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Energy Balance of the Periparturient Dairy Cow

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Introduction

Selection for increased milk yield has had a temporal association with declines in fertility and reproductive efficiency in dairy cows. In the US, an average annual decrease of 0.5% in conception rate at first service occurred between 1975 and 1997 (Beam and Butler, 1999). High merit cows partition a greater proportion of their available energy to milk rather than body tissue (Bauman et al., 1985; Veerkamp and Emmans, 1995; Reynolds, 2004). This has contributed to a perception that high merit cows experience more severe negative energy balance for a longer duration, which makes them less fertile than low merit cows. These associations have generated considerable interest and concern because decreased fertility is one of the primary reasons to cull cows and represents a major economic loss to dairy producers. Although these temporal associations indicate the potential for milk yield and negative energy balance to impact reproductive performance, associations do not necessarily identify direct effects. An examination of the underlying biology is needed to ascertain the reason(s) for these associations. The goal of this presentation is to provide an overview of energy balance, factors that affect energy balance of the periparturient dairy cow, and how energy balance can impact reproductive performance of the contemporary cow.

Methods to Determine or Assess Energy Balance

Energy balance is the difference between the amount of energy consumed (energy intake) and the amount of energy used or expended (energy required) by an animal. Energy intake is determined by the amount of feed consumed and the energy content of the feed. Energy required by an animal is the sum of all energy expenditures and includes energy used to maintain the body, to produce products (body tissue, milk, fetus), and for activity. If energy intake is greater than required, the animal will be in positive energy balance and if the duration is sufficient, the animal will gain body weight and condition. If energy intake is less than required, the animal will be in negative energy balance and if the duration is sufficient, the animal will lose body weight and condition. Energy intake and energy expenditure must be measured or estimated in order to determine energy balance. Energy intake is simply the product of energy content of the feed and how much feed is consumed, but there are various ways to measure or estimate each value. With sufficient effort, accurate estimates of feed intake can be determined. Total energy content of a feed can easily be determined in a bomb calorimeter, but not all of the energy in the feed is available to the animal. For this reason, feed energy content is partitioned into components to account for what is available and what is not available to the animal.

The energy system used most commonly for dairy cows in the United States is the net energy (NE) system where energy for maintenance and for milk synthesis are expressed in terms of NE for lactation (NEL). Although NE based systems can account for most sources of energy loss during digestion and metabolism of consumed feed, NE systems have limitations. Most of these occur because procedures required to measure NE of feeds are expensive in both time and resources. As a result, NE values for most feeds have been estimated rather than measured directly. The National Research Council (2001) converted to a chemical based system to estimate feed NEL values and incorporated a more dynamic approach to adjust for the effect of feed intake on energy availability. Previous versions of the NRC tended to overestimate energy content of feeds because adjustments (decreases) for effects of increased feed intake on available energy content were static and often insufficient. This revised system should provide more accurate estimates of the available energy content of feeds. Additional improvements could be achieved with a refined understanding of the effects of intake on energy availability, additional data on the impact of dietary additives on feed energy availability, and a better understanding of environmental effects (especially heat stress) on energy requirements.

There are a number of methods used to measure or to estimate energy expenditure. The most accurate methods use direct or indirect calorimetry to measure heat production by the animal. This technique is based on the knowledge that energy not captured or retained by the animal as a product (milk, body tissue, etc.) is lost as heat. Energy used by the animal is therefore the sum of energy lost as heat and energy retained by the animal. Although this is the most accurate method, it is expensive, involves complicated equipment, and is very labor intensive. Thus, measurements are made only during short intervals and have been made in only relatively few experiments. A much more common method to estimate energy expenditure of the lactating cow is to calculate energy expenditure from estimates of the amount of energy required for maintenance and milk production. This technique is based on the knowledge that maintenance energy requirements are associated with body weight of an animal and that production requirements are associated with the chemical composition and quantity of milk produced. Additional expenditures of energy need to be included if the animal is pregnant, has increased activity, or is exposed to an environment or other conditions that increase energy expenditure. Advantages of this method include longer intervals (a portion of or an entire lactation) of measurement and no need for specialized, expensive equipment.

There are opportunities for errors to occur in each method of estimating energy balance, but sources of error in this most common method are relatively apparent and most can be controlled. For example, accurate measurements of feed intake, feed energy content, body weight, milk production, and milk composition are required in this method. Of these measurements, the one with the most uncertainty is available energy content of the feed. Accurate measurement of body weight is another likely source of error. During early lactation, actual body weight of the cow decreases because body tissue is mobilized to compensate for insufficient energy intake. Feed intake increases at the same time for the same reason. Measured body weight therefore likely overestimates actual body weight and loss of body weight is underestimated. The consequence of errors associated with these measurements depends, at least in part, on how the final energy balance values will be used. For example, some errors might result in minimal problems for comparison of treatments within a study, especially if the error is similar for all treatments in the study. However, the same errors or same types of errors could pose greater problems for comparison of treatments among studies.

Body condition score (BCS) is frequently used as an indirect assessment of energy balance, but it is change in BCS rather than BCS itself that indicates energy balance during a previous interval. Change in BCS can provide a useful assessment of previous energy balance (Crooker and Otterby, 1991), but is limited due to its subjective nature and the fact that change in visceral and intermuscular fat is not included (they are not visible or palpatable) in BCS. These fat depots represent a significant proportion of mobilized body fat (Butler-Hogg et al., 1985), are mobilized quickly, and are replenished before subcutaneous fat. Thus, the cow returns to positive energy balance and begins to replenish these depots before change in BCS is apparent. Circulating concentration of non-esterified fatty acids (NEFA) can also be used as an indirect assessment of energy balance because NEFA concentrations increase when animals mobilize body tissue. However, other factors can also affect plasma NEFA concentrations so these results need to be coupled with other information about the animal to be useful.

Energy Needs of the Dairy Cow During Early Lactation

Some species (rodents and humans for example) lose very little body weight or condition during the periparturient period because they rely primarily on increased feed intake to meet the increased energy demands of lactation (Bauman, 2000). Other species (seals, bears, and baleen whales) rely almost entirely on mobilized tissue to meet the energy demands of lactation (Oftedal, 1993). Dairy cows belong to a group of species that rely upon both increased feed intake and mobilized body tissue to meet their energy needs during early lactation. As cows transition through the postpartum period, they receive signals that result in gradual increases in intake until intake meets their metabolic needs for continued milk synthesis and replenishment of tissue mobilized in early lactation. Natural consequences of the physiological mechanisms that enable the cow to achieve greater yields of milk include an interval of negative energy balance and suppressed immune and reproductive function. The proportion of milk energy derived from feed exceeds the proportion derived from mobilized tissue, but disruptions in feed intake can magnify the need to mobilize body tissue. Thus, it is imperative to provide an environment (management conditions) that encourages increased intake in early lactation.

Adjustments in feed intake occur more slowly than the periparturient increases in milk yield. For example, a daily intake of 15 kg of dry matter prepartum and an increase to 20 kg/d during the second week of lactation would be considered good for a mature Holstein cow. If the cow weighed 650 kg and produced 60 kg of 3.5% fat corrected milk (FCM) during the second week of lactation, she would need 10.3 Mcal NEL for maintenance and 41.4 Mcal of NEL for milk synthesis. If she is fed a diet that contains 1.7 Mcal/kg of dry matter, she would need to consume 6.1 kg/d to meet her maintenance energy needs. She would need to consume another 24.4 kg of the same diet to supply the energy needed to synthesize the milk she produced. An intake of 20 kg/d would only provide 34.0 Mcal/d. Despite the 33% increase in intake, her daily energy requirement increased 4 fold and she would experience a deficit of 17.7 Mcal/d. She would need to increase her intake another 10.4 kg/d to reach positive energy balance. The cow can consume 30 kg/d, but peak intake typically occurs during week 10 to 12 of lactation, some 6 to 8 weeks after peak FCM yield. The cow therefore enters a period of negative energy balance. However, duration of negative energy varies considerably among cows. Some cows achieve positive energy balance very early (before week 4), most by week 7 to 10, and others later in lactation.

This is an interactive process and, especially during early lactation, homeorhetic mechanisms within the cow function to increase energy intake to meet the increased demands of milk synthesis in a coordinated manner. The cow can accept and adapt to an episode of negative energy balance, but if energy intake is limited, production will be limited. This is an insidious problem for the producer in that the cow appears healthy, appears to be performing well with no outward or obvious indication that production is limited by an insufficient energy supply. Retrospective analysis indicates that every unit increase in peak milk yield equates to an additional 127-unit increase in total milk yield for the lactation (Baumgard et al., 2006). Although feed intake needs to be maximized so that peak milk yield is maximized, if the process is disrupted by disease or metabolic disorders, the magnitude of negative energy balance can becomes excessive or the interval prolonged and incidence of reproductive problems increased.

Effect of Increased Milk Yield on Energy Balance

Selection for milk yield and improvements in management have more than doubled milk yield per cow in the last 40 years. Genetic correlations between milk yield and reproductive measures are not favorable, so on average, selection for increased milk yield alone is expected to decrease fertility of dairy cows. Breeding programs in the US have been weighted heavily in favor of milk yield and the minimal attention to reproductive traits in the selection process has contributed to the downward trends in reproductive performance. Given the genetic correlation between milk yield and fertility, failure to select for fertility traits will make it increasingly difficult for producers to achieve sufficient reproductive performance in their herds (Weigel, 2004). Regardless of the strategy, improvements in management programs must keep pace with the continued improvements in genetic merit for milk yield. Failure to do so will eventually result in situations where management is insufficient and reproductive performance will suffer. For example, if a new mix of superior “reproductive genes” could be introduced into the cow today, management would still need to be sufficient to enable the cow and the manager to recognize that conditions were appropriate for conception. Inadequate management efforts that result in insufficient nutrition, less than optimal health, decreased cow comfort, and less effective reproductive programs have negative impacts on both lactation and reproductive performance.

Pursley et al. (1997) and Peeler et al. (2004) have reported that despite similar genetic potential for milk yield, pregnancy rates are greater in nulliparous Holstein heifers than cows. Genetics of the heifer do not change when she becomes a cow so these results provide a strong implication that either the greater milk yield of the cow or insufficient management of cow (or both) is (are) responsible for the decrease in reproductive performance. These results demonstrate the strong influence of environment, support the need for management to match phenotypic performance, and contribute to the perception that milk yield and negative energy balance impact reproductive performance. Indeed, Beam and Butler (1999) have demonstrated a significant negative association between days to energy balance nadir (its most negative value) and days to first postpartum ovulation. These results indicate recovery from the daily energy balance nadir (initiation of the return to positive energy balance) is associated with return to cyclicity. However, this association only explains about 10% of the variation in days to first postpartum ovulation (Beam and Butler, 1999).

Several studies have demonstrated that selection for increased milk yield has produced cows that partition a greater portion of their available energy to milk synthesis rather than body tissue accretion (Bauman et al., 1985; Veerkamp and Emmans, 1995; Reynolds, 2004). These results contribute to a perception that cows with a greater genetic merit to produce milk mobilize more tissue and experience a greater and more prolonged interval of negative energy balance than experienced by cows that produce less milk and that this is a major reason for reduced fertility of the contemporary cow. However, other data indicate that magnitude and duration of negative energy balance does not differ between low and high merit cows and that high merit cows simply partition more energy to milk synthesis for a greater portion of the lactation. This delays replenishment of mobilized tissue until later in lactation and is an argument for extended lactations.

We have examined effects of selection for milk yield on energy balance using contemporary cows and a population of cows that have had a stable genetic merit for milk yield since 1964 (Crooker et al., 2001). Under identical conditions and when consuming the same diet, the low producing control (1964 genetics) and high producing contemporary cows had similar negative energy balance (length and severity) through the first 70 days in milk even though milk yield of the two lines differed by more than 3,500 kg/lactation (Crooker et al., 2001). Although the contemporary cows produced more milk, they also consumed more feed. These results indicate that cows strive to reach energy balance and will do so if given the opportunity. Despite the similar energy balance, early postpartum anestrous was more prevalent in contemporary cows (Lucy and Crooker, 2001). However, cows that produce more milk partition a greater proportion of consumed energy to milk and delay when they begin to replenish tissue previously mobilized. It should not be surprising that they also delay when they partition sufficient energy towards other functions, including reproduction.

Energy Balance and Reproductive Performance

Severity and duration of negative energy balance during early lactation vary with body condition score (BCS) at calving, parity, milk yield, management and environmental factors (Macmillan et al., 1996). Although increased milk yield has been associated with reduced BCS and a greater negative energy balance (Berry et al., 2003), several studies have demonstrated that milk yield is not an absolute indicator of negative energy balance and that variation in energy balance during early lactation is more associated with energy intake (Staples et al., 1990; Crooker et al., 2001). Cows that were anestrous during the first 63 d postpartum consumed less feed, produced less milk, and lost more body reserves than cows that resumed estrous activity prior to 63 days in milk (Staples et al., 1990). Did these cows experience something that limited feed intake? Increased milk yield and good reproductive performance do occur in many dairies and indicate the important role of management in reproductive performance (Lucy, 2001). However, even within well-managed herds, the highest producing cows do not necessarily have the poorest reproductive performance. Plots of accumulated energy balance during the first 28 days postpartum against days to first increase in plasma progesterone typically indicate no discernable pattern among healthy herdmates identified as low, medium, or high producers or when identified as pregnant or nonpregnant by 100 days in milk. Some high producing cows have large energy deficits in early lactation, yet begin to cycle soon after calving and conceive at their first insemination after the voluntary wait period. What is different between these cows and their apparently healthy herdmates that produce less and have minimal to moderate energy deficits, yet fail to cycle and fail to conceive?

Fertility and reproductive performance have been more associated with changes in BCS than with daily milk yield. Days to first postpartum ovulation increased from 30 d when cows lost 0.5 units or less of body condition to 50 d when cows lost more than 1 unit of BCS during the first month of lactation (Beam and Butler, 1999). Negative energy balance and loss of body weight and condition have a negative impact on follicular growth and development. A reduction in energy balance is accompanied by an increase in the number of small (3-5 mm) and medium (6-9 mm) follicles and a decrease in the number of large (>10 mm) follicles (Lucy et al. 1991a; 1991b). Pulse frequency of LH is decreased in cows in negative energy balance. During the early postpartum period, follicular dynamics in cows in poor condition are characterized by waves of follicular growth and artresia without ovulation (Lucy, 2001). In addition, during intervals of negative energy balance, dominant follicles in cows require more time and need to attain a larger size before blood estradiol concentration is sufficient to induce ovulation (Lucy, 2001). Even though lactating cows have larger ovulatory follicles, they have similar or lower circulating estradiol concentrations than dry cows or heifers (Sartori et al, 2002; Sartori et al, 2004). This indicates reduced synthesis by the follicle and/or greater metabolism contribute to reduced estradiol concentrations in the lactating cow.

Growth and development of follicles during periods of negative energy balance lead to impaired development of the corpus luteum (CL) and reduced progesterone secretion (Butler, 2000). Cows that produce more milk have smaller CL in early lactation (Lucy, 2000) and CL size has been correlated positively with circulating progesterone concentration (Sartori et al., 2002). In addition, clearance rates of progesterone increase with feed intake due, in part, to an increase in hepatic metabolism (Sangsritavong et al, 2000). Therefore, both decreased synthesis and increased metabolism contribute to reduced progesterone in cows that produce more milk.

In addition to reduced concentrations of steroid hormones, duration of estrus is about 15 h in cows that produce 25 to 30 kg/d but is less than 5 h in cows that produce more than 40 kg/d (Lopez et al., 2004). Wiltbank et al. (2006) used these results to develop a physiological model to explain at least a portion of the reduced reproductive performance of the contemporary dairy cow. They propose that circulating estradiol concentrations increase at a slower rate in the high producing cow due to the greater rate of steroid metabolism. This allows a greater time for follicular growth because it takes longer to elevate estradiol sufficiently (combination of concentration and time) to induce a GnRH/LH surge. In addition to the reduced initial concentration, estradiol concentration is likely reduced more rapidly due to the more rapid rate of steroid metabolism. This reduces duration of estrus. Longer exposure of the follicle and oocyte to elevated LH pulses likely produces a prematurely activated, less fertile oocyte. Thus, the producer has less time to detect estrus and if the cow is bred, the resulting oocyte is less fertile.

Changes in circulating concentrations of hormones that regulate intermediary metabolism of carbohydrate, fat, and protein also occur. Glucose is the major source of energy for the bovine ovary (Rabiee et al., 1999) and preovulatory follicular status is associated with increased intrafollicular insulin and glucose concentrations. These results suggest insulin is involved in follicular maturation and the effect of short-term nutrition on ovulation rate may be mediated by a direct ovarian action of insulin and glucose (Downing et al., 1999; Landau et al., 2000). Furthermore, insulin concentration follows an estrous-like rhythm in that it peaks around estrous. This indicates insulin is most important during the follicular phase (Landau et al., 2000). It has been suggested that insulin is also a key regulator of estradiol production (Wathes et al., 2003).

In early lactation, cows are in negative energy and nutrient balance and expression of the liver-specific isoform of the growth hormone receptor (GHR-1A) is reduced (Radcliff et al., 2003; 2006). Reduced hepatic GHR-1A expression likely contributes to the reduced circulating concentrations of IGF-I. Although hepatic expression of GHR-1A appears to return to prepartum values by 21 DIM in well-fed cows (Radcliff et al., 2006), concentrations of IGF-I remain reduced for a longer duration in high merit cows (Crooker et al., 2001; Gong, 2002). Circulating concentration of IGF-I is important for initiation of cyclicity and in the development and fertility of the oocyte (Thatcher, 2006). Retrospective analysis indicates that circulating IGF-I concentrations are reduced in cows that fail to conceive (Taylor et al., 2004). These differences are likely related to differences in metabolism and have a strong impact on follicle and CL development (Thatcher et al., 2006). They also likely reflect homeorhetic alterations associated with the metabolic drive to partition nutrients toward greater milk yield.

Summary

Reproductive success is the result of multiple relationships among several factors including genetics, nutrition, cow comfort and health. Because postpartum intakes are initially insufficient to meet the metabolic demands of lactation, cows experience a postpartum interval of insufficient dietary nutrient and energy supply. Negative energy balance is one factor that has adverse effects on reproductive performance. Considerable variation in the duration of negative energy balance exists among cows and is affected by the environment and the ability of the cow to effectively partition nutrients and energy toward the production of milk. As long as the cow is healthy and management is not limiting her lactation or reproductive performance, variation in the onset of reproductive function postpartum should be expected. After cows return to positive energy balance, conception could be delayed further due to decreased circulating steroid concentrations as a result of increased feed intake and metabolism. Some normal, healthy cows might not be able to achieve a 12-month calving interval because their ability to partition nutrients and energy into milk remains a greater priority than reproduction for a longer interval.

A greater understanding of energy balance, the physiological changes that occur in early lactation, and how energy balance impacts these changes can improve our ability to feed and manage the dairy cow to simultaneously minimize occurrence of health and reproductive problems and increase milk yield.

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Energy Balance and Dairy Cattle Reproduction

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Normal Reproductive Cyclicity

Reproduction is a finely tuned, complicated process consisting of hormones, target tissues, and a centrally located neural control system. Simplistically, normal reproductive function is the result of carefully coordinated processes under the control of the hypothalamic-pituitary-ovarian (HPO) axis. While these three structures do not control all aspects of reproduction, they serve as a great starting point in understanding the complexities surrounding follicular development, ovulation, luteinization and overall control of the bovine estrous cycle. (Note: much of the information regarding normal reproductive physiology was taken from Senger's textbook Pathways to Pregnancy and Parturition)[1]

The hypothalamus is a very specialized area of the ventral portion of the brain that is divided into a surge center, a tonic center and the paraventricular nucleus (PVN), each of which has a direct role in the control of reproduction. The surge and tonic centers both produce gonadotropin releasing hormone (GnRH) while the PVN produces oxytocin. The hypothalamus produces the GnRH that is responsible for causing the release of follicle stimulating hormone (FSH) and luteinizing hormone (LH) from the pituitary gland. These gonadotropins are responsible for controlling many aspects of follicular development and ovulation.

Normal cyclicity requires a functional hypothalamic-pituitary-ovarian axis. The tonic center of the hypothalamus secretes GnRH in a spontaneous, pulsatile pattern. These pulsatile episodes occur about every 2 hours in the absence of progesterone, but in the presence of progesterone, such as in the luteal phase of the cycle, these episodes only occur every 4-6 hours. The hypothalamus secretes GnRH into a portal vasculature that flows directly to the anterior lobe of the pituitary gland and results in secretion of FSH and LH from the pituitary gland. These two hormones are released into systemic circulation and travel to the ovaries, where they help regulate follicular dynamics and ovulation.

The third component of the HPO axis is the ovary. The ovary is the site of follicular development, ovulation, and luteinization and its structures respond to gonadotropins, but not in a one-way fashion. Follicular recruitment, growth, development and death are an ongoing process. Small groups of follicles are recruited by the pulsatile action of FSH and begin to grow in size. During the early part of this growth phase, levels of FSH are high, while LH, estradiol, and inhibin levels remain low. Follicles grow at different rates and some begin to produce estradiol and inhibin. Estradiol works in a positive feedback manner once its concentration reaches a critical threshold to cause a surge release of LH via increased secretion of GnRH from the hypothalamus. On the other hand, estradiol (along with inhibin) causes a negative feedback on the production of FSH. Larger follicles are able to adapt and continue growing despite the lower levels of FSH by becoming more dependent on LH. Smaller, less developed follicles are not able to continue growing and undergo a degenerative process of atresia. This selection process leads to the formation of one or sometimes two dominant follicles that will continue to grow in size and function until receiving the signal to ovulate. Cows exhibit behavioral signs of estrus once the level of estradiol reaches a critical threshold. This rising level of estradiol from the healthy dominant follicle creates a positive feedback on GnRH production leading to a surge in LH levels, which induces ovulation of the dominant follicle. Typically, ovulation occurs 24-32 hours after the onset of standing estrus and about 28 hours after the surge in LH.

As the dominant follicle ovulates and releases the oocyte, tiny blood vessels in the wall of the follicle also rupture, resulting in bleeding and ultimately, the formation of a blood clot in the cavity that previously held the follicular fluid and oocyte. This bloody structure, called a corpus hemorrhagicum, is present for 1-3 days and is the early precursor of the CL. It is comprised of the newly formed blood clot, along with granulosa and theca cells which once lined the follicle.

These two types of cells undergo hypertrophy and hyperplasia, respectively, over the next several days and become the corpus luteum (CL). The corpus luteum will produce progesterone during the luteal phase of estrus, which will last 10-12 days. Progesterone will act on the hypothalamus to dampen the frequency of GnRH pulses. As a consequence, new follicular waves are initiated from the lower level pulsatile secretions of FSH, but due to the depressed release of GnRH, LH levels fail to rise sufficiently to result in ovulation. Once progesterone levels decline as a consequence of normal luteolysis, rising estradiol levels can once again induce the necessary rise in LH to induce ovulation.

Progesterone also has an indirect effect on expression of estrus. Cows do not normally display estrus while under the influence of progesterone, but progesterone still has a very important role in the display of estrus that often is overlooked. The first post-partum ovulation is often called a “silent heat” because cows do not display estrus despite having a normal rise in estradiol and experiencing ovulation of a dominant follicle. The reason for this truly silent heat is that there has not been adequate priming of the behavioral centers of the brain by progesterone. After the first ovulation, a corpus luteum forms that produces progesterone that primes the behavioral centers and facilitates behavioral expression of estrus at the next ovulation.

In order for cows to achieve ovulation and express estrus, they must first remove the effects of progesterone produced by the corpus luteum (CL). The process of decomposition of the CL is termed luteolysis and occurs during a one to three day period towards the end of the normal estrous cycle. Interestingly enough, the CL initiates its own demise. After a period of progesterone priming as a result of the CL’s production of progesterone, the endometrial oxytocin receptors become activated. Activation is the consequence of increasing estradiol levels from the growing, but doomed, dominant follicle that precedes the follicular wave containing the ovulatory follicle. The cow’s CL contains surprisingly large quantities of oxytocin. The activation of the oxytocin receptors in the endometrium by oxytocin leads to the release of prostaglandin F2? (PGF2?). The release of PGF2? is not an all or none scenario, but rather occurs in pulses. Oxytocin release causes a release of PGF2? from the endometrium, which in turn causes ovarian oxytocin release in a positive feedback manner. Multiple pulses of PGF2? over a 24-hour period are required to induce luteolysis and the high pulsatile release then continues for approximately two additional days. When cows become pregnant, the developing conceptus produces a substance known as interferon tau that serves to block the activation of the oxytocin receptors prior to the onset of luteolysis. This signal must occur by day 15-17 of the cycle or normal luteolysis will occur despite the presence of an early pregnancy.

Post-partum Physiology and the Onset of Cyclicity

During pregnancy, progesterone levels are elevated and cause a negative feedback on the hypothalamus, thus preventing LH secretions from occurring sufficiently to promote complete follicular development and ovulation. Follicular activity continues to occur, even during pregnancy, but high progesterone levels depress GnRH activity, which in turn, prevents follicles from developing to the point of achieving ovulatory capacity by depressing levels of LH.

After calving, progesterone levels are very low and remain this way for a period of three weeks to three months or more. During this time, small cohorts of follicles may develop, but are unable to mature to ovulatory capacity and their size does not usually exceed 8 mm in diameter. Estradiol levels do not rise significantly, cows do not show heat (anestrus), and ovulations do not occur (anovulatory). This condition is often called AA for anestrus and anovulatory and cattle can experience AA for a variety of reasons including pregnancy, lactation / presence of a calf, stress, and health problems.

The periparturient period in dairy cattle is a time of rapidly increasing energy demands from milk (and colostrum) production and a slowly increasing, but lagging, feed intake. Energy balance (EB), defined as the difference between dietary intake of utilizable energy and the energy expended for body maintenance and milk production, goes negative due to the discrepancy between energy input and output.[2] In normal dairy cows, regardless of milk production level, this negative energy balance (NEB) is usually at its most negative point (energy balance nadir) during the first 1-2 weeks after calving. After this NEB nadir, the cow’s energy intake increases as her feed intake continues to rise, resulting in positive energy balance. For most normal animals, positive energy should be reached by 45-60 days in milk, but may be delayed until 10-12 weeks in lactation or beyond.[3] However, due to the poor sensitivity of body condition scoring, producers or consultants may not recognize a positive change in body condition until 120 days in milk or later.

As an evolutionary protective mechanism, the dairy cow has developed a way to partition energy so that she is more likely to pass her genes on to the next generation. Her first priority is maintenance of self, followed by the protection of the current offspring in the form of ensuring production of milk. In this hierarchy, once an animal has provided for itself and its current dependent offspring, it will then use energy to produce the next offspring by putting nutrients and energy toward reproductive purposes (producing the next generation). As a result, reproduction is a type of luxury, occurring only after there are positive signs that the negative energy problem is improving.

The resumption of cyclicity is dependent upon the resumption of the normal pulsatility of LH release. Follicle stimulating hormone pulses actually resume within the first 2-7 days in most cows. Cyclicity (first postpartum ovulation) resumes before positive energy balance is reached, but after the energy balance nadir. Canfield and Butler showed time to first ovulation to be a function of days to NEB nadir (1^{st} Ovulation = 10.4 + 1.2*Days to nadir, r^2 = 0.77).[4,5] In their work, nadir occurred at approximately 14 days in milk for lactating cows, thus putting first ovulation at 27 days.

Much attention has been placed on finding a direct signal or link between energy balance and the resumption of LH activity. During periods of negative energy balance, the cow will metabolize fat stores to meet her energy demands, but this utilization of fat does not yield a net increase in glucose. The mobilization of fat leads to increased blood levels of non-esterified fatty acids (NEFA). Later, we will see how elevated levels of NEFA and depressed levels of glucose can have direct effects on oocyte and embryonic quality. The compound with the greatest evidence of having a direct effect on LH secretion is insulin-like growth factor 1(IGF-1). IGF-1 receptors have been found in the hypothalamus and the anterior lobe of the pituitary. Work by Zurek did not find a link between IGF-1 levels and duration of ovarian recovery, but there was a positive association between IGF-1 and LH pulse frequency.[6] Their conclusion was that IGF-1 may act as a mediator of ovarian recovery, instead of being the direct signal.

Impact of NEB on Reproductive Performance and Management:

Negative energy balance in early lactation is the largest contributor to nutritionally-related reproductive challenges in the dairy cow. A meta-analysis by Lopez-Gatius et al., demonstrated a large, negative effect of early lactation NEB, as evaluated by changes in body condition score, on first service conception risk and number of days open.[7] Cows experiencing more than 1 body condition score (BCS) loss had a 10% reduction in first service conception risk and accumulated an average of 11 more days open as compared to cows losing less than 0.5 BCS. In other work, Butler and Smith demonstrated that cows losing > 1 BCS had a first service conception risk of 17% as compared to 53% for cows only losing 0.5 to 1 BCS from calving to first service.[8]

More recent work by Walsh et al., also illustrates the impact that NEB and the resulting postpartum anovulatory condition has on reproductive performance.[9] Their work utilized approximately 1300 cows located in 18 herds and classified cows as anovular if progesterone levels from skim milk samples taken 14 days apart at 46 and 60 days in milk were less than 1.0 ng/ ml. Anovular cows inseminated using timed AI were 55% less likely to conceive to first insemination and had a median days open of 156 vs 126 for cycling cows (figure 1).

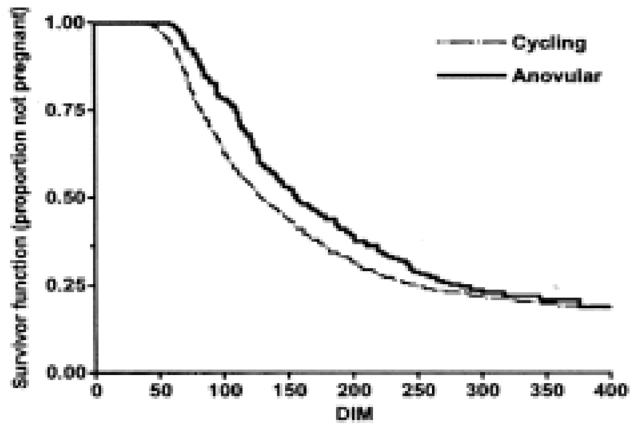

Figure 1. Calving-to-conception survival analysis curves for 1,341 lactating dairy cows classified as cycling or anovular based on skim milk progesterone levels > 1 ng/ml at 46 and 60 days in milk. (J Dairy Sci 2007; 90:315-324)

There is little doubt regarding the negative effects of prolonged or more extreme NEB on reproductive performance of dairy cattle. The net result of this problem is prolonged calving-to-conception intervals and greater probability of culling due to reproductive failure. Energy balance issues can exert their effect on reproductive efficiency through several different ways. One way is through impaired GnRH secretion from the hypothalamus which leads to inadequate LH release from the anterior pituitary. There is evidence that LH pulse frequency may be adjusted or regulated by serum insulin and IGF-1 concentrations. These compounds usually reflect a cow's nutrient status, rising as dry matter intake increases during the postpartum period.[10]

As a consequence, there can be a couple of scenarios for the cow that is emerging from the effects of NEB. In scenario one, there is inadequate LH pulsatile secretion to continue follicular growth. Small follicles emerge with a new follicular wave since FSH levels are usually not a problem. However, due to the inadequate LH support, small follicles are not able to continue growing and instead, undergo atresia within days of the start of a follicular wave. With the aid of ultrasound, in cows with inadequate LH support, we would see small "static" ovaries with very little follicular activity or alternatively, see multiple very small follicles less than 8 mm in diameter.[11]

In the second scenario, there is partial recovery of the hypothalamus/ GnRH with adequate pulsatile release of LH, but failure to achieve a surge release. As a consequence, one might find large follicles (10-25 mm in diameter) and/ or follicular cysts (follicular structure $\geq$ 25 mm present and persistent for 10 days or more, but in the absence of a CL).[12] In either case, there is inadequate/ unhealthy growth leading to poor quality follicles.

In these AA cows, estrogenic function is compromised and errors result in heat detection. Cows with small follicles that turn over rapidly should never truly display signs of estrus and cows with large follicles or follicular cyst would have estrogenic potential but probably would not express estrus due to the absence of progesterone priming of the behavioral centers of the brain. If these follicles are forced to ovulate via exogenous administration of GnRH, fertility is depressed, at least to that ovulation.

Negative energy balance can also affect oocyte quality and developmental competence of early embryos. Cows in NEB have varying levels of clinical or subclinical ketosis and the presence of ?-hydroxybutyrate (BHBA), or perhaps, more importantly, the reduced levels of glucose, may have direct effects on early embryonic development following fertilization. Leroy et al., exposed developing oocytes to different levels of glucose and BHBA and then used in vitro fertilization techniques to create embryos that could then be followed through various stages of development.[13] Under conditions that mimicked subclinical and clinical ketosis, they observed impaired early embryonic development including blocked cumulus expansion and a reduced blastocyst rate. Additional work by some of the same research group showed a negative effect of NEB, non-esterified fatty acids (NEFA), and BHBA on follicular steroidogenesis of granulosa cells.[14,15] Granulosa cells become large luteal cells after ovulation and luteinization, and together with theca (small luteal cells), are the cells in the corpus luteum that produce progesterone. If steroidogenesis is impaired, future production of progesterone is likely to be depressed, resulting in impaired fertility, ie., lower follicular quality, less intensive signs of estrus, decreased probability of fertilization, and increased risk of embryonic loss.

An entirely separate pathway for impaired fertility due to NEB relates to the systemic effects on liver and immune function. Cows that must mobilize excessive amounts of protein and adipose tissue undoubtedly experience ketosis, impaired liver function and impaired neutrophil function. Cows are designed to conserve glucose and to utilize ketones, but in somewhat limited amounts. If excessive triglycerides are broken down in response to energy demands, NEFA levels in the circulation increase. Once in circulation, NEFA's have 3 potential fates: 1) they can be utilized by the mammary gland for milk fat synthesis, 2) they can be used by peripheral tissue as energy source (but with no net production of glucose), or 3) they can be re-esterified by the liver into triglycerides. Once in the liver, these fats can be incorporated into very low density lipoproteins and exported out or they accumulate in the liver due to failed or slow export. Unfortunately for cows, fatty accumulation in the liver is a very common sequela due to a limited capacity to produce apoprotein B, a compound necessary for exportation of fats. Negative protein balance combines with NEB to impair immune function. Severe or prolonged energy deficiency can lead to an accumulation of ketoacids in the blood, impairing lymphocyte, neutrophil, and macrophage function. The result is an overwhelmed, fatty liver with impaired function and an increased risk of metritis, endometritis, and reduced fertility.

Artificial insemination has been a wonderful tool for dairies to improve their rate of genetic progress, decrease dystocia risk, increase cow units (by decreasing resources dedicated to natural service sires), remove the dangers of handling and housing bulls, and in many cases, improve the reproductive efficiency of the herd. However, the limiting factor in most cases is usually estrus detection. Dairy cattle are often maintained on concrete floors that may not offer the traction necessary to facilitate optimal expression of estrus and lameness issues may preclude normal expression. As a consequence of the heat detection challenges, synchronization strategies such as Presynch, Ovsynch, and Cosynch, have become very popular. These strategies can be negatively impacted by EB, but in some cases, these protocols can actually be utilized to mitigate some of the issues created by NEB.

Many herds have begun using a combination of Presynch-Ovsynch or Presynch-Cosynch to manage first insemination in dairy herds. In either case, two injections of prostaglandin are given 12-14 days apart, prior to the first GnRH injection of the Ovsynch or Cosynch protocol (as shown in figure 2). The rationale for the early prostaglandins is two-fold. One, cows that have endometritis or subinvolution

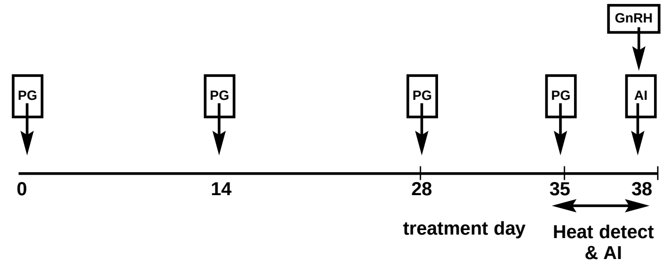

Figure 2. An example of the scheduling of the combination of Presynch-14 and Cosynch-72.

present may benefit from estrus induction and removing the effects of progesterone. Second, cows have a higher expected conception risk to the timed AI of either Ovsynch or Cosynch if the first GnRH is given at the optimal time of the cow's cycle.

However, cows that struggle with NEB will not have a CL present at the first injection (depending on the starting time), often do not have one by the second prostaglandin injection, and sometimes have not begun cycling by the start of Ovsynch or Cosynch. These problems are compounded in herds that insist on starting their Presynch series prior to 30 days in milk. As noted previously, work by Canfield and Butler suggested that first ovulation in normal cows would occur at around 27 days in milk.[4,5] In order to get a consistent treatment response, prostaglandin should not be given until about day-6 of the estrous cycle. Putting this information together suggests that in order to maximize expected responsiveness, the first injection of Presynch probably should not be given across a population of lactating dairy cows until at least 33 days in milk.

As a consequence of the impact of NEB on first ovulation and cyclicity, apparent conception risk to the various timed AI protocols can be negatively affected. In work by Santos et al., cycling cows completing a Presynch-Ovsynch that included estrus detection or timed AI had a first cycle pregnancy rate of 40% as evaluated at 31-d.[16] In the same study, cows classified as anestrus had an average first cycle pregnancy rate of only 26%. The reproductive management approach used in this study is similar to the management plan used by many dairies. An examination of the range in values between cycling and anestrus cows illustrates one potential source of variation for on-farm reported conception results – differences in proportion of cows cycling by the start of the breeding period.

