Management, Nutrition, Lameness and Immunity in the Large Herd Environment

D. J. Tomlinson, Ph.D., M. T. Socha, Ph.D., and J. M. DeFrain, Ph.D.
Zinpro Corporation, 10400 Viking Dr., Suite 240, Eden Prairie, MN 55344
Email: dtomlinson@zinpro.com

INTRODUCTION

Today's dairy producers demand greater performance and efficiency from their cows. These expectations dictate that cows are productive and remain reproductively efficient throughout their lifetime. Reproductive performance has declined in modern dairy systems, while genetic progress for high milk yield continues (Royal et al., 2002; Berry et al., 2003). This problem is apparently international among diverse combinations of dairy production systems. Examples include high-yielding TMR systems, typical of North America, and lower yielding pasture-based systems, typical of New Zealand (Harris and Kolver, 2001; Lucy, 2003). Nutritional insufficiency clearly has negative effects on re-establishment of pregnancy in early lactation. However, often unrecognized are the effects of the immune system on reproductive function and how stressors tied to lameness, mastitis, and heat stress impact immune function and establishment of normal cyclicity.

The objective of this paper is to review the link between nutritional factors and activation of the immune system by common maladies such as lameness, mastitis, and heat stress on reproduction in dairy cattle. In addition, this paper will address the role trace minerals play in improving reproductive performance.

NUTRITION AND REPRODUCTION

It is common knowledge that cows in negative energy balance suffer with poor reproductive performance. However, energy balance is not the sole nutritional factor that affects reproduction (Chagas et al., 2007; Lucy, 2003). Specific nutrients that act independently of energy balance have been reported to directly or indirectly alter reproductive efficiency and fertility. Among these are protein (Armstrong et al., 2001), starch (Armstrong et al., 2001; Burke et al., 2006; Roche et al., 2006), macro and micro minerals (Underwood and Suttle, 2001), and fats (Staples et al., 1998; Boken et al., 2005) including specific lipids such as n-3 fatty acids (Ambrose et al., 2006), rumen inert fats (Staples et al., 1998), and possibly conjugated linoleic acid (Baumgard et al., 2005). The roles of these nutrients are often complex, and experimental results have been inconsistent.

For example, 11 of 14 studies examining the effect of supplementary fat on reproductive success showed a positive effect, while 3 showed a negative effect (Staples et al., 1998). Similarly, inclusion of dietary starch may shorten the duration of negative energy balance, reducing the BCS nadir and increasing the level of circulating IGF-I. However, starch supplements are also reported to reduce oocyte quality (Armstrong et al., 2001), thus they may negate any potential benefits from improved energy balance and reduced postpartum anestrous interval (**PPAI**).

Minimizing postpartum loss of BCS and increasing IGF-I shortens PPAI. Recent research indicates that cows may have an ideal or optimal target BCS in the early postpartum period at which they can achieve optimal health, fertility, and lifetime performance (Garnsworthy, 2010). This research suggests that slightly thinner cows with BCS of 2.5-3.0 in the prepartum period go on to lose less weight in early lactation and are then better able to withstand the challenges of early lactation, achieve higher DMI, and return to normal ovarian activity sooner.

The effects of protein and its metabolites are unclear. Both Sinclair et al. (2000) and Armstrong et al. (2001) reported a reduction in oocyte quality when dietary protein was increased. Reduced oocyte quality may explain decreased conception rates observed with increased rumen degradeable protein (**RDP**; Canfield et al., 1990). Nevertheless, in pasture-based production systems, where the availability of RDP can be twice the level required by the rumen, conception rates are generally better than those seen in systems in which balanced diets are offered (Royal et al., 2000; Harris, 2005). However, it is unlikely that any of these specific dietary components will provide simple solutions to the problem of subfertility associated with lactation in high-yielding dairy cows. Further research is required to better understand the effect of these individual nutrients and the interactions among different nutrients on reproductive success.

RELATIONSHIP BETWEEN TRACE MINERALS AND REPRODUCTION

Probably less well recognized by dairy producers are the effects of trace minerals on reproductive performance. Improving status of trace minerals such as zinc, manganese, copper, cobalt, and selenium can enhance reproductive performance, as they play vital roles in reproductive function.

