONS

Inadequate intake of nutrients and inadequate body reserves during early lactation are the major factors affecting reproductive performance of dairy cows. Improving energy balance by increasing energy intake through additional non-fiber carbohydrates or supplemental fat in the diet reduces days to first ovulation and improves

conception postpartum. Strong evidence suggests that management of cows during the prepartum period affects uterine health. Inadequate intake of nutrients prepartum and altered feeding behavior increases the risk of metritis in dairy cows.

Supplementation with unsaturated FA of the n-3 and n-6 families usually improves fertility, as long as it does not interfere with rumen microbial metabolism. It is critical that improved methods to protect these unsaturated FA are required if precise calculations of the supply of unsaturated lipids are to be utilized in dairy cattle ration formulation to improve fertility.

Source of Se might influence health and reproduction of dairy cows, but response seems to be dependent upon the background Se concentrations in dietary ingredients. Lastly, although lactating dairy cows can consume substantial amounts of gossypol with no detrimental effects on health and lactation, when plasma gossypol concentrations exceed 5 µg/ml, embryo development and establishment and maintenance of pregnancy are compromised.

## REFERENCES

- Ambrose, D.K., J.P. Kastelic, R. Corbett, P.A. Pitney, H.V. Petit, J.A. Small, and P. Zalkovic. Lower pregnancy losses in lactating dairy cows fed a diet enriched in  $\alpha$ -linolenic acid. *J. Dairy Sci.* 89:3066-3074.
- Bonczek, R.R., C.W. Young, J.E. Wheaton, and K.P. Miller. 1988. Responses of somatotropin, insulin, prolactin, and thyroxine to selection for milk yield in Holsteins. *J. Dairy Sci.* 71:2470-2478.
- Butler, W.R. 2003 Energy balance relationships with follicular development, ovulation and fertility in postpartum dairy cows. *Livest. Prod. Sci.* 83:211-218.
- Butler, S.T., A.L. Marr, S.H. Pelton, R.P. Radcliff, M.C. Butler, and W.R. Butler. 2003. Insulin restores GH responsiveness during lactation-induced negative

- energy balance in dairy cattle: effects on expression of IGF-I and GH receptor 1A. *J. Endocrinol.* 176:205-217.
- Cerri, R.L.A., R.G.S. Bruno, R.C. Chebel, K.N. Galvão, H. Rutigliano, S.O. Juchem, W.W. Thatcher, D. Luchini, and J.E.P. Santos. 2004. Effect of fat sources differing in fatty acid profile on fertilization rate and embryo quality in lactating dairy cows. *J. Dairy Sci.* 87(Suppl. 1):297 (Abstr.).
- Chenoweth, P.J., C.C. Chase, Jr., C.A. Risco, and R.E. Larsen. 2000. Characterization of gossypol-induced sperm abnormalities in bulls. *Theriogenology* 53:1193-1203.
- Coscioni, A.C., M. Villaseñor, K.N. Galvão, J.E.P. Santos, B. Puschner, and L.M.C. Pegoraro. 2003a. Effect of gossypol intake and plasma gossypol concentrations on follicle development and luteal function in dairy heifers. *J. Dairy Sci.* 86(Suppl. 1):240 (Abstr.).
- Coscioni, A.C., M. Villaseñor, K.N. Galvão, R. Chebel, J.E.P. Santos, J.H. Kirk, B. Puschner, and L.M.C. Pegoraro. 2003b. Effect of gossypol intake on plasma and uterine gossypol concentrations and on embryo quality and development in superovulated Holstein dairy heifers. *J. Dairy Sci.* 86(Suppl. 1):240 (Abstr.).
- Curtis, C.R., H.N. Erb, C.J. Sniffen, R.D. Smith, P.A. Powers, M.C. Smith, M.W. White, R.B. Hillman, and E.J. Pearson. 1983. Association of parturient hypocalcemia with eight periparturient disorders in Holstein cows. *J. Am. Vet. Med. Assoc.* 183:559-561.
- De Fries, C.A., D.A. Neuendorff, and R.D. Randel. 1998. Fat supplementation influences postpartum reproductive performance in Brahman cows. *J. Anim. Sci.* 76:864-870.
- Ferguson, J.D., D. Sklan, W.V. Chalupa, and D.S. Kronfeld. 1990. Effects of hard fats on in vitro and in vivo rumen fermentation, milk production, and reproduction in dairy cows. *J. Dairy Sci.* 73:2864-2879.
- Galvão, K.N., J.E.P. Santos, A.C. Coscioni, S.O. Juchem, R.C. Chebel, W.M. Sisco, and M. Viollaseñor. 2006. Embryo survival from gossypol-fed heifers after transfer to lactating cows treated with human chorionic gonadotropin. *J. Dairy Sci.* 89:2056-2064.
- Goff, J.P. 2006. Transition cow nutrition: effects on immune function and postpartum health. In *Proc. 1<sup>st</sup> Annual Meeting and Conv., Dairy Cattle Reproduction Council*, Denver, CO, pp. 1-8.
- Gong, J.G., W.J. Lee, P.C. Garnsworthy, and R. Webb. 2002. Effect of dietary-induced increases in circulating insulin concentrations during the early postpartum period on reproductive function in dairy cows. *Reproduction* 123:419-427.
- Goshen, T., and N.Y. Shpigel. 2006. Evaluation of intrauterine antibiotic treatment of clinical metritis and retained fetal membranes in dairy cows. *Theriogenology* 66:2210-2218.
- Grant, R.J., and J.L. Albright. 1995. Feeding behavior and management factors during the transition period in dairy cattle. *J. Anim. Sci.* 73:2791-2803.
- Hammon, D.S., I.M. Evjen, T.R. Dhiman, J.P. Goff, and J.L. Walters. 2006. Neutrophil function and energy status in Holstein cows with uterine health disorders. *Vet. Immun. Immunop.* 113: 21-29.
- Hileman, S.M., L.S. Lubbers, H.T. Jansen, and M.N. Lehman. 1999. Changes in hypothalamic estrogen receptor-containing cell numbers in response to feed restriction in the female lamb. *Neuroendocrinology* 69:430-437.
- Huzzey, J.M., D.M. Veira, D.M. Weary, and M.A. von Keyserlingk. 2007. Prepartum behavior and dry matter intake identify dairy cows at risk for metritis. *J. Dairy Sci.* 90:3220-3233.
- Jordan, E.R., and R.H. Fourdraine. 1993. Characterization of the management practices of the top milk producing herds in the country. *J. Dairy Sci.* 76:3247-3256.
- Juchem, S.O. 2007. Lipid digestion and metabolism in dairy cows: effects on production, reproduction and health. Ph.D. thesis, University of California, Davis.
- Kendrick, K.W., T.L. Bailey, A.S. Garst, A.W. Pryor, A. Ahmadzadeh, R.M. Akers, W.E. Eyestone, R.E. Pearson, and F.C. Gwazdauskas. 1999. Effects of energy balance on hormones, ovarian activity, and recovered oocytes in lactating Holstein cows using transvaginal follicular aspiration. *J. Dairy Sci.* 82:1731-1740.