Another costly impact on reproductive performance that is associated with NEB is an increased risk of pregnancy loss. Cows that are not cycling are not normally inseminated based on heat detection since these cattle do not actually show heat, but with timed AI programs, pregnancies do occur, albeit with a lower probability. However, cows that succeed in becoming pregnant have been shown to have a higher risk of pregnancy loss. In the previously mentioned study by Santos et al., pregnancies were evaluated at 31-d post-insemination and then again at 45-d. Cows classified as cycling incurred a pregnancy loss of 10.4% vs 17.5% loss for anestrus cows evaluated in the same manner. One potential reason for greater loss pertains to the level of progesterone as previous work has shown an association between lower progesterone levels and increased risk of loss.[17,18] Anestrus cows that conceive to a timed AI (and any cow that conceives during periods of NEB) are more likely to have compromised CL's that produce lower levels of progesterone.[19] The CL of pregnancy forms from the previously ovulated follicle and in anestrus cows, this follicle developed under conditions of low progesterone.

Limiting the Impact of NEB on Reproduction:

The incidence of anovulatory cows at the end of the voluntary waiting period varies widely from herd to herd with estimates of 10 to over 50%. However, many consider 20% as a typical mean when cows are evaluated at approximately 50-60 days in milk.[9] There are a variety of ways to try to limit the impact of NEB on reproduction, but the first priority should be on decreasing the incidence of cows experiencing prolonged or more severe NEB. Nutritional management is critical, but this paper will not address specific transition / fresh cow feeding approaches such as high fiber vs increased carbohydrate transition strategies, or high fat vs high protein vs one group fresh cow feeding approaches. Regardless of the specific approach, perhaps the most important consideration is total dry matter intake. Management should concentrate on removing stressors that limit feed intake or increase energy demands such as overcrowding, excessive pen moves, mixed parity grouping, heat stress, poor cow comfort, and excessive idle standing.

Once it is determined that a high proportion of cows are anovulatory, there are limited options for trying to induce cyclicity and these approaches typically involve increasing the level of circulating progesterone. Progesterone is very important to fertility, both for the quality of the developing follicle and for the maintenance of pregnancy following fertilization. Previous work has shown a positive correlation between serum progesterone prior to AI and the subsequent conception risk.[20] One approach to improve fertility during or shortly after periods of NEB is to provide additional progesterone during the reproductive protocol prior to insemination. A couple of options are supported by research using some form of progesterone-containing intravaginal insert. In the U.S., the only legally approved product for use in lactating dairy cows is the CIDR®, an intravaginal insert containing 1.3 mg progesterone that is approved for use at 14-d post-insemination for resynchronization of estrus. However, its use in any other manner is considered extra-label and should only be done under the direction of a licensed veterinarian. Work by Folman et al., demonstrated a higher conception risk in cows that received a progesterone-releasing intravaginal device during the 7-d preceding the second prostaglandin injection in a Presynch-14 program. However, these cows were inseminated based on detection of estrus and not timed AI. Chebel et al., examined the effectiveness of CIDR on induction of cyclicity and on fertility in anovulatory cattle.[21] In this study, a CIDR was used in conjunction with a modified Presynch-Ovsynch protocol using the following schedule: injection of prostaglandin at d-35 and 49, CIDR from d-42 to 49 and either estrus detection or timed AI using

Ovsynch-24 at d-72. The use of the CIDR in this manner increased induction of cyclicity by d-62 in anovulatory cows but did not improve fertility.

An alternative approach that is gaining in popularity is the use of a CIDR within a traditional Ovsynch protocol. In this case, the CIDR insert is placed in the cow at the time of the first GnRH injection and is removed 7-d later at the time of prostaglandin injection. Work in noncycling suckled beef cows showed improved conception risk following heat detection-based insemination or timed AI.[22] In dairy cattle, there have been somewhat mixed results depending upon cycling status, with strong support for the use of CIDR in anovulatory cows to provide additional progesterone during a timed AI protocol.[23] Stevenson et al., performed a large, multi-site trial and showed that non-cycling cows treated with Ovsynch+CIDR had a conception risk of 33% vs. only 17% for Ovsynch treated cows.[24] Also, in the same study, cycling cows benefited from use of a CIDR, but only if there was not an active CL prior to the prostaglandin injection (Ovsynch+CIDR = 38% vs. Ovsynch = 19%). Overall, pregnancy loss between the first examination at 28-d and the second exam at 56-d was greater for noncycling cows, but incorporation of the CIDR into the protocol resulted in less pregnancy loss for noncycling cows that did not have a CL induced by the first GnRH injection (Ovsynch+CIDR = 24% loss vs Ovsynch = 42% loss). As a result of these studies, it appears that noncycling cows may benefit from going through the Ovsynch protocol, especially when combined with a CIDR. Noncycling cows that have a large follicle present typically respond to the first GnRH by developing a CL and these cows have higher conception risk and lower pregnancy losses than nontreated cows.

Conclusion

Just as the reproductive function of dairy cattle is a complex system of tissues and hormones, so is their postpartum metabolic function. The interactions between the metabolic and reproductive pathways following parturition involve many different signals that still have not been completely elucidated. In short, the period of NEB that follows calving inhibits normal secretion of LH and delays first ovulation. It is not until the cow has turned the corner and is headed toward a positive EB that the HPO axis is signaled to begin partitioning energy to ovulation and reproduction. In order to maximize early return to cyclicity in high producing cows, the period of NEB must be shortened and decreased in magnitude. There are many nutritional and management strategies that have been proposed, but the main goal is to minimize the prepartum depression in feed intake and to maximize feed intake in the postpartum period. For cows that are suffering from prolonged anovulatory condition as a consequence of NEB, progesterone is key to reestablishing normal cyclicity. Exogenous progesterone in the form of CIDR's or utilization of synchronization programs such as Ovsynch or Cosynch to induce ovulation of a growing follicle can improve reproductive performance. However, care should be taken to reevaluate early pregnancies since these cows are prone to a higher risk of embryonic loss.

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The Effects of Heat Stress on Energy Balance and Metabolism

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Introduction

Heat stress negatively impacts a variety of dairy parameters including milk yield and reproduction and therefore is a significant financial burden (~$900 million / year in the USA; St. Pierre et al., 2003) in many dairy-producing areas of the world. This is probably a conservative estimate as last years heat wave may have cost the California dairy industry close to $1 billion and some meteorological experts predict 2007 will be considerably warmer than in 2006. Advances in management (i.e. cooling systems; Armstrong, 1994; VanBaale et al., 2005) and nutritional strategies (West, 2003) have alleviated some of the negative impact of thermal stress on dairy cattle, but production continues to decrease during the summer. Accurately identifying heat stressed cows and understanding the biological mechanism(s) by which thermal stress reduces milk synthesis and reproductive indices is critical for developing novel approaches (i.e. genetic, managerial and nutritional) to maintain production or minimize the reduction in dairy cow productivity during stressful summer months.

Biological Consequences of Heat Stress

The biological mechanism by which heat stress impacts production and reproduction is partly explained by reduced feed intake, but also includes altered endocrine status, reduction in rumination and nutrient absorption, and increased maintenance requirements (Collier and Beede, 1985; Collier et al., 2005) resulting in a net decrease in nutrient / energy availability for production. This decrease in energy results in a reduction in energy balance (EBAL), and partially explains (reduced gut fill also contributes) why cows lose significant amounts of body weight when subjected to heat stress.

Reductions in energy intake during heat stress result in a majority of lactating cows entering into negative energy balance (NEBAL), and this is likely stage of lactation independent. Essentially, because of reduced feed and energy intake the dairy cow is putting herself in a bioenergetic state, similar (but not to the same extent) to the NEBAL observed in early lactation. The NEBAL associated with the early postpartum period is coupled with increased risk of metabolic disorders and health problems (Goff and Horst, 1997; Drackley, 1999), decreased milk yield and reduced reproductive performance (Lucy et al., 1992; Beam and Butler, 1999; Baumgard et al., 2002; 2006). It is likely that many of the negative effects of heat stress on production, animal health and reproduction indices are mediated by the reduction in EBAL (similar to the way it is during the transition period). However, it is not clear how much of the reduction in performance (yield and reproduction) can be attributed or accounted for by the biological parameters effected by heat stress (i.e. reduced feed intake vs. increased maintenance costs).

Effect of Heat Stress on Rumen Health

Heat stress has long been known to adversely affect rumen health. One way cows dissipate heat is via panting and this increased respiration rate results in enhanced CO_2 (carbon dioxide) being exhaled. In order to be an effective blood pH buffering system, the body needs to maintain a 20:1 HCO_3^- (bicarbonate) to CO_2 ratio. Due to the hyperventilation induced decrease in blood CO_2, the kidney secretes HCO_3^- to maintain this ratio. This reduces the amount of HCO_3^- that can be used (via saliva) to buffer and maintain a healthy rumen pH. In addition, panting cows drool and drooling reduces the quantity of saliva that would have normally been deposited in the rumen. Furthermore, due to reduced feed intake, heat-stressed cows ruminate less and therefore generate less saliva. The reductions in the amount of saliva produced and salivary HCO_3^- content and the decreased amount of saliva entering the rumen make the heat stressed cow much more susceptible to sub-clinical and acute rumen acidosis (see review by Kadzere et al., 2002).

Due to the reduced feed intake caused by heat stress and the heat associated with fermenting forages, nutritionists typically increase the energy density of the ration. This is often accomplished with extra concentrates and reductions in forages. However, this needs to be conducted with care as this type of diet can be associated with a lower rumen pH. The combination of a "hotter" ration and the cows reduced ability to neutralize the rumen (because of the reduced saliva HCO_3^- content and increased drooling) directly increases the risks of rumen acidosis and indirectly enhances the risk of negative side effects of an unhealthy rumen (i.e. laminitis, milk fat depression, etc.).

Metabolic Adaptations to Reduced Nutrient Intake

A prerequisite of understanding the metabolic adaptations which occur with heat stress, is an appreciation of the physiological and metabolic adaptations to thermal-neutral NEBAL (i.e. underfeeding or during the transition period).

Cows in early lactation are classic examples of when nutrient intake is less than necessary to meet maintenance and milk production costs and animals typically enter negative energy balance (Moore et al., 2005a). Negative energy balance is associated with a variety of metabolic changes that are implemented to support the dominant physiological condition of lactation (Bauman and Currie, 1980). Marked alterations in both carbohydrate and lipid metabolism ensure partitioning of dietary derived and tissue originating nutrients towards the mammary gland, and not surprisingly many of these changes are mediated by endogenous somatotropin which is naturally increased during periods of NEBAL (Bauman and Currie, 1980). One classic response is a reduction in circulating insulin coupled with a reduction in systemic insulin sensitivity. The reduction in insulin action allows for adipose lipolysis and mobilization of non-esterified fatty acids (NEFA; Bauman and Currie, 1980). Increased circulating NEFA are typical in “transitioning” cows and represent (along with NEFA derived ketones) a significant source of energy (and are precursors for milk fat synthesis) for cows in NEBAL. Post-absorptive carbohydrate metabolism is also altered by the reduced insulin action during NEBAL with the net effect of reduced glucose uptake by systemic tissues (i.e. muscle and adipose). The reduced nutrient uptake coupled with the net release of nutrients (i.e. amino acids and NEFA) by systemic tissues are key homeorhetic (an acclimated response vs. an acute/homeostatic response) mechanisms implemented by cows in NEBAL to support lactation (Bauman and Currie, 1980). The thermal-neutral cow in NEBAL is metabolically flexible, in that she can depend upon alternative fuels (NEFA and ketones) to spare glucose, which can be utilized by the mammary gland to copiously produce milk.

Production Adaptations to Heat Stress

Heat stress reduces both feed intake and milk yield and the decline in nutrient intake has been identified as a major cause of reduced milk synthesis (Fuquay, 1981; West, 1994). However, the exact contribution of declining feed intake to the overall reduced milk yield remains unknown. To evaluate this question, we utilized a group of thermal neutral pair-fed animals to eliminate the confounding effects of nutrient intake. Lactating Holstein cows in mid-lactation were either cyclically heat stressed (THI = ~80 for 16 hrs/d) for 9 days or remained in constant thermal neutral conditions (THI = ~ 64 for 24 hrs/d) but pair-fed with heat stressed cows to maintain similar nutrient intake. Cows were housed at the University of Arizona’s ARC facility and individually fed ad libitum a TMR consisting primarily of alfalfa hay and steam flaked corn to meet or exceed nutrient requirements (NRC, 2001). Heat stressed cows had an average rectal temperature of ~105° F during the afternoons of the treatment implementation. Heat stressed cows had an immediate reduction (~5 kg/d) in dry matter intake (DMI) with the decrease reaching nadir at ~ day 4 and remaining stable thereafter (Figure 1). As expected and by design, thermal-neutral pair-fed cows had a feed intake pattern similar to heat stressed cows (Figure 1). Heat stress reduced milk yield by ~14 kg/d with production steadily declining for the first 7 days and then reaching a plateau (Figure 2). Thermal neutral pair-fed cows also had a reduction in milk yield of approximately 6 kg/d, but milk production reached its nadir at day 2 and remained relatively stable thereafter (Figure 2). This indicates the reduction in DMI can only account for ~40-50% of the decrease in production when cows are heat stressed and that ~50-60% can be explained by other heat stressed induced changes.

Despite the fact that producing additional milk results in extra metabolic heat production, bST has demonstrated to be effective in a variety of management and environmental conditions (Collier et al., 2005). The mechanism by which bST remains effective during heat stress is due to its homeorhetic properties as it causes increased milk production via coordinating metabolism in almost all body tissues (Collier et al., 2005). This coordination includes an increased capacity to sweat and thus an enhanced ability to dissipate heat (Manalu et al., 1991).

To evaluate the effectiveness of rbST during extreme heat stress, we used lactating Holstein cows in mid-lactation that were either cyclically heat stressed (THI = ~80 for 16 hours/day) for 7 days or remained in constant thermal neutral conditions (THI = ~ 64 for 24 hours/day) but pair-fed with heat stressed cows to maintain similar nutrient intake. On the 7th day, both heat-stressed and underfed cows received bST (supplemental bST was provided through administration of POSLIAC® 500 mg dose) and remained either heat-stressed or pair-fed for an additional 7 days. Similar to our previous experiments, feed intake, milk yield and daily NEFA data indicate marked differences that were independent of feed intake. Despite being extensively heat-stressed (average afternoon rectal temperature of ~105° F), and underfed, bST increased milk yield by ~10 and 15% in heat-stressed and thermal neutral cows, respectively (Wheelock et al., 2006).

Similar to thermal neutral cows (Bauman, 1999), evaluating daily blood bioenergetic variables (NEFA, PUN, glucose etc.) and using a range of metabolic challenges, we have demonstrated that bST reduces systemic insulin sensitivity in heat-stressed cows. Comparable to thermal neutral cows, this reduction in insulin action partially explains the partitioning of nutrients to the mammary gland to support increased milk synthesis during heat stress.

Metabolic Adaptations to Heat Stress

Estimating EBAL during heat stress introduces problems independent of those that are inherent to normal EBAL estimations (Vicini et al., 2002). Considerable evidence suggest increased maintenance costs are associated with heat stress (7 to 25%; NRC, 2001), however due to complexities involved in predicting upper critical temperatures, no universal equation is available to adjust for this increase in maintenance (Fox and Tylutki, 1998). Maintenance requirements are increased, as there is a large energetic cost of dissipating stored heat. Not incorporating a heat stress correction factor results in overestimating EBAL and thus inaccurately predicting energy status.

Due to the reductions in feed intake and increased maintenance costs, and despite the decrease in milk yield heat-stressed cows enter into a state of NEBAL (Moore et al., 2005b). In a similar trial as to the one described above, heat-stressed cows entered into and remained in NEBAL (~4-5 Mcal/d) for the entire duration of heat stress (Figure 3; Wheelock et al., 2006). However, unlike NEBAL in thermal neutral conditions, heat stressed induced NEBAL doesn't result in elevated plasma NEFA (Figure 4). This was surprising as circulating NEFA are thought to closely reflect calculated EBAL (Bauman et al., 1988). In addition, using an IV glucose tolerance test, we demonstrated that glucose disposal (rate of cellular glucose entry) is greater in heat stressed compared to thermal neutral pair-fed cows (Figure 5; Wheelock et al., 2006). Furthermore, heat-stressed cows have a much greater insulin response to a glucose challenge when compared to underfed cows (data not presented). Both the aforementioned changes in plasma NEFA and metabolic/hormonal adjustments in response to a glucose challenge can be explained by increased insulin effectiveness. Insulin is a potent antilipolytic signal (blocks fat break down) and the primary driver of cellular glucose entry. The apparent increased insulin action causes the heat-stressed cow to be metabolically inflexible, in that she does not have the option to oxidize fatty acids and ketones. As a consequence, the heat-stressed cow becomes increasingly dependant on glucose for her energetic needs and therefore less glucose is directed towards the mammary gland.

As stated earlier, the NRC (2001) arbitrarily indicates that mild to severe heat stress will increase maintenance requirements by 7 to 25% but indicates, "insufficient data are currently available to quantify these effects accurately". A typical lactating dairy cow will have a maintenance requirement of 9.7 Mcal/d (or 0.08 Mcal/kg $BW^{0.75}$; NRC, 2001). In our experiment, ~8 kg of milk/d could not be explained by the reduction in feed intake (Figure 1 and 2) and this has an energetic value of approximately 6.1 Mcal/d (or 63% of a thermal neutral animals daily maintenance requirements). If all of the difference in milk synthesis (~8 kg/d) could be explained by the increase in maintenance requirements then heat-stressed cows would have an increase in maintenance requirements of 63%. However, we are currently unable to identify how much of the 8 kg of milk can be explained by enhanced maintenance needs, but if 25, 50 and 75% of the 6.1 Mcal/d was in fact utilized for increased maintenance, it would represent a 16, 31 and 47% increase in maintenance requirements, respectively. Deciphering how much of the milk yield differential can be explained by increased maintenance costs vs. other altered biological systems (i.e. reduced nutrient absorption, altered endocrine status etc.) is of primary interest.

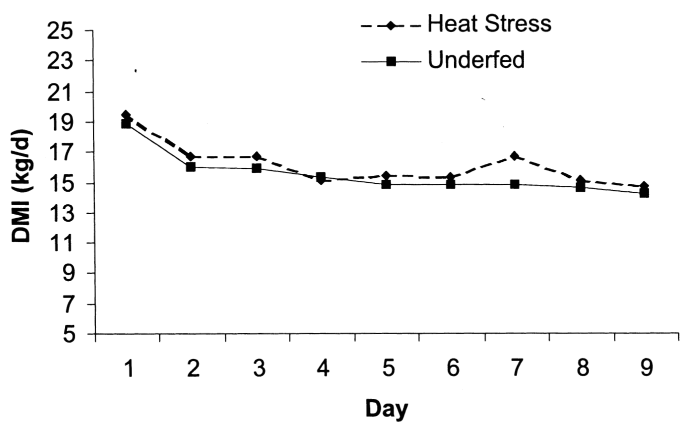

Figure 1. Effects of heat stress and pair-feeding thermal neutral conditions on dry matter intake in lactating Holstein cows

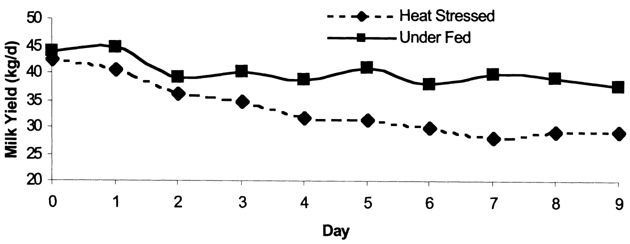

Figure 2. Effects of heat stress and pair-feeding thermal neutral conditions on milk yield in lactating Holstein cows. M.L Rhoads and L.H. Baumgard, unpublished.

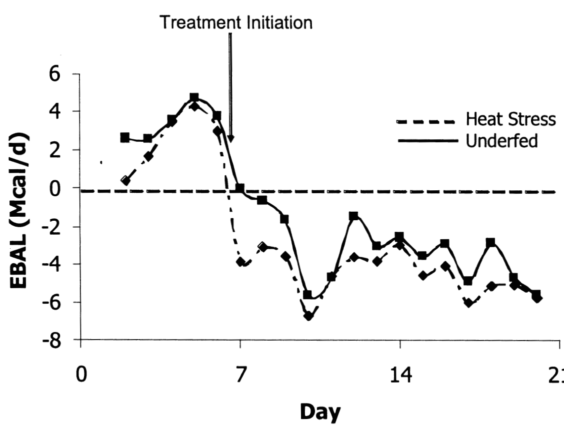

Figure 3. Effects of heat stress and pair-feeding thermal neutral conditions on calculated net energy balance in lactating Holstein cows. Adapted from Wheelock et al., 2006.

Well-fed ruminants primarily oxidize (burn) acetate (a rumen produced VFA) as their principal energy source. However, during NEBAL cows also largely depend on NEFA for energy. Therefore, it appears the post-absorptive metabolism of the heat-stressed cow markedly differs from that a thermal-neutral cow, even though they are in a similar negative energetic state. The apparent switch in metabolism and the increase in insulin sensitivity is probably a mechanism by which cows decrease metabolic heat production. Typically *in vivo* glucose oxidation yields 38 ATP or 472.3 kcal of energy (compared to 637.1 kcal in a bomb calorimeter) and *in vivo* fatty acid oxidation (i.e. stearic acid) generates 146 ATP or 1814 kcal of energy (compared to 2697 kcal in a bomb calorimeter; Brody,1999). Despite having a much greater energy content, due to differences in capturing ATP efficiencies, oxidizing fatty acids generates more metabolic heat (~2 kcal/g or 13% on an energetic basis) compared to glucose. Therefore, during heat stress, preventing or blocking adipose mobilization/breakdown and increasing glucose "burning" is presumably a strategy to minimize metabolic heat production.

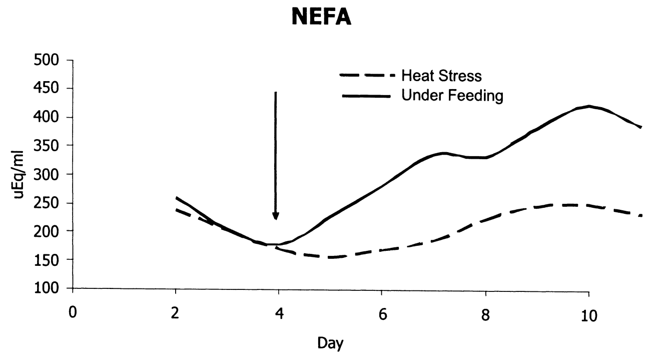

Figure 4. Effects of heat stress and pair-feeding thermal neutral conditions on circulating non-esterified fatty acids (NEFA) in lactating Holstein cows. Adapted from Wheelock et al., 2006.

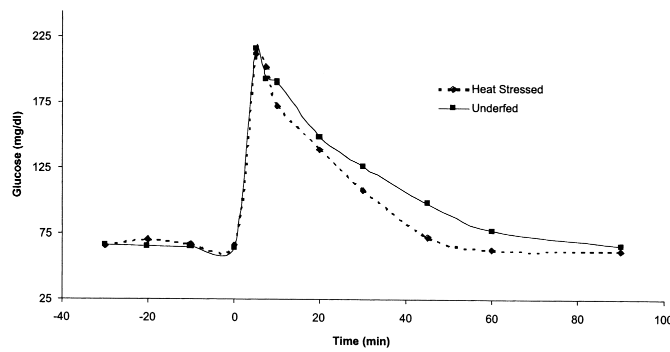

Figure 5. Effects of heat stress and pair-feeding thermal neutral conditions on plasma glucose response to a glucose challenge. Adapted from Wheelock et al., 2006.

The mammary gland requires glucose to synthesize milk lactose and lactose production is the primary osmoregulator and thus determinant of milk yield. However, in an attempt to generate less metabolic heat, the body (primarily skeletal muscle) appears to utilize glucose at an increased rate. As a consequence, the mammary gland may not receive adequate amounts of glucose and thus mammary lactose production and subsequent milk yield is reduced. This may be the primary mechanism which accounts for the additional reductions in milk yield that cannot be explained by decreased feed intake (Figures 1 and 2).

In addition to heat stressed cows requiring special attention with regards to heat abatement and other dietary considerations (i.e. concentrate:forage ratio, HCO_3^- etc.) they also have an extra requirement for dietary or rumen-derived glucose precursors. Of the three main rumen-produced volatile fatty acids, propionate is the one primarily converted into glucose by the liver. Highly fermentable starches such as grains increase rumen propionate production, and although propionate is the primary glucose precursor, feeding additional grains can be risky as heat stressed cows are already susceptible to rumen acidosis.

Summary

Clearly the heat-stressed cow implements a variety of post-absorptive changes in both carbohydrate and lipid metabolism (i.e. increased insulin action) that wouldn't be predicted based upon their energetic state. The primary end result of this altered metabolic condition is that the heat-stressed lactating dairy cow has an extra need for glucose (due to its preferential oxidization by extra-mammary tissue). Therefore, any dietary component that increases propionate production (the primary precursor to hepatic glucose production), without reducing rumen pH, will probably increase milk yield. In addition, reducing systemic insulin sensitivity will increase glucose availability to the mammary and thus also probably increase milk yield.

Note: This paper has article adapted from a paper first published by the authors in the Proceedings in the 2007 Southwest Nutrition Conference.

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Rethinking Energy for Dry Cows

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Introduction

Many dairy operations large and small continue to be plagued by a high incidence of metabolic disorders and infectious diseases around calving. Turbulent transitions increase health care expenses, decrease milk production, impair reproductive performance, and result in premature culling or death. Farm profitability and animal well-being both suffer. Despite many years of research and field emphasis, practical management strategies to minimize health problems while still promoting high milk production have remained elusive.

Over the last 20 years, higher energy and nutrient density rations have been fed during the close-up (pre-fresh) period, generally beginning around 3 weeks before expected calving. This approach was designed on the basis of research showing advantages in adaptation of the rumen microbial population and rumen papillae to higher nutrient diets fed after calving, decreased body fat mobilization and fat deposition in liver, and maintenance of blood calcium concentrations. Although each of these ideas were sound and based on good research data, the ability of higher-energy close-up or "steam-up" diets to minimize production diseases in research trials and field experience has been disappointing and frustrating. Overall, data fail to demonstrate that steam-up diets reliably and repeatedly improve production, body condition, reproduction, or health after calving.

We have been frustrated by this lack of success in both research and field settings and have searched for a better approach to dry cow nutritional management. The concepts presented in this paper in many ways are nothing new, as they center on formulating dry cow rations to dietary energy densities that were established many years ago by the National Research Council (NRC). Rethinking what these data and previous knowledge tell us about dry cows has led us to a new interpretation relative to the existing dogma, and to develop a practical system suitable for modern dairy management practices on both small and large dairies.

Controlled Energy Intake During the Dry Period

Our research group has investigated whether controlling energy intake during the dry period might lead to better transition success (Grum et al., 1996; Drackley, 1999; Drackley et al., 2001, 2005; Dann et al., 2005, 2006; Douglas et al., 2006; Loor et al., 2005, 2006). Our research drew both from our ideas and observations as well as from field experiences by individuals such as Dr. Gordie Jones and Dr. Peter Drehmann. The data we have collected demonstrate that cows fed even moderate-energy diets (0.68 – 0.73 Mcal NE_L / lb DM) will easily consume 40 – 80% more NE_L than required during both far-off and close-up periods. Cows in these studies were all less than 3.5 body condition score at dry-off, were housed in individual stalls, and were fed diets based on corn silage, alfalfa silage, and alfalfa hay with some concentrate supplementation. We have no evidence that the extra energy and nutrient intake was beneficial in any way. More importantly, our data indicate that allowing cows to over-consume energy to this degree may predispose them to health problems during the transition period if they face additional management challenges that create stress responses or limit feed intake.

We have collected a variety of data indicating that prolonged over-consumption of energy during the dry period can result in poorer transitions. These data include whole-animal responses important to dairy producers such as lower post-calving dry matter intakes and slower starts in milk production (Douglas et al., 2006; Dann et al., 2006). We also have demonstrated that overfeeding results in negative responses of metabolic indicators, such as higher nonesterified fatty acids (NEFA) in blood and more triglyceride or fat in the liver after calving (Douglas et al., 2006; Janovick Guretzky et al., 2006). From a basic-science standpoint, there are alterations in cellular (Litherland et al., 2003) and gene-level responses (Loor et al., 2005, 2006) that potentially explain many of the changes at cow level.

Our data demonstrate that allowing dry cows to consume more energy than required, even if cows do not become noticeably over-conditioned, results in responses that would be typical of overly fat cows. Because energy that cows consume in excess of their requirements must either be dissipated as heat or stored, we speculate that the excess is accumulated preferentially in internal adipose tissue (fat) depots in some cows. The NEFA and signaling molecules released by some of these visceral adipose tissues go directly to the liver, which may cause fatty liver, subclinical ketosis, and other secondary problems with liver function. Humans differ in their tendencies to accumulate fat in different locations, and central obesity is a greater risk factor for disease. Similarly, cows might also vary in the degree to which they accumulate fat internally. In many cases, the mechanisms we have been studying in dry cows are similar to those from human medical research on obesity, type II diabetes, and insulin resistance.

Other research groups around the US (Holcomb et al., 2001) and in other countries (Agenas et al., 2003; Kunz et al., 1985; Rukkwamsuk et al., 1998) have reached similar conclusions about the desirability of controlling energy intake during the dry period. Our work has extended the ideas to show that over-consumption of energy is common even when feeding typical dry period diets thought to be "safe", and that this may be a predisposing factor to poor health. We also have extended the idea of the high-straw, low-energy ration as a simple and practical approach to achieve the control of energy intake.

Our solution to the potential for cows to over-consume energy is to formulate rations of relatively low energy density (0.59 – 0.63 Mcal NE_L / lb DM) that cows can consume free choice without greatly exceeding their daily energy requirements. Note that we are not proposing to limit energy intake to less than cows' requirements, but rather to feed them a bulky diet that will only meet their requirements when cows consume all they can eat. We have termed this the "Goldilocks diet" (Drackley and Janovick Guretzky, 2007) because, like the story of Goldilocks and the three bears, we don't want the cow to consume too much or too little energy, but rather just the right amount to match her requirements.

To accomplish the goal of controlled energy intake requires that some ingredient or ingredients of lower energy density be incorporated into diets containing higher-energy ingredients such as corn silage, good quality grass or legume silage, or high quality hay. Cereal straws, particularly wheat straw, are well-suited to dilute the energy density of these higher-energy feeds, especially when corn silage is the predominant forage source available. Lower quality grass hays also may work if processed appropriately, but still may have considerably greater energy value than straw and thus are not as effective in decreasing energy density.

We are aware of no controlled data comparing different types of straw, but it is the general consensus among those who have years of experience using straw that wheat is preferred. Barley straw is a second choice, followed by oat straw. While reasons for these preferences are not entirely clear, wheat straw is more plentiful, is generally fairly uniform in quality, and has a coarse, brittle, and hollow stem that process easily, is palatable, and seems to promote desirable rumen fermentation conditions. Barley straw lacks some of these characteristics. Oat straw is softer and as a result does not process as uniformly. In addition, oat straw generally is somewhat more digestible and thus has greater energy content.

It is critical that the straw or other roughage actually be consumed in the amounts desired. If cows sort out the straw or other high bulk ingredient, then they will consume too much energy from the other ingredients and the results may be poor. A TMR is by far the best choice for implementing high-straw diets to control energy intake. Some TMR mixers can incorporate straw without pre-chopping and without overly processing other ingredients, but many mixers cannot. Straw may need to be pre-chopped to 2-in or less lengths to avoid sorting by the cows.

Advantages and Beneficial Outcomes

Based on our research and field observations, adoption of the high-straw, low-energy TMR concept for dry cows might lead to the following benefits:

- Successful implementation of this program essentially eliminates occurrence of displaced abomasum. This may result from the greater rumen fill, which is maintained for some period of time even if cows go off feed for some reason, or from the stabilizing effect on feed intake (Janovick Guretzky et al., 2006).
- Field survey data collected by the Keenan company in Europe (courtesy of D. E. Beever, Richard Keenan and Co., Borris, Ireland) show strong indications of positive effects on health. In 277 herds (over 27,000 cows) in the United Kingdom, Ireland, France, and Sweden, changing to the high-straw low-energy TMR system decreased assisted calvings by 53%. In addition, the change decreased milk fevers by 76%, retained placentas by 57%, displaced abomasum 85%, and ketosis by 75%. Using standard values for cost of these problems, the average increase in margin per cow in these herds was $114 just from improved health alone. While these are certainly not controlled research data, they are consistent with the results in our research as well as field observations in the USA.
- The same sources of observational data indicate that body condition, reproductive success, and foot health may be improved in herds struggling with these areas.

- Although data are limited, milk production appears to be similar to or slightly lower than results obtained with higher-energy close-up programs. There is some evidence that persistency may be improved, with cows reaching slightly lower and later peak milk. Therefore, producers should be careful to not evaluate the system based on early peaks and should look at total lactation milk yield, daily milk, and, over time, indices of reproduction and other non-milk indicators of economic value.
- Straw and corn silage generally are lower in potassium and thus help control the dietary cation-anion difference (DCAD) without excessive addition of anionic salt mixtures.
- The program may simplify dry cow management and ration composition in many cases.
- Depending on straw cost, the ration likely will be no more expensive than the average cost of far-off and close-up diets, and could be cheaper where straw is plentiful.

Single Diet Dry Cow Management?

Our most recent research (Janovick Guretzky et al., 2006) as well as considerable field experience indicates that a single-diet dry cow program can be successful using these principles. Dry matter intakes remain more constant as cows approach calving when fed the high-straw low energy diets (Dann et al., 2006; Janovick Guretzky et al., 2006) than in cows fed high-energy close-up diets (Grummer et al., 2004). Single-group systems would have the advantage of eliminating one group change, which may decrease social stressors as described by University of Wisconsin researchers (Cook, 2007). Single-group management may work particularly well for producers managing for shorter dry periods.

A variation is to maintain far-off and close-up diets, with essentially the same diet for both except that a different concentrate mix or premix is used for the close-ups, which may incorporate anionic salts, extra vitamins and minerals, additional protein, or selected feed additives. The optimal high-forage low-energy dry cow ration will contain the primary forages and grains to be fed in the lactation diet, but diluted with straw or low-quality forage to achieve the desired energy density. In this way, the rumen still can be adapted to the types of ingredients to be fed after calving without excessive energy intake during the dry period.

If producers desire to maintain the conventional two-group or “steam-up” philosophy for dry cow feeding, our research has shown that the most critical factor is to ensure that the energy density of the far-off dry period diet is decreased to near NRC (2001) recommendations (NE_L of 0.57 - 0.60 Mcal/lb DM) so that cows do not over-consume energy (Dann et al., 2006). In this research, wide extremes in close-up nutrient intake had very little effect compared with the effect of allowing cows to consume excess energy during the far-off period.

Specifications for Dry Period Diets

The controlled energy system works best for producers who are relying on corn silage as a primary forage. The combination of straw and corn silage is complementary for many reasons, including energy content, low potassium contents, starch content, and feeding characteristics.

The NE_L requirement for 1500-lb Holstein cows is between 14 and 15 Mcal per day (NRC, 2001). Some suggested guidelines for formulation of controlled energy diets to meet that requirement are as follows, on a total ration DM basis.

- Dry matter intake: 25 to 27 lb per day. For far-off cows, intakes by individual cows have often exceeded 30 lb DM per day.
- Energy density: 0.59 – 0.63 Mcal NE_L/lb DM (discussed in more detail in a later section).
- Protein content: 12 to 14% of DM as CP; >1,000 g/day of metabolizable protein as predicted by the NRC (2001) model or CNCPS/CPM Dairy model.
- Starch content: 12 to 16% of DM.
- Forage NDF: 40 to 50% of total DM, or 10 to 12 lb daily (0.7 to 0.8% of body weight). Target the high end of the range if more higher-energy fiber sources (like grass hay or low-quality alfalfa) are used, and the low end of the range if straw is used.
- Total ration DM content: <55% (add water if necessary). Additional water will help hold the ration together and improve palatability.
- Follow standard guidelines for mineral and vitamin supplementation. For close-ups, target values are 0.40% magnesium (minimum), 0.35 – 0.40% sulfur, potassium as low as possible, a DCAD of near zero or negative, 0.27% phosphorus, and at least 1,500 IU of vitamin E. Recent data suggests that calcium does not have to be increased beyond 0.6% of DM (Lean et al., 2006).

An example formulation is included in Table 1, from a recently completed experiment by our group (Janovick Guretzky et al., 2006). The example is for the far-off dry cow group, but the close-up diet was essentially identical except for the addition of anionic salts.

As long as the lactation diet is formulated appropriately, there seems to be little difficulty in transitioning to the lactation diet immediately after calving. Many producers have found that inclusion of 1 to 2 lb of chopped straw in the lactation diet improves rumen function and animal performance, particularly when physical fiber is borderline adequate. Addition of the straw postpartum also may help to ease the transition from the lower-energy dry cow diet.

Deciphering NE_L Values

The NE_L value specified for the same diet may vary considerably depending on method used to derive the value. While we have used NE_L widely to formulate and evaluate high-straw low-energy diets, nutritionists, veterinarians, and producers have expressed confusion on how to arrive at the "correct" NE_L content of the rations. Because of the confusion, it may be better to focus on providing the recommended intakes of forage NDF (10 - 12 lb/day) as a primary guideline for achieving the correct energy density. Nevertheless, NE_L values are important and useful if applied and interpreted carefully.