Improving the availability of trace minerals prior to parturition positively impacts postpartum reproductive performance. Research has demonstrated that complexed sources of trace minerals are more bioavailable (Wedekind et al., 1992) and have better animal retention than inorganic sources (Nockels et al., 1993). Replacing inorganic zinc, copper, and cobalt with complexed sources of these minerals in diets of pre- and postpartum cows reduced uterine infections (Rakes et al., 1993). Responses to supplying additional zinc, manganese, copper, and cobalt in complexed form are enhanced under certain conditions. Campbell et al. (1999) observed small numeric improvements in reproductive performance when cows fed complexed zinc, manganese, copper, and cobalt did not retain the fetal membrane. However, when the placenta was retained, cows fed complexes showed estrus 37 d sooner, first luteal activity 11.8 d earlier, and first corpus luteum (**CL**) 5.4 d earlier than cows that did not receive mineral complexes (Campbell et al., 1999). Results from this study indicate that cows fed complexed trace minerals were better able to respond to stress such as a retained placenta, as evidenced by the quicker return to normal ovarian activity. In another study, feeding complexed zinc, manganese, copper, and cobalt prior to calving reduced incidence of retained placentas, cystic ovaries, and mastitis/metritis (Nocek, 1994).

In a summary of seventeen studies dairy cows supplemented with complexed zinc, manganese, copper, and cobalt both before and after parturition showed improved milk production (1.0 kg/d, $P < 0.0001$), energy-corrected milk (1.1 kg/d, $P < 0.0001$), reduced SCC (34,000 cell/mL, $P < 0.03$),

Table 1. Comparison of reproductive performance between 1990 and 2000 (Olson, 2001).

Item	1990	2000
Days to first service	82	85
Days open	130	153

and days open (**DO**) (7d, P < 0.14; Ballantine et al., 2002; Ferguson et al., 2004; Griffiths et al., 2007; Kellogg et al., 2003; Kincaid and Socha, 2004; Nocek et al., 2006; Siciliano-Jones et al., 2008; Toni et al., 2007; Uchida et al., 2001). It should be noted that the control diets fed in most of these studies exceeded NRC requirements for these trace minerals, in some cases by several fold. Claw integrity was also evaluated in some of these studies and supplementing pre- and postpartum cows with a combination of complexed zinc, manganese, copper, and cobalt reduced incidence of claw lesions (Ballantine et al., 2002; Ferguson et al., 2004; Nocek et al., 2006; Siciliano-Jones et al., 2008).

While trace mineral status plays a key role in determining enzyme and immune function and productive performance, supplementation with highly bioavailable complexed trace minerals may further enhance animal performance even when status is considered adequate.

IMPACT OF LAMENESS ON REPRODUCTION

Although only about 16 % of cows (NAHMS, 2007) are culled for lameness, lameness may increase the number of cows culled due to reproductive failure. According to a 2007 National Animal Health Monitoring System survey of dairy management practices, 26.3 % of cows are culled due to reproductive failure. A summary of data collected from DHI records processed in Provo, Utah indicates that fertility may not be improving in our dairy cattle. Between 1990 and 2000, DO increased by 23 d (Olson, 2001; Table 1). Some management specialists would argue that this increase in DO should be attributed to dairy producers intentionally delaying rebreeding while using rBST to maintain profitability, thus increasing lactation length. However, the Provo DHI records indicate that this is not the case as days to first service during this same period have increased by only 3 d.

Although a survey of 13 Dutch dairy herds (Bakerma et al., 1994) indicated no relationship between reproduction and lameness, a growing database contradicts these findings. Researchers found lame cows are open between 11 and 28 d longer than cows not lame (Argaez-Rodriguez et al., 1997; Collick et al., 1989; Lee et al., 1989; Lucey et al., 1986). Furthermore, type of claw disorder may affect the impact of lameness on fertility (Hernandez et al., 2000). Cows with abscesses/sole ulcers or cows with two or more claw disorders had more days open (P < 0.05) than cows without claw disorders (Table 2). Cows with abscesses/sole ulcers were open 63 d longer than healthy cows, while cows with two or more claw disorders were open 76 d longer. Furthermore, a lower percentage of cows with abscesses/sole ulcers were pregnant at the end of lactation than healthy cows (Table 2).

Lameness may also impact fertility by lowering the first service conception rates and increases incidence of ovarian cysts as indicated by results of a University of Florida study (Melendez et al., 2002). Cows that were clinically lame due to a claw disorder in the first 30 d postpartum had a

Table 2. Effect of claw lesion on reproductive performance of dairy cattle (Hernandez et al., 2000)

Variable	Healthy, No Claw Disorders	Digital Dermatitis	Abscess/ Sole Ulcer	Foot Rot	Two or More Claw Disorders
Number of cows	464	23	39	4	18
Days to first service	70	70	71	71	77
Days open	92[y]	120[yz]	155[z]	106[yz]	168[z]
Percent pregnant at end of lactation	97[y]	96[yz]	90[z]	100[yz]	94[yz]

[yz] Within row, means differ (P<0.05

58.9 % decrease in first service conception rates (P < 0.05), a 125 % increase in ovarian cysts, and an 8.2 % decrease in pregnancy rate at 480 d postpartum (Table 3). Probably the most noteworthy observation was that 30.8 % of cows that were lame during the first 30 d of lactation were culled prior to recording any reproductive event compared to 5.4 % of non-lame (control) cows.