- Kimura, K, J.P. Goff, M.E. Kehrl, Jr., and T.A. Reinhardt. 2002. Decreased neutrophil function as a cause of retained placenta in dairy cattle. *J. Dairy Sci.* 85:544-550.
- Markusfeld, O. 1985. Relationship between overfeeding, metritis and ketosis in high yielding dairy cows. *Vet Rec.* 116:489-491.
- NAHMS. 1996. Dairy 1996 Part III: reference of 1996 dairy health and health management. Online. Available: <http://nahms.aphis.usda.gov/dairy/dairy96/DR96Pt3.pdf>.
- Nebel, R.L., and M.L. McGilliard. 1993. Interactions of high milk yield and reproductive performance in dairy cows. *J. Dairy Sci.* 76:3257-3268.
- Petit, H.V., and H. Twagiramungu. 2006. Conception rate and reproductive function of dairy cows fed different fat sources. *Theriogenology* 66:1316-1324.
- Radcliff, R.P., B.L. McCormack, B.A. Crooker, and M.C. Lucy. 2003. Plasma hormones and expression of growth hormone receptor and insulin-like growth factor-I mRNA in hepatic tissue of periparturient dairy cows. *J. Dairy Sci.* 86:920-3926.
- Randel R.D., C.C. Chase Jr., and S.J. Wyse. 1992. Effects of gossypol and cottonseed products on reproduction of mammals. *J. Anim. Sci.* 70:1628-1638.
- Rhoads, R.P., J.W. Kim, B.J. Leury, L.H. Baumgard, N. Segoale, S.J. Frank, D.E. Bauman, and Y.R. Boisclair. 2004. Insulin increases the abundance of the growth hormone receptor in liver and adipose tissue of periparturient dairy cows. *J. Nutr.* 134:1020-1027.
- Risco, C.A., C.A. Holmberg, and A. Kutches. 1992. Effect of graded concentrations of gossypol on calf performance: toxicological and pathological considerations. *J. Dairy Sci.* 75:2787-2798.
- Rutigliano, H. 2006. Effects of source of supplemental Se and method of presynchronization on health, immune responses, reproductive efficiency, uterine health, and lactation performance of high producing dairy cows. M.S. thesis, University of California, Davis.
- Santos, J.E.P., H.M. Rutigliano, and M.F. Sá Filho. 2008. Risk factors for resumption of postpartum estrous cycles and embryonic survival in lactating dairy cows. *Anim. Reprod. Sci.* Accepted.
- Santos, J.E.P., S.O. Juchem, R.L.A. Cerri, K.N. Galvão, R.C. Chebel, W.W. Thatcher, C. Dei, and C. Bilby. 2004a. Effect of bST and reproductive management on reproductive and lactational performance of Holstein dairy cows. *J. Dairy Sci.* 87: 68-881.
- Santos, J.E.P., W.W. Thatcher, R.C. Chebel, R.L.A. Cerri, and K.N. Galvão. 2004b. The effect of embryonic death rates in cattle on the efficacy of estrous synchronization programs. *Anim. Reprod. Sci.* 82-83C:513-535.
- Santos, J.E.P., M. Villaseñor, E.J. DePeters, P.H. Robinson, and C.H. Holmberg. 2003. Type of cottonseed and gossypol in diets of lactating dairy cows: Plasma gossypol, reproduction, and health. *J. Dairy Sci.* 86:892-905.
- Staples, C.R., J.M. Burke, and W.W. Thatcher. 1998. Influence of supplemental fats on reproductive tissues and performance of lactating cows. *J. Dairy Sci.* 81:856-871.
- Schingoethe, D.J., and D.P. Casper. 1991. Total lactational response to added fat during early lactation. *J. Dairy Sci.* 74:2617-2622
- Silvestre, F.T. 2008. Effect of differential fatty acid supplementation during the peripartum and breeding periods on postpartum health, reproduction, immunity and lactation in high producing dairy cows. Unpublished.
- Silvestre, F.T., D.T. Silvestre, C. Crawford, J.E.P. Santos, C.R. Staples, and W.W. Thatcher. 2006a. Effect of selenium (Se) source on innate and adaptive immunity of periparturient dairy cows. *Biol. Reprod.* 39<sup>th</sup> Annual Meeting. Special Issue. p 132.
- Silvestre, F.T., D.T. Silvestre, J.E.P. Santos, C. Risco, C.R. Staples, and W.W. Thatcher, 2006b. Effects of selenium (Se) sources on dairy cows. *J. Anim. Sci.* 89 (Suppl. 1):52.
- Sklan, D., U. Moallem, and Y. Folman. 1991. Effect of feeding calcium soaps of fatty acids on production and reproductive responses in high producing lactating cows. *J. Dairy Sci.* 74:510-517.
- Sklan, D., M. Kaim, U. Moallem, and Y. Folman. 1994. Effect of dietary calcium soaps on milk yield, body weight, reproductive hormones, and fertility in