In calculating NE_L values, some confusion has resulted from the changeover to the NRC (2001) equations and calculation methods, and some is related to differences in how feed analysis laboratories calculate and report NE_L values. Those working to formulate and monitor the rations must use consistent units for evaluating dietary NE_L density to avoid confusion. Moreover, users should realize that it is difficult to compare NE_L values across locations and laboratories, so a consistent system within a farm or nutrition practice is more important.

An example of the potential confusion in using NE_L values for high-straw low-energy rations is shown in Table 1. The diet was fed to one group of cows and heifers in our most recently completed experiment (Janovick Guretzky et al., 2006). Feed ingredients were sampled weekly, formed into monthly composites, and analyzed by Dairy One Laboratory (Ithaca, NY) using wet chemistry techniques. Using the actual measured cow variables and analyzed feed composition, we compared the NE_L density of the ration calculated four different ways. The value for the total diet calculated by the NRC (2001) model was 0.62 Mcal/lb DM. By using the analytical values for monthly composites of feed ingredients in the Cornell Net Carbohydrate and Protein System (version 5.0), the comparable NE_L value was 0.59 Mcal/lb. If we used the NE_L values from Dairy One for individual ingredients to additively calculate the total dietary NE_L density, the value was 0.55 Mcal/lb DM. However, if we used the values for individual ingredients provided by Dairy One as "NRC values" for dry cows, the total diet NE_L was 0.67 Mcal/lb DM! Why the large discrepancy? Which is "correct"?

The NE_L value is technically correct only for the feed that a cow actually eats (NRC, 2001) because ingredients in a diet influence rumen digestibility of other ingredients, some positively and some negatively. A classic example is that concentrates added to a diet decrease digestibility of the NDF components in forages by changing the rumen environment. Consequently, the NE_L density of a diet cannot be determined accurately by adding together the calculated NE_L values of individual ingredients. The NE_L value of an individual feed ingredient is only correct if it is fed as the only feed ingredient to a cow, which of course is uncommon.

In addition, the digestibility of the dietary DM decreases as total feed intake increases. This decrease is more pronounced for the NDF fraction than for starch, and is greater for grass-type forages than legumes. The NRC incorporates a standard reduction of 4 percentage units digestibility for each multiple of maintenance intake. Because different components of the diet are affected differently by the intake effect, Van Soest (Cornell University) devised a variable discount system. These discounts are used by Dairy One, for example, to report an NE_L value at 3? maintenance, which would be equivalent to the intake needed to produce about 66 lb of milk (see www.dairyone.com/Forage/FactSheet/NRC_201_Energy_Values.htm. and www.dairyone.com/Forage/Newsletters/199903.pdf). Because the NE_L value of straw is severely penalized by the Van Soest variable discount system, the calculated value of the diet is considerably lower than the NRC-model value for the total ration (Table 1). On the other hand, using the laboratory values assigned to individual ingredients by the laboratory using NRC principles and then reconstructing an "average" value of the ration overestimates the NE_L density relative to the value determined for the total diet as consumed using the NRC (2001) model.

An alternate approach is to use net energy for maintenance (NE_M) values instead of NE_L. The NE_M of a ration should, by definition, be equal to NE_L at maintenance intakes (NRC, 2001). When we used NE_M provided by Dairy One for individual ingredients to calculate energy values for the diet shown in Table 1, the total ration NE_M (0.60 Mcal/lb DM) was close to the NE_L value calculated for the total diet (0.62) by the NRC (2001) model.

The bottom line is that those formulating and monitoring diets must be consistent in which energy and laboratory units are being applied, and realize that comparison of dietary energy values across studies, laboratories, or farms must be done carefully and with understanding of how the values were derived. Using the assigned NE_L values from analytical laboratories may not be appropriate for dry cows fed mixed diets. Values for NE_L of the total diet calculated by using the NRC (2001) or CNCPS/CPM models will always be more accurate predictors. Use of NE_M values for individual ingredients to calculate an NE_M value for the total diet may be the most accurate unit for reconstructing a total diet value from individual analyses.

Practices Important for Success

Three factors are critical to successfully implement this approach: 1) prevention of sorting, 2) ensuring continuous and non-crowded access to the TMR, and 3) careful monitoring of DM content and attention to detail. Where "train-wrecks" have been reported, one or more of these factors has been faulty, not the dietary approach itself.

The straw must be chopped into a particle size that cows will not sort out of the ration. In general, this means less than 2" particles. If the straw is pre-chopped, an appropriate chop is indicated by having about 1/3 of the particles in each of the three fractions of the Penn State shaker box. Because of the bulky nature of straw and the resulting TMR, producers may think that cows are sorting excessively when they are not. To verify that cows are not sorting, the feed refusals should be monitored carefully and compared to the original TMR. One simple way to evaluate sorting is to shake out the TMR with the Penn State box and then repeat the analysis on the feed refusals the next day. Results should not differ by more than 10% from TMR to refusal. Another way to monitor sorting is to collect samples of the feed refusal from several areas of the feedline and have it analyzed for the same chemical components as the TMR fed. Again, composition of NDF, CP, and minerals should not vary by more than 10% between ration and refusal if cows are not sorting. If cows sort the straw, some cows will be consuming a higher energy diet than formulated, and some (the more timid cows) will be left with a much lower quality ration than desired. Herds in which sorting is a problem will be characterized by pens of dry cows that range widely in body condition: some will be over-conditioned and some under-conditioned, while of course some may be "just right".

Another common pitfall is poor feedbunk management that limits the ability of cows to consume feed ad libitum. Because of the bulky nature of the diet, cows may have to spend more time eating to consume enough feed to meet energy and nutrient requirements. Bunk space must be adequate and feed pushed up frequently. If feed is not pushed up, cows likely will not be able to consume what they need to meet requirements.

Other common problems arise when the DM content of straw, hay, and silages changes markedly from assumed values. This may happen, for example, if the straw is rained on or the DM content of silage changes without the feeders knowing it. Changes in DM of the ingredients mean changes in the DM proportions of the total diet unless the mix is corrected. Thus, energy intake may increase or decrease relative to the target, and producers may experience a rash of calving-related health problems until the situation is corrected.

While the nutritional concepts of these rations are simple, the approach and implementation are not problem-free. Attention to detail is a must. The system is not an "easy" or a lazy approach to dry cow care. When implemented correctly, results have been exceptional. However, high-straw low-energy diets are not remedies for poor feeding management or bad facilities. Applied in these situations, results may be poor.

Additional Considerations

As mentioned earlier, the combination of straw and corn silage, along with other lactation ration ingredients, works well because of the complementary features of the components in the total diet. Straw has many desirable characteristics that seem to improve health and digestive dynamics in the rumen. The slow digestion and passage rate of straw certainly seems to be important in prevention of DA. We feel that the control of energy intake is a critically important factor in maintaining a more constant energy intake during the dry period and in preventing other disorders around calving such as ketosis and fatty liver.

Whether other low-energy ingredients will produce the same desirable results remains uncertain. We are not aware of research that has compared other low-energy ingredients such as poor-quality hay, oat hulls, cottonseed hulls, corn stalks, soybean residue, or flax shives to straw or to conventional rations, although we have anecdotal reports from producers and nutritionists with varying reports of success. With roughage-type materials, the key consideration is uniform processing and palatability so that cows do not sort and the formulated profile of nutrients is actually consumed. For concentrate-type or finely ground ingredients, energy content is low but particle size is so small that rate of passage can be too fast, allowing particles to escape more quickly even though they are not digested. In this case, DMI by the cows may increase so that total energy intake still exceeds requirements considerably.

Good-quality straw is a consistent (but low) source of nutrients, although its composition still can be variable (NRC, 2001). Table 2 shows means, standard deviations, and ranges for straw samples over two years during two recent experiments from our group (Dann et al., 2006; Janovick Guretzky et al., 2006). The mean values are close to those reported in NRC (2001), although CP was lower and NDF higher in our samples. Also of note, analyzed concentrations of potassium and sodium were considerably lower than means reported by NRC (2001).

Just because straw or other low-energy ingredients are "low quality" by conventional standards of evaluation based on protein or energy content does not mean that other measures of "quality" can be ignored. Straw or other feeds that are moldy, severely weather-damaged, or have fermented poorly should not be fed to dry cows, especially the close-ups.

Comparisons of high-straw low-energy diets with conventional diets in cows of widely differing body condition scores are not available. In the field, the diets seem to work well in both thin and fat cows. In fact, many producers have concluded that these diets are the best way to manage obese cows through calving to minimize the usual problems expected with fat cows.

Conclusions

High-straw low-energy rations are exciting for their potential to markedly improve health during the transition period. The key concept is to strive to meet the requirements of cows for energy and all other nutrients, but to not allow cows to exceed their requirements for energy by large amounts for the duration of the dry period. Provided that these high-straw low-energy rations are formulated, mixed, and delivered properly, results have been positive. Research and field observations indicate that the rations result in better energy balance after calving, with subsequent improvements in health. Milk production is maintained, and field observations suggest that reproductive success may be improved also, although data are lacking. Research is needed to explore other low-energy bulky ingredients as options to straw.

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Table 1. Example high-straw, low-energy diet fed during the far-off dry period (Janovick Guretzky et al., 2006)

Item	Amount in ration (DM basis)
Ingredients	
Corn silage, %	35.3
Chopped wheat straw, %	31.8
Chopped alfalfa hay, %	17.1
Corn grain, ground, dry, %	3.6
Soybean meal, solvent, 48% CP, %	5.1
SoyPlus, %	4.0
Urea, %	0.9
Minerals and vitamins, %	2.2
Composition	
Forage NDF, %	50.4
NFC, %	25.4
CP, %	14.4
NRC Metabolizable protein,	
g/d at 26.5 lb DMI	1,085
NE_L, Mcal/lb DM[a]	0.62
NE_L, Mcal/lb DM[b]	0.59
NE_L, Mcal/lb DM[c]	0.55
NE_L, Mcal/lb DM[d]	0.67
NE_M, Mcal/lb DM[e]	0.60

[a] Calculated for the total diet using the NRC (2001) model and analyzed chemical composition for corn silage, wheat straw, alfalfa hay, and concentrate mixture.
[b] Calculated for the total diet using the CNCPS (version 5.0) model and analyzed chemical composition for corn silage, wheat straw, alfalfa hay, and concentrate mixture.
[c] Calculated additively using NE_L values assigned by Dairy One Laboratory for individual ingredients, using the Van Soest variable discount factors and correct at intake of 3? maintenance.
[d] Calculated additively using NE_L values provided by Dairy One Laboratory using NRC 2001 equations (Ohio State summative equation) for individual ingredients, at intake appropriate for dry cows.
[e] Calculated using NE_M values for individual ingredients as specified by Dairy One Laboratory.

Table 2. Chemical composition of wheat straw in University of Illinois experiments.[1]

Component	Mean	Standard Deviation	Maximum	Minimum
DM, % as fed	93.3	0.82	94.5	91.2
CP, % of DM	3.8	0.83	5.3	2.4
Soluble protein, % of CP	44.2	9.6	65.0	25.0
NDF, % of DM	79.6	3.7	85.2	69.9
ADF, % of DM	53.3	2.9	59.0	45.8
NFC, % of DM	11.6	3.0	19.2	6.8
TDN, %	49	1.4	53	47
NE_M, Mcal/lb DM	0.35	0.06	0.43	0.12
Ca, % of DM	0.27	0.11	0.57	0.08
P, % of DM	0.08	0.03	0.14	0.05
Mg, % of DM	0.12	0.04	0.26	0.09
K, % of DM	1.30	0.12	1.53	0.95
S, % of DM	0.07	0.03	0.18	0.04
Na, % of DM	0.02	0.01	0.06	0.01
Fe, ppm of DM	117	68	303	53
Zn, ppm of DM	16	11.6	59	7
Cu, ppm of DM	8	4.1	18	4
Mn, ppm of DM	75	15.3	119	51

[1] Values are from 21 monthly composite samples from two experiments (Dann et al., 2006; Janovick Guretzky et al., 2006) analyzed by wet chemistry techniques at the same laboratory (Dairy One, Ithaca, NY).

Lipids and Longevity

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Introduction

Poor reproductive performance was the first or second reason for culling dairy cows from the herd in 10 states based upon DHI records (Hadley et al., 2006). On average, about 19% of the culling was due to poor reproductive performance. Poor reproductive performance (e.g. low conception rates) has been increasing in U.S. dairy herds for at least 30 years (Lucy, 2001). Many reasons for this decline in reproductive efficiency have been offered, including an increase in postpartum disease (ketosis, mastitis, retained fetal membranes, cystic ovaries, fatty liver, etc.), an increase in herd size resulting in increased management challenges, an increase in the proportion of milking heifers in the herd which cycle later, an increase in genetic inbreeding, and an increase in milk production (Lucy, 2001).

The influence of nutrition on reproductive performance is a growing field of study, including the effect of feeding supplemental fat. If fat supplementation can improve pregnancy rates, then cow longevity is improved. The purpose of this paper is to review some of the effects of fat supplementation on reproductive tissues and pregnancy.

Fats Defined

Many different types of supplemental fat have been fed to lactating cows. Some fat sources fed are listed in Table 1. Each fat source is composed of a different mix of individual fatty acids. Rendered fats include animal tallow and yellow grease (recycled restaurant grease) and are composed mainly of oleic acid (~43%). Granular fats are dry fats and are composed mainly of palmitic acid (36-50%). Examples include Energy Booster 100, EnerG-II, and Megalac-R. Canola oil is high in oleic acid. Cottonseed, safflower, sunflower, and soybean oils are high in linoleic acid. Flaxseed is high in linolenic acid. Fish oil contains eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), fatty acids found in fish tissue due to their consumption of marine plants. Fresh temperate grasses contain 1 to 3% fatty acids of which 55 to 65% is linolenic acid (Chilliard et al., 2001). Corn silage lipid contains much more linoleic acid (49%) than linolenic acid (4%) due to the presence of corn grain (Petit et al., 2004).

The short-hand notation for identifying fatty acids is to give the number of carbons and double bonds in the molecule. For example, a designation of 18:2 indicates a fatty acid chain of 18 carbons having 2 double bonds. Fats that have double bonds are classified as unsaturated fats. The term "omega" refers to the location of the double bond in the carbon chain. An omega-6 fatty acid has its first double bond located between the 6^{th} and 7^{th} carbon counting from the methyl end of the chain. An omega-3 fatty acid has its first double bond located between the 3^{rd} and 4^{th} carbon counting from the methyl end of the carbon chain. Linoleic acid, abbreviated C18:2, is an essential omega-6 fatty acid. Linolenic acid, abbreviated C18:3, is an essential omega-3 fatty acid. Two additional omega-3 fatty acids are EPA (C20:5) and DHA (C22:6).

Dietary Fats Are Modified in the Rumen by Bacteria

The ruminal microbes will convert unsaturated fats to saturated fats by replacing the double bonds with single bonds between the carbons (called biohydrogenation). Some scientists have speculated that this act of biohydrogenation by bacteria is an attempt to protect the bacteria, as unsaturated fats can be toxic especially to fiber digesters. The majority of the consumed unsaturated essential fatty acids, C18:2 and C18:3, are converted by the bacteria to C18:0. Whereas approximately 20 g of C18:0, 280 g of C18:2, and 40 g of C18:3 are consumed daily, approximately 370 g of C18:0, 40 g of C18:2, and 4 g of C18:3 leave the rumen daily because of biohydrogenation. Several intermediate forms of fatty acids, called trans fatty acids, also are formed during biohydrogenation. Some of the trans fatty acids, such as the trans-10, cis-12 conjugated linoleic acid (CLA) and the trans-10 C18:1, can influence the cow's metabolism, including depressing milk fat synthesis. This intervention by ruminal bacteria to change essential fatty acids in the diet to other fatty acids has made the study of dietary fat effects on reproduction quite challenging.

Fat Supplementation and Conception Rates

According to the scientific literature, a variety of fat supplements have benefited conception rates of lactating dairy cows (Table 2). The conception rates are sometimes reported for first insemination or for accumulated inseminations. Feedstuffs stimulatory to conception included calcium salts of palm oil distillate, tallow, Energy Booster (prilled tallow), flaxseed (formaldehyde-treated or rolled), MegaPro Gold (which is a calcium salt of palm oil plus rapeseed meal and whey permeate) fed to grazing cows, calcium salt of a mixture of soy oil and monounsaturated trans fatty acids, Megalac-R, CLA, and fish meal. The average improvement in conception rate was 21 percentage units. This is not to imply that the feeding of one of these feedstuffs to cows on a commercial dairy farm will increase herd conception rate by 21 percentage units. Any benefit experienced on a commercial dairy farm will likely be less than 10 percentage units because management is usually not as tight as that exercised on an experiment.

Other studies have reported no positive pregnancy benefit to fat-supplementation (Table 3). The average response was 44.6 vs. 41.8% for control and test-fat treatment groups.

From the studies listed in Table 2, it is very difficult to determine which fat supplements or which fatty acid(s) may be most efficacious. When cows fed fats containing mainly palmitic and oleic acids (tallow, Energy Booster, and Ca salts of palm oil distillate) were compared against a no supplemental fat control, the fat-supplemented cows had better conception rates. In 3 head-to-head comparisons of fat supplements, cows fed calcium salts of palm oil distillate did not conceive as well as those fed either formaldehyde-treated flaxseed (Petit et al., 2001), a calcium salt mixture of soybean oil and monounsaturated trans fatty acids (Juchem et al., 2004), or CLA (Castaneda-Gutierrez et al., 2005; Table 2). Therefore fats containing mainly palmitic and oleic acids may not be as effective. Studies utilizing 3 diets are needed (e.g. no fat, fat type 1, and fat type 2) in order to better assess the effect of fat and fat source on pregnancy.

Focus on Flaxseeds. Although the fatty acids in fresh grass can contain a high proportion of linolenic acid, flaxseeds are the only concentrated source of linolenic acid (~20% of DM as C18:3) available. Flaxseeds have been evaluated as a promotant of reproductive performance of lactating dairy cows with mixed results. First service conception rate was increased from 50 to 87% when lactating cows in the United Kingdom were fed formaldehyde-treated flaxseed at 17% of a ryegrass silage-based diet between 9 and 19 weeks postpartum (Petit et al., 2001). Control cows were fed a calcium salt of palm oil (5.6% of diet) and flaxseed meal. Cows had been on their diets for 6 weeks prior to insemination. Production of uncorrected milk (41.0 vs. 43.7 lb / day) and 4% fat-corrected milk (44.5 vs. 50.5 lb / day) was less for cows fed flaxseed but DM intake was not changed. In a Canadian study involving 121 Holstein cows (Ambrose et al., 2006b), cows fed coarsely rolled flaxseed at 9% of the diet had a better first service conception rate ($P < 0.07$) compared to the control cows fed rolled sunflower seeds at 8.7% of dietary DM (48.4 vs. 32.2%). Although the overall pregnancy rates were not different between the two groups (67.7 vs. 59.3%), the proportion of pregnant cows that delivered a calf favored those fed flaxseed (90.2 vs. 72.7%), indicating that early and late pregnancy loss was less for cows fed flaxseed. Diets were fed for 28 days prior to insemination using a timed AI protocol and continued for 32 days after AI. Dry matter intake (49.6 vs. 47.0 lb / day) but not milk yield (80.9 vs. 79.4 lb / day) tended to be greater by cows fed flaxseeds. In a second Canadian study conducted on two commercial dairy farms, conception rate was not different between cows fed whole flaxseed at 10.6% of the diet and those fed micronized soybeans starting at calving (Petit and Twagiramungu, 2006). However those fed flaxseed had less ($P < 0.07$) embryonic loss. Three recent studies involving a greater number of dairy cows did not report any pregnancy advantage to cows fed flaxseed. Holstein cows (n = 356) on a commercial dairy in Spain were fed diets of either 5.5% extruded whole flaxseed or 4.9% extruded soybeans plus 1% calcium salts of palm oil between 4 to 20 weeks postpartum (Fuentes et al., 2007). Cows were detected in estrus using visual observation and the Afimilk system. First service (39 vs. 39%) and overall conception rates (40 vs. 34%) did not differ between soybean and flaxseed groups, respectively. Yield of 4% fat-corrected milk was less for cows fed flaxseeds (83.1 vs. 78.0 lb / day) due to a lower milk fat concentration (2.65 vs. 2.86%). A commercial dairy in Oregon (n = 303 cows) was used to evaluate rolled flaxseed, fed from about 32 days postpartum through 31 days after timed AI (Ambrose et al., 2006b). Cows were on diets at least 28 days prior to AI. Conception rates at 94 days after AI were not different, being 36.7% for controls and 25.6% for cows fed flaxseeds when all cows were considered. When only cows that responded to synchronization were included in the data set (n = 169), conception rate was lower for cows fed flaxseed at 31 days post AI (51.2 vs. 35.3%). Loss of embryos between 31 and 94 days post AI was not affected by diet but 9 control cows for their embryos whereas 4 flaxseed-fed cows lost their embryos. Lastly, lactating dairy cows fed rolled flaxseed (8% of diet DM) had a similar conception rate (43.3%; n=141) to those fed a mixture of tallow and Ca salt of palm oil distillate (41.6%; n=125) at 35 days post AI (Ambrose et al., 2006, personal communication). Although not different, embryo loss was 8% vs. 16% for cows fed flaxseed vs. control fat. Although the evidence is not strong, it appears that feeding flaxseed may not improve initial pregnancy rates but may reduce embryonic loss.

Other oil seeds have not been well evaluated for their ability to improve conception. Although the oil in many oil seeds contains more than 50% C18:2 (Table 1), the delivery of C18:2 past the rumen to the small intestine is not the same for all oil seeds. Based on the C18:2 content of milk fat, soybeans appear to be most effective and cottonseeds seem to be ineffective to deliver C18:2 to the tissues (Table 4). Sunflower seeds and safflower seeds also can increase the C18:2 of milk fat, but not quite as effectively as that of soybeans. The processing of whole seeds also can influence their ability to deliver unsaturated fat past the rumen. Roasting of soybeans and rolling of sunflowers seemed to increase delivery of C18:2. Although, whole flaxseeds fed at about 10% of the diet can deliver some C18:3 to the tissues, grinding the flaxseed may deliver even more C18:3 (Table 4). Obviously, more research needs to be done to better identify the most effective fat sources, whether from seeds, oils, or calcium salts.

Although the main nutrient in fish meal is protein and not fat, it is included here because the oils unique to fish may play a role in establishing pregnancy. The inclusion of fish meal in the diet (2.7 to 7.3% of dietary DM) has improved either first service or overall pregnancy rate in four studies. In some of these studies, fish meal partially replaced soybean meal resulting in a reduction of an excessive intake of ruminally degradable protein. Therefore, the improved conception rates may have been due to the elimination of the negative effect of excessive intake of ruminally degradable protein on conception. However, in a field study in which the concentration of ruminally undegradable protein was kept constant between dietary treatments, cows fed fish meal had a better conception rate (Burke et al., 1997) suggesting that the positive response was due to something other than a reduction in intake of ruminally degradable protein.

Amount of Fat to Feed

A frequent asked question is "How much fat or a specific fatty acid should be fed in order to try to improve reproduction?" In the studies listed in Table 2, the fat sources were fed at a minimum of 1.5% of dietary DM. We know that feeding these amounts were effective. We do not know if feeding a smaller amount of fat would be effective as well. It is certainly possible that feeding supplemental fat at a lower rate such as 0.25 or 0.5 pounds per day could be effective. The key fatty acids (whether it is linoleic, linolenic, trans fatty acids, EPA, DHA, or something else) that do reach the small intestine of the cow are absorbed into the blood stream and deposited into tissues, including her reproductive tissues. Some of these can accumulate over time. In a Florida study, hepatic fat concentration of EPA increased from approximately 0.05 to 0.5 to 0.9% in liver samples collected at 2, 14, and 28 days in milk from cows fed linseed oil starting 5 weeks prepartum. A small but steady supply of these key fatty acids streaming to the tissues will allow the tissues to accumulate the fatty acids and have them ready at the proper time for reproductive purposes. Therefore, even a fat-feeding rate smaller than the 1.5% could prove beneficial.

When to Initiate Fat Supplementation

Fat feeding must be initiated long enough ahead of time before the fats are needed for restoring the reproductive tissues to a new fertile state. This would involve the involution of the uterus, the return of the ovaries to growing and ovulating new follicles, and the uterus to receiving and maintaining a new embryo successfully. As will be discussed later, cows fed selected fat sources have responded with larger (still of acceptable size) ovarian follicles. Since ovarian activity usually returns within the first 4 weeks of calving, initiating fat feeding prepartum would allow the absorbed fatty acids to influence early ovarian activity. Feeding supplemental fat for at least 21 days, preferably for 40 days, prior to the desired physiological response is our recommendation. We have begun supplementing cows in the close-up nonlactating period (3 to 5 weeks before the calculated due date). This allows the tissues to begin storing the key fatty acids prior to when they will be most needed. We conducted an experiment to test whether the initiation of fat supplementation (Megalac-R at 2% of dietary DM) should begin at 5 weeks prepartum, at calving, or at 28 days postcalving (Cullens, 2005). Cows fed fat starting in the prepartum period had fewer health problems in the first 10 days after calving than cows in the other groups. If some fat sources provide a benefit to the cow's immune system, then the fat feeding should begin during the transition period.

How Might Fat Supplementation Help Improve Conception Rates?

<u>Improving Energy Status?</u> Those lactating dairy cows which experience a prolonged and intense negative energy state have a delayed resumption of estrous cycles after parturition which can increase the number of days open. If fat supplementation can help increase energy intake, then possibly the negative energy state can be lessened and estrous cycles start sooner and conception occur sooner. While adding an energy dense nutrient such as fat to the diet will usually increase the cow's energy intake, the energy status of the cow is usually not improved because of a slight to moderate depression in feed intake and/or an increase in milk production. Dairy cows fed tallow at 3% of dietary DM tended to have a

greater pregnancy rate (62 vs. 44%; Son et al., 1996) despite having a more negative calculated mean net energy status from weeks 2 to 12 postpartum compared to cows not fed tallow. Likewise cows fed calcium salts of CLA (Castaneda-Gutierrez, 2005) or palm oil distillate (Garcia-Bojalil et al., 1998; Sklan et al., 1991) had better conception rates without an improvement in energy balance. Although there is evidence that the feeding of fat can improve the energy status of lactating dairy cows, an improvement in reproductive performance occurred in several instances apart from an improving energy status of the experimental animals. Therefore fat supplementation likely is improving reproductive performance by other means.

Meeting an Essential Fatty Acid Requirement? Linoleic acid and linolenic acid are essential fatty acids for the cow because neither her body nor her ruminal microorganisms can synthesize them. Both linoleic and linolenic acid in forages can decrease during storage. As we have moved our dairy cows from pastures to barns and fed them stored forage, their intake of linolenic acid and possibly linoleic acid has likely decreased. Although current wisdom in the dairy industry is that the dietary intakes of linoleic and linolenic fatty acids are sufficient for meeting the lactating cow's requirements, the recently developed fat sub model of the Cornell-Penn-Miner (CPM) Institute Dairy Ration Analyzer v3.0.7a (Moate et al., 2004) indicates that the modern cow is exporting more linoleic acid in her milk than she is absorbing from her diet; that is, she is in a negative linoleic acid balance. For example, using data from a recent study at the University of Florida, the model calculated that the diet supplied 33 grams of linoleic acid but the milk put out 53 grams of linoleic acid, a 20 gram/day deficiency. The remainder must have been supplied from adipose tissue. The pools of C18:2 in adipose tissue are likely very dynamic. Feeding fat sources rich in linoleic acid that can reach the small intestine may reduce the negative balance of linoleic acid and improve performance. Nonruminant animals, such as pigs and poultry, had their reproductive performance greatly improved when an essential fatty acid deficiency was solved. Certainly the lactating cow does not show obvious signs of fatty acid deficiency such as scaly skin and dandruff so if a deficiency does exist, it is not overtly obvious. Early research results indicate that some fat supplements may prove helpful to the health of the cow as well, but much more work is needed.

Healthier Ovarian Follicles? In the initial days of the estrous cycle, a group of small follicles grow up on each ovary. From this group, one follicle (called the dominant follicle) continues to grow while the others regress. This will usually happen two or three times during a single estrous cycle. These dominant follicles increase in diameter from a detectable size of 3 mm up to about 15 to 18 mm before regressing or ovulating. After the dominant follicle releases its egg into the oviduct, the ruptured follicle forms a yellow structure called a corpus luteum, which produces the very important hormone called progesterone. Progesterone not only prepares the uterus for implantation of the embryo but helps coordinate the nutrients for development of the embryo and also maintains pregnancy until parturition. Cows that have a greater concentration of progesterone in their blood after insemination (during days 4 to 15) also have a better chance of becoming pregnant. What leads to greater progesterone in the blood? A large corpus luteum formed from a large dominant follicle that ovulated. Therefore larger dominant follicles (up to about 20 mm in size) are often beneficial. Ovulation of smaller follicles is associated with a lower conception rate.

The size of the dominant follicle is often larger in lactating dairy cows receiving supplemental fat. On average, the size of the dominant follicle was 3.2 mm larger (a 23% increase) in fat-supplemented cows compared to control cows (Table 5). As shown in Table 5, a variety of dietary fat sources have had this effect on cow ovaries. Yet are certain fats more effective? Some studies did compare fat sources head-to-head. In two studies, it was the feeding of fats enriched in omega-6 (linoleic acid) or omega-3 fatty acids (linolenic or EPA and DHA) (Staples et al., 2000; Bilby et al., 2006) that stimulated larger dominant follicles compared to fats enriched in oleic acid. Thus the polyunsaturated fats were most effective in increasing follicle size. However, just the ovulation of larger follicles has improved fertility apart from elevated progesterone (Peters and Pursley, 2003) suggesting a more viable oocyte.

Better Quality Embryos Produced? All embryos are not created equal. Embryos are classified as high quality when they have a symmetrical and spherical mass with individual cells that are uniform in size, color, and density. These are most likely to become established and result in a diagnosed pregnancy. 154 California dairy cows were supplemented with either a calcium salt blend of linoleic acid and trans C18:1 (EnerG I Transition Formula®) or a calcium salt of palm oil (EnerG II®) (Virtus Nutrition) from 25 days before calving through 60 days postpartum at which time the cows underwent timed AI. Five days after AI, the uterus was flushed out to recover and evaluate the fertilized structures (Cerri et al., 2004). A greater proportion of the cows fed the mixture of linoleic acid and trans fatty acids tended to have fertilized structures compared to those fed the other fat source (87 vs. 73%), they had more sperm attached to each structure collected (34 vs. 21), and they tended to have more of their embryos classified as high quality (73 vs. 51%). In a larger set of cows numbering 397, conception rate at first AI was greater for cows fed the linoleic and trans acid mixture (33.5 vs. 25.6%) (Juchem et al., 2004). It is not clear if linoleic acid or the trans fatty acid in this mixture was most responsible for this benefit. The fatty acids in the supplement likely changed the fatty acid makeup of the cell membranes of these structures flushed from the cow's uterus, improving their quality. In a second study, the embryos collected from superovulated Holstein cows fed whole unprocessed flaxseed and transferred to Holstein heifers resulted in a better gestation rate than embryos coming from cows fed Megalac (58.8 vs. 29.3%) (Petit et al., 2004). The diet of the donor animal was more important than the diet of the recipient animal in this study suggesting that the dietary fat helps the cow develop a robust embryo. Embryos recovered from superovulated cows fed whole flaxseeds (10% of diet) or sunflower seeds had greater cell numbers than embryos coming from superovulated cows fed tallow (Thangavelu et al., 2006). Intake of supplemental fat was about 1.65 lb / day. The feeding of polyunsaturated fats appears to have a more positive impact on embryo development than do monounsaturated or saturated fat supplements.

Less Embryonic Loss? Here too, progesterone plays an important role. The embryo must signal to the uterus that it is present, so that the uterus does not release prostaglandin $F_{2\alpha}$. If prostaglandin $F_{2\alpha}$ is released by the uterus, the corpus luteum will disappear, progesterone synthesis will drop, the embryo will die for lack of support, and the cow will start a new estrous cycle. About 50% of embryos die (~40% during the first 28 days after AI and ~14% between 28 and 45 days after AI). Embryonic loss is a significant problem in the dairy industry.

Omega-3 fatty acids stored in the uterus from the diet can aid the process of embryo preservation by helping to reduce the synthesis of prostaglandin $F_{2\alpha}$. Can omega-6 fatty acids have a similar beneficial effect? Not likely, because omega-6 fatty acids are used to synthesis prostaglandin $F_{2\alpha}$. As proof, lactating dairy cows fed soybeans or sunflower seeds (both good sources of linoleic acid, the omega-6 fatty acid) had increased concentrations of prostaglandin $F_{2\alpha}$ in their blood when the uterus was artificially stimulated with an oxytocin injection. Cows that are fed omega-3 fatty acids partially replace the omega-6 fatty acids stored in the uterus so that there is less omega-6 inventory for the cow to draw from for synthesis of prostaglandin $F_{2\alpha}$. In demonstration of this effect, cows fed omega-3 fatty acids in the form of fish oil, flaxseed, or fish oil plus flaxseed in 4 different studies had lower concentrations of prostaglandin $F_{2\alpha}$ in their blood when the uterus was artificially stimulated by an oxytocin injection.

If dietary omega-3 fatty acids are exerting a suppressing effect on $PGF_{2\alpha}$ around the time of embryo recognition, then embryo loss should be reduced. Holstein cows (n = 121) were allotted to one of two dietary treatments initiated at 55 ± 22 days postpartum (Ambrose et al., 2006). Diets were isonitrogenous, isoenergetic, and isolipidic. Diets contained either rolled flaxseed (high in linolenic, omega-3) or rolled sunflower seed (high in linoleic, omega-6). Cows fed flaxseed were twice as likely to become pregnant. Embryo mortality from day 32 post AI to calving was lower for cows consuming flaxseed compared to those fed sunflower seeds (9.8 vs. 27.3%). In summary, supplementation with omega-3 fatty acids may aid in suppressing prostaglandin $F_{2\alpha}$ to prevent regression of the corpus luteum in order to maintain progesterone synthesis and sustain pregnancy (e.g. prevent early embryonic death).

Summary

It has been known for many years that early postpartum dairy cows usually produce more milk when fed a moderate amount of supplemental fat. There is growing evidence, as summarized in Table 2, that lactating dairy cows can benefit reproductively as well. Fat sources enriched in omega-6 or omega-3 fatty acids that deliver these fats to tissues beyond the rumen may be the most effective ones to feed but this can not be firmly concluded because other fats having very low amounts of these omega fatty acids have improved conception rates in single studies. The fats were fed at a minimum of 1.5% of the diet in studies in which conception rates were improved. Feeding less fat than this may be beneficial, but there is no supporting research behind it. Improved conception rates by fat-supplemented cows have been associated with an improved progesterone status of the cow by 1) increasing the size of the dominant follicle and corpus lutea on the ovaries and 2) by helping the corpus luteum survive and continue to produce progesterone during the early days of pregnancy. If fed in moderate amounts, start feeding the fat when the cows enter the close-up group, especially if benefits to cow health and the ovaries are desired.

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Table 1. Major fatty acid composition of select dietary fat sources.

	Fatty acid						
Fat source	C14:0 Myristic	C16:0 Palmitic	C16:1 Palmit-oleic	C18:0 Stearic	C18:1 Oleic	C18:2 Linoleic	C18:3 Linolenic
Tallow	3	25	3	18	43	3.8	<1
Yellow grease	2	21	4	11	44	14	<1
Energy Booster 100 [1]	3	40	1	41	10	2	<1
Megalac; EnerG-II [1]	1	50	<1	4	36	8	<1
Megalac-R[1]	1	36	<1	4	26	29	3
Canola oil	<1	4	<1	2	63	19	9
Cottonseed oil	1	23	1	3	18	54	1
Flaxseed oil	<1	5	<	3	20	16	55
Rapeseed oil	<1	5	<1	2	54	22	11
Safflower oil	<1	7	<1	2	12	78	<1
Soybean oil	<1	11	<1	4	23	54	8
Sunflower oil	<1	7	<1	5	19	68	1
Menhaden fish oil [2]	7	16	8	3	12	1	2

[1]Commercial preparations considered partially inert in the rumen.
[2]Also contains 14% C20:5 and 9% C22:6.

Table 2. Studies Reporting Improved Conception Rates (first service or cumulative services) of Lactating Dairy Cows Fed Supplemental Fatty Acids (P < 0.10). Unless otherwise indicated with a footnote, the control diet did not contain a fat supplement.

Reference	Fat source and concentration or amount in diet	Number of cows in trial	Control treat-ment	Fat treat-ment
			---- % ----	
Ferguson et al., 1990	2% Ca-palm oil	253	43	59[1]
Sklan et al., 1991	2.6% Ca-palm Oil	99	62	82
Scott et al., 1995	1 lb / d Ca-palm oil	443	93	98
Garcia-Bojalil et al., 1998	2.2% Ca-palm oil	43	52	86
Son et al., 1996	3% tallow	68	44	62
Frajblat and Butler, 2003	1.7% Energy Booster	81	58[2]	86
Petit et al., 2001	17% formaldehyde-treated flaxseed	30	50[3]	87[1]
Ambrose et al., 2006b	9% rolled flaxseed	121	32[4]	48[1]
McNamara et al., 2003	3.3 lb / d MegaPro Gold	129	35	54
Juchem et al., 2004	1.5% (Soy + Trans C18:1)	397	26[3]	34[1]
Cullens, 2004	2% Megalac-R	42	27	58[1]
Castaneda-Gutierrez al., 2005	0.3 lb / d Ca-et CLA	32	44[3]	81
Bruckental et al., 1989	7.3% fish meal	132	52	72
Armstrong et al., 1990	1.8 lb / d fish meal	80	44	64
Carrol et al., 1994	3.5% fish meal	44	68	89[1]
Burke et al., 1997	2.8% fish meal	300	32	41
Average			50.2	71.4

1 First insemination.
2 Control diet contained equal energy to fat-supplemented diet. Fat was fed prepartum only.
3 Control diet contained Ca salt of palm oil distillate.
4 Control diet contained rolled sunflower seeds.