Motivating dairy producers to change management, environmental, or nutritional practices to reduce lameness in their herds is difficult, as prevalence and severity of lameness is often underestimated. In a Michigan State University study, dairy producers estimated that only 4.5 % of their cows were clinically lame, while independent observers identified 52 % of cows as clinically lame (Kopcha et al., 2003).

Sprecher et al. (1997) found that using a locomotion scoring system based on back posture of cows, both standing and walking, was an effective means of assessing potential for reproductive failure. This system identifies cows on a 1 to 5 scale with 1 representing normal healthy animals and 5 as clinically lame. The Sprecher work (1997) found cows scoring a 3 or greater were 2.8 times more likely to have increased days to first service, 15.6 times more likely to have increased DO, and 9.0 times more likely to have increased services per conception (Table 4). In addition, cows scoring 3 or greater were 8.4 times more likely to be culled.

Table 3. Effect of lameness during the first 30 d of lactation on reproduction[a] (Melendez et al., 2002).

Item	Lame cows	Control
Days to first service	99	94
First service conception rate, %	17.5[y]	42.6[yz]
Ovarian cysts, %	25.0[y]	11.1[z]
Pregnant @ 480 d postpartum, %	85.0[y]	92.6[z]
Culled before any reproductive event, %	30.8[y]	5.4[z]

[a] Fertility of 190 cows was evaluated (cows bred under timed insemination were not included in evaluation). Sixty-five cows showed claw lameness within 30 d postpartum. These cows were compared with 130 cows that did not exhibit lameness during the first 150 d of lactation.

[yz] Within row, means differ ($P < 0.05$)

Table 4. Impact of locomotion on reproduction and culling: Risk of reduced fertility for cows scoring greater than 2 (Sprecher et al. 1997).

Reproductive Parameter	Predictive Risk of Happening
Increased days to first service	2.8 X more likely
Increased days open	15.6 X more likely
Increased services/conception	9.0 X more likely
Culled (Exit herd)	8.4 X more likely

Cows with poor feet and legs tend to seek soft, comfortable locations to lie which may be unclean alleys, wet areas, or stalls without dividers or neck rails. Increased stress due to lameness may depress the immune system and; therefore, the combination of unclean resting surfaces and depressed immune function may lead to higher incidence of mastitis.

IMPACT OF MASTITIS ON REPRODUCTION

Mastitis has been implicated in decreasing reproductive performance of dairy cows. Moore et al. (1991) reported a negative correlation between clinical mastitis and reproduction due to altered inter-estrus intervals and decreased length of the luteal phase in cows with clinical mastitis caused by gram-negative mastitis pathogens. In a retrospective study looking at the records of 1001 cows, Santos et al. (2004) observed cows that develop mastitis prior to breeding are almost twice as likely to abort the pregnancy as cows that do not develop mastitis prior to breeding. University of Tennessee (Table 5) research indicates that mastitis both before first service or between first service and being confirmed pregnant increased days to first service, services/conception, and DO. Reduced fertility as a result of mastitis may be attributed to endotoxin release, which may induce luteolysis (regression of the CL) and influence conception and early embryonic survival by release of inflammatory mediators (Moore and O'Connor, 1983).

University of Florida researchers (Risco et al., 1999) reported 2.7 times higher risk of abortion in cows experiencing an incident of clinical mastitis in the first 45 d of lactation. Hockett et al. (2001) reported an increase in days to first service of 22.6 d (71 to 93.6 d) for cows with clinical mastitis before first service. Services per conception were also increased from 1.6 for cows without mastitis to 2.9 for those with clinical mastitis after first service. Barker et al. (1998) indicated an increase in days to conception from 92.1 for cows without mastitis to 136.6 for those with clinical mastitis after first service. Furthermore, Schrick et al. (2001) reported that cows with either clinical mastitis or subclinical mastitis have impaired reproductive capabilities. Schrick et al. (2001) summarized that endotoxins released by the death of gram-negative bacteria significantly lower gonadotropin releasing hormone (**GnRH**) pulse amplitude, lower GnRH and luteinizing hormone (**LH**) concentrations, increase cortisol and progesterone (**P4**) while increasing body temperature. Inflammation stimulates the immune system, resulting in the release of cytokines which may inhibit the action of FSH on LH receptors. Therefore, mastitis may influence reproductive function via alterations in LH and FSH activity or function, affecting follicular development, and (or) oocyte maturation (Schrick, 2001).

Table 5. Effects of time of mastitis occurrence on reproductive performance.