- first parity and older cows. *J. Dairy Sci.* 77:1652-1660.
- Staples, C.R., J. M. Burke, and W.W. Thatcher. 1998. Influence of supplemental fats on reproductive tissues and performance of lactating cows. *J. Dairy Sci.* 81:856-871.
- Staples, C.R., and W.W. Thatcher. 2005. Effects of fatty acids on reproduction of dairy cows. Pages 229-256 in *Recent Advances in Animal Nutrition*, ed. P.C. Garnsworthy and J. Wiseman, Nottingham University Press, England.
- Urton, G., M.A. von Keyserlingk, and D.M. Weary. 2005. Feeding behavior identifies dairy cows at risk for metritis. *J. Dairy Sci.* 88: 2843-2849.
- Vasconcelos, J.L.M., S. Sangsritavong, S.J. Tsai, and M.C. Wiltbank. 2003. Acute reduction in serum progesterone concentrations after feed intake in dairy cows. *Theriogenology* 60:795-807.
- Velasquez-Pereira, J., P.J. Chenoweth, L.R. McDowell, C.A. Risco, C.A. Staples, D. Prichard, F.G. Martin, M.C. Calhoun, S.N. Williams, and N.S. Wilkinson. 1998. Reproductive effects of feeding gossypol and vitamin E to bulls. *J. Anim Sci.* 76:2894-2904.
- Villa-Godoy, A., T.L. Hughes, R.S. Emery, T.L. Chaplin, and R.L. Fogwell. 1988. Association between energy balance and luteal function in lactating dairy cows. *J. Dairy Sci.* 71:1063-1069.
- Villaseñor, M. A., C. Coscioni, K.N. Galvão, R.C. Chebel, and J.E.P. Santos. 2008. Gossypol disrupts embryo development in heifers. *J. Dairy Sci.* Accepted.
- Wade, G.N., and J.J. Jones. 2004. Neuroendocrinology of nutritional infertility. *Am. J. Regul. Integr. Comp. Physiol.* 287:1277-1296.
- Weiss, W. P., 2003: Selenium nutrition of dairy cows: comparing responses to organic and inorganic selenium forms. P. 333-343 in *Proc. Alltech's 19th Ann. Symp., Nutritional Biotechnology in the Feed and Food Industries*, Ed. T.P. Lyons and K.A. Jacques, Nottingham University Press, UK.
- Whiteford, L.C., and I.M. Sheldon. 2005. Association between clinical hypocalcaemia and postpartum endometritis. *Vet. Rec.* 157:202-203.