Table 3. Studies Reporting a Negative Effect or No Improvement in Conception Rates (first service or cumulative services) of Lactating Dairy Cows Fed Supplemental Fatty Acids. Unless otherwise indicated with a footnote, the control diet did not contain a fat supplement.

Reference	Fat source and concentration or amount in diet	Number of cows in trial	Control treat-ment	Fat treat-ment
			---- % ----	
Schneider et al., 1988	1.1 lb / d Ca-palm oil	108	43	60[1]
Sklan et al., 1989	1.1 lb / d Ca-palm oil	108	28	44[1]
Carroll et al., 1990	5% prilled fat	46	33	75[1]
Holter et al., 1992	1.2 lb / d Ca-palm oil	38	50[2]	44[1]
Lucy et al., 1992	3% Ca-palm oil	40	44	12[a]
Sklan et al., 1994	2.5% Ca-palm oil primiparous cows	40	74	33[1,a]
Sklan et al., 1994	2.5% Ca-palm oil multiparous cows	62	42	33[1]
Salfer et al., 1995	2% partially hydrogenated tallow	32	32	33[1]
Juchem et al., 2002	1.6% (Ca-palm + fish oils)	500	41[3]	43[1]
Bernal-Santos et al., 2003	0.3 lb / d Ca-CLA	30	27[4]	42
Bruno et al., 2004	1.5% (Ca-palm + fish oils)	331	26[3]	27[1]
Petit and Twagiramungu, 2006	10.6% whole flaxseed	70	58[5]	64
Ambrose et al., 2006a	9% rolled flaxseed	309	37[6]	26[1]
Ambrose et al., 2006 personal comm.	8% rolled flaxseed	266	42[7]	43
Fuentes et al., 2007	5.5% extruded flaxseed	356	39[8]	39[1]
Carroll et al., 1994	3.5% fish meal	18	67	33[1,a]
Burke et al., 1997	2.7% fish meal	341	65	60
Average			44.6	41.8

1 First insemination.
2 Control diet contained whole cottonseed at 15% of dietary dry matter.
3 Control diet contained tallow.
4 Control diet contained Ca salt of palm oil distillate.
5 Control diet contained micronized soybeans.
6 Control diet contained Ca salt of palm oil distillate and High Fat Product from ADM.
7 Control diet contained Ca salt of palm oil distillate and tallow.
Control diet contained extruded soybeans and Ca salt of palm oil distillate.
a Significant dietary effect, P < 0.05.

Table 4. Effect of Feeding Various Oilseeds on the Essential Fatty Acid Concentration of Milk Fat From Dairy Cows.[1]

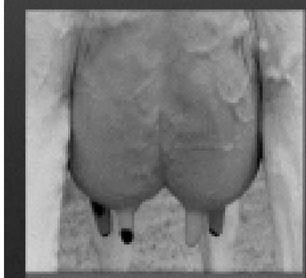
Reference	Seed type	Diet Control	+Oil Seed
C18:2			
Dhiman et al., 1995	0% vs. 16% soybeans	3.2%	6.2%*
Holter et al., 1992	0% vs. 15% whole cottonseeds	4.0%	4.2%
Markus et al., 1996	0% vs. 7.1% whole sunflower seeds	2.3%	2.8%*
Petit et al., 2004	0% or 9.6% whole sunflower seeds	3.2%	3.8%
Stegeman et al., 1992	0% or 10% rolled sunflower seeds	2.2%	3.3%*
Tice et al., 1994	19.7% raw vs. roasted whole soybeans	5.5%	6.7%*
Stegeman et al., 1992	0% or 10% rolled safflower seeds	2.2%	3.1%*
C18:3			
Petit et al., 2004	0 vs.9.7% whole flaxseed	0.6%	1.1%*
Gonthier et al., 2005	0% vs. 12.5% ground flaxseed	0.4%	1.3%*

* Values under the oilseed column having an asterisk were significantly different from the control values.

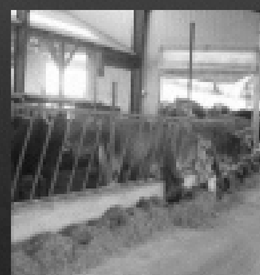
Table 5. Diameter of the dominant ovarian follicle of lactating dairy cows fed fat supplements was greater than that of cows fed the control diet ($P < 0.10$).

Reference	Fat source	Experimental diets Control	Fat
Lucy et al., 1991	Ca salt of palm oil	12.4	18.2
Lucy et al., 1993	Ca salt of palm oil	16.0	18.6
Oldick et al., 1997	Yellow grease	16.9	20.9
Beam and Butler, 1997	Tallow - Yellow grease	11.0	13.5
Staples et al., 2000	Soybean oil, fish oil	14.3	17.1
Robinson et al., 2002	Protected soybeans	13.3	16.9
Bilby et al., 2006	Megalac-R or Flaxseed oil	15.0	16.5
Ambrose et al., 2006b Rolled flaxseeds		14.1	16.9
Average		14.1	17.3

NUTRITION AND MASTITIS: *Food for thought!*

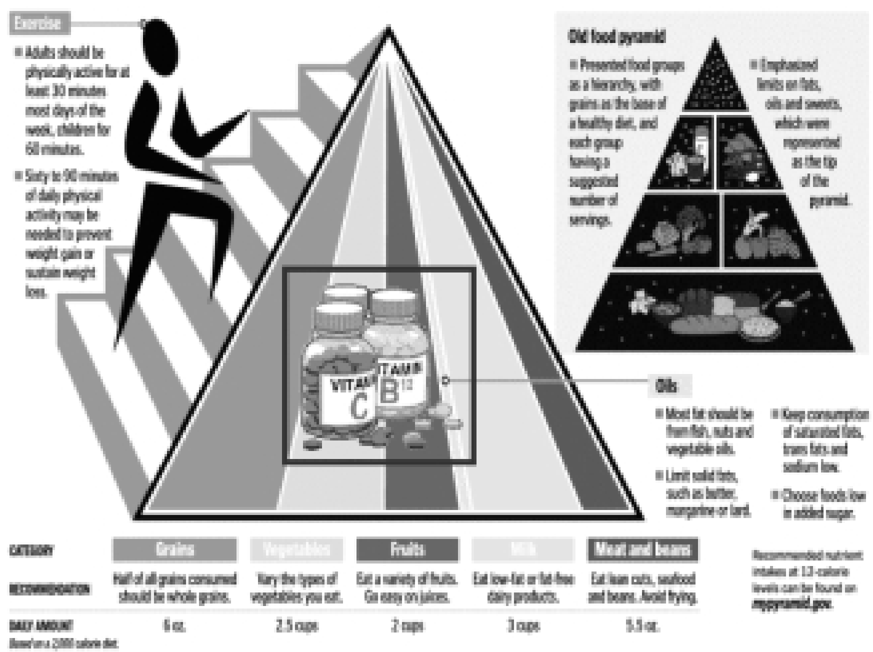


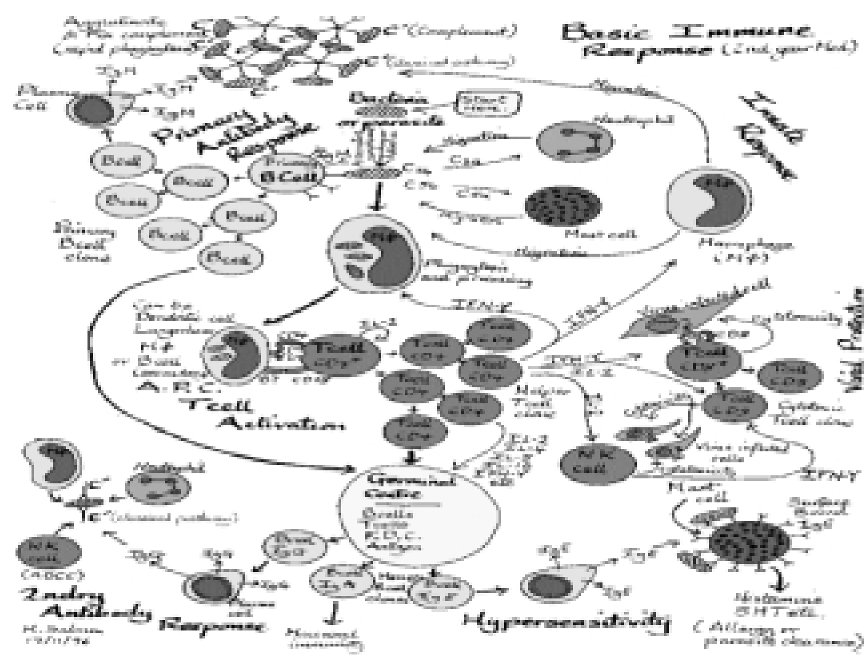
Leo Timms
Iowa State U.



NUTRITION AND MASTITIS

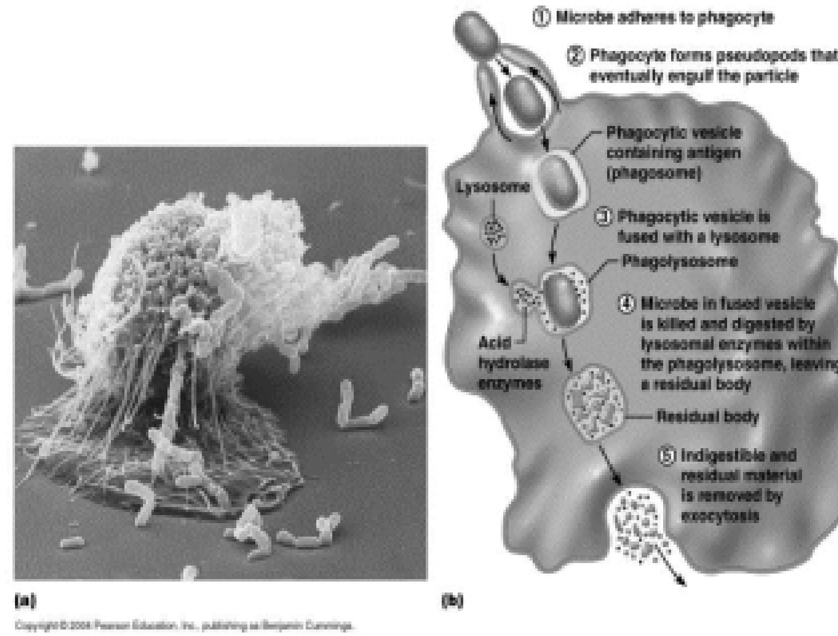
- Direct effects: clinical trials show direct impact on mastitis / SCC (very limited but needed!)
- Indirect effects: impact on immune cells / function (in vivo / vitro)
  - Associations or trends: relationship between nutrient status and mammary health

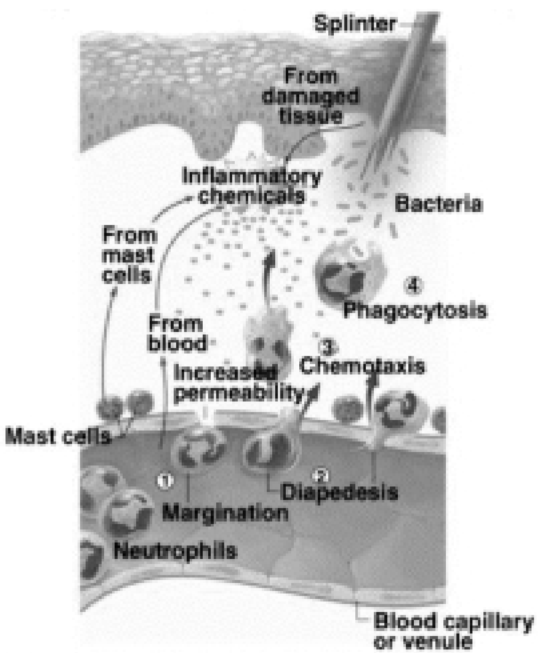


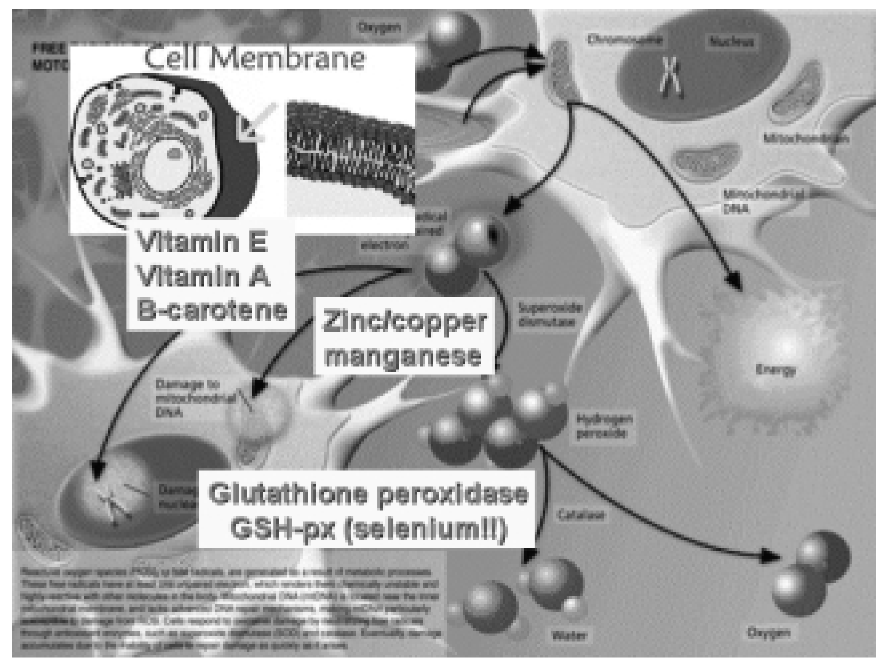


Immune suppression at calving

- Ability of neutrophils to move toward and kill invading bacteria
  ↓ about 40%.
- Ability of lymphocytes to produce antibody **↓ about 30%**







Nutrients and Health: The anti – oxidants.

- Selenium
- Vitamin E
- Copper
- Zinc
- Vitamin A (beta – carotene)
- Others ?

Vitamin E / Se and Udder Health

- Many associative studies around the world show Vit E / Se related to decreased disease incidence and severity!
- Effects usually seen on reproduction first (or sometimes only reproduction).
- Not all studies show association, especially with Vit E.
- Depends on initial status of animals

Vitamin E / Se and Udder Health

- 80 cows; 20 cows per trt.
- Dry period study: Clinical mastitis (CM)
- Control, 740 IU E, .1 mg Se inj, E+Se
- Vit E: 37% reduction in CM (no Se eff)
- Duration of infection: decreased

* Vit E: 44% * Se: 46% E+Se: 67%

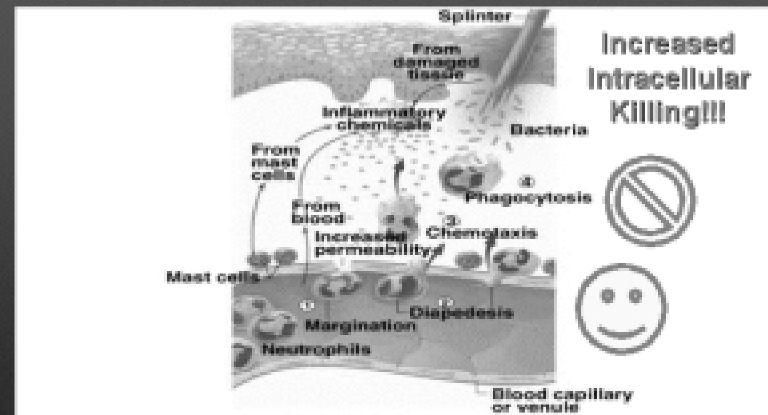
Smith et al., JDS 1984

Vitamin E / Se and Udder Health

- 20 heifers: 10 heifers per trt.
  - 3 mo prepartum – lactation
- Se- .04 ppm supp.; Se+ .2 ppm
- IMM challenge: wk 14 postpartum
  - E. coli / S. aureus
- **Se+: faster response, decreased bacterial shedding / clinical signs (E. coli)**

Erskine et al., AJVR 1989, 1990

Vitamin E / Se and Udder Health



Hogan et al., JDS 1990/ 92; Batra, JDS 1993; Ndinene and Finch, 1995/96

Vitamin E / Se and Udder Health

- Dramatic drop in Vit E near calving
  - Injecting Vit E prepartum
- 3000 IU 10/ 5 d (Weiss, JDS 1992)
- 3000 IU IM 14 d (Erskine, JAVMA 1997)
- 3000 IU SQ 7 d (LeBlanc, JDS 2002)
- Increased serum tocopherol (still drop)
  - Effects on RP, reproduction
- No detectable effects on mastitis!!
- Marginal E status! Primiparous!

Vitamin E / Se and Udder Health

- 66 cows: 22 cows per trt.
- 60 days prepartum – (lactation)
- 100, 1000 (500), 4000 (2000) IU supplemental vitamin E per cow per day.
- Blood selenium 0.05 micrograms/ml plasma – less than optimal (.1ppm supp.)

Weiss et al., JDS 1997

Vitamin E and Udder Health (Older Cows)

Mastitis	100 IU	1000 IU	4000 IU
Mastitis Infections (% of glands)	17.9	14.9	10.0
% Clinical Mastitis	17.9	17.9	3.8

Vitamin A and Beta Carotene

- 2 trials: dry period and 3 w pre-10 wk post
- 3 supp. trts.: 53,000 IU A; 173,000 IU A; 53,000 IU A + 300 mg B-carotene(BC)
- Trial 1: lower % new IMI at calving 49-50 % (low and high A) vs 27% (BC)
- Trial 2: SCC reduction

225,000 (low A); 125,000 (high A); 85000 (BC)

Dahlquist and Chew, Chew and Johnston JDS abstracts 1985

Vitamin E and Udder Health (First Parity)

Mastitis	100 IU	1000 IU	4000 IU
Mastitis Infections (% of glands)	56.2	57.2	20.9
% Clinical Mastitis	37.4	14.2	0

Weiss et al. 1997. JDS 80:1728-1737.

Vitamin A and Beta Carotene

- **82 cows: 2 w pre- 6 wk postpartum**
  - **50,000 IU A; 170,000 IU A**
  50,000 IU A + 300 mg BC
- **No effects on:**
  - **New dry period /calving IMI**
  - **Clinical mastitis**
  - **Plasma BC 10mg/l (Chew 2.5)**
- **Plasma BC for optimum udder health: >3 mg/l**

Oldham et al., JDS 1991

Vitamin A and Beta Carotene

- Many associative studies around the world show Vit A / BC related to decreased disease incidence and severity!
  - Effects usually seen on reproduction first (or sometimes only reproduction).
- Not all studies show association, especially with B-carotene.
  - Depends on initial status of animals

➢ **Vit A assoc. w 60% decrease CM and NEFA increased problems (LeBlanc, 2004)**

Zinc and Mammary Gland Health

- **40 cows: 3 w prepartum – lactation**
- **~ 50 ppm zinc (25 basal, 25 supp.)**
- **Inorganic and zinc proteinate (ZP)**
  - **Dry: 260 mg inorg; 200 io, 60 ZP**
- **Postcalve: 390 inorg; 140 io, 250 ZP**

- NO EFFECT ON MASTITIS / SCC.

Whitaker et al., Vet J 1997

Zinc and Mammary Gland Health

- **11 individual trials (early-mid 1990's)**
  - **Summarized / analyzed together**
    - **Diets suppl.: 180 – 400 mg Zn**
      - **Zn – methionine complex**

- **SCC reduction**

196,000 (ZnMe+) vs 294,000

- **50% basal diets below NRC**

Kellogg et al., PAS 2004

Copper and Mammary Gland Health

- 28 Holstein Heifers
  - 60 d pre-partum to 42 DIM
- ~6.5 ppm Cu- vs. 20 ppm supp. CU+
  - E. coli challenge: 34 DIM
- **At calving Cu+ animals had higher liver Cu (163 vs 33).**
  - **Cu+: faster response, decreased bacterial shedding / clinical signs**
- **Similar to 1994 studies: abstracts only**

Scarletti et al., JDS 2003

NRC 2001 REQUIREMENTS

- **Vitamin A**: 110 IU/kg BW
  * 77,000 IU day suppl. A (Holstein)
- **Beta carotene**: no established rqt.
- **Vit E:** 1.6 IU/kg BW (dry); .8 (lact).
  * 1000 IU (dry) and 500 IU (lact) supp.
- **Selenium**: 0.3 ppm (US FDA)
- **Zinc**: 40-60 ppm (supp) (udder?)
- **Copper**: 20 ppm (supp). (udder?)

OTHER INGREDIENTS

- Vitamin C : need in ruminants?
  - ✓ Decreased plasma C (subclinical / CM)
    - ✓ Swarup et al., Vet Res. Com 2005, Kleczkowski, Pol J Vet Sci 2005
  - ✓ E. coli challenge: decreased plasma/milk milk Vit C assoc. with clinical severity
    - ✓ Weiss et al., JDS 2004
- Manganese
- Chromium
- Cobalt

(Manganese, Chromium, Cobalt: Variable results)

OTHER INGREDIENTS

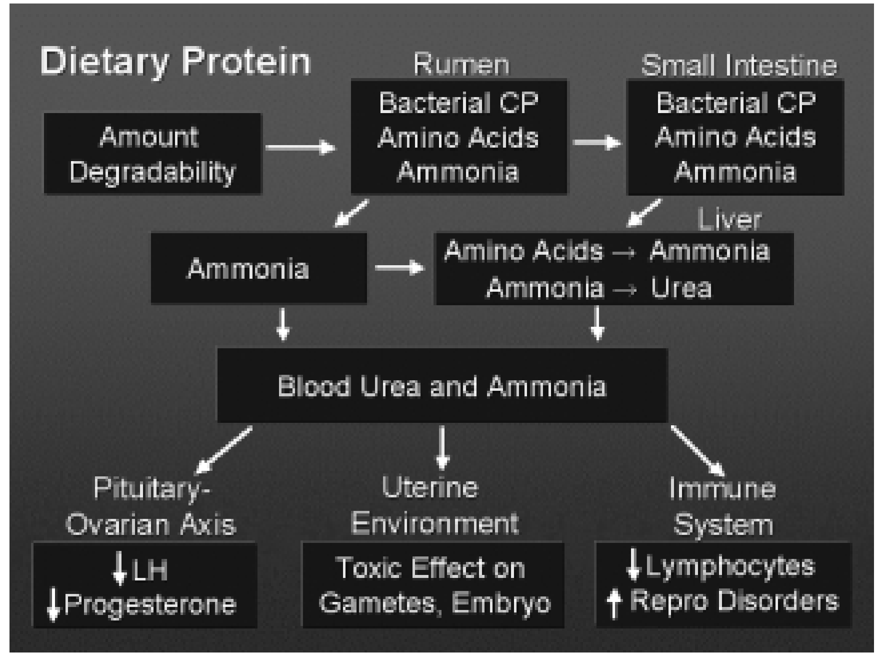
- B- vitamins : need in ruminants?
  - Vit B2 single IV infusion: lower SCC, increased cell function, no S. aureus cure
  - Biotin: increased milk, foot health, glucose
  - Choline (rumen protected): repro, energy
- Vitamin D (D_3)
  - Variable: stimulate lymph.; immunsuppressive

OTHER INGREDIENTS

- CALCIUM
  - ✓ decreased sphincter / muscle activity
  - ✓ milk fever: Zn ↓ at calving – larger, longer
  - ✓ MF assoc.(odds) : Erb et al, JAVMA 1983
    * mastitis: 8.1 *coliform mastitis: 9.0
    * dystocia: 6.5 * RP: 3.2 * ketosis: 8.9
- Higher energy/protein intake last 3 weeks of dry period decreased risks!

Energy: Balance / Immune Function

- "Epidemiological studies indicate energy balance during early lactation and increased susceptibility to infectious diseases such as mastitis."
- Ketone bodies inhibit migration of PMNL with a decrease in phagocytosis.
  (Kremer et al. (1993) J. Dairy Sci. 76:3428 – 3436.
- Overconditioned cows at calving: increased weight loss and NEFA: decreased lymphocyte function 2005
- Supplemental energy to Johne's cows: (stuffed) increased lymphocyte and immune function 2003
- Monensin summary: decreased ketosis but no impact on mastitis (Duffield et al., JDS 2002)



Energy: Fat / Immune Function

- 3 diets: isonitrogenous, isocaloric
- flaxseed vs Megalac vs micrion. soybeans

➢ All diets showed decreased immune responses at calving

➢ Response prolonged 1 week with flax

Lessard et al., JDS 2003

INDIVIDUAL INGREDIENTS: QUANTITY

- Deficient vs adequate
- EXCESS!!! Can be detrimental / TOXIC!
- Interaction with other compounds!
  - Vit E and Se
  - copper/zinc/Mo
  - CHO / protein

Nutritional Immunology

Order of Importance of nutrients to Immune system

F I B E R

Energy

Protein

Calcium

vitamin A

vitamin E

Copper, Zinc, Selenium

F I B E R

Trace Mineral Fortification / Source

- 532 cows: 2 lactation trial (plus dry)
- 4 different treatments: Zn, Mn, Cu, Co
  - 75% NRC complexed Zn, Mn, Cu, Co (75C)
  - 100% NRC inorganic (sulfates) (100I)
  - 100% NRC complexed (4 Plex) (100C)
  - 100% inorganic / complexed (100IC)
- Mn: 3.3X NRC; *Co: 9.1X NRC.
- No difference on mastitis incidence!

INDIVIDUAL INGREDIENTS: QUALITY

- Form or composition of ingredient
  - *a* tocopherol acetate - selenite / selenate
  - Pasture vs stored feeds
- Chelated or organic minerals
  - complexed or chelated minerals
  - organic selenium

Trace Mineral Fortification / Source

- 100% C or IC: lower SCC multiparous
- 100% C: more milk than 75%C
- 100% IC: most milk, lowest SCC, best reproduction

??? Supplementing for milk or health???

Nocek et al., JDS 2006

Organic selenium: Se yeast

- Se incorporated into methionine (yeast –Su)
  - 100 cows: low Se status (.005ug/ml plasma)
  - .2 ppm Se selenite or Se-yeast for 8 weeks
  - Both increased plasma SE (.09 and .16)
  - yeast: 1.4X blood GSH, 1.9 blood, 2.7X milk
  - Both showed significant decreased IMI
  - No difference in IMI between treatments!

Malbe et al., Zentialbl Veterinaned A 1995

Organic selenium: Se yeast

- Se incorporated into methionine (yeast –Su)
  - Drop in plasma SE at calving (45 and 23%)
  - yeast: 1.4X serum Se (cows and calves)
  - yeast: 1.8X Se: milk and colostrum
  - No difference in cell function between trt.!
  - No difference in challenge response between treatments!

Weiss and Hogan, JDS 2005

Organic selenium: Se yeast

- Se incorporated into methionine (yeast –Su)
  - 40 cows: 60 d pre – 30 days post calving
  - .3 ppm Se selenate (SS) or Se-yeast (SY)
  - 28 d post: WBC function assessed
  - IM endotoxin challenge: 28 d post

Weiss and Hogan, JDS 2005

INDIVIDUAL INGREDIENTS: QUALITY

- Form or composition of ingredient

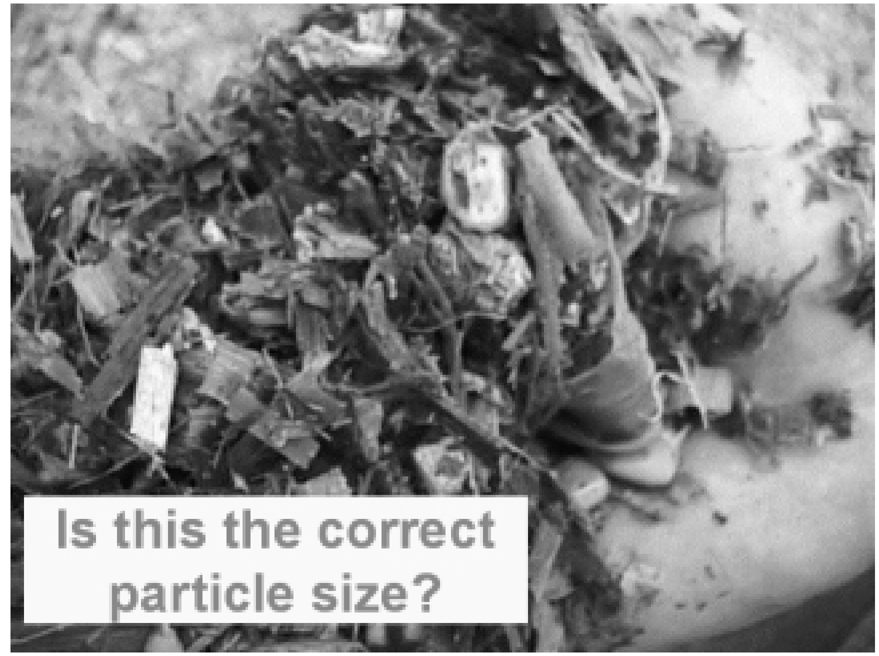
- *a* tocopherol acetate - selenite / selenate

- Chelated or organic minerals

- complexed or chelated minerals

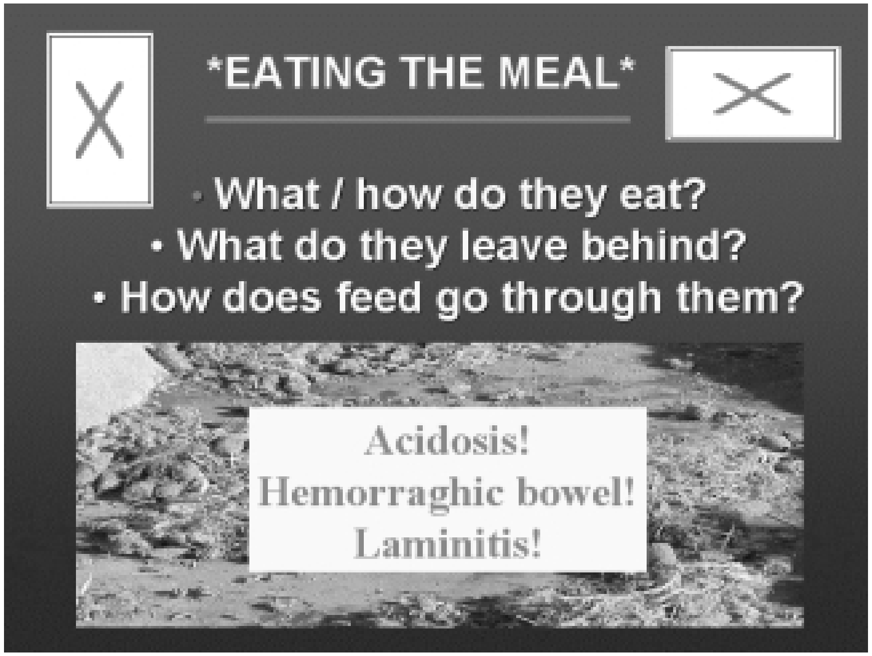
- organic selenium

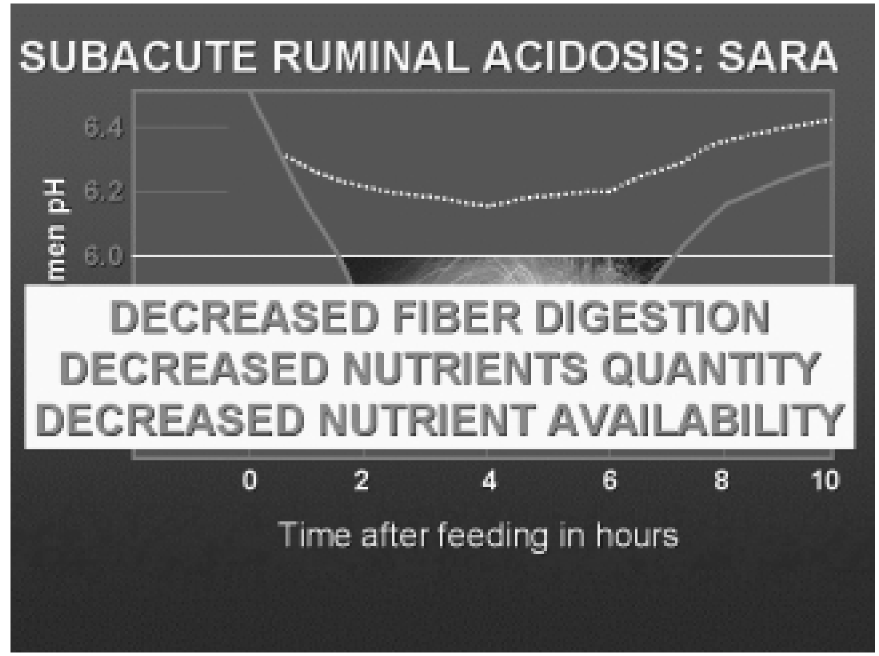
FORAGE QUALITY!!

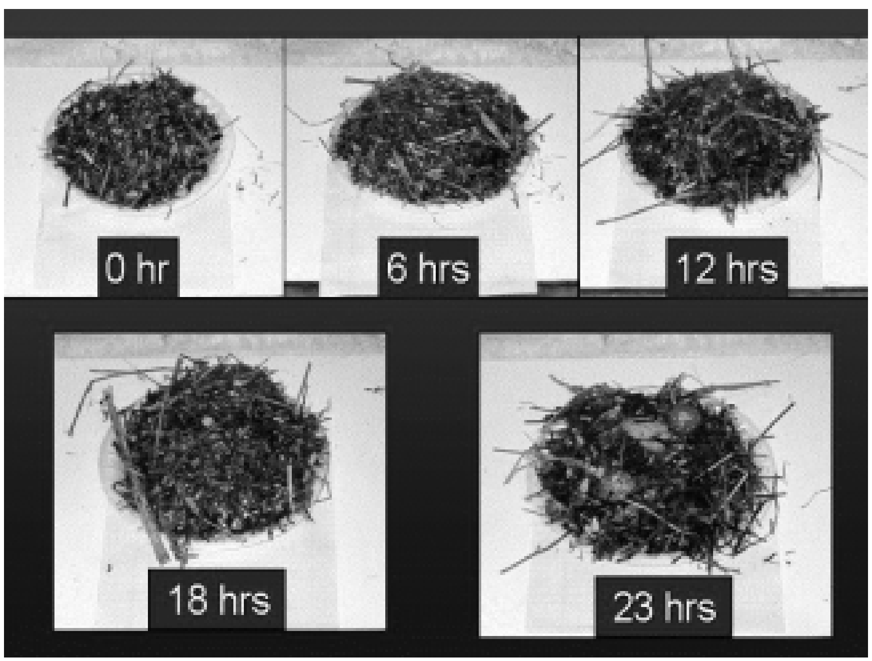

Is this the correct
particle size?

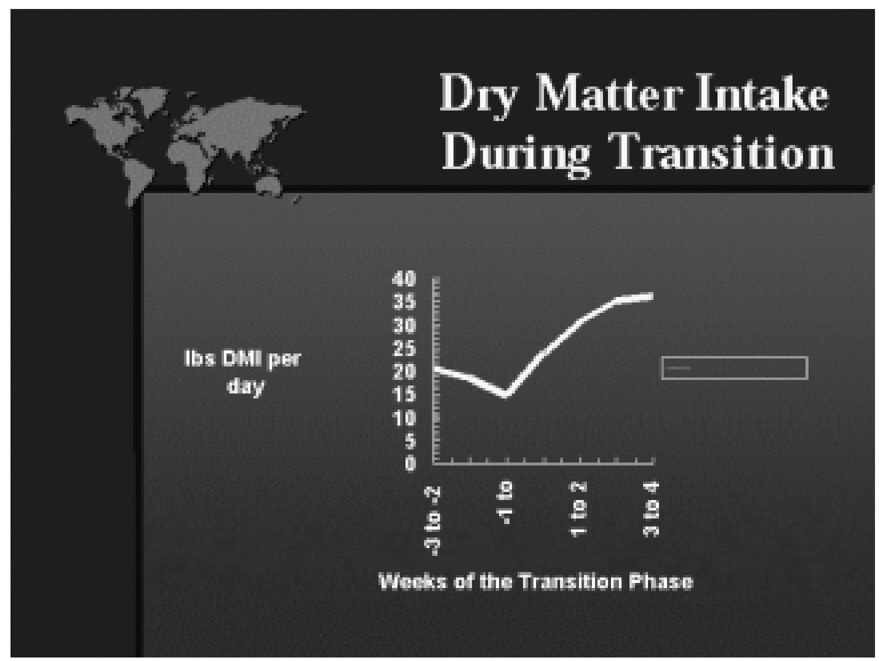

MIXING THE INGREDIENTS
• Proper ingredients
• Proper mixing
DC Allen Co.