Mastitic Insult	Days to First Service	Days Open	Services/Conception
Before first service	75.7	106.2	2
First service to pregnancy	75.2	143.5	3.1
After preg. or uninfected	67.8	85.4	1.6

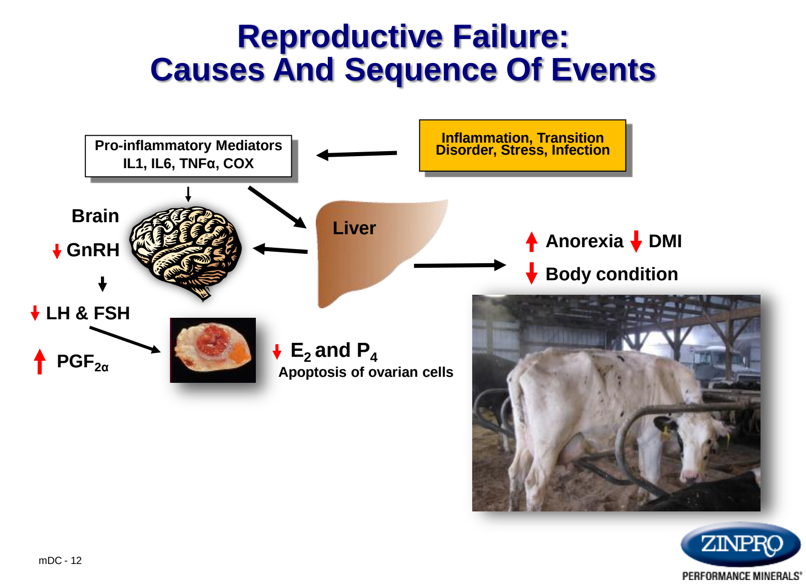
Oliver, S. P. et al., 2000.

IMPACT OF INFLAMMATION ON REPRODUCTION

A growing body of evidence indicates that immune activation may be one of the primary causes of pregnancy failure (Bertoni et al., 2008; Erlebacher et al., 2004; Grimble, 1990). Common pro-inflammatory cytokines (TNF-α, IL-1, IL-6, and COX, immune cell chemical messengers) produced during stressful insults such as heat stress, lameness, water deprivation, infection (mastitis or metritis), metabolic diseases, parasites, trauma, and endotoxins from the gut have been reported to induce ovarian resistance toward gonadotropins (Belknap et al., 2002; Grimble, 1990; Schrick, 2001). These cytokines are known to be primary mediators of endotoxic shock and tissue damage (Belknap et al., 2002; Lambert et al., 2002). This response ultimately results in pregnancy failure by inhibiting ovarian progesterone production (Erlebacher et al., 2004; Figure 1).

For example: heat stress often results in increased core body temperature, decreased dry matter intake, depressed milk yield, and reproductive failure. However, an unforeseen response to this stress may be increased gut permeability. It is this increase in gut permeability to endotoxin, a component of the walls of Gram-negative bacteria that causes local and/or systemic

Figure 1. Impact of inflammation and infection on reproductive failure.



inflammatory reactions (Lambert et al., 2002). The inflammatory response is marked by production of TNF-α and IL1-α; which are both pro-inflammatory and responsible for systemic changes in blood flow while stimulating production of prostaglandins (Lambert et al., 2002).

Similarly, Belknap and coworkers (2002) investigated the effects of grain feeding acidosis on production of pro-inflammatory mediators in feedlot cattle. They found acute rumen acidosis resulted in a marked increase in production of TNF-α, IL-1, IL-6, and COX possibly as the result of lipopolysaccharide (**LPS**) leakage from the gut. The occurrence of acute acidosis in commercial dairy cows is low; whereas the prevalence of subacute rumen acidosis (**SARA**) is widespread. For example, surveys indicate that in Wisconsin, 19 to 26 % of lactating cows fed TMR diets experienced SARA (Garrett et al., 1997; Oetzel et al., 1999), and in Ireland, almost 50 % of grazing cows from 12 herds experienced moderate to severe SARA (O'Grady et al., 2008). Subacute ruminal acidosis causes the dairy industry significant financial losses associated with lameness, treatment of sick animals, and decreased milk production (Krause and Oetzel, 2006) and may be another cause of reproductive failure.

SUMMARY

A vast body of evidence supports the premise that nutrition, inflammation (immune activation), heat stress, lameness, and infection individually or combined may significantly impact fertility of dairy cattle. Research has shown that cows that are stressed, lame, contract mastitis, or are heat stressed have increased DO and reduced reproductive efficiency. Therefore, management strategies must be established to address cow comfort, including heat abatement, detection and correction of lameness, and prevention of mastitis in an effort to minimize their negative effects on fertility. Trace minerals play key roles in preventing lameness and mastitis and in maintaining reproductive function. Supplementing cows with highly bioavailable trace mineral sources helps ensure they will have adequate trace mineral status even when dietary, management, and environmental conditions may be less conducive to mineral absorption.

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