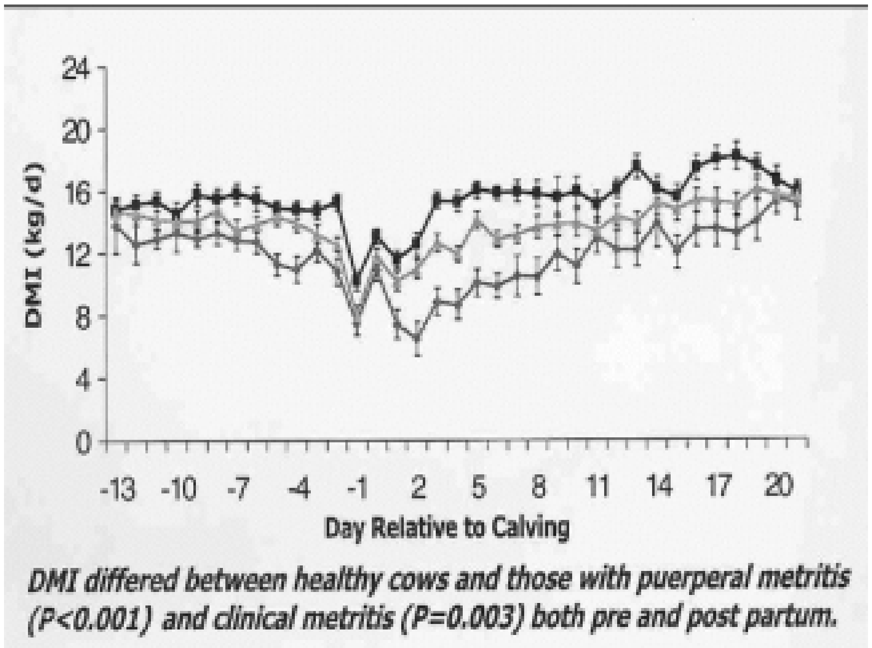

FEED DELIVERY
• What's it look like?
• What's it taste like?
PIZZA
Henkese
lltop Dairy

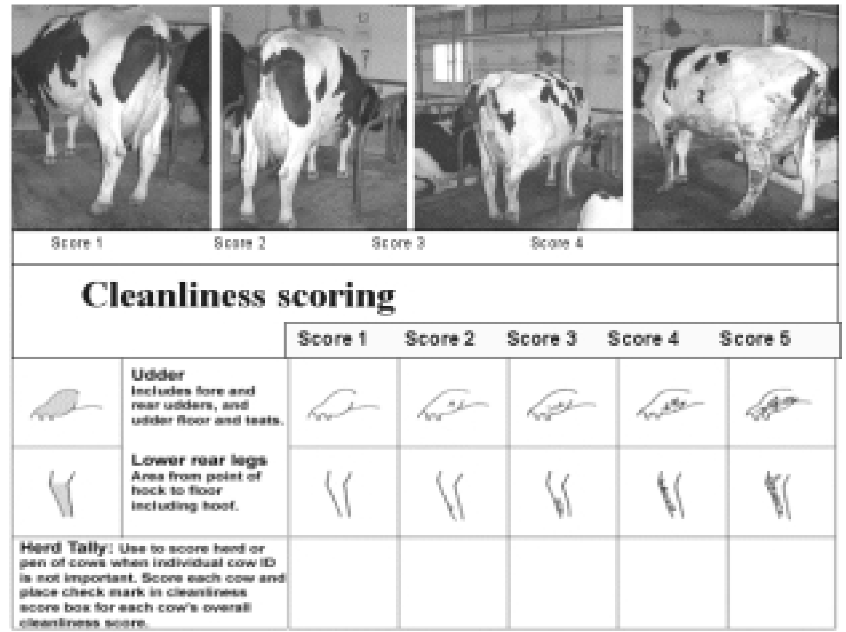

EATING THE MEAL
What / how do they eat?
• What do they leave behind?
• How does feed go through them?
Acidosis!
Hemorraghic bowel!
Laminitis!

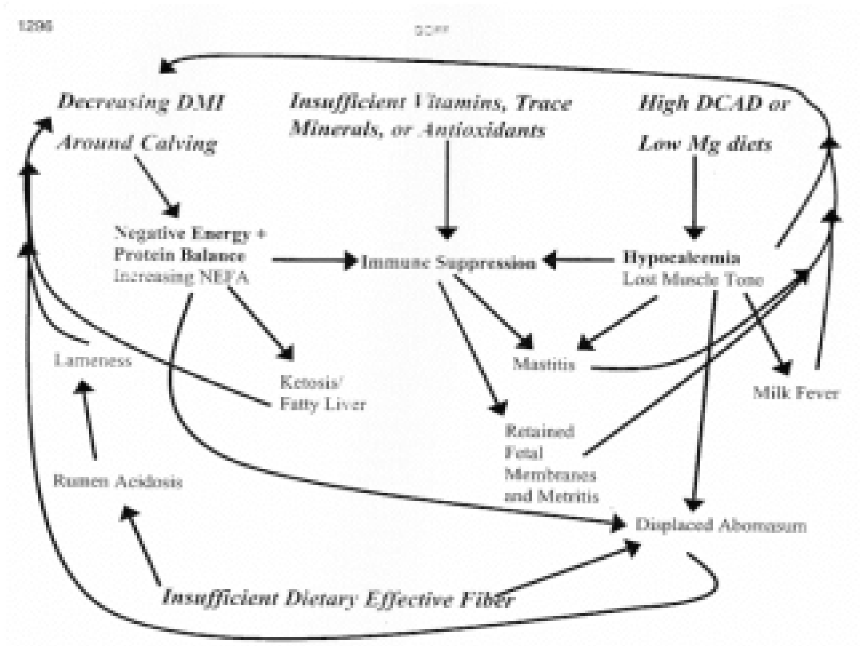

SUBACUTE RUMINAL ACIDOSIS: SARA
men pH
6.4
6.2
6.0
DECREASED FIBER DIGESTION
DECREASED NUTRIENTS QUANTITY
DECREASED NUTRIENT AVAILABILITY
0
2
4
6
8
10
Time after feeding in hours


0 hr
6 hrs
12 hrs
18 hrs
23 hrs


Dry Matter Intake
During Transition
lbs DMI per day
40
35
30
25
20
15
10
5
0
-3 to -2
-1 to
1 to 2
3 to 4
Weeks of the Transition Phase

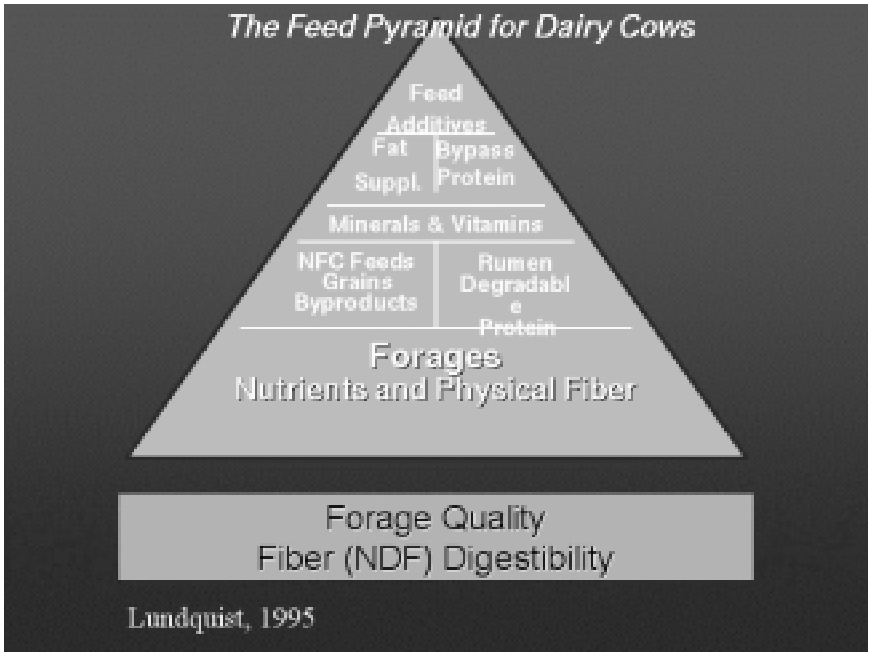






Managing to Improve Udder Health

- Overall Management Program
- "You can't shake management out of a feed sack."
- Clean environment
- Milking procedures and equipment
- Nutrition
- Base feeds on farm / supplements!



SUMMARY

- Mastitis is an expensive and unavoidable disease in dairy cattle.
- Nutritional status of the animal influences immune function and can therefore affect mammary gland health.
- A total management plan should be developed, with nutrition as a key component.

Troubleshooting Herd Nutrition and Health with Control Charts

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How consistently are your clients' dairy farms managed? How consistent and compliant are employees at carrying out the management protocols? It is common knowledge that dairy cows thrive well when herd management is consistently excellent. They perform best when they are healthy, are milked exactly the same way every day, and fed palatable diets that consistently provide all nutrient requirements.

Variation is the opposite of consistency and is considered the enemy to process performance. Excessive variation interferes with the evaluation of performance. While it is true that high variability makes performance outcomes unpredictable and difficult to interpret, understanding variation is the diagnostic key to improving process. Statistical process control (SPC) is an analytical approach utilizing basic statistical principles to identify with a defined certainty when process performance is improving, staying the same or getting worse. Control charts are one of the several SPC tools used to monitor process quality. There are several types of control charts utilized in SPC. Each type of control chart has its own data requirements, application niche, advantages and disadvantages. So far researchers and practitioners have found P charts, I charts and CUSUM charts most appropriate to plot data being collected on dairy farms. Appropriate choice and design of an SPC chart determines its effectiveness in detecting signals of true (not random) variation; therefore, further reading on the subject is recommended (18, 23).

Why use SPC in dairy management?

Dairy farm managers and their consultants have in the past restricted their analysis to limited comparisons of performance means without full consideration of variation, for example, comparing last month's average of herd performance variable with this month's average. Such an analysis may not only be misleading, it is usually out of context with the daily management activity. Ironically, although consistency in herd management is intuitively sought, analysis of variation in process output has been neglected. Consequently consultants and / or employees may be blamed or rewarded for random variation in performance and not on the basis of "real" change. This leads to management decision errors and frustration for everyone—the consultants, the managers and their employees (6). There is an apparent need for management tools that would help make decision making more fact-based (11) and make data interpretation not purely intuitive and subjective but supported with a defined level of certainty. Applying statistical methods to analyze data already available on the farm has the potential of improving process and personnel performance monitoring, thus providing more effective management tools for the dairy farm managers and their consultants. Moreover, it can assure more timely performance feedback to those directly responsible for the process (i.e. milkers, feeders, breeders) as compared with the retrospective monitoring garnered from once per month record analysis that is often out of time order context with daily management.

SPC has proven to be an effective quality management tool in manufacturing for over 80 years, improving product quality and reducing process waste. First attempts to implement principles of SPC in livestock industry go back to 1977 with Wrathall et al. (31) studying applicability of individual measurement SPC chart application. Since then, the use of SPC charts has been researched in all the four major livestock species: swine (14, 15, 30), beef (20, 24, 25), poultry (4, 21) and, more recently, dairy (7, 17, 22). Wrathall and Hebert (32) first identified the need for SPC application in livestock because of growing herd size and increasing remoteness between managers and livestock. More current studies underline the applicability of SPC methods in continuous improvement effort at the farm (5, 19, 20, 25). Although the research in SPC application in livestock production has at least a 28-year history, only recently has the idea become practical. This has been largely due to advances in computer capability. Practical application dairy software (i.e. 100-Day Contract Manager™)[1] and websites that automatically chart process output variables on SPC charts (MilkLab™ at www.dairyperformance.com) are available. In addition, increased use of on-farm technology with computerized milking, feeding and estrous detection systems provide enormous amounts of data available on a daily or hourly basis. Analyzed properly, this data can be helpful in monitoring the performance of these critical processes as well as the employees that carry them out.

The goal of a commercial dairy farm is to consistently produce high quality and safe milk in a manner that enhances animal health and productivity (23). Controlled basic research and field studies provide cause and effect knowledge of the effectiveness of a management or product intervention. Such studies are not practical under day-to-day conditions on commercial dairy facilities. There is no control group, only a single stream of data. Yet, it is important to determine with some degree of certainty whether a management intervention or product introduction is working and whether the processes themselves are improving or getting worse. It is in this circumstance that SPC analysis is not only appropriate but superior to other statistical or monitoring techniques. This argument alone provides a compelling reason for the application of the SPC tools in commercial dairy production systems. However, it should be remembered that since before and after comparisons are being made from a single stream of data, it is important to emphasize a need for the process to be stable (in a state of statistical control) and that confounding factors are minimized before the new protocol or product is introduced to be sure that any observed process change was valid. It should be further noted that the smaller the process variation is prior to introducing a known intervention, the greater the sensitivity for detecting small changes before and after comparisons.

The authors conclude that SPC can be successfully applied in dairy production systems. The time is right. The availability of large amounts of automatically collected data, the advances in computer capability, and the obvious need for more timely fact-based information for day-to-day management make SPC application the next step forward in improving herd management quality.

Examples of Control Chart Use

Example 1. Cow activity monitoring for early disease detection.

Monitoring dairy cow activity with pedometers has been shown to help detect developing metabolic disorders (8). Figure 1 is an example of a Shewhart I chart of daily single cow activity (Dr. Dick Wallace, University of Illinois, personal communication, May 2005). To develop the chart, an arithmetic mean was calculated and a sigma estimated from the average moving range of size two. A center line has been plotted at the mean along with upper and lower control limits 3 sigma above and below the center line. Applying Western Electrics run rules (2 and 3) identified a significant drop in activity as a result of developing ketosis as early as 7/22, four days before the clinical diagnosis was made.

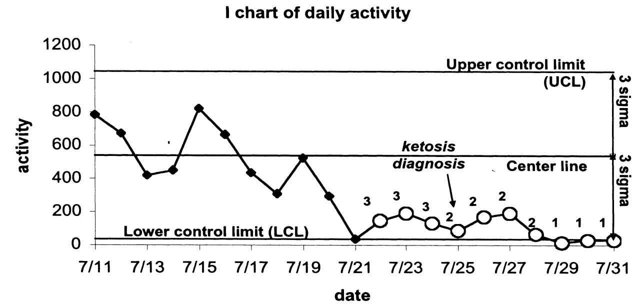

Figure 1. Anatomy of an I chart. Upper (UCL) and lower control limits (LCL) are marked as lines 3 sigma away from the center line (CL). The data point labeled by the white circle indicates a point out of control. Number above data points indicate which Western Electric Rule identified the point to be out of control. The arrow indicates when the clinical diagnosis of ketosis was made.

Example 2. Percent of fresh cows in the first week post calving with fever monitored by a P chart.

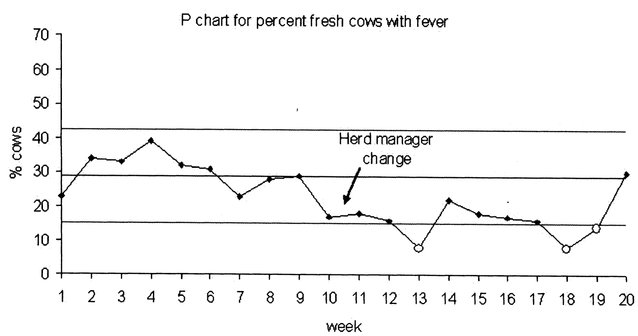

Figure 2. P chart for monitoring percent fresh cows with fever. The data points labeled by the white circles indicate points out of control according to the 3 sigma rule. The arrow indicates the time a new herd manager was hired.

The number of fresh cows with fevers during the first ten days after calving is indicative of dry, close up and fresh cow management (Mark Kinsel, Ag Information Management Inc., Ellenburg, WA, personal communication, June 2005). On this 2000-cow dairy, the proportion of cows with fever was being monitored daily and compiled on a weekly basis giving a sample size of around 40 (Figure 2). For simplicity it is assumed that the sample size (number of cows calving per week) is fairly constant throughout the year. Three “out of control” points on the lower side of the mean following a herd manager change indicate a significant decrease in the percent of cows calving with fever and provide excellent feedback to the owner on his hiring decision. This is assuming both the old and new managers recorded all the fever incidences among fresh cows.

Example 3. Butter fat depression in a group of first lactation cows.

Figure 3 is an I chart of milk fat depression of the first lactation group of Holstein cows preceding an episode of displaced abomasums. An investigation into the root cause of the increase in the occurrence in displaced abomasums (DAs) revealed a problem with the feeding process. A newly hired feeder had been routinely over mixing the TMR prepared for the heifer group causing the feed for that group to be deficient in effective fiber, resulting in milk fat depression and increase in DA occurrence in the group. There were 5 DAs in that group the week following the control chart "signal."

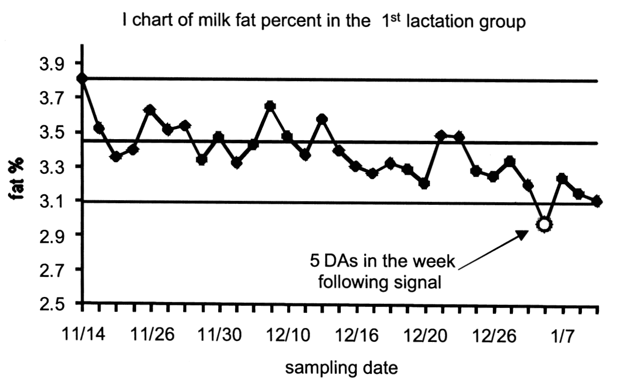

Figure 3. I chart for monitoring daily milk fat percent in the first lactation heifer group sampled with a line sampler. The data points labeled by the white circles indicate points out of control according to the 3 sigma rule. The arrow indicates the time of signal.

Example 4. Milk Urea Nitrogen (MUN) response to changes in dietary protein.

It has been well documented that MUN responds quickly to dietary changes (28). Figure 4 shows a response of the bulk tank milk urea nitrogen to known changes in crude protein concentration in the diet of a late lactation group of cows at the University of Minnesota research herd in Morris, MN. The herd was being fed a balanced diet with 15% CP and at the time had a mean MUN of 6.8. The diet was adjusted to 16% using soybean meal. There was no change in herd milk production, however, the bulk tank MUN significantly increased within 48 hours.

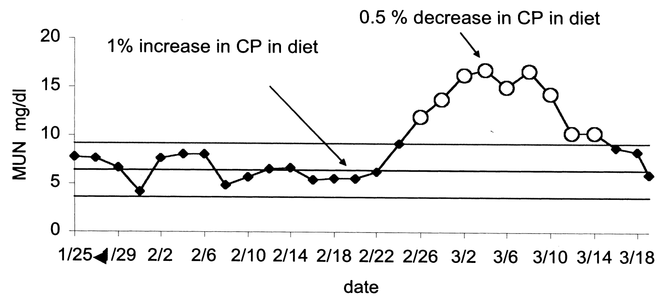

Figure 4. I chart monitoring the milk urea nitrogen (MUN) response to dietary crude protein change. The data points labeled by white circles indicate points out of control according to the 3 sigma rule. Arrows indicate the time of change in crude protein (CP) concentration change in diet.

Factors affecting protein efficiency and nitrogen excretion

Dairy animals of all stages of growth, production and reproduction ultimately have a requirement for amino acids to be absorbed and used by target tissues (NRC 2001). Metabolizable protein is the protein which is digested in the small intestine and absorbed as amino acids. Metabolizable protein consists of microbial protein, rumen undegraded protein and a small amount of endogenous protein. (1)

Ruminant animals benefit greatly from the synergistic and symbiotic relationship of rumen microbes. Various bacteria attach to feed particles and together secrete enzymes which digest starch, fiber and protein. This results in a supply of carbohydrates, peptides and amino acids which are consumed by bacterial cells and used to grow and reproduce. The rate at which this occurs depends on a synchronized supply of energy and peptides or amino acids. However, if energy is limited, amino acids will be deaminated (nitrogen containing amine group removed). The remaining carbon compound will be converted to VFA to use for energy and the amino group converted to ammonia.

Because ammonia is toxic, due to its reactive state, ammonia must be excreted from the bacteria cell. Ammonia that is excreted from the bacterial cell accumulates as a gas, readily diffuses across the rumen wall and is absorbed into the blood stream. Because it is also toxic to the ruminant animal, it is transported to the liver where it is converted to urea which is a neutral compound.

2 NH_ +CO_ Urea (NH_ –CO—NH_) + 2H+

Once urea is formed in the liver, it moves back into the blood stream where it can have several fates. The preferred option is that it diffuses into saliva in the saliva glands and returns to the rumen where it potentially can be used by rumen bacteria. This is known as urea recycling and can account for 40 to 45% of urea. (16) The least desirable result is that it is filtered through the kidney and excreted in the urine. All non-recycled urea is excreted by the kidney and over 50% of excess nitrogen can be lost this way (27). However, there is great variation between farms on the amount of N loss in the urine (10). In the future, dairy producers and nutritionists will be obligated to reduce ammonia emissions from dairy animals. Ruminants are the single largest producers of ammonia among livestock (2). The best way to reduce N losses as ammonia in livestock is by controlling dietary input (28). Strategies to do this include:

- animal grouping to minimize variation in nutrient requirements of individual animals in the group
- avoid overfeeding protein (85% of excess N is excreted)
- balancing for metabolizable protein and/or amino acids
- more precise matching of rate of protein and carbohydrate release to rumen bacteria
- utilizing monthly DHI testing in conjunction with bulk tank MUN values to monitor cow diets and feeding management on the farm (13)

Urea will also readily diffuse from the blood into milk in the mammary gland. Because of this, MUN can be an indicator of excess protein in the diet. It may also indicate a lack of synchronization of rumen degradable protein and carbohydrate supply. Maryland researchers (12) developed an equation to predict urinary N losses based on MUN levels (see appendix 1).

Average MUN levels for herds of different sizes are presented in Appendix 1. Presented estimates are based on MUN and milk production data for each milk pickup for two years for 1135 Upper Midwest dairies. The table also includes estimates of N intakes and outputs and the potential impact of reducing protein feeding to result in an average 8 mg/dl MUN level, the suggestion minimum MUN level by Jonker et al, (13), Chapa (3).

Benchmarking variation as a tool in managing feeding consistency

Benchmarking variation is not traditionally recognized as an SPC technique. Benchmarking is, however, a recognized quality management tool for determining the strengths and weaknesses of a business and an excellent method of motivating improvement. Because many dairy databases are standardized, benchmarking between farms is possible. Since each Shewhart control chart provides calculation of the process variable means and a sigma value, comparisons of process variation between farms is possible. The following dairy experience provides an example of how benchmarking variation can give insight into process quality and/or protocol consistency.

W. E. Deming summarizes his Theory of Management in this often quoted sentence: *"If I had to reduce my message to management to just a few words, I'd say it all has to do with reducing variation."* While we have found this idea intuitive among dairy managers, study of herd data indicates there is a great amount of process variation found on dairy farms today. Answering the question, "how consistently do your clients manage their livestock operations?" is important in assessing the quality of herd management. Understanding process variation will be helpful in differentiating whether it is the process or the personnel or both that need improvement.

There are two factors needing consideration in assessing process quality. The first is the process itself as measured by a variable mean. The second factor to consider is the process variation. Low day-to-day sigma values (variation) are a strong indication that personnel are applying protocols consistently every day. High sigma values (variation), on the other hand, would indicate a need to improve the consistency in applying process protocols. Benchmarking of process means and sigma values can serve as a method of determining answers to the common management questions: "Is this a process problem?" or "Is this a personnel problem?" Therefore, if you know a herd's average and the day-to-day variation (sigma), you can determine the process quality relative to both the level of herd management and/or the consistency with which protocols are being applied at the farm.

Can analysis of day-to-day variation pounds milk fat, protein, milk urea nitrogen (MUN), dry matter (DM), dry matter intake (DMI), lbs of milk per cow per day, or feed efficiency give insight into feeding management? Although the jury is still out, evidence is building that SPC use could be a useful tool for managing dairy herd nutrition. Regardless of how well formulated a diet, it needs to be fed consistently to achieve its desired results. Variation between the formulated diet and that consumed by the cow is common. This variability can be caused by variability in the feeds, the feeder or the cow (26, 29).

BT Milk Components	20th percentile	40th percentile	60th percentile	80th percentile
FAT	0.05	0.06	0.08	0.12
PROTEIN	0.02	0.03	0.04	0.05
MUN	1.00	1.20	1.40	1.69

Table 1. Daily or every other day variation of bulk tank milk components and MUN on Upper Midwestern dairies.

Table 1 shows the spectrum of day-to-day variation in bulk tank butterfat % , protein % for milk pickup during 2003-2006 and MUN for Upper Midwest dairies monitored at each milk pickup during 2005 & 2006. It is currently thought that benchmarking day-to-day variation of milk components can be useful in giving insight to dairy farm feeding management of lactating cows. Generally speaking, low day-to-day variation in milk protein, fat and MUN implies that a very consistent feeding program is being implemented on the farm. High variation would then imply the opposite is true. However, since larger dairies have several feeding groups, greater sensitivity in assessing the feeding process variation can be achieved by collecting line samples from each feeding group (9). Then each feeding group could have control charts completed for lactating group inputs (i.e. DMI) and process outputs (i.e. milk components and average lbs / cow / day) simultaneously charted providing well-rounded real time feedback to facilitate more timely day-to-day nutritional management decisions.

If the variation is high, this suggests a need to improve process compliance and consistency. When the variation is low, the good news is that the feeds, the employees and the cows are consistent. The bad news is that if the cows are still not performing up to expectation, then maybe some things are being done consistently wrong. For example, poor quality forages are consistently being fed or routinely over mixing the TMR. What should be done? Take a closer look at how all tasks are performed, take measurements and make observations. Your evaluation should include bunk space, feed dry matter change, TMR mixing time, manure score, particle size of feed that is fed to the cows and the refusals, just to mention a few. As was previously mentioned but is well worth repeating, experience has shown that it is best to start by improving consistency and protocol compliance. By first reducing the variation in performance, when changes are made to the procedures used, it will be easier to determine if the implemented changes actually resulted in any real improvement in process quality.

Summary

SPC techniques have been used successfully for 80 years in manufacturing as a quality management tool to improve the timeliness and accuracy of management decisions as well as improve personnel performance. Benchmarking the mean and variation of variables that reflect herd nutritional management can also be an insightful means of assessing farm nutritional management quality. There is an urgent need in the dairy industry to fine tune and reduce variation in nutritional management at the farm. Numerous studies show that dairy cows utilize protein more efficiently than other ruminants. Regardless, dairy cows excrete large amounts of N in manure and urine. Inefficient protein feeding increases milk production cost and contributes to environmental pollution. Protein efficiency and N excretion can be controlled by skillful diet manipulation. However, without real time monitoring, adjusting diets to minimize excess protein feeding without sacrificing production is difficult. Frequent bulk tank MUN monitoring (at each pickup) provides an accurate way of guiding protein and carbohydrate feeding to improve protein efficiency and reduce nitrogen excretion. It is apparent that SPC control chart techniques can be applied to dairy nutritional management and will improve herd management and profitability.

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Appendix 1. Environmental and feeding impact of reducing CP intake to average 8mg/dl MUN in bulk tank milk on Upper Midwest dairies. Herds in the dataset represent 4.8% (n=1135) of the total dairy herd population of the Upper Midwest. MUN data was collected for every pickup over a two year period. Herd size category was estimated from total milk sold assuming an average of 70 lbs/cow.

	Current status			Change if average MUN was reduced to 8 mg/dl					
Herd size category	MUN [mg/dl]	Monthly urinary N excretion [lb N][1]	Monthly N uptake [lb N][2]	Monthly urinary N excretion [lb N][1]	Monthly N uptake [lb N][2]	Lb of 48% SBM[3]	Monthly cost of additional N_{EL} requirement[4,5]	Feed cost (assuming 48% SBM is replaced with corn 1:1)[5,6]	Total Monthly feed cost savings
less than 25 cows	10.8	189	423	-49	-59	-765	-$25	-$31	$56
between 25 and 50 cows	11.4	443	965	-133	-160	-2,088	-$69	-$85	$154
between 50 and 100 cows	11.8	853	1,826	-277	-334	-4,346	-$143	-$178	$321
between 100 and 250 cows	12.2	1,963	4,147	-678	-817	-10,635	-$351	-$435	$786
more than 250 cows	12.1	6,639	14,013	-2,256	-2,719	-35,405	-$1,167	-$1,448	$2,615
Total for all herds in dataset	-	918,117	2,922,811	-206,734	-249,173	-3,244,438	-$235,356	-$291,999	$527,355

[1]Urinary N (g/day) = 0.0259 x MUN (mg/dl) x BW (kg), BW=600 kg
[2]Daily N intake (g/day) = (UN (g/day) + Milk N (g/day) + 0.97)/0.83, Milk N = (milk true protein content) / 6.38 + NPN, MUN = 0.5 x Milk NPN. No change in milk true protein content due to changes in diet formulation is assumed.
[3]CP=6.25 x N
[4]100 g access CP = loss of 0.2 Mcal N_{EL} due to hepatic conversion of plasma ammonia N to urea N, corn N_{EL} = 0.92 Mcal/lb DM, corn DM = 85%
[5]Corn price: $0.13 per kg ($3.4/bushel)
[6]SBM price: $0.22 per kg ($200/Ton)

The Midwest Dairy Consortium: Partnering for Progress

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Introduction

We live in an increasingly global society where we are connected to people at great distances by email and the internet in ways that were impossible a decade ago. These capabilities have transformed our lives and livelihoods. Our universities have adopted new technologies to teach students, bring information to producers and agribusiness professionals, and conduct research that continues to improve productivity and well-being of dairy cattle.

However, the Land-Grant universities serving the dairy industry of the four-state area and the rest of the Midwest are struggling to maintain educational, extension, and research capacity in dairy science. The universities are now state-assisted rather than state-supported, as direct support by the states continues to erode and student tuition pays a greater proportion of the costs of university operation. Federal support to the agricultural experiment stations under the Hatch Act has been constant since the early 1980's, resulting in a dramatic drop in real purchasing power. Many of the universities recently have faced several years of flat or even declining state support. At the same time, input costs have increased, wages and salaries have grown, and regulatory requirements have become an increasingly expensive burden for animal programs.

As a consequence of these changes, dairy facilities have not been maintained, support personnel have been eliminated, and faculty positions have gone unfilled. Dairy science and other areas of production agriculture are not viewed as "sexy" by students, university administrators, or granting agencies. Consequently, programs in dairy science at many of the universities have taken an above-average hit in funding and capacity. The immediate result of these changes is a decreased ability to teach all classes needed, decreased capacity to provide extension services as before, and a decreased ability to perform the type of research that benefits dairy producers and the industry that supports them. Corporate leaders and dairy managers are beginning to realize that their pool of potential employees is shrinking as these changes accelerate at our universities.

Along with many of my university colleagues, I have grown weary of the downward trend in the "information industry" represented by our universities and colleges. In many ways, this parallels the struggles of the Midwestern dairy industry. As a life-long resident of the Midwest, I have a deep-seated and passionate commitment to the vitality of its rural areas and its dairy industry in particular. I believe it is time for an alternate approach for the information industry, rather than business as usual. Hence, I have been a proponent of the Midwest Dairy Consortium, and recently agreed to become its first Director.

What is the Midwest Dairy Consortium?

The Midwest Dairy Consortium (MDC) is a partnership of the Midwestern Land-Grant Universities and the dairy industry, broadly defined. We hope to bring in other universities, colleges, technical schools, state dairy organizations, and dairy producers themselves as participants in the activities of the consortium.

The MDC currently constitutes dairy faculty and staff from 10 universities: the University of Illinois, Iowa State University, Michigan State University, the University of Minnesota, the University of Nebraska, North Dakota State University, The Ohio State University, Purdue University, South Dakota State University, and the University of Wisconsin. Each of these has committed financial and/or in-kind resources to jump-start the MDC and provide operating capital for at least 3 years, although the specifics vary among the individual universities. In addition, as of early May 2007, we have two founding "Gold Partners" in MSC (Dundee, IL) and Standard Nutrition (Omaha, NE), and a "Silver Sponsor" in Diamond V (Cedar Rapids, IA). We are in negotiations with many other corporate entities and individuals, so that by the time you read this the list should be longer.

The vision of the MDC is to foster multi-state, multi-disciplinary education and research programs of direct relevance to the Midwest dairy industry. The MDC will seek to create a framework for cooperation across state boundaries that will promote synergistic use of the scarce resources available for research, education, and outreach activities. It is my firm belief that if the product of the MDC activities is not truly something that is bigger and better than individual faculty members at the individual Midwest universities, or individuals at single agribusinesses, could accomplish on their own, then the consortium is of little value.

As an 18-year faculty member that has run a large research program, taught graduate and undergraduate students, and been actively engaged with the dairy industry, I have come to appreciate very well that collaborations cannot be forced by administrators but must arise naturally among creative investigators who are given the motivation to do so. Consequently, the MDC will provide the incentive of a new funding pool that will be distributed competitively to initiate new activities and programs that ultimately will benefit the dairy industry. Collaborative opportunities that arise from the faculty and industry level and have teams organized to address them are the most likely to maintain peoples' enthusiasm and energy, and therefore are most likely to succeed.

What Will the MDC Do?

The mission of the MDC will be to create new support mechanisms to enhance student education and training, promote research relevant to the Midwest dairy industry, and deliver information to end-users more effectively. A fundamental concept is that we will bring together experts from more than one state or organization to form the teams to carry out these activities. While individual universities may not have been able to maintain experts in all disciplines of dairy science, most of these are well-represented somewhere across the Midwest region.

While it is not my intent to dictate the agenda of the MDC, a few examples of activities or general areas that may be supported are outlined below.

Support Shared Graduate Courses

With the declining number of faculty members training graduate students, it becomes a problem for all universities to provide the specialized coursework that is needed in all areas of dairy production. It is not cost-effective, and in many cases is impossible, to teach a semester-long course to a handful of students at one university. Why not bring together students across the Midwest for these specialized courses?

The form of delivery can be left to the faculty members interested in developing these courses. Students could be brought to one location for a one- or two-week intensive "short course" with face-to-face and hands-on training, or some courses can be taught via distance education or internet-based technologies. The MDC will provide support for faculty members who have the interest in developing such courses. In many cases, industry technical specialists could be brought in to teach a portion of these courses and provide much-needed expertise.

Opportunities provided by the MDC could extend to shared undergraduate courses as well. One can think of many types of courses that would be of interest and value to students that currently have limited availability. For example, shouldn't all students that are training for careers in the dairy industry have a general course in dairy products and processing?

Professional Master's Degrees

A market exists for post-graduate training directed at early- or mid-career industry professionals who wish to re-train or acquire additional educational credentials, but who cannot leave their current positions to attend graduate school full-time. The MDC could provide an ideal framework for universities to develop non-thesis professional degree programs. Students might obtain training from faculty and industry experts across the Midwest through a combination of short-course, distance education, and field experiences.

Undergraduate Internships

Because fewer and fewer students enter our universities with dairy farm backgrounds or experience, internship opportunities must be increased to provide interested but inexperienced students with on-farm training. While most of our universities have active internship programs, in many cases these are dominated by agribusiness opportunities and may be limited by financial constraints or difficulty in matching students with potential internship opportunities. The MDC is interested in assisting with these issues.

Graduate Fellowships

The biggest limitation to being able to train graduate students for careers in the dairy industry is the financial resources needed by the faculty mentor to support the student for two to four years. A graduate assistantship may require $20,000 to $30,000 per year depending on what tuition and fee costs must be borne by the faculty member. The MDC aims to build its funding base to provide several graduate fellowships annually to students that are working on applied dairy problems with faculty members across state lines.

Coordinated Web-Based Information Resources

The Midwest boasts several highly successful multi-state collaborations in extension that have served as models for other regions of the country. It may very well be possible that these multi-state programming efforts can be enlarged and enhanced if a central source of coordination and financial assistance were available. Efforts at the national level to support "eExtension" activities might be capitalized on by the participating states. A "one-stop" web portal that links into existing resources of the participating universities and companies would provide a valuable and easy resource to access dairy information and services in the Midwest.

Applied Research Relevant to the Modern Dairy Industry

The dairy industry lacks fundamental mechanisms to support research in many areas that are directly applicable to dairy production issues. In most cases, funding to the state agricultural experiment stations, which used to provide this mechanism, has declined so much that it only supports a few salaries for faculty and staff but leaves no funds for them to do anything! That is, there are no funds available for student labor, supplies, analytical costs, or research costs for the dairy farms involved.

The current USDA National Research Initiative competitive grants program, the "flagship" federal program in agricultural research, is pitifully underfunded relative to other areas such as the National Institutes of Health. Moreover, the program primarily supports fundamental or "basic" research whose benefits to the dairy industry, if any, may be years away. Agribusinesses fund a substantial amount of research and product-testing at our region's universities. Understandably, however, they have the ability and interest to fund only those projects where a direct competitive advantage can be obtained, and companies are unlikely to fund research that will benefit their competitors as much as them. In many cases, companies are unable or unwilling to fund the true cost of dairy cattle research, which is very high relative to other species.

The dairy industry also is hampered by an inability to fund production research directly from producer contributions. The dairy check-off program by law is prevented from funding production-related research, as it was written to increase milk and dairy product utilization in a time of milk surplus. Instead, this enormous pot of money collected annually from dairy farmers goes to support dairy product development, human nutrition research, and advertising. While these are important goals and activities, they do nothing to directly help dairy farmers with day to day production challenges. In contrast, other commodity groups (beef, pork, corn, soybeans, to name a few that are important in the Midwest) have substantial funding for production–related research that comes from producer check-off funding.

Our vision of the MDC is that we can grow the "pot of gold" needed to fund such research activities important for Midwest dairy producers and the industry that works with them. Corporate and producer partners in the MDC will provide funds that can be pooled to support these activities. We believe that a large "buy-in" by the industry will demonstrate the need and commitment for dairy-related research and education, and convince state and federal governments that they too should invest in the programs supported by the MDC.

Research funds will be distributed competitively within the Midwest to teams assembled across more than one state. A hallmark of the program will be a commitment to *relevance* and *accountability*, in which the investigative team will need to demonstrate how they will disseminate their findings to the industry, in more direct ways than just publication in a peer-reviewed scientific journal. Findings also would be made available via the MDC website, and could be presented in an annual symposium sponsored by MDC, either a stand-alone program or in conjunction with one of the existing multi-state conferences.

How is the MDC Structured?

The MDC has a director (me) who is supported by an administrative assistant from the Department of Animal Sciences, University of Illinois. In addition, support for financial management and information technology is being provided by the Department of Animal Sciences and College of Agricultural, Consumer and Environmental Sciences at the University of Illinois. A governing board, consisting of one individual from each of the 10 participating universities, will provide oversight to the director and the MDC. An advisory board is currently being established, with a representative from each university and also each organization that joins the MDC at Platinum Partner ($20,000 annually) or Gold Partner ($10,000 annually) levels.

Organizations who want to become members of MDC must commit funding, either at the partner levels described above or at "Silver Sponsor" ($5,000 annually) or "Bronze Sponsor" ($1,000 annually) levels. Others who wish to support the goals and activities of MDC can be designated as "Friends of MDC" for contributions of less than $1,000. Funding provided enters the general pool of funding for MDC activities, with no strings attached. In this way, the universities, agribusiness, dairy organizations, and producers all share the burden of supporting activities for the general good of the dairy industry in the Midwest. Concerns about loss of competitive advantage should be minimized in this way.

The MDC has a dedicated website (www.mwdairy.org) and telephone number (217-244-5540). Email correspondence can be directed to mdc@mwdairy.org.

What's Next?

Success of the MDC will only come from engaged individuals who have good ideas and bring them forward to the MDC. It is not my intention to dictate specific activities or direction of the MDC. Rather, we aim to help establish the general areas of emphasis, develop calls for proposals in those areas, and help guide the distribution of funds in support of the activities, whether for development of new courses, establishing new extension programs, or performing research. In no way do I see the MDC as diminishing the importance or stature of any individual university; on the contrary, a successful MDC should boost all participating institutions as well as benefit the dairy industry.

Over the next several months I will continue to visit and correspond with the Midwest educational institutions, agribusinesses, and state dairy organizations. I welcome your input and suggestions, and would be glad to consider visiting your organization personally to talk to you about the benefits and possibilities provided by the MDC. I am convinced that by partnering via the MDC, we can provide increased service, knowledge, and quality personnel for the Midwest dairy industry. That would indeed be progress.

Facts and Myths About the Effects of Milk Fatty Acids on Human Health

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There has been and continues to be an unexplainable desire by dieticians and other "health" professionals to associate or link dietary components, particularly animal food products, with human disease (coronary heart disease, cancer, etc.). However, that perceived link is becoming increasingly ambiguous and is especially true with regards to ruminant derived products. In fact, not only is the link between dietary beef/dairy and disease suspect, there are a variety of micro-components in these high quality foods that are actually potent disease-fighting molecules.

History of Nutritional Guidelines

The hypothesis that dietary fat is somehow deleterious to humans is over 50 years old. Ruminant lipid tends to be more saturated than other animal fats and this is especially true when compared to some common vegetable oils. The saturated fat content is the lightening rod for nutritionists and others as it has historically been the component identified as connecting diet and disease (Keys and Grande, 1957). Despite lacking a traditional scientific relationship (for an excellent description on the history of the dietary fat link with health, see review by Taubes, 2001) and regardless of recent reports contradicting the dogma, the 2000 Dietary Guidelines for Americans is as follows: "choose a diet that is low in saturated fat and cholesterol and moderate in total fat". The American Heart Association suggests to "choose foods like vegetables, fruits, whole-grain products and fat-free or low-fat dairy products most often" and the American Cancer Society indicates that "limiting saturated fat may be particularly important to reduce risk for both cancer and heart disease. Choose lean meats and low-fat dairy products, and substitute vegetables oils (like canola and olive) for butter or lard".

The Women's Health Initiative (WHI) Dietary Modification Trial

Until 2006, the reports linking diet, and specifically animal products, with cancer and other health disorders were primarily from epidemiological trials (Rose et al., 1986; WHO, 2003). Many of our national dietary recommendations are based on these international epidemiological trials. However, a large number of comparison trials recently published (within the last decade) do not support the hypothesis that dietary fat, specifically animal fat, increases the risk for cancer (Table 1) and it is perplexing as to why these reports are ignored by the American healthcare community. Nevertheless, comparison trials are limited by a number of scientific variables and results obtained should be used as initial suggestions for further randomized controlled investigations.

Table 1. Recent reports on the effects of total dietary and saturated fat on the incidence and risk of differing types of cancers.

Observ.	Cancer	Total Fat Risk	Saturated Fat Risk	Reference
4,980	Breast	↔	↔	Hunter et al., 1996
Cohort	Colorectal	↔	↔	Howe et al., 1997
Cohort	Breast	↔	↔	Lee & Lin, 2000
Cohort	Breast	↔	↔	Zock, 2001
Cohort	Colorectal	↔	↔	Zock, 2001
Cohort	Prostate	↔	↔	Zock, 2001
3,482	Breast	NR	↓	Shin et al., 2002
Cohort	Colorectal	NR	↓	Cho et al., 2004
910	Breast	NR	↓	Wirfalt et al., 2005
48,835	Breast	↔	↔	Prentice et al., 2006
48,835	Colorectal	↔	↔	Beresford et al., 2006
1,123	Skin	↓	NR	Granger et al., 2006

↔: no relationship
↓: Decreased risk
NR: Not reported
Cohort: a review of multiple trials

The WHI trial was designed in the early 1990's as a randomized controlled study with the goal of definitively testing the effects of dietary fat and its specific components on a variety of human diseases. The trial included more than 160,000 women (50-79 years old) from 40 different centers across the country, lasted for approximately 8 years and cost more than $700 million dollars. The women were either assigned to a low fat diet (while simultaneously increasing vegetable and fruit intake) or advised to stay on their usual eating pattern. Women on the low-fat diet had saturated fat intakes that represented about 7% of their total energy intake. Results from the largest and most comprehensive study on dietary fat in American history indicate that there is NO relationship between either total dietary fat or saturated fat on the incidence/risk of colorectal (Beresford et al., 2006) or breast (Prentice et al., 2006) cancer or on cardiovascular disease (Howard et al., 2006).

It is unclear why there are so many inconsistencies in the epidemiological literature with regards to dietary fat, specifically fat from animal products, on human health. The fact that there are such large inconsistencies makes it especially confusing as to how the dietary fat dogma became entrenched in the medical community. Regardless, the recent WHI controlled experiment should (in addition to the latest reports in Table 1) assist in creating new and more accurate nutritional guidelines and provide strong evidence as to why milk and other ruminant food products should remain an important part of a balanced healthy diet.

It is important to note that many organizations appearing to be concerned with public health (Table 2) may actually front for animal rights groups (i.e. People for the Ethical Treatment of Animals: PETA; Animal Liberation Front: ALF). They have unsuccessfully persuaded the general American public that consuming animal products is immoral and unethical, but convincing consumers that the products are unhealthy is an alternative means to an end (elimination of animal agriculture). An example is the Physicians Committee for Responsible Medicine (incidentally, less than 5% of its members are physicians; Newsweek, 2004), which advocates that a vegetarian diet reduces the risk of cancer and other health disorders as stated on their website: "vegetarian foods may help prevent cancer and even improve survival rates". These groups have done an excellent job of convincing the public and media that they are legitimate scientists and actual health care professionals with a genuine concern for the public health.

Table 2. "Health organizations" that recommend decreasing animal food product consumption

Organization	Website
Center for Food Safety	www.centerforfoodsafety.org
Center for Science in the Public Interest	www.cspinet.org
Physicians Committee for Responsible Medicine	www.pcrm.org

Anticarcinogens in ruminant food products

Numerous studies have been conducted with various human cancer cell lines and animal models showing that milk components can prevent the development and progression of cancer (see review: Gill and Cross, 2000). Many of these components are in the milk fat fraction and include butyric and vaccenic acids, ether lipids, sphingomyelin, Vitamin A and carotene (Parodi 1997). An additional molecule receiving considerable attention and the one most extensively studied is conjugated linoleic acid (CLA). For a detailed description on CLA ability to prevent different types of cancer, see recent reviews (Belury, 2002; Ip et al., 2003)

CLA describes positional and geometric isomers of linoleic acid, with the double bonds being separated by a single methylene group. CLA are synthesized in the rumen through biohydrogenation of polyunsaturated fatty acids and therefore are found naturally in dairy products and ruminant meat (Bauman et al., 2001). The *cis*-9, *trans*-11 isomer is the most abundant CLA isomer found in ruminant products, though both *cis*-9, *trans*-11 and *trans*-10, *cis*-12 have shown anticarcinogenic properties (Ip et al., 2003).

Although there is a wealth of evidence demonstrating that synthetic, purified CLA isomers have anti-cancer properties, recent attention has turned to CLA effects when presented as it would be in a normal diet (at smaller concentrations and in combination with many other fatty acids). In a recent study, mice were fed CLA (*cis*-9, *trans* -11/*trans*-10, *cis*-12 mixture) in combination with either a vegetable oil blend, corn oil, or beef tallow. Data indicate that CLA was more effective at decreasing tumors when beef tallow was added to the diet (Hubbard et al., 2006). Additionally, fatty acids extracted from beef (<1% CLA content) had a greater anti-proliferative effect on cancer cells than a synthetically enriched CLA diet (De La Torre et al., 2006). Collectively, these trials suggest CLA found naturally in ruminant-derived products may potentially be significant contributors to a healthy and cancer preventive diet.

Increasing the CLA content in ruminant products

CLA is an intermediate in rumen biohydogenation of linoleic acid (C18:2; Bauman et al., 2001), but it primarily derived via desaturation of vaccenic acid (*trans*-11 C18:1, also a product of rumen polyunsaturated fatty acid biohydrogenation) by the Δ^9-desaturase enzyme (Corl et al., 2001; Kay et al., 2004). Vaccenic acid is also an intermediate of linolenic acid (C18:3) biohydrogenation (Bauman et al., 2001) so including both fatty acids in the diet of ruminant animals has the potential to increase the rumen output of *trans*-11 C18:1 and thus enhance the content of *cis*-9, *trans*-11 CLA in food products.

The milk fat CLA content from TMR-fed cows can markedly be increased (i.e. ≥ 5-7 fold) by adding a variety of plant oils (i.e. sunflower, linseed etc.) to dairy rations. Altering the oils with TMR-fed cows can increase the CLA content so that it is equal to or greater than that found in pasture-fed cows (which typically have an enhanced CLA content, Kelly et al., 1998). For a detailed description on successful methods to enhance the CLA content in dairy products see a recent review (Lock and Bauman, 2004).

Dairy Calcium and Weight Loss

Milk is a rich source of a number of vitamins and minerals (potassium, chloride, sodium, calcium etc.) that are required in the human diet such as fat-soluble vitamins (A, D, E, and K), as well as the B vitamin family, specifically thiamin, riboflavin, B_6, and B_{12}. Recently, calcium intake, particularly from dairy sources, has been implicated in decreased incidence of obesity within the human population. Dietary calcium is crucial to the regulation of energy metabolism, in that it has been found to attenuate adipocyte lipid accretion during over consumption of energy-dense diets, as well as to increase lipolysis and preserve thermogenesis during caloric restriction, leading to accelerated weight loss (Zemel, 2003). It has been demonstrated that calcium supplementation, in rodent and human models, decreases visceral adiposity, a precursor to the metabolic syndrome (Zemel et al., 2004; Azadbakht et al., 2005; Liu et al., 2005). The proposed mechanism of action for the role of calcium in decreasing adiposity is that supplementation of calcium results in a reduced concentration of intracellular calcium, via suppression of 1,25-(OH_2)-D, which leads to a coordinated deactivation of fatty acid synthetase (Sun and Zemel, 2004) and an increase in lipolysis (Shi et al., 2001; Zemel, 2001). In addition, it might also increase uncoupling proteins and thus increase metabolic heat production (Shi et al., 2001) and this might be the mechanism by which dairy products help with weight loss even though these people are not necessarily on a lower calorie diet.

A number of studies have been conducted utilizing calcium to modulate obesity ranging from epidemiological and observational studies to those investigating the mechanism of action utilizing a transgenic obese mouse model. It has been demonstrated that a dairy source of calcium, rather than a synthetic supplemental source such as calcium carbonate, has greater impacts on weight loss (Zemel et al., 2000, 2004). In a study conducted by Zemel and coworkers (2004), it was demonstrated that calcium supplementation in obese adults, particularly in the form of dairy products, significantly increased weight loss, decreased body fat percentage and reduced waist circumference. Furthermore, individuals consuming high calcium diets in the form of dairy products had a significant reduction (44%) in circulating insulin levels. In a study conducted by Liu and co-workers, (2005), it was determined that consuming dairy products in middle-aged and older women was associated with a decreased incidence of metabolic syndrome. Women consuming a high calcium diet (>1,500 mg/day) exhibited decreased waist circumference, BMI, hypertriglyceridemia, high blood pressure, and incidence of type 2 diabetes and increased HDL cholesterol.

Recent evidence demonstrates that calcium has an anti-obesity effect, particularly when it comes in the form of dairy products. Utilizing yogurt, or non-fat dry milk in studies, regardless of the subject (rodent or human), increased weight loss and decrease fat percentage to a greater extent than calcium from a synthetic source such as calcium carbonate. Milk is a rich source of many bioactive compounds which either act independently or synergistically with calcium to accelerate lipolysis and/or effect nutrient partitioning between adipose tissue and skeletal muscle. Therefore, supplementation of calcium, in the form of low-fat dairy products, attributes to increased weight loss.

Summary

The link between dietary fat, and specifically fat derived from ruminant animals, with human disease is incredibly small at best and probably does not exist. Unfortunately, the hypothesis that animal food products are “unhealthy” has become dogma in popular culture (driven in part by organizations with ulterior and covert motives) and even people with little or no biological knowledge now affiliate ruminant food products with “heart attacks” and “cancer”. In stark contrast to the “doom and gloom” message we have consistently heard from the medical community and dieticians for the past four decades, there are a variety of micro-components in dairy and beef products that are strongly associated with prevention and treatment of disease (cancer, obesity, etc.). A coordinated and concerted effort by agricultural and biological scientists AND the animal agriculture industry is necessary to re-educate consumers about biology and nutrition.

Note: This article has been partially adapted from a paper first published by the authors in the Proceedings in the 2006 Minnesota Nutrition Conference.

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SEXED SEMEN: PROFIT OR PITFALL?

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Introduction

Sexed semen is a reproductive management technology that many dairymen have been anticipating for years. This tool is now a commercial reality and is available from a variety of semen providers. There have been various approaches developed that have allowed researchers to separate bovine semen into fractions containing higher than normal concentrations of X-bearing sperm, but the primary commercial application today is via flow cytometry. This method was first used in the 1980's, but early results produced dead sperm. Johnson et al. helped refine the technique of using fluorescence-activated cell sorting.[1-4] The current method of using flow cytometric techniques for sperm sorting was licensed to XY, Inc (www.xyinc.com) for commercial development. This approach uses technologies developed by the U.S.D.A., Colorado State University and DakoCytomation, which is a company that develops advanced flow cytometers for commercial use.

Briefly, the process involves identification of differences in DNA content.[5,6] X-bearing sperm contain 3.8% more DNA than the Y-bearing counterparts. Sperm is diluted to a very low concentration and then stained with a harmless DNA-specific fluorescent dye. This dilute and dyed sperm sample is then sent through the flow cytometer at speeds of approximately 60 mph under pressures of 40-60 psi. The sperm are aligned in a specific manner, single-file and are passed through a laser beam. The stained DNA emits fluorescence and the small difference in the amount of fluorescence, based on the differences in DNA mass, is detected. In order for this process to work correctly, sperm heads must be precisely oriented during the cytometric evaluation by using a specially designed beveled nozzle. Without the proper orientation, differences in DNA content can not be accurately determined.

Depending upon the relative amount of florescence, positive or negative charges are applied to each droplet containing a single sperm. Sperm then pass through charged deflector plates and positively charged particles go one direction, negatively charged in another, and uncharged droplets pass straight through. The uncharged particles may contain multiple sperm, uncharged sperm of either sex, or potentially damaged material. The result is a process that is able to repeatedly separate sperm with greater than 85% purity. XY Inc., holds the patent for the flow cytometry semen sorting process, but licenses this technology to various companies for on-site sexed semen production.

The sorting process runs sperm past the laser in single file fashion at a rate of about 30-35,000 per second, resulting in 3-5,000 sorted X-bearing sperm per second. Despite dramatic improvements over the last few years, the handling and transit through the flow cytometry system is still somewhat inefficient, and some sperm end up compromised or misidentified. Recoverable numbers of marketable, sexed product are only about 10-15% of the original sample entering the machine and as a consequence, commercially available straws of semen usually contain only about 2 million sperm, as compared to traditional semen straws which contain closer to 20 million.

Expected Results and Potential Sources of Value Associated with Using Sexed Semen

Early expectations were that sexed semen would produce 85-90% female calves. Among single births, DeJarnette and his colleagues report that 90% of calves have been females when evaluating over 3,000 single births using sexed semen, as compared to 48% female in over 10,000 single births using conventional semen. (Mel DeJarnette, Select Sires, personal communication) This group also examined the effect of sexed semen on abortion risk and found no difference as compared to conventional semen.

Most dairymen seem to always need or want more replacement heifers for their business. The presence of more heifers in their replacement pipeline provides additional sources of value for dairies and provides additional business management options. These animals can be raised and then added back into the herd as lactating animals replacing an older, less productive animal or they may allow for herd expansion if sufficient housing and feeding area is available. In addition, dairymen are also better able to cull out poor performing or chronically ill heifers that might ordinarily be retained in herds with inadequate numbers of replacements available.

Alternatively, females can be sold as wet calves for replacement purposes for a premium (currently) compared to male calves destined for beef production, or can be raised for variable periods of time and sold as needed to supplement cash flow on the dairy.

Virgin heifers calving female calves typically have a slightly lower risk of dystocia (calving difficulties) as compared to delivering bull calves. Dystocia usually represents one of the largest periparturient risk factors for culling or disease issues in heifers and this risk can be reduced by having more female calves, assuming similar management between sexed and traditional semen, including sires utilized in the breeding program.

With careful attention to selection of females for sexed semen breeding, herds can also make more rapid genetic progress, again assuming equal quality of sires are utilized as compared to traditional breeding. Now, selection pressure can be applied to both the female and the male side where previously, genetic progress was largely limited to the male side since replacements were produced from both high genetic merit cows and lower quality cows out of necessity. Of course, in order to successfully capitalize on this potential source of value, excellent records must be maintained and utilized in order to select only the top quality heifers from a genetic potential.

While not a significant issue in virgin heifers, there is the potential to reduce the risk of freemartin twins. Freemartins result from cows carrying male-female co-twins in utero. By utilizing sexed semen, this risk is reduced since approximately 90% of the sperm are X-bearing. This source of value in virgin heifers is very small, however, since virgin heifers typically only have about a 1% or less risk of twinning.

Potential "Watch-Outs"

While there are some solid sources of potential value associated with the use of sexed semen, there are also some very important issues that must be considered prior to jumping on the bandwagon. First, there is the cost differential; using sexed semen products is not inexpensive. The sorting procedure is a slow, inefficient and costly process that results in the recovery of only about 10-15% of the sperm entering the $250,000 sorting machine. As a consequence of these issues, there is a significant premium for sexed semen. Typically, a straw of sexed semen will cost about $25-40 more than conventional semen from the same sire.

Another issue that plagues current sexed semen products is a decline in fertility. In heifers, clinical impressions are that conception risk is reduced by approximately 10-40%, with most herds reporting a drop of 25-30%. In other words, if the baseline conception risk for virgin heifers is approximately 60%, expectations for conception risk are reduced to about 42-45% using sexed semen and these impressions appear to be consistent with early reports from larger data sets that are being compiled in the field. Following the evaluation of over 16,000 inseminations, first service conception risk across more than 100 herds was found to be 44% as compared to a baseline level of about 60%.(Mel DeJarnette, personal communication)

In order to minimize the drop in fertility, semen handling and placement practices must be optimized. Straws should be thawed according to recommendations from the AI stud and equipment must be clean and sanitary. Care should be taken to minimize risk of cold shock by warming equipment prior to loading, protecting the straws between thawing and placement, and avoiding the use of any spermicidal lubricants. Better AI technicians should be handling the breeding duties when using sexed semen and care should be taken to ensure that heifers are truly cycling and are actually in estrus prior to breeding. (Timed AI programs are not recommended currently for sexed semen). The classic AM-PM rule should be utilized as opposed to the once-a-day approach many now use for conventional breeding.

Commercialization currently involves the marketing of low sperm numbers per straw (only about 2 million as compared to more typical numbers of closer to 20 million for conventional semen). In addition, sexed semen is packaged in 1/4 ml straws versus more conventional 1/2 ml straws. The combination of reduced sperm numbers and smaller straws requires more careful handling during the thawing process and use of experienced personnel in order to achieve acceptable, albeit reduced, conception rates.

Generally speaking, producers are willing to pay more for better genetic merit sires. However, with sexed semen, the best sires that are in highest demand are not likely to be utilized. Consider that the sorting process results in a loss of 85-90% of the initial sperm numbers entering the machine. High demand bulls are already commanding a premium on the open market and sexing these sires would reduce the number of units available for purchase in addition to commanding an even higher premium.

How Should Sexed Semen Be Used?

Based on the previously listed issues around sexed semen, current recommendations are to use it only in virgin heifers. Depressed conception rates in this class of animals are usually quickly overcome due to better fertility and a higher probability of displaying signs of estrus. The use of sexed semen in embryo transfer programs or in lactating dairy cows is strongly discouraged due to both the cost of the implementation of this technology and the large downside risk of conception failure. Most producers are limiting its use, even in virgin heifers, to the first service or two. In this scenario, producers are able to produce additional female calves, but still have time to get most of the remaining non pregnant animals in calf. However, one major determination in the potential value derived from using sexed semen is the value differential between bull and heifer calves.

I have modeled the potential value of sexed semen use in virgin heifers in a fairly simplistic spreadsheet approach. This approach predicts the expected economic returns (as determined by wet calf values) of using sexed semen for either the first cycle only or for both the first and second potential breeding cycles with the following assumptions:

Assumptions used in the spreadsheet:
1. Value of a fresh heifer = $1900 and value of a culled, non-pregnant heifer = $700
2. Conception risk of 44% for sexed semen compared to 64% for first service with conventional semen (or 60% over all conventional breedings)
3. Estrus detection risk of 60% over 8 potential breeding cycles
4. Sexed semen premium of $30
5. Total lost opportunity cost for delayed entry into lactating herd (including an average daily feeding cost $1.50) of $2.00/ day
6. Stillbirth risk of 12% for bull calves and 8% for heifer calves
7. 47% fertile heifers using conventional semen and 90% for sexed semen
8. Outcomes are based upon wet calf values
9. ***There was no attempt to model the impact of abortions or the potential increases in genetic merit for the herd with more selective use of sexed semen***

Below are two charts demonstrating the predicted value of using sexed semen, expressed as total net returns/ heifer entering the breeding management program. The top row in each chart represent potential heifer calf values and the first column in each chart reflects potential bull calf values.

Scenario 1:
Estimated return (per heifer in the breeding group) of using sexed semen for the first potential breeding cycle only, followed by conventional semen for all other inseminations.

Bull Calf Price	Heifer Calf Price: $200	$250	$300	$350	$400	$450	$500	$550	$600
$25	($13)	($8)	($3)	$2	$7	$12	$18	$23	$28
$50	($16)	($11)	($6)	($0)	$5	$10	$15	$20	$25
$75	($18)	($13)	($8)	($3)	$2	$7	$13	$18	$23
$100	($21)	($16)	($11)	($5)	($0)	$5	$10	$15	$20
$125	($23)	($18)	($13)	($8)	($3)	$2	$8	$13	$18
$150	($26)	($21)	($16)	($10)	($5)	($0)	$5	$10	$15
$175	($28)	($23)	($18)	($13)	($8)	($3)	$3	$8	$13
$200	($31)	($26)	($21)	($15)	($10)	($5)	$0	$5	$10

Scenario 2:
Estimated return (per heifer in the breeding group) of using sexed semen for the first two potential breeding cycles, followed by conventional semen for all other inseminations.

Bull Calf Price	Heifer Calf Price: $200	$250	$300	$350	$400	$450	$500	$550	$600
$25	($32)	($23)	($14)	($5)	$4	$13	$21	$30	$39
$50	($36)	($27)	($18)	($10)	($1)	$8	$17	$26	$35
$75	($41)	($32)	($23)	($14)	($5)	$4	$13	$21	$30
$100	($45)	($36)	($27)	($18)	($10)	($1)	$8	$17	$26
$125	($49)	($41)	($32)	($23)	($14)	($5)	$4	$13	$21
$150	($54)	($45)	($36)	($27)	($18)	($10)	($1)	$8	$17
$175	($58)	($49)	($41)	($32)	($23)	($14)	($5)	$4	$13
$200	($63)	($54)	($45)	($36)	($27)	($18)	($10)	($1)	$8

As shown in the charts above, the potential profit (or loss) depends (at least in part) upon the expected heifer calf value and the value of a bull calf. The predicted breakeven for scenario 1 is a heifer vs. bull calf differential of approximately $300. In scenario 2, the breakeven is now about $350, based on the previously described assumptions. It is critical to remember that heifer calves must be priced significantly higher than bull calves in order to break even, not considering the potential genetic merit value if a more selective approach to using sexed semen is applied.

Other costs/ values may also have rather large impacts on predicted returns. Cost of the technology, currently set at a $30 premium, is a big driver and larger premiums severely impact the economic feasibility of using sexed semen. The cost of additional non-productive days (for delayed days to pregnancy and thus, calving), anticipated drop in conception risk, and proportion of fertile females realized all have large impacts on predicted returns.

Nationally, dairymen are using this technology and many are banking on the high heifer values as a way of making a profit with sexed semen. However, this approach is potentially very risky. While it is true that the early adopters have been able to capitalize on historically high calf values, future prices may not be as strong, especially as more heifers are born from the use of sexed semen.

Of course, there are other reasons for using sexed semen such as an increased ability to ensure an adequate supply of home-raised heifers or an attempt to improve the rate of genetic gain by using this technology in only the best heifers. However, in both of these approaches, one must remember that additional investment capital will be required. Cash flow will be negatively impacted as a consequence of up front investment in semen premiums, followed by additional investment in calf rearing costs such as hutches, bottles, milk, feed, etc. Producers should carefully consider these additional costs that are present for nearly 3 years prior to getting any of these animals into milk production.

Conclusion

Sexed semen is an exciting technology that is currently being utilized by producers across the country. Potential benefits include a greater ability to ensure adequate replacements, an improved rate of genetic improvement, a greater potential for more critical culling of poorly performing young growing heifers as well as under-performing lactating cows, and perhaps a reduction in calving difficulties. However, before investing heavily into sexed semen, consider the following issues as well: there is a significant upfront investment cost with sexed semen including a higher semen cost and more heifers to house and feed, conception rates are typically only about 70-75% of conventional semen in virgin heifers, heifer prices may decline and producing additional heifers above your farm's needs may not yield the same return as it has in the recent past. If you have carefully considered both the positive and negative risks of using sexed semen and think that producing a few more heifers would improve your herd's economic performance, work to optimize your potential returns by ensuring that only well grown and cycling heifers are inseminated during the first and possibly second breeding cycle by someone that is well trained in semen handling and AI.

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Dietary Component and Rumen Environment Interactions on Milk Fat

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Introduction

Nutrition affects both the quantity and composition of milk fat, and a striking example is milk fat depression (MFD). Diet-induced MFD represents a challenging problem and our understanding of the interrelationship between rumen lipid metabolism and milk fat synthesis has progressed significantly over the last decade. The 'biohydrogenation theory' represents a unifying concept to explain the basis for diet-induced MFD where intermediates of ruminal fatty acid biohydrogenation (BH) escape the rumen, are absorbed, and signal a decreased expression of lipoganic enzymes and a reduction in milk fat synthesis in the mammary gland. The first rumen BH intermediate shown to effect milk fat synthesis was *trans*-10, *cis*-12 conjugated linoleic acid (CLA; Baumgard et al., 2000). Effects are specific for milk fat and subsequent studies demonstrated a curvilinear relationship between increasing *trans*-10, *cis*-12 CLA dose and the reduction in milk fat yield (de Veth et al., 2004), with as little as 2.0 g/d being sufficient to cause a 20% reduction in milk fat production. Recently, two additional BH intermediates that regulate milk fat synthesis have been identified, *trans*-9, *cis*-11 CLA (Perfield II et al., 2007) and *cis*-10, *trans*-12 CLA (Saebo et al., 2005). MFD has been observed over a wide range of feeding situations including diets high in concentrates and low in fiber, and diets supplemented with plant or fish oils. Although the cause of all types of diet-induced MFD involves inhibition of milk fat synthesis by unique BH intermediates, troubleshooting milk fat issues on dairy farms remains one of the more challenging tasks within overall nutritional management of dairy cows. Clearly, small quantities of specific BH intermediates produced in the rumen and subsequently taken up by the mammary gland are sufficient to induce substantial decreases in milk fat content and yield. Escape of these intermediates from the rumen is influenced by ruminal passage rate, bacterial BH capacity and dietary polyunsaturated fatty acid (PUFA) concentration and profile. Bacterial BH capacity is intrinsic to the bacterial population, and numerous factors are known to cause an altered ruminal fermentation with a propensity towards production of BH intermediates that are associated with MFD. Therefore, the induction of MFD requires both an altered rumen fermentation and the presence of PUFA in the rumen, and within each of these categories there are a number of potential risk factors and areas to address when developing nutritional strategies designed to minimize effects on milk fat production (Table 1).

The focus of the following sections will be to discuss the impact of dietary components and rumen environment interactions on milk fat. Experience indicates that MFD occurs as a result of several concurrent diet or management factors rather than as a result of a single factor. It will always be a challenge to troubleshoot MFD when the magnitude of decrease in milk fat (e.g. 3.8 to 3.2%) may be caused by 1 to 2 g/d or less of *trans*-10, *cis*-12 CLA or a related intermediate passing to the small intestine. Although we do not fully understand all of the ruminal conditions that may trigger MFD, an improved understanding of the impact of dietary components and their interaction during rumen fermentation will provide the critical framework with which to better troubleshoot this issue.

Rumen Biohydrogenation

Since unsaturated fatty acids are toxic to many rumen bacteria, the majority of dietary lipids are biohydrogenated through a series of fatty acid intermediates that ultimately results in saturated fatty acids being produced (Palmquist et al., 2005). Accordingly, there is an extensive metabolism of lipids in the rumen and this has a major impact on the profile of fatty acids available to the dairy cow (Lock et al., 2006a). Generally, BH of linoleic acid produces *cis*-9, *trans*-11 CLA and *trans*-11 18:1 (Palmquist, et al., 2005). Under certain dietary situations, however, the rumen environment is altered and a portion of BH occurs via a pathway that produces *trans*-10, *cis*-12 CLA and *trans*-10 18:1 (Figure 1). Therefore, dietary situations causing MFD alter the pathways of rumen BH resulting in changes in the specific TFA and CLA isomers available for uptake by the mammary gland and incorporation into milk fat. As shown in Figure 2, this '*trans*-10 shift' in BH pathways, and the associated increase in the *trans*-10 18:1 content of milk fat, is indicative of the complex changes in ruminal BH pathways characteristic of MFD. Although *trans*-10 18:1 does not directly inhibit mammary synthesis of milk fat (Lock et al., 2007), it is relatively easy to analyze compared to *trans*-10, *cis*-12 CLA and other CLA isomers. Therefore, in general, this fatty acid can serve as a surrogate marker for the type of alterations in rumen BH that characterize diet-induced MFD. Also shown in Figure 1 are the three predominant ways in which dietary components can impact the risk of milk fat depression: 1) through increasing substrate supply of 18-carbon unsaturated fatty acids, 2) by altering the rumen environment and BH pathways, and 3) via changes in the rate of BH at various steps in the BH process. These three areas are discussed in the following sections.

Supply of Unsaturated Fatty Acids

Given that the specific fatty acids that cause MFD are intermediates produced during ruminal BH of PUFA, it is logical that the amount of initial substrate (linoleic acid and perhaps linolenic acid) may be related to the amount of the key BH intermediates that are produced. Linoleic and linolenic acids represent a large percentage of the fatty acids found in most forages and other plant-based feedstuffs fed to dairy cattle, with linoleic acid representing the predominant PUFA in corn and corn byproducts. As a result, under typical US situations linoleic acid is the major dietary fatty acid, particularly when corn silage comprises the majority of the forage base in the ration and oilseeds are the major source of added dietary fat. Estimates of linoleic acid intake using CPM-Dairy indicates that in these situations linoleic acid intake can approach and even exceed 400 to 500 g / d (Table 2). Therefore, it would appear that typical rations have more than enough substrate as linoleic acid to meet the required presence of PUFA for MFD to occur if rumen fermentation is altered. Nevertheless, this is a moving threshold which depends on the rate at which the PUFA become available to the rumen bacteria and the extent to which perturbations in rumen fermentation occur. With the increased availability of corn byproducts (e.g. distillers' grains) an additional important consideration is their fat content because they can contain a considerable amount of lipid which is predominately linoleic acid. In particular, the fat content of corn distillers' grains is highly variable (e.g. ~5 to 15% of DM), and this degree of variation can significantly alter the dietary supply of unsaturated fatty acids to the dairy cow, thereby increasing the risk of MFD.

The feeding of supplement fat can be challenging since various lipids and fatty acids can trigger a number of changes in rumen metabolism. Space does not permit a detailed discussion of specific fat sources, but readers are directed to a recent review by Staples (2006) which discusses the influence of different fat supplements on milk fat. In general, as you increase the degree of unsaturation of supplemental fat and / or the availability of the fatty acids present (e.g. extruded vs. roasted oilseeds), the chances of MFD occurring will increase. Recently, Relling and Reynolds (2007) examined the impact of feeding rumen-inert fats differing in their degree of saturation on performance of lactating dairy cows. Cows were fed a Control mixed ration ad libitum, and treatments were the dietary addition (3.5% of ration dry matter) of 3 rumen-inert fat sources differing in fatty acid profile. As shown in Table 3, as the unsaturation of the supplemental fat increased, this was associated with reduced milk fat content and yield.

It is also clear that cows consuming diets that contain corn silage as the only or major forage source appear to be more susceptible to MFD when unsaturated fats are supplemented. Partial substitution of corn silage with another forage such as alfalfa may alleviate this negative effect. For example, Ruppert et al. (2003) showed that changing the forage in the diet from predominantly corn silage to alfalfa silage offset the depressing effect that tallow can have on milk fat. The concentration of *trans* 18:1 BH intermediates in milk fat tended to increase to a greater extent when tallow was fed in the corn silage-based diets than in the alfalfa silage-based diets. Although not reported in this study it is most likely that the profile of *trans* 18:1 fatty acids also shifted to favor *trans*-10 18:1 with the corn silage-based diets. This is supported by a study by Onetti et al. (2004) which observed that replacing half the dietary corn-silage with alfalfa silage negated the negative effect of tallow on milk fat yield (Table 4). Furthermore, the addition of alfalfa silage to the diet attenuated the tallow-induced increase in *trans*-10 18:1 formation in the rumen and subsequent incorporation into milk fat (Table 4).

The example shown in Table 4 raises a number of interesting questions relating to substrate supply of unsaturated fatty acids. Since it appears to be 18:2 BH intermediates that are responsible for MFD, we have typically only looked at PUFA when considering substrate supply. These data, however, suggest that it may be appropriate to more broadly consider overall 'unsaturated load' in the rumen when troubleshooting MFD. Increasing the dietary supply of oleic acid (*cis*-9 18:1) from tallow or other sources (e.g. palm fatty acid distillate), will not directly increase the rumen outflow of 18:2 BH intermediates because these fat supplements supply very little PUFA and, as we showed previously, under some circumstances we can feed high levels of oleic acid without inducing MFD (Hinrichsen et al., 2006). In some circumstances, however, it would appear that the increase in unsaturated load from increasing oleic acid supply is sufficient to alter BH pathways to favor the production of *trans*-10, *cis*-12 CLA and related intermediates from the PUFA already in the diet. This hypothesis is supported by a recent study using continuous cultures and ^{13}carbon-labeled oleic acid. As expected, lowering culture pH to 5.5 reduced the concentration of *trans*-11 18:1 and increased *trans*-10 18:1 concentration. The ^{13}carbon enrichment of *trans*-10 18:1, however, was lower at pH 5.5 compared with pH 6.5 indicating that more of the *trans*-10 at low pH originated from sources other than oleic acid (Abu-Ghazaleh et al., 2005). This must come from PUFA sources and will presumably be driven through BH pathways that also promote the formation of *trans*-10, *cis*-12 CLA or related intermediates, thereby increasing MFD risk (Lock et al., 2006b).

Alteration of the Ruminal Environment

Factors that alter rumen environment are traditionally first considered when troubleshooting MFD on dairy farms. One major change in the rumen environment that leads to flux of fatty acids through alternate pathways of ruminal BH is low ruminal pH. Factors that can result in marked changes in ruminal pH through any 24-h period include: dietary carbohydrate profile and rates of degradation of the carbohydrate fractions as affected by source, processing, and moisture; physically effective NDF (peNDF) supply as affected by source and particle size; and production of salivary buffers as a function of peNDF supply and source (Shaver, 2005). Despite our general understanding of these factors, the degree and duration of low ruminal pH required to cause sufficient flux of PUFA through alternative pathways of ruminal BH is not known. Although data are limited, changes in rumen pH are most likely associated with MFD because they cause a change in the bacterial population favoring those that have alternative BH pathways. A common misconception, however, is that acidosis is a prerequisite for MFD to occur. This is not the case and in most situations rumen health appears excellent and there are no overt signs of ruminal acidosis (Overton et al., 2006). For example, Harvatine and Allen (2006a) reported increased duodenal flow of BH intermediates and MFD with no change in ruminal pH measured every 5 seconds over 4 d. Again, this highlights the fact that only small changes in the rumen environment can lead to increased risk of MFD.

A cursory review of the literature highlights the impact of different dietary carbohydrates on the risk of MFD as affected by source, processing, and moisture, presumably as a result of differences in the rate of rumen fermentation. A somewhat extreme example was reported by Jurjanz et al. (2004) which compared the effect of different starch sources (potato vs. wheat) on rates of milk fat synthesis; although there were no significant differences in milk yield, the wheat diet significantly reduced milk fat yield by 11%. Of greater relevance, a number of studies have reported an effect of corn processing method on risk of MFD. For example, Guyton et al. (2003) reported a 10% reduction in milk fat yield when steam-flaked corn replaced dry-ground corn. Clearly, careful consideration should be given to the fermentation rate of starch sources when troubleshooting MFD issues. As we have highlighted previously, however, no single factor tends to result in low milk fat and an example of the impact of some of these dietary interactions is highlighted in Table 5. Oba and Allen (2003) fed diets containing high moisture and dry ground corn at either a high or low starch level. At the low starch level there was no significant effect of grain processing on milk fat parameters, whereas at the high starch level high moisture corn significantly reduced milk fat yield by 15% compared to dry ground corn.

The preceding paragraphs have discussed situations in which changes in dietary components and their interactions have resulted in alterations in the rumen environment and BH pathways. It is worth noting, however, that risk of MFD can also be increased not only by changes in dietary components, but also via changes in how the diet is presented to the cow. An example of this is shown in Table 6 in which the effect of forage particle size on risk of MFD is reported (Grant et al., 1990). Cows were fed total mixed rations containing either fine (2.0 mm), medium (2.6 mm), or coarse (3.1 mm) ground alfalfa silage as 55% of dietary DM. Intake of DM and NDF was not influenced by particle size of the ration. Milk production also was unaffected, but milk fat decreased from 3.8% for cows fed the coarse ration to 3.0% for cows fed the fine ration. The decrease in milk fat secretion with reduced size of silage particles was also associated with reduced rumination and total chewing times and a lower rumen pH (Table 6).

Although the implications of low ruminal pH for production of the MFD-causing intermediates have been considered, it is probable that other factors can also cause changes in the rumen bacteria population resulting in an increased flow of fatty acids through alternate pathways of ruminal BH (Palmquist, et al., 2005). Overton et al. (2006) hypothesized that factors such as ensiled feeds with abnormal fermentation profiles (particularly high acetic acid corn silages) or moldy feeds may also cause the changes in BH required to cause MFD, however, these factors remain unstudied in a controlled manner. Additional issues that warrant further attention include environmental factors such as heat stress as well as management factors such as stocking density. Finally, when considering factors related to rumen environment, the impact of changes in rate of passage out of the rumen should also be considered; cows with higher DMI have higher rates of passage which potentially will 'flush' more BH intermediates out of the rumen. Cows with slower rates of fermentation, potentially increasing DMI and passage rate to compensate, and cows with higher DMI in general (e.g. higher producing cows) are, therefore, more likely at risk of MFD, and thus the margin of error is less in these animals (Overton, et al., 2006).

Alteration of Rates of Biohydrogenation

Under some circumstances specific feed components can alter rumen fermentation in a manner that results in changes in BH rates of fatty acids. Altering these rates can potentially increase the rumen outflow of *trans*-10, *cis*-12 CLA and related intermediates responsible for MFD, thereby increasing risk of MFD. This is a facet of troubleshooting MFD which is not typically considered when thinking about the traditional 'supply of PUFA' or 'altered fermentation' groupings, even though these changes are a result of changes in the rumen environment. Monensin is an example of a feed ingredient that can affect BH rates through altering rumen fermentation and the bacterial species present. In some cases during established lactation monensin supplementation can result in decreased milk fat percentage and yield (Duffield and Bagg, 2000). These effects are likely the result of interactions with other dietary or management factors that predispose cows to experience MFD. Monensin increases maintenance requirements of gram positive bacteria in the rumen which renders these bacteria less competitive in the ruminal environment (Duffield and Bagg, 2000). The net result is changes in the ruminal bacterial population that appear to decrease rates of BH of PUFA in the rumen. Very few species of bacteria have been identified that can convert *trans*-18:1 fatty acids to stearic acid (18:0), and most of these have been identified as being gram positive. Thus the final step in BH is already the 'rate-limiting' step; therefore decreasing the number of bacteria that can carry out this process can potentially lead to a 'build-up' of BH intermediates in the rumen thereby increasing their passage to the small intestine. This was highlighted by Fellner et al. (1997) when they examined the effect of monensin on the formation of BH products when linoleic acid was infused continuously into rumen fermentors. With an unsupplemented diet the rate of 18:0 formation was 7.5 mg/L/hr whereas this decreased to only 2.7 mg/L/hr when monensin was supplemented (Fellner et al., 1997). It is important to remember, however, that an increased rumen outflow of BH intermediates will not be a problem if typical BH pathways are present. However, even if a small proportion of dietary PUFA are being biohydrogenated through pathways that produce *trans*-10, *cis*-12 CLA and related intermediates, Monensin can potentially increase the passage of these to the small intestine and increase the risk of MFD.

Dietary fatty acids can also modify ruminal fermentation and may shift BH towards the production of intermediates that cause MFD. For example, Harvatine and Allen (2006b) reported that fat supplements affected fractional rates of ruminal fatty acid BH and passage in dairy cows; increasing the unsaturation of the fat supplement slowed down the BH of 18:1 to 18:0 while causing a significant reduction in milk fat yield. It is also well known from experimental diets that the addition of fish oil to the diet alters ruminal fermentation towards increased production of BH intermediates. Long chain n-3 PUFA present in fish oils appear to affect rumen bacteria catalyzing the terminal step in BH, thereby increasing the rumen outflow of these intermediates. In vitro studies with mixed cultures of rumen bacteria have established that docosahexaenoic acid is a specific n-3 PUFA responsible for this effect (AbuGhazaleh and Jenkins, 2004), though it is likely that other fatty acids may have similar effects. We have previously taken advantage of the effects of fish oil on rumen lipid metabolism as a method to facilitate the production of *cis*-9, *trans*-11 CLA-enriched milk (e.g. Lynch et al., 2005). Interactions are once again key; if normal BH pathways are maintained then the rumen outflow of *trans*-11 18:1 and *cis*-9, *trans*-11 CLA will increase. Small changes, however, in rumen fermentation as a result of fish oil feeding can alter these pathways thereby increasing the rumen outflow of intermediates that cause MFD. This is highlighted by recent studies by our group that emphasize the impact of feeding pattern of fish oil on MFD risk. In our first study we infused fish oil into the rumen 4X / day and observed a 24% decrease in milk fat yield. However, a follow up study which utilized a similar basal diet but infused the fish oil 6X / day resulted in no MFD (McConnell, Lock and Bauman, unpublished). Due to these multifaceted interactions it has proven difficult to experimentally distinguish the effect of PUFA as increased substrate vs. its potential role as a modifier of rumen fermentation.

Conclusions

Low milk fat percentage and yield is an important economic issue to dairy farms across North America. The available evidence indicates that all situations of MFD are due to changes in rumen BH of unsaturated FA and the passage of specific intermediates out of the rumen that subsequently reduce milk fat synthesis in the mammary gland. These changes in ruminal microbial processes are an essential component for the development of MFD and are centered on both an altered rumen environment and an alteration in the rumen pathways of PUFA BH. In general, no single dietary factor is responsible for MFD, and this paper has highlighted the interactions between various dietary components that can increase the rumen outflow of BH intermediates associated with MFD. Dietary components can increase the risk of MFD by increasing substrate supply, altering rumen BH pathways, and altering rates of BH. With the latter, it is important to consider factors that alter rates of BH (e.g. monensin) as not being causative for MFD per se; rather they interact with a predisposing condition (e.g., altered ruminal BH pathways) to accentuate the effects on milk fat. Finally, our understanding of the effect of specific BH intermediates on milk fat synthesis in the mammary gland has advanced at a much greater rate than our knowledge of their production in the rumen. Therefore, further research is required to better understand the ruminal conditions that promote the formation of BH intermediates that may trigger MFD. An improved understanding of these events will provide the critical framework with which to better troubleshoot MFD.

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Table 1. Partial list of potential risk factors for reduced milk fat and areas to address when developing nutritional strategies designed to avoid diet-induced MFD.[1]

Altered Rumen Environment	Supply of PUFA
• Low rumen pH/low peNDF intake)	• Amount (esp. linoleic acid
• Feed particle size	• Availability
• Fiber PUFA:SFA Starch (NSC)	• Feeding pattern
• Rumensin	• Variation in fat content and FA composition of feed ingredients
• Feeding pattern	

[1]Adapted from Bauman and Lock (2006) and Overton et al. (2006).

Table 2. Modified CPM Dairy lipid submodel output showing the sources of dietary fatty acids from a diet formulated for a cow producing 100 lbs milk/d.

	Fatty Acid (g/d)					
	C16:0	C18:0	C18:1*c*	C18:2	C18:3	Total
Alfalfa Silage	15	3	2	13	31	80
Corn Silage	30	4	32	79	14	166
Soybean Hulls	3	1	3	8	3	20
Corn Grain Ground	28	4	51	117	3	211
Soybean Meal	14	3	10	42	7	78
Blood Meal	2	2	2	1	0	7
Cottonseed Whole	92	9	58	217	1	384
Megalac	107	9	75	15	0	210
Ration	290	35	234	496	59	1161

Table 3. The effect of rumen-inert fats containing mostly saturated fatty acids (SFA), mostly monounsaturated fatty acids (MUFA), or mostly polyunsaturated fatty acids (PUFA) on dry matter intake (DMI), milk yield and milk fat synthesis in midlactation dairy cows.[1]

	Diet				*P*[1]
	Control	SFA	MUFA	PUFA	
DMI, kg/d	23.8	23.1	22.1	22.0	0.12
Milk, kg/d	36.9	37.3	35.8	34.8	0.44
Fat, %	3.37	3.86	3.32	2.61	0.03
Fat, g/d	1,249	1,436	1,184	911	0.02

[1]Adapted from Relling and Reynolds (2007)
[2]Probability comparing the difference between saturated and unsaturated fat supplements (SFA vs. MUFA and PUFA).

Table 4. Effect of feeding tallow on rumen fermentation and milk fat synthesis in dairy cows fed diets based upon corn silage (CS) or alfalfa silage (AS) with, or without tallow supplementation.[1]

	Treatment[2]		
	CS	CST	AST
DMI, kg/d	27.6	25.9	26.5
Milk, kg/d	44.9	44.3	43.6
Fat, %	3.12	2.68	3.32
Fat, kg/d	1.38	1.17	1.45
trans-10 18:1, %	0.75	2.15	0.78

[1]Adapted from Onetti et al. (2004).
[2]CS = 50% corn silage + 50% conc; CST = 50% corn silage + 50% conc + 2% tallow; AST = 25% corn silage + 25% alfalfa silage + 50% conc + 2% tallow.

Table 5. Effect of corn grain processing method and starch intake on milk fat synthesis.[1]

	High starch		Low starch	
	High moisture corn	Dry ground corn	High moisure corn	Dry ground corn
Milk yield (kg)	38.8	38.4	33.4	34.3
Milk fat %	3.05[b]	3.59[a]	3.95 [a]	3.73 [a]
Milk fat yield (kg)	1.17 [b]	1.35 [a]	1.33 [ab]	1.27 [ab]

[1]Adapted from Oba and Allen (2003). Treatment significance (*P* < 0.05) indicated by differences in superscript letters.

Table 6. Effect of corn grain processing method and starch intake on milk fat synthesis.[1,2]

	Treatment[3]			
	Fine	Medium	Coarse	P
Dry Matter Intake, kg/d	22.4	22.0	22.2	0.88
Milk Yield, kg/d	31.5	32.1	31.1	0.56
Milk Fat, %	3.0	3.6	3.8	0.001
Milk Fat Yield[4]	945	1156	1182	—-
Rumen pH	5.3	5.9	6.0	0.1
Rumination Time, min/24 h	374	466	531	0.001
Total Chewing Time, min/24 h	570	671	735	0.001

[1]Adapted from Grant et al. (1990).
[2]Arithmetic mean particle size of the fine and course silages used in the study were 2.0 and 3.1, respectively.
[3]Rations formulated on 55:45 silage:concentrate basis.
[4]Calculated from reported values.

Figure 1. Generalized scheme of ruminal biohydrogenation of linoleic acid under normal conditions (left side) and during diet-induced milk fat depression (dotted lines, right side). Adapted from Bauman and Griinari (2003). The grey boxes highlight three potential means by which dietary components can increase the risk of milk fat depression.

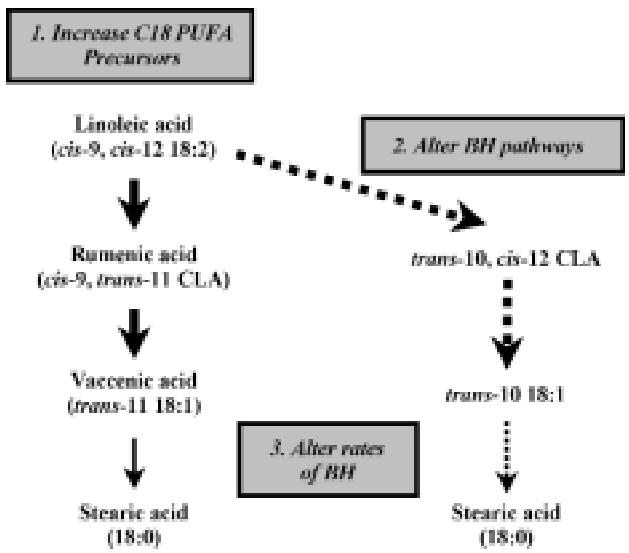
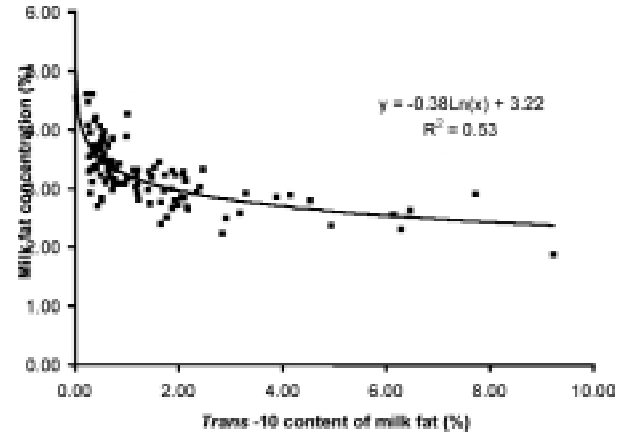


Figure 2. The relationship between the content of trans-10 18:1 in milk fat and milk fat percent. Adapted from Hinrichsen et al. (2006).



Dietary Effective Fiber, Particle Length and Sorting

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Introduction

It is well known by dairy producers, veterinarians and nutritionists that dairy cows require fiber and also that cows require a portion of their diet to have adequate physical length to promote optimal rumen function. Because the long particles consumed by cows are virtually entirely from the more fibrous parts of plants it is common to confuse the requirement for long fiber with total fiber. The long fiber is often called 'effective fiber' but I will always call it physically effective fiber and reserve the term effective fiber for something broader, more holistic and admittedly vaguer. Physically effective fiber is essential to provide rumen fill and prevent abomasal displacement. Physically effective fiber forms a thick rumen mat that slows passage of smaller fibrous feed particles and increases their digestion. Because most structural fibers are degraded at a slower pace than starches, sugars and soluble fiber, slowing these fibers down by matting is an important way ruminants have evolved to digest these more recalcitrant sources of carbohydrate. Physically effective fiber enhances rumination and salivation, providing a better buffer source for the rumen. The latter is a very important concern for cows eating large quantities of feed, much of which is rapidly fermented to organic acids in the rumen. Finally physically effective fiber is related to rumen fill and can limit feed intake. It is possible that limiting feed intake on any given day may help reduce variation in day to day feed intake without drastically reducing average feed intake, but the potential for reduction in average feed intake is clerly present in overly long diets. Although limiting feed intake usually is a definite negative, it is also one way to reduce the likelihood of acidosis so this feed intake limitation can also be one of the 'positive' effects of physically effective fiber. This talk focuses on how we make sure cows consume an adequate physically effective fiber. I discuss this in terms of the role that coarse fiber has in complementing the remainder of the dietary NDF. I will not discuss the importance of many carbohydrate characteristics such as NDF digestibility, starch availability and rate of degradation, the effect of starch vs. sugar or the role of non-NDF fiber. All of these characteristics are important in determining the final carbohydrate 'balance' of the diet.

While ignoring particle length is just plain wrong, focusing on only long fiber in balancing dairy diets leads to erroneous thinking about the requirement for fiber. One good way to express the requirement for long fiber was to suggest that the diet has 21% of diet dry matter as NDF from forage. This was a much better recommendation than requiring 28% NDF and 75% of the NDF from forage, but it still has its problems. This 21% forage NDF guideline alone would assume that all forage had identical length. Because particle size of forages varies, guidelines exist to ensure that forage sieving results meet some minimum requirement (say 15% of as fed forage mass retained on the top Penn State screen). Separating these two requirements is problematic. If the primary role of forage NDF, vs. non-forage NDF, is to provide physically effective fiber, then there must be a tradeoff where less of a coarser forage (plus some non-forage, fine fiber) would equal more of a finer forage. Having separate, rigid guidelines for % forage and % above a screen does not allow for this tradeoff to be done quantitatively. A less obvious problem with 21% forage NDF as a requirement is that it essentially ignores the remainder of the NDF in the diet. There is very good information that NDF from byproduct feeds or finely ground forages that have no physical effect in the rumen are nonetheless valuable in balancing the rumen chemistry by providing energy without providing more starch. It is important to separate out the concepts of physically effective (that is particles long enough to affect rumen consistency and rumination) and other useful chemical attributes that belong to both long and short fiber alike. Many short fiber particles result from the grain pericarp and legume leaves and are relatively highly digestible sources of fiber. Once we accept that there is chemical value to fiber that is separate from the value of long particles which are fiber rich, we can begin to imagine a more systematic way of thinking of meeting fiber requirements. The work in this area is no where near complete, but advances continue to be made. Numerous ideas can be implemented now but also with an eye toward improved systems that incorporate (and suggest) more information that should be collected.

Myth Only the particles on the very top screens are physically effective.

Reality Any feed or diet has a distribution of particles of various sizes. These distributions can be hard to describe in simple, understandable terms. Mean particle length and standard deviation are technically the appropriate terms to use. However, given the unusual shape of the particle size distribution, mean particle length values are actually difficult to interpret. Having seen many diets and their calculated particle sizes, I know that my own intuitive assessment of the diet is much longer than the correctly calculated mean particle length. Because of this, one easy way to describe a target for how a forage or diet should 'look' was to set a minimum for the percentage on the top screen. It is not surprising that many people understood this (incorrectly) to mean that the material on the top screen was what provided all the physically effective fiber.

Let's look at some field data on particle sizing These data are revealing and tell us that modern forage choppers were designed by engineers who apparently all read the same textbooks because they appear to provide a very similar distribution of particle sizes. As the theoretical cut of these machines is adjusted to make coarser or finer silages, the entire distribution is pretty well described by the mean particle size, but also by the % of the particles above a middle point. This is shown in figure 1 where the relationship of mean particle size and the % of particles above the 9 mm (diagonal) screen of the Wisconsin separator is shown. A similar tight relationship exists for particles above the 5.6 mm (next smallest) screen. Finding data to measure the physical effectiveness of any particular fiber length is actually quite difficult given the strong fit shown in figure 1 and the fact that a true precision chopping is really impossible. If we were always dealing with feeds chopped by the same broad class of forage harvester, all this might be somewhat irrelevant as all the measures would be interchangeable. However the danger of depending on only very long fibers with no 'middle screen' will be highlighted in the remainder of this talk. Providing very long fiber (particles several inches long or more) that has not gone through a conventional forage harvester will distort the relationships shown in figure 1 and render using the % on the top screen less useful that using the % above a more 'central' screen.

In order to test the effect of 'greater mean particle length' versus 'more long particles' we conducted the trial described in figure 2. Basically we harvested oatlage in such a way as to provide two diets with similar mean particle size but one diet with lots of long and short particles and one with more medium particles. Our results suggest these diets performed about the same. Long particles will raise the mean particle length and therefore the physical effectiveness of the diet. Medium particles that raise the mean particle length to the same level (which requires more mass of medium particles) were just as effective, or at least too close to measure a difference. It is important to note that figure 2 reports the average particle size of the diet the cows were offered, which brings us to the importance of sorting.

Sorting

We have conducted a series of trials to measure TMR sorting by dairy cows. Most of these trials, especially the early ones, focused on getting observations on numerous cows while also exploring diet composition effects. Therefore most of the data was colleted in tie stalls with individual cow feeding behavior measured. The data on individual cow behavior is summarized in figure 3. Sorting was measured by determining the physical distribution of the feed refused by each individually housed cow. Actual as fed intake of each screen (total offered – amount in refusals) was calculated directly. This number was divided by the predicted as fed intake for that same screen, where predicted intake for a screen is the as fed intake for that cow (total offered – total refused) multiplied by the as fed distribution of the total mixed ration (**TMR**) on that screen. So the predicted intake is the 'value on paper' for the diet and the numbers we show are the actual cow intakes of each screen presented as percent of the predicted. When expressing data this way, screens less than 100% are being sorted against and screens more than 100% are being selectively consumed. If one screen is less than 100%, some other screen will have to be more than 100%. In general, screens with a small amount on them (like the coarsest screen) can deviate from 100% more than screens with a lot of material on them and it is important to remember that to avoid over-interpreting the data. An example calculation for a simple 1 screen separation is shown in Table 1.

Two important facts are apparent in figure 3. One is that sorting differs cow to cow. Some cows will sort extensively. There are the cows that consume less than 20% of the longest dietary particles and more than one cow in our studies refused this portion of the diet entirely. The other fact is that not all cows do this and in a pen of cows it would be easy to miss the fact that a few individual cows were sorting aggressively when sieving pooled weigh backs. Looking for 'sorting holes' early in the feeding cycle may in fact be more informative. A second point is that the medium screen particles are not sorted extensively by any cows. Taken together what does this mean? Adding 'top Wisconsin screen fiber' to the TMR will certainly increase the mean particle size of the diet offered and of the diet consumed by the 'average cow'. However it may do absolutely little for a small group of cows and nothing for a few outlier individuals. Since a few percentage points increase in the incidence of displaced abomasum is not a minor issue, this could be an important underlying factor. If however the diet mean particle size is raised by increasing the medium length particles, this will help all the cows. The latter approach is therefore much more desirable.

We did an experiment to compare sorting of tie-stall and free stall housed cattle. We were not able to get individual cow behavior in the free stall group, but we did a switch back trial that provided some meager replication and at least an attempt at a statistical analysis. These data are shown in figure 4. The data suggest more sorting by cows housed as a group than by the average of the same cows housed individually. This was what we predicted would happen. Cows housed in tie-stalls that sort early in the feeding cycle will be presented with a more and more fibrous diet as the day proceeds. In a loose housing feeding situation 'sorter' cows may move to a relatively unsorted part of the TMR left by 'non-sorter' cows. An aggressive cow, who also happens to be an aggressive sorter (we have no reason to believe they are linked), may be particularly susceptible to behaving in this manner.

Measuring Sorting in the Field and feed bunk management

The particle size of the feed refused by a cow (or a group of cows) is not only dependent on the sorting that has occurred but also very much by the amount of weigh back remaining. Figure 5 shows this effect graphically for a theoretical situation. To put it simply if there is no weigh back at all then the single cow has not sorted, and in the group of cows average sorting was zero. Remember average sorting of zero could mean sorting against long particles by one cow is compensated for by another cow. We do not see a great deal of sorting in favor of long particles in our studies with individually fed cows, but in a group fed, limit fed pen situation, cows may be coerced into this behavior. The second point is that if weighbacks are extremely large relative to the amount consumed, the effect of sorting is not so obvious. At 'infinite weighback' the orts will be the same particle size distribution as the diet no matter how much sorting occurs. Obviously we never get near to 'infinite weighback' in practice, but the shape of the curve on the low weighback side is very informative. So if sieving of weighback is done, the amount of weighback must also be determined to have any real quantitative information. Also remember that the Penn state top screen pools the longest and next longest particles shown in figure 3, so will be less sensitive. Pulling out long particles from the top Penn State screen and counting them may be more informative than simply the total weight on the top screen.

The amount of weighback to leave is not a simple economic question, especially when no alternative feed use (heifers) of the refused feed is possible. Weighback is expensive and creates a nutrient management problem because unconsumed feed is used with an efficiency of 0. Careful feed management, dry matter measurements, cow number monitoring, observation at appropriate intervals in the feeding cycle and anticipation of weather effects are all helpful but not automatic in minimizing wasted feed. On a hot diet limited feed access is one way to control acidosis, but where cows have limited access to bunk space and have to wait in line to eat this is a troubling approach even in a very well managed operation. Using limited feed to minimize sorting is something I would only consider after all my other better options (i.e. proper chopping and proper diet moisture) were implemented and even in that case I think the cure would usually be worse than the disease.

How much physically effective fiber

I believe the best way to determine physically effective fiber is to measure the amount of NDF above the 9 mm screen or some similar 'middle' screen. Unfortunately most research, including our own, has not used this measure. This measurement should replace the concept of calculating a 'physical effectiveness factor' based on mean particle length and then multiplying this factor times the diet NDF. The reason I do not like the latter approach is that if you add very fine fiber to a diet in place of fine starch, the 'physical effectiveness factor' will not change. However, because the NDF of the diet increases, the apparent content of physically effective NDF will increase. It is quite clear that adding fine NDF to low forage diets is a positive step but I think it is fundamentally incorrect to call this physically effective fiber. Clearly this fine fiber, because of its chemical difference from starch, is 'effective', but not 'physically effective. I believe a final system will have to consider both physically effective NDF and total NDF (in addition to other carbohydrate characteristics.

My firm impression of the literature (with mid-lactation cows primarily and often short feeding periods) is that the requirement for particle length on 'normal' diets is actually lower than most people in the field think. Methods for average particle size distribution vary among studies based on the sieving device used and if DM or as fed is used. My interpretation of the literature is that positive milk fat yield responses stop somewhere below 5 mm, and that responses in chewing stop at about 7 mm. That is we increase the physically effective fiber content between 5 and 7 mm but the physically effective requirement was met by 5 mm. Intake reduction is common above 5 mm. In figure 1, 5 mm corresponds to only 38% of as fed material on the top 3 Wisconsin screens. This would probably be somewhat higher % on the Penn State screen (maybe ~45%) but we do not know of a large body of comparative data for the two techniques. It is certainly reasonable to feed longer mean particle size to cows at calving so one group TMR's would have to accommodate that presumed increased requirement. Diets that have a great deal of their digestible energy from NDF, and possibly from soluble fiber, can get by with less particle size in mid-lactation cows. The advantages of lower particle size can occur in the silo as well as in the cow. Diet economics will often favor adding by-product fiber in place of forages and exploring this economic option requires consideration of the overall characteristics of the diet carbohydrate. Physically effective fiber consumed is only one aspect of this balancing act.

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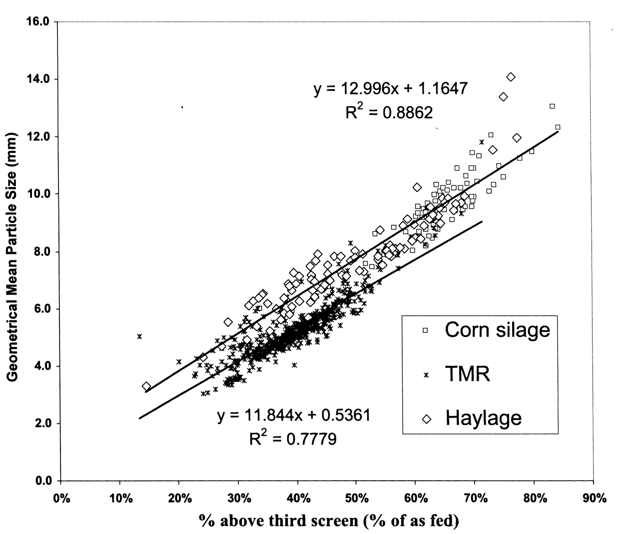

Figure 1

Figure 1. Relationship of mean particle size and % of particles above the third screen (9mm diagonal opening) of the Wisconsin separator. A positive relationship is obviously expected but the quality of the fit is very good indicating that one screen in the middle of the distribution does a very good job of predicting the entire distribution. The fourth screen (5.6 mm) also showed a good relationship but larger and smaller screens were less predictive. The regression for alfalfa and corn silage were nearly identical and a single regression equation is shown where x is a decimal value (50%=.5) and y is given in mm. The TMR regression (lower line and equation) is also given and is different because the non-forage feeds in the TMR follow a different distribution than the alfalfa and corn silage yet this regression still explains 78% of the variation in TMR mean particle size and most of the large deviations are above the regression line.

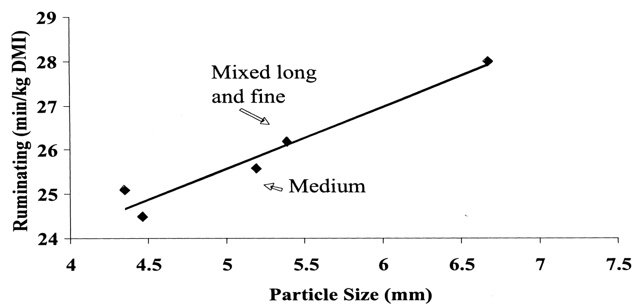

Figure 2

Figure 2: Results from a trial where particle size of oatlage based TMR was distorted by mixing finely chopped (left hand points) and long silage (right hand point) to achieve about 5.4 mm in TMR with a bimodal distribution (mixed long and fine) or by using a middle setting on the forage harvester (medium). These diets had similar mean particle size and similar physically effective fiber suggesting no greatly enhance effect of longer fibers other than what is incorporated into mean particle length. See figure 6 for particle size actually consumed.

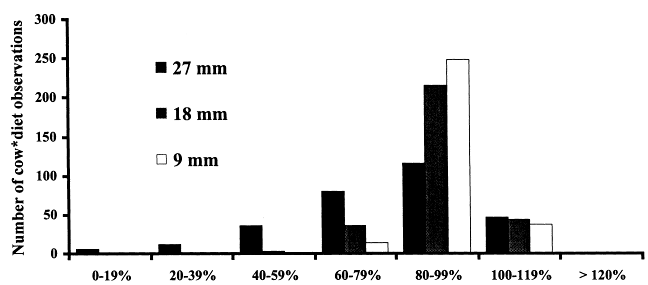

Figure 3

Figure 3: Sorting of the three top screens of the Wisconsin separator. Many cows eat less than 50% of the material on the very coarsest screen (black bar) while the sorting expressed on a percentage basis is much less for the material passing the 18 mm screen and retained on the 9 mm screen (open bar). This is certainly partly due to the small amounts of feed on the very top screen so a small absolute amount of sorting makes a large percentage change. But these feeds also represent material that cows can push away easily with the one tool at their disposal: a 6 inch wide nose.

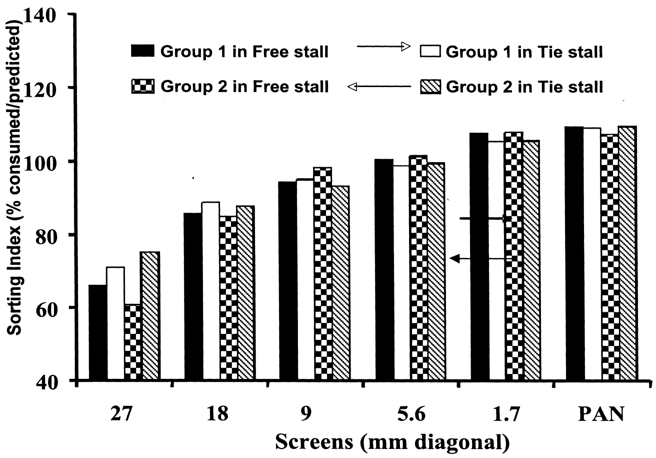

Figure 4

Figure 4: Sorting by the same cows housed individually in tie-stalls or as a group in a single freestall pen. Cows appeared to sort more in the freestall and the difference was larger than could be attributed to chance based on observed variation of the cows in the tie-stalls.

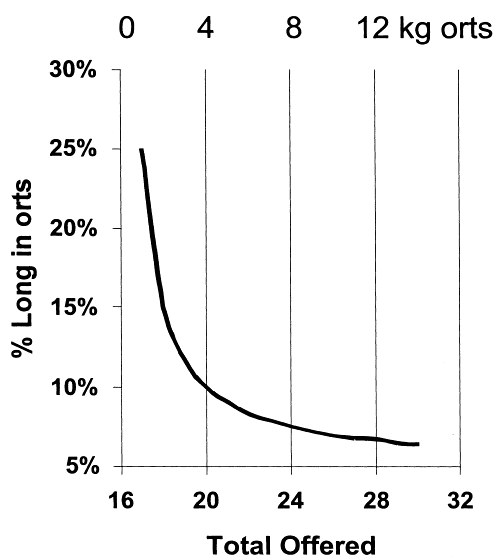

Figure 5

Figure 5. A theoretical example. The TMR is 5% long particles and animal is consuming 16 kg. As more feed is offered and more orts (weighback) is left the weighback begins to look just like the diet eaten though sorting has not changed. in this example the animal was consuming only 75% of these long particles. Note that at low levels of orts the composition of the weighback is very sensitive to amount of weighback een though we fixed the sorting at 75%. Weight and particle distribution of both the weighback and TMR offered must be known to determine sorting. How to do the calculation is shown in table 1.

	offered %	offered kg	eaten kg	Orts	really eaten	sorting index
Diet	100%	20	16	4 kg 100%	16	
Long	5%	1	0.8* (.05x16)	0.4 kg 10%	0.6 (1-.4)	.6/.8 = **75%**
Short	95%	19	15.2* (.95*16)	3.6 kg 90%	15.4 (19-3.6)	15.4/15.2 =101%

Table 1

Table 1: Calculating a sorting index. Sieving data of the TMR offered (as %) is shown in the second column. Absolute amounts offered in column 3 are based on the amount of feed offered (in this case DM per cow, but can be as fed per pen) and the % in column 2. Diet eaten (the difference between total offered and total orts) is calculated from orts weight which must be taken. 'Expected'* consumption of long particles is determined by percentage of diet offered that is long times total intake. This is what a 100%, non sorting cow would eat. If the orts are 10% long (indicating some sorting against long particles) the actual consumption of long particles is determined to be .6, which is 75% of the expected .8.

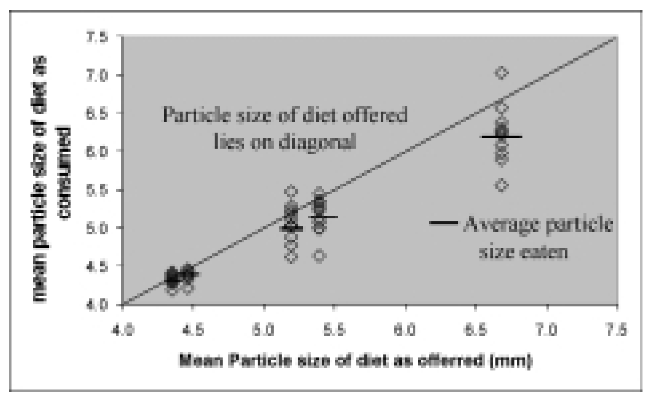

Figure 6

Figure 6: Particle size of diet offered, particle size of diets consumed by individual cows in tie-stalls, and average particle size of diets consumed. These data are the same as used in figure 2. Note the range of particle size consumption within a given diet verses the spread between fairly fine diets (4.5 mm) and coarse diets (6.7 mm). The lowest point for the 6.7 mm diet is actually the same as the distribution offered in the 5.4 mm diet.

Getting the Most Out of Your Dry and High-Moisture Corn

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Final Exam: Advanced Dairy Nutrition 504. Circle all correct answers.

1. Cereal grains are fed to lactating cows because they are:
   a. Least cost energy sources. b. Convenient. c. Promoted by salespeople
2. What is the major source of net energy for lactation from corn grain?
   a. NDF. b. Fat. c. Protein. d. Non-fiber carbohydrate. e. Ash. f. Water
3. What is the major source of net energy for lactation from corn silage?
   a. NDF. b. Fat. c.Protein. d. Non-fiber carbohydrate. e. Ash. f. Water
4. On a dry matter basis, corn silage that contains 30% starch probably has:
   a. Too much starch. b. 33% grain. c. 43% grain. d. 55% grain.
5. Compared with corn silage at 30% DM, corn silage at 35% DM has:
   a. No more starch. b. 2% more starch. c. More NDF. d. 5% more starch.
6. Compared to #2 yellow dent corn, #1 yellow dent corn has:
   a. 5% less value. b. 2% more value. c. Equal value. d. I don't know.
7. Compared with rolled grain, finely ground corn has:
   a. Less feeding value. b. Greater digestibility. c. Less acidosis potential.
8. Starch digestibility of rolled or ground corn is most closely related to:
   a. Particle size. b. Duration of storage. c. Moisture content.
9. Compared with high moisture corn, finely ground dry corn has:
   a. Lower digestibility. b. Greater digestibility. c. Less acidosis potential.
10. Ideally, high moisture corn should contain:
    a. 15% moisture. b. 24% moisture. c. 30% moisture. d. Moisture does not matter.
11. Fermentation of high moisture corn:
    a. Is complete in 2 weeks. b. Lasts a full month. c. Can take 6 months or more.
12. For dry rolled corn, what percent if the starch is digested in the rumen?
    a. 25%. b. 50%. c. 80%. d. 90%.
13. What percent of dietary starch from high moisture corn is fermented in the rumen?
    a. 25%. b. 50%. c. 80%. d. 90%.
14. Most energy loss between harvest and feeding of high moisture corn grain occurs:
    a. In the first week. b. From the silage face. c. Due to loss of carbon dioxide.
15. Starch digestibility of high moisture corn is most closely related to:
    a. Particle size. b. Duration of storage. c. Moisture content.
16. Following grain processing, relative to small corn kernels, large corn kernels:
    a. Have equal feed value. b. Have more NDF. c. Have more feeding value.
17. More extensively processed corn grain or corn silage:
    a. Causes acidosis. b. Decreases TDN. c. Should be fed at lower levels.
18. In the rumen, harder, more vitreous corn kernels, when fed as rolled or ground grain:
    a. Are more fully digested. b. Are fermented more rapidly. c. Yield less acid.
19. When fermented or steam flaked, more vitreous of corn kernels:
    a. Are equal to floury kernels. b. Have greater feeding value. c. Have less value.
20. Starch digestibility of steam rolled or steam flaked grain is related to:
    a. Initial grain bushel weight. b. Flaked bushel weight. c. Flake thickness.
21. Flaked corn decreases in feeding value when:
    a. Flakes get old. b. Flakes are broken from mixing. c. Flakes remain hot and moist.
22. During flaking,:
    a. Starch is formed. b. Protein is lost. c. Phosphorus disappears.
23. Corn kernels in manure are:
    a. Hollow and unimportant. b. Incompletely digestion. c. Good bird food.
24. Starch digestibility by lactating cows:
    a. Is complex to measure. b. Can be estimated from analysis of feed and feces.
25. A corn hybrid ideal to flake or use to produce high moisture corn:
    a. Also is ideal when dry rolled. b. May not yield ideal dry rolled grain.

26. Compared to typical hybrids, a corn hybrid selected for maximum ethanol yield:
    a. Would be ideal to feed. b. May provide less NEl. c. Makes intoxicating sweet corn.
27. Starch availability measurements reliably predict digestion:
    a. In the rumen. b. In the intestines. c. In the total digestive tract.
28. Starch digestion in the rumen is proportional to total tract starch digestion for:
    a. Flaked grain. b. High moisture grain. c. Rolled or ground grain.
29. To properly assess grain digestibility and processing responses, NRC (2001) needs:
    a. A sliding PAF. b. Revised digestibility depression values. c. New TDN equations.

Reasoned (but not necessarily exclusive) answers:

1. Though more convenient to handle and process than forages and most byproducts, cereal grains are fed to cows primarily because they are the lowest cost sources of net energy for lactation. As competition with ethanol plants drives up the price of cereal grains, byproducts can displace grains as least cost sources of energy. To fully use ethanol production byproducts, diets need to be formulated on the basis of least cost *milk production*, not simply least cost dietary *energy*. To lower feed cost, some slight sacrifice in milk production or quality may prove economically rewarding.

2 and 3. Non-fiber carbohydrate is the primary source of net energy in both corn grain and corn silage (Table 1).

Table 1. Contributions to TDN

Component	Corn grain	Corn grain	Corn silage	Corn silage
	% of DM	% of TDN	% of DM	% of TDN
NFC	76.1	77.5	40.8	50.3
Protein	9.4	9.6	8.3	9.5
Fat	4.2	7.5	3.3	7.2
NDF	9.5	5.4	44.6	33.3

Though corn silage selection often is based on NDF content and digestibility, over half of the truly digested energy from corn silage is derived from nonfiber carbohydrate, primarily starch. Nonfiber carbohydrate provides more than three-quarters of total digested energy from corn grain. Processing adjustment factors for steam flaked and high moisture corn increase the NFC contribution to energy to 78.2% of total while increasing TDN by 3.3%. However, compared with ground corn, cracked corn has 4.1% less TDN and the NFC contribution decreases to 76.6% of total digested energy. Note that digestibility of NFC is estimated at 98% according to this standard formula. Additional adjustments for corn silage where starch digestibility can be as low as 80% have been proposed by Shaver (2006).

4. Corn grain contains about 70% starch. Thus, corn silage with 30% of its dry matter as starch contains about 43% (30/0.7) of its dry matter as grain. Corn silage with higher starch content will reduce the quantity of grain that needs to be supplemented to maximize milk production, a factor of increased economic importance when grain prices are high. Though some nutritionists have expressed concern that corn silage high in grain is "too hot to feed," adjustments in the forage to grain ratio can compensate easily for corn silages that are rich in grain.

5. Surprisingly, as corn silage matures from 30% to 35% dry matter, almost all of the increase in weight is starch (Figure 1). Some of this change may reflect conversion of sugar to starch, but with maturation, NDF content of the corn plant, unlike other forages, remains relatively stable. Thus, NDF percentage of silage decreases because it is dilution by the additional grain. Hazards involved with delaying harvest of corn silage in order to increase starch content would include a) more difficulty in packing and air exclusion during ensiling and b) potential decreases in starch digestibility, especially with corn silage that has not been kernel processed adequately or has not been stored for a sufficient time to increase starch availability from corn kernels.

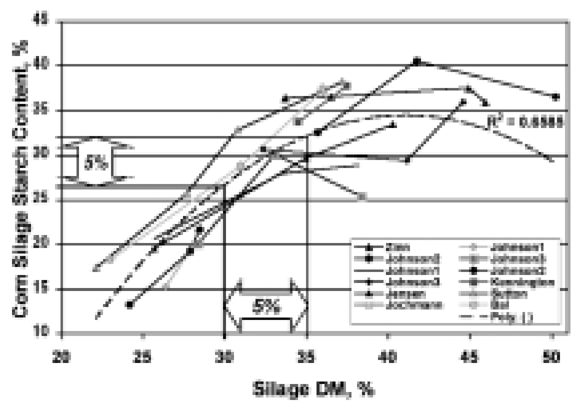

Figure 1. Influence of corn silage DM content on starch content of corn silage.

6. Grain grading standards developed by the USDA to classify corn grain were designed primarily to enhance grain preservation and avoid grain storage problems. As noted in Table 2, higher concentrations of moisture and foreign matter cause discounts in the USDA grade. Lower test weight has been associated with generation of more fine particles during grain handling that, combined with presence of foreign matter, retard air movement through grain. Combined with higher moisture content, decreased aeration increases the likelihood of mold and fungal damage during grain storage.

Table 2. Official US Standards for Grain.

Grade	Minimum Test Weight Per Bushel (Pounds)	Moisture	Broken Corn and Foreign Material	Total	Heat-Damaged Kernels
			Maximum Limits of	Damaged Kernels	
		Percent			
U.S. No. 1	**56.0**	**14.0**	**2.0**	**3.0**	**0.1**
U.S. No. 2	**54.0**	**15.5**	**3.0**	**5.0**	**0.2**
U.S. No. 3	**52.0**	**17.5**	**4.0**	**7.0**	**0.5**
U.S. No. 4	**49.0**	**20.0**	**5.0**	**10.0**	**1.0**
U.S. No. 5	**46.0**	**23.0**	**7.0**	**15.0**	**3.0**

Bitzer and Riddell (1984), in discussing these standards, stated, "The main factors used in determining the feeding value of corn grain are content of total digestible nutrients (TDN) and crude protein. The test weight per bushel and moisture content do not affect the feeding value of the grain on a dry matter basis. Broken corn may not be reduced in feed value. However, broken kernels are more susceptible to mold invasion and insect infestation and will not store as well as sound corn. Foreign material may contribute to damage sustained during storage if it interferes with needed aeration or fumigation. The effect of foreign material on feeding value would be directly related to sustained damage and the type and quantity of foreign material present. Unless certain weed seeds are present, intake by animals would probably not be affected." Hence, feeding value of corn grain cannot be appraised directly from its USDA grade. More recently, Koch (2005) summarized that corn grain that has a lower test weight actually has a more net energy value when fed as dry rolled grain to cattle. Fine particles derived from corn kernels during handling should not decrease the energy value of the grain. Commercial shelled corn samples contain an average of 1.3% less starch than cleaned corn samples. This may reflect dilution or blending of commercial grains to the maximum limit (2%) of foreign matter for #2 yellow corn. Composition of this foreign matter will dictate the degree to which energy value of the grain is diluted by foreign matter. Livestock producers that grow their own grain, those that purchase grain directly from growers, and those that use identity preserved grain can avoid this potential source of energy dilution.

7. Summaries of research trials with dairy cows indicate that as compared with more coarsely rolled corn grain, finely ground corn is more extensively digested both in the rumen (Figure 2) and in the total digestive tract (Figure 3). Intake of large amounts of fine corn particles will increase the incidence of subclinical acidosis, but cattle and bunk management (avoiding separation of fines in the bunk and feed sorting; feeding an adequate level of forage) will help avoid acidosis.

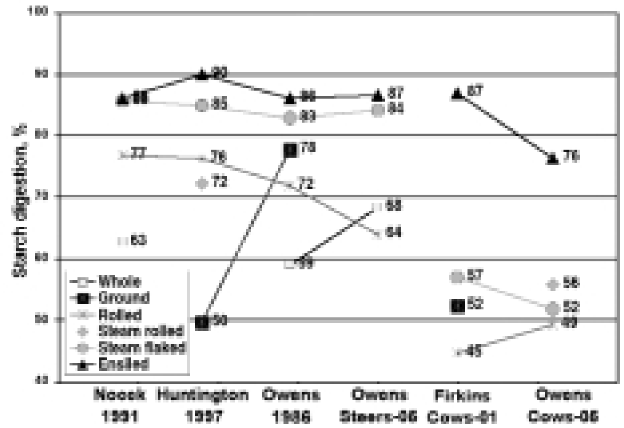

Figure 2. Digestion of starch in the rumen of cattle as a fraction of starch from corn grain that was fed with grain processed by various methods.

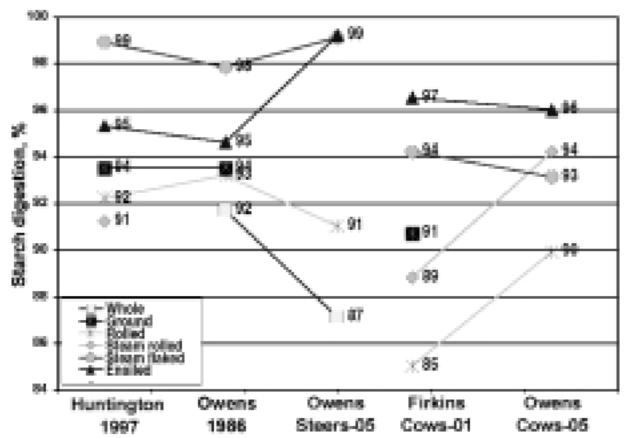

Figure 3. Mean values for total tract digestion by cattle of starch from corn grain processed by various methods based on literature reviews by various authors.

8 and 9. Starch digestion from rolled or ground corn is closely related to particle size. But fine grinding cannot increase starch digestibility to the same extent as more extensive grain processing can (high moisture fermentation; steam flaking; Figures 2 and 3).

10. For maximum feeding value, high moisture corn should contain more than 26% moisture. Indeed, adding water to dry grain seems to yield a product with a similar advantage of dry corn in net energy as seen with high moisture corn grain. But at 20 to 24% moisture, corn grain often has a lower feeding value than grain that is either wetter or drier! On the high side, to maximize grain yield, harvest of high moisture corn should be delayed until grain reaches physiological maturity (presence of kernel black layers).

11. Fermentation of high moisture corn can continue for more than a year as judged by ruminal starch digestion and solubility of the corn protein (Benton et al., 2005). Because starch availability continues to increase, diets formulated with a similar amount of high moisture corn that is 9 months old is considerably more likely to cause acidosis than high moisture corn stored for 3 months. Diet reformulation based on duration of fermentation should help avoid “spring acidosis.”

12 and 13. Only about half of the starch from dry rolled corn is fermented in the rumen leaving half to flow to the small intestine (Figure 4). In nearly 30% of the digestion site studies with lactating cows fed dry rolled corn, more starch disappeared PAST the rumen than WITHIN the rumen. Compared to steers, lactating cows have a greater postruminal supply and greater postruminal digestion of starch, probably because high feed intakes and NDF levels of lactating cows decrease the time that starch particles spend in the rumen to be digested by microbes. Ruminal digestion of high moisture corn often exceeds 80% of dietary starch. Compared with rolled or ground grain, this leaves considerably less starch to be digested or fermented in the intestines.

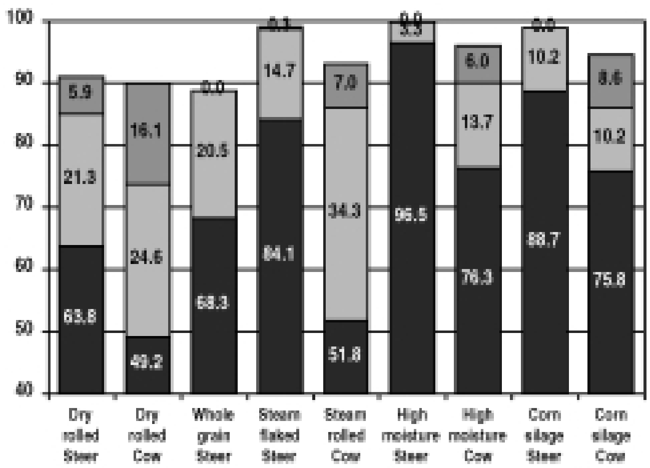

Figure 4. Site of starch disappearance (% of dietary starch) from corn grain and corn silage fed to steers and cows. Lower section represents digestion in the rumen, midsection represents digestion in the small intestine, and top section represents fermentation in the large intestine.

14. Dry matter loss of high moisture corn from ensiling to feeding normally ranges from 2 to 5%. Loss of energy during fermentation alone should be less than 1% for high moisture corn handled appropriately (ground, packed, and sealed). Most loss occurs during removal from storage (as reflected by heating of the mass) from oxidation and from volatiles (ethanol; lactate, other acids) lost from the silage surface and feed bunk.

15. Starch digestibility from high moisture corn appears most closely related to moisture content of the ensiled grain; higher moisture content increases both ruminal and total tract digestion of starch, but a longer duration of storage also increases its starch digestibility. Either microbial activity or chemical action of various fermentation end products renders corn protein more soluble; that liberates more of the starch for digestion.

16. The larger a structure, the lower its surface area to volume ratio. Therefore, larger kernels have less surface (pericarp) per unit weight (kernel). As the pericarp is nearly 90% NDF, larger kernels have a lower percentage of NDF. Because NDF is less digestible than other fractions of the kernel, larger kernels have a more net energy as noted in steer feeding trials by Jaeger et al. (2004). In addition, large kernels are more likely to be damaged during grain processing (rolling, grinding). Consequently, the increased digestibility associated with particle size reduction is more probable for larger than smaller corn kernels. Size uniformity is important for processing.

17. Potential for acidosis increases with more extensive processing of either corn grain or silage because more starch is exposed for rapid fermentation within the rumen. Whenever feeds with greater starch content or starch availability are fed, diets should be formulated with the correct ratio of grain to roughage to maintain proper rumen function.

18. Dent corn grain is the product of an ancient cross between floury and flinty grain parents. Hence, dent corn contains both floury endosperm with loosely packed starch (that forms flour when ground) and a densely packed more crystalline endosperm with a starch fraction denoted as flinty, vitreous, horny, or hard. The ratio of floury to vitreous starch differs due to genetics and maturity of the grain, often increasing as the grain matures. When dried and ground, more flour is generated from corn samples that have floury endosperm. Small, floury particles are rapidly and extensively digested in the rumen. Consequently, extent of ruminal digestion and acid production from dry rolled grain is greater for corn grain with a higher percentage of floury endosperm as nicely outlined by Shaver (2003). Though the relationship is not perfect, grain samples with lower bushel weight often have a higher percentage of floury endosperm and would be preferred to maximize extent of ruminal digestion for dry rolled or dry ground grain.

19. The differences in ruminal and total tract digestion with dry grain that are associated with

kernel vitreousness disappear when corn grain is steam flaked (Corona et al., 2006) or fermented to produce high moisture corn grain (Szasz et al., 2005).

20. Starch availability and digestibility are closely related to the bulk density of flaked corn grain, a standard index of flake quality used by most flaker operators. The lower the flake density, the thinner the flake and the more accessible the starch for microbial and enzymatic attack and digestion. Because extraneous factors (flake temperature, packing, drying) can influence flake density, additional indices of starch availability (gas production rate; release of glucose during incubation with enzymes) often are employed.

21. Picturesque corn flakes are large and flat with few fines preferably fed to cattle while still warm. However, research indicates that a) aged flakes have equal value to fresh flakes and b) digestibility of flakes is not reduced by the extensive mixing that reduces size of the flakes. However, enzymatic availability of starch from flakes decreases if flakes remain hot and moist for more than an hour following flaking, probably due to starch retrogradation (hardening). Retrogradation may reduce digestibility or shift more starch from the rumen to the intestines for digestion.

22. Steam and pressure involved with steam flaking grain increase the availability of starch for digestion by microbes or enzymes and has been suggested to decrease protein and phosphorus content of grain. Because no compounds are volatilized or chemically changed by flaking, such changes probably are artifacts of analysis or of sampling. Greater accessibility of starch from flaked grain speeds its digestion during analysis. Compositional analyses for corn grain harvested and processed by various methods were compiled using the data base provided by DairyOne (2007). Starch and NFC content averages about 2% greater for flaked corn than for dry shelled corn. This higher starch and lower protein and NDF content of flaked grain probably reflect sampling errors associated with separation of fine particles, particularly from the germ, from large flakes.

23 and 24. Whole corn kernels found in manure contain as much starch as unfed kernels; they represent incomplete digestion. Whole kernels will not be detected if grain is more finely ground or more completely processed. But the mere absence of whole kernels does not necessarily mean that starch digestibility has been increased. Small kernel fragments are more difficult to spot than whole kernels. For accurately estimating starch digestibility, starch analysis is required. Starch digestibility can be roughly appraised by analyzing fecal samples for starch. If some other constituent of feed and feces that is indigestible (e.g., lignin; insoluble ash) or has a known digestibility (e.g., protein) is measured, starch digestibility can be calculated directly. To be certain that a fecal sample represents an average for the herd, samples from several animals should be obtained and mixed for analysis.

25. Soderlund (2007) has outlined hybrid by processing interactions. Hybrids or grain samples with floury endosperm are preferred for maximum digestibility when grain is dry rolled. But vitreousness of the grain does not limit digestibility of high moisture or flaked corn grain. In contrast, for preparing consistent flakes with few fine particles, more vitreous grain is preferred by feedlots. For high moisture corn, a slow rate of field drying is important so that the time window for harvest is extended. Regardless of the processing method, ideally grain should be rich in energy content (low in ash, NDF), discounted for moisture content, and free of damage from mold, mycotoxins, and insects.

26. Grain can be fermented to ethanol either in large vats or within the rumen. A range of 7% in ethanol yield among corn grain hybrids has been observed. Ethanol is derived primarily from starch, so an ideal grain hybrid for ethanol production should be particularly rich in starch. Hybrids with greater starch content have less protein and oil. Because protein and oil are digested and provide energy for cattle, higher starch content alone has limited impact on digestible energy content of the grain. However, this 7% range in ethanol yield among hybrids is double the range in starch content observed among hybrids (3.5% of starch in Figure 3). Thereby, the availability of starch rather than starch content of the grain alone must limit ethanol yield. If hybrids selected for high ethanol yield have greater accessibility of starch, their feeding value may be greater, particularly for grain that is dry rolled. Less advantage for high ethanol yield hybrids would be expected if grain were processed more extensively (high moisture or steam flaking) because these processes generally obliterate the differences in feeding value among samples or hybrids.

27 and 28. Most estimates of starch availability involve incubation of samples with enzymes or ruminal bacteria with or without sample drying with or without sample grinding; thereby measure immediate accessibility of starch for digestion (Sapienza, 2004; Blasel et al., 2006). Such tests should be useful to appraise rate of ruminal digestion and potential for acidosis. Direct application of results to total tract digestibility relies on the concept that ruminal and total tract digestion are closely

correlated. Based on published values where ruminal and total tract starch digestion has been measured with feedlot or lactating cattle, the relationship of ruminal and total tract starch disappearance is reasonably good for high moisture corn grain and steam flaked corn samples (R^2 = 0.92 and 0.72) but surprisingly low for dry rolled corn (R^2 = 0.01). If only 1% of the variation in total tract starch digestion can be attributed to differences in ruminal starch digestion by cattle, extrapolation from ruminal to total tract starch digestion seems questionable. Further research to develop or improve tests to assay both site and extent of digestion of grain components will increase our ability to differentiate feeds and develop improved products for livestock.

29. PAF values should be more adjustable based on specific factors that alter NFC or by laboratory measures of starch availability. Depressions in digestibility based on level of feed intake, though appropriate for forages, seem excessive for processed grains. Certain components of the TDN equation (e.g., true protein digestibility) need re-examination.

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Corn Ethanol Byproducts - Present and Future

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Introduction

Distillers grains have long been recognized as a valuable supplement due to its rumen undegraded protein and fat content. Dried distillers grains with solubles has been a very common ingredient in dairy cattle concentrate mixtures, but generally at modest levels. As ethanol production increases, the price of distillers grains makes it an attractive feed at much higher levels in the dairy diet, with 20% of diet dry matter fed successfully in more than one research trial. In practice, uncertainty about the exact nutrient composition of distillers grains and the inability (or unwillingness) to adapt the remainder of the diet to work with distillers grains, puts tighter constraints on its inclusion rate. In general the limitations of feeding distillers grains are the low lysine content of the undegradable protein (an inherent property of the Zein protein from the endosperm but made even worse if the feed is heated to harshly), its relatively rich content of free, largely unsaturated oil, and its Phosphorous content. All of these are definite pluses of distillers when present as a minor component to supplement the diet, but can represent challenges when trying to maximize its use to reduce feed cost.

Dry-Grind Ethanol

The booming business of converting corn to ethanol is based primarily on a relatively simple process that is often called dry milling but more correctly should be called dry grinding. Milling implies a separation of constituents of the grain and true dry milling of corn really does occur in processing corn for human foods with byproduct animal feeds like hominy feed and corn bran resulting from thi non-ethanol dry milling process.. Although modern dry grind ethanol plants, with their stainless steel and state of the art computerized control and inventory systems, are more efficient than their backwoods ancestors, the basic process is not changed. Dry shelled corn is ground, mixed with enzymes to break down the corn starch to sugar, and fermented (mashing process). The resulting 'beer' is distilled to yield ethanol. Most of the starch is thereby removed as ethanol and carbon dioxide leaving behind the remainder of the corn fiber. protein, ash and fat in the whole stillage. These nutrients are distributed in an easily removed 'cake' or coarse grain fraction and in a dilute solution of nutrients dissolved or dispersed in water ('thin stillage'). The ratio of dry matter is somewhere in the vicinity of 50:50 in these two fractions. The thin stillage is concentrated by evaporators to yield a condensed syrup or 'solubles'. When the cake and solubles are combined and dried, distillers dried grains with solubles (DDGS) are formed. Either stream could be sold separately as distillers dried grains and condensed distillers solubles, but it is most common for most of the two streams to be combined. By definition, distillers dried grains with solubles contains at least 3/4 of the whole stillage dry matter produced, and in practice excess solubles may also be produced. Distillers wet grains is defined more loosely but contains solubles even though it doesn't explicitly appear in the name and there is no official definition for wet distillers grains with solubles. A plant that routinely diverts soluble from the combined distillers grains and soluble stream will produced a distillers grains lower in fat and P, and higher in NDF. Modified wet distillers are distillers wet grains that have undergone partial oven drying.

Traditional wet milling

Wet milling of corn is the process whereby corn starch, corn sweeteners, corn germ, corn gluten meal, and corn gluten feed are produced. In wet milling the fibrous outer coat of the corn grain (the pericarp or bran, rich in fiber), the germ (rich in fat and protein), and the endosperm are separated. The endosperm is also physically separated into a protein fraction and a relatively pure starch fraction. It is this starch fraction that is used to generate starch, and corn syrup. The resulting relatively pure starch can also be fermented to produce ethanol. In this case, a very pure substrate is being fermented so little residue is left from the fermentation [process and the main byproducts are the gluten feed (bran plus concentrated steep water), gluten meal, and corn germ. The corn germ can be processed to form corn oil and corn germ meal. This is a flexible but energy intensive process and the plants that do this are much larger than the typical 40-80 million gallon/year dry mill ethanol plants currently proliferating.

Modified milling processes in ethanol production

Recently several 'add ons' to the basic dry grind distilling process have been introduced. Many of these processes mimic the steps in wet milling because, prior to mashing and fermentation, dry shelled corn is physically separated into a high fiber barn, germ, and endosperm. These processes are designed to generate a starch enriched substrate for the fermentation tanks to increase the ethanol titer and yield of ethanol per tank. The endosperm stream is not as pure as the starch slurry generated by traditional wet milling as it still contains the endosperm protein which would have been separated as gluten meal in the traditional wet milling process. The endosperm (both protein and starch) is then fermented. The process will yield less ethanol per bushel of corn than wet milling or dry grind because some starch still remains in the bran and germ. One other complication is that these processes may be wet (the Solaris process being used at Badger) or various forms of dry processing as used in the Broin BFrac system or the process to be used in the new Jefferson WI milling plant.

Many products can arise from these new processes. From the pre-fermentation physical milling processes we can obtain a high fiber feed from the bran, a whole germ, or a defatted germ meal if the oil is extracted. The whole stillage resulting from fermentation of the 'purified' endosperm will also contain a solid residue and condensed solubles or syrup. These fermentation residues will be lower in fiber and fat, as well as lower in P, than the typical cake and solubles obtained by fermenting the entire grain, and will also be higher in protein. In addition the protein in these fermentation residues comes from the endosperm only and is therefore likely to be more rumen undegradable and lower in lysine than DDGS, while the germ or germ meal will be just the opposite (higher rumen degradability and higher lysine). It is too bad that the high RUP feed doesn't have more lysine, but unfortunately that is the result of the basic nature of corn zein protein and not a result of the ethanol process itself. Given the multitude of streams coming off with these new pre-fermentation milling techniques, it is easy to see that they can be combined in any number of combinations and different proportions. If they are all combined together, the resulting feed should be similar to DDGS, perhaps with a bit more residual starch. Officially, parts of the corn that have not gone through the fermentation process cannot be called distillers grains, so the naming and marketing of the various hybrid products will no doubt become confusing. What is important for feeding dairy cows is to have an accurate estimate of the crude protein, fat (actual, not minimum), neutral detergent fiber and phosphorous content of the feed. Even then, protein degradability, true fatty aid content, NDF digestibility and lysine content are likely to remain unknown.

Fat removal from dry grind solubles

An alternative process that will result in a reduced fat DDGS is an add-on to the back end of the dry milling process. Glacial Lakes Energy in Watertown SD is removing a portion of the fat from the dissolved solids obtained after fermentation of the whole grain. If this could be done effectively it would seem to be an ideal way to lower the fat content of the resulting distillers grains and also provide a fat stream for biodiesel or oil production. From informal reports, it does not seem that fat yields are very high at this point, but even a slight reduction in fat content of distillers should improve its potential inclusion rate in many dairy diets. Although phosphorous content would still remain a problem, it is one of nutrient management not of animal performance. If dairy manure can be used on acres growing corn for nearby ethanol plants, a sustainable loop could be formed to utilize this phosphorous in an environmentally responsible way.

Other Developments

Plants are looking for innovative ways to provide heat for their operation. One plant (Corn Plus, Winnebago Minn.) is using a fluidized bed to burn its solubles as a source of heat for the plant to replace natural gas. This is an obvious plus from the energy efficiency and CO_2 exhaust perspective and it should result in a DDG which is low in P and fat and higher in fiber than DDGS. The P will find its way into ash produced by the plant and maybe sold as fertilizer.

Chemical content and opportunities

Variation in the chemical content of 'standard' DDGS and Wet DG is a significant issue in its practical use. Variation in techniques used to measure the composition is also a problem and leads to overestimation of the true variability in DG. This is especially true for the ether extract or crude fat content of the feed. Recently the ethanol industry has proclaimed standard assay methods, but the widespread adoption of these is unknown and lab variation will still exist. Use of a consistent and accurate assay of various byproduct streams will become even more important as new and different processes are adopted. The new products represent new opportunities for using distillers grains. Low fat, low protein and low P corn bran fractions could be included in dairy rations in large amounts. Proteins from the endosperm residue and germ meal could be blended to better match the RDP and lysine requirement of the cow and content of other feeds used. Corn oil, if priced right, could be adjusted independently to provide an optimum return. Plants have an opportunity to montor and blend products to provide a more consistent and targeted feed. However, if using up all of the end products is still the primary goal of the ethanol plants, there will be less flexibility to provide a consistent and desirable product tailored to dairy cattle.

	Grain %	Germ %	Bran %	Endosperm %
Kernel DM	**100**	**11.1**	**8.1**	**82.9**
Starch	73.4	8.3	7.0	87.6
Protein	9.1	18.4	4.5	8.0
Oil	4.4	33.2	1.1	0.8
Ash	1.4	10.5	0.9	0.3
Sugars	1.9	10.8	0.5	0.6
NDF	9.5	11.0	90	?
Residual (?)	.3	7.8	0	2.7
Phosphorus	0.29	1.33	0.42	0.14
Lysine (% CP)	2.84	4.8		1.6

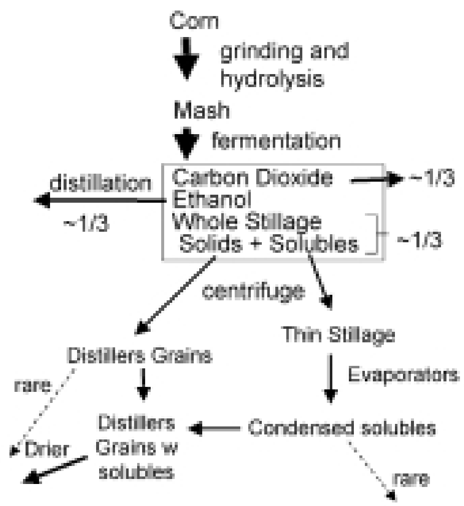
Table 1: Composition of whole corn kernel and carefully dissected parts. Actual milling fractions will not be as pure as these fractions. The first row shows the composition of the Kernel, other rows show the chemical composition of the kernel and its sub parts. Adapted from Corn Chemistry and Technology, P.J. White and L.A. Johnson, second edition, 2003

	Grain – Starch	Germ – Oil	Endosperm – Starch
	DGS?	Germ meal	Gluten meal?
Starch %	0	14.6	0
Protein %	34.2	32.4	64.5
Oil %	16.5	0	6.5
Ash %	5.3	18.5	2.4
Sugars %	7.1	19.0	4.8
NDF %	34.4	16.5	
Phosphorus %	1.1	1.99	1.1
Lysine (% CP)	2.84	4.8	1.6

Table 2: This shows the theoretical results of removing starch from the grain or from the pure endosperm, and also removing oil from the pure germ. In actual milled products the starch removal by milling is not likely to be complete but removal by fermentation will be very high.

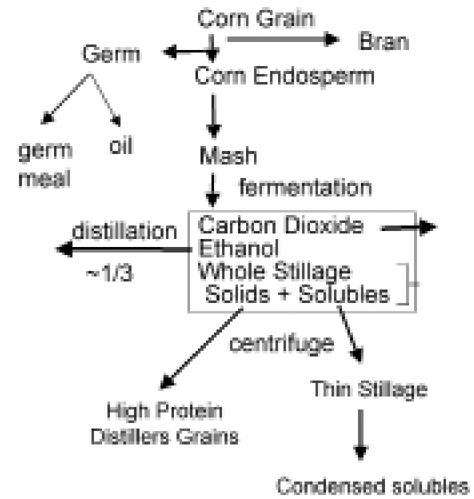
Classic Dry Milling for Ethanol production

- Common in older beverage and most recent fuel plants
- No physical separation of corn grain parts (germ, bran, endosperm) prior to fermentation
  - grinding without separation



New processes

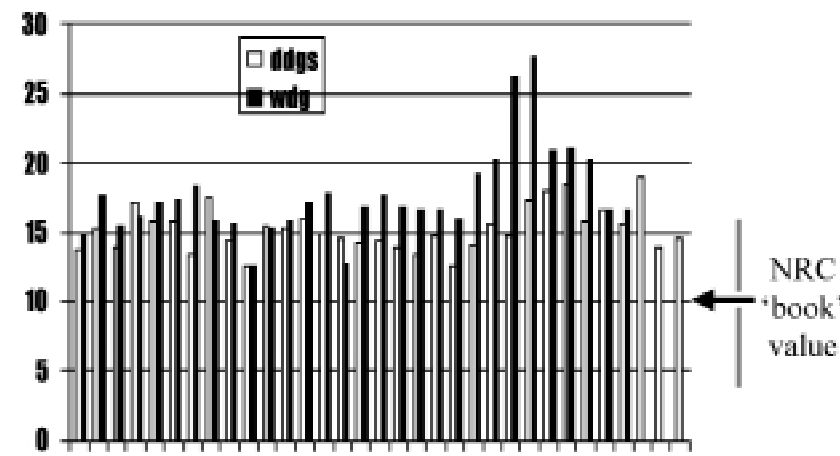
- add separation prior to fermentation
  - bran (hi NDF)
  - germ (CP and Oil)
  - endosperm
- Entire endosperm (and only endosperm) is fermented
  - low fiber/low fat/low P/higher CP DG results
- Bran, germ meal, oil, high protein DG, and solubles may be recombined in numerous ways!!
- solubles lower in fat and P



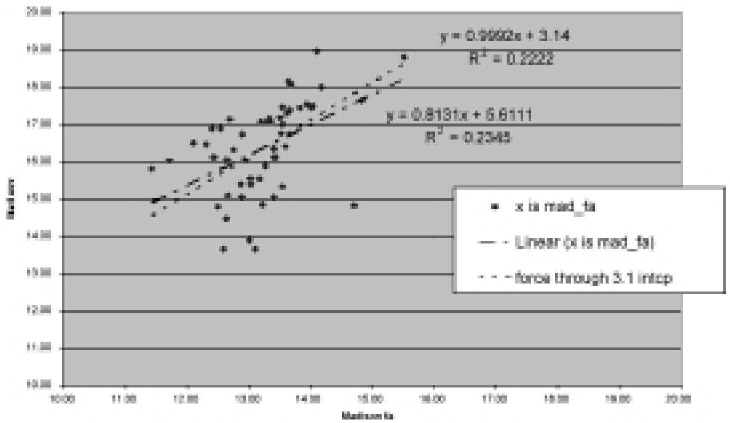
Classic Wet Milling

- separation (independent of fermentation) of
  - bran → **gluten feed**
  - germ
  - endosperm starch
  - endosperm protein (zein) → **gluten meal**
- Germ can be 'crushed'
  - oil
  - **germ meal (some → gluten feed)**
- Starch can be:
  - sold as starch
  - converted enzymaticaly to sugars (corn syrup)
  - sugars can be fermented and distilled to Ethanol
    - this is NOT the recent or projected growth in Ethanol
    - solubles (which differ from dry mill solubles) often added back to gluten feed

Oil content in Distillers Grains – High and Variable



Ether Extract vs. Fatty Acids



Distillers Grains w solubles -variation

	Mean	St dev	66% range	Number samples
Phosphorous	.83	.14	.69 - .97	649
Crude Protein	29.7	3.3	26.4 - 33.0	879
NDF	38.8	7.8	31.0 - 46.6	493
NDF CP	8.6	3.4	5.2 - 12.0	37

This includes variation among processing plants

Wet grains will also have DM variability

Thiex SDSU Fat Analysis Data

- Di-ethyl ether extract AOAC 990.03
  - 9.22 mean, .28 sdev (intralab SDSU)
  - 10.22, .84 sdev (n=7 labs)
- Pet Ether AOAC 945.16
  - 8.85 mean, .24 sdev
  - 9.13 mean, .27 (n=8 labs)
- Hexane AOAC 2003.06
  - 9.00, .19 sdev
  - 8.85 mean, .48 sdev, (n=5 labs)
- Acid Hydrolysis AOAC 954.02
  - 13.03 mean, .57 sdev
  - 11.84 mean, .96 sdev (n=9 labs)

NFC composition of DGS

	Dry DG	Wet DG
	% of DM	
NDF	27.0	21.4
NDFCP	2.8	1.8
CP	30.2	28.6
NDF+CP	54.4	48.2
EE	12.9	12.2
Ash	4.7	5.6
Cum Sum	72.0	66.0
NFC	28.0	34.0
Starch	4.7	5.0
NDSF	13.1	11.0
TESC	13.1	14.8
Cum Sum	102.8	96.8
Org Acids	-2.8	3.2

Nebraska Protein analysis

Kelzer, Kononoff et al. 2007

	Germ	Bran	HPDDGS	DDGS1	DDGS2	WDG	WCGF
CP % of DM	16.3	13.5	47.2	30.1	28.9	29.9	26.7
RUP % of CP	16.5	20.7	55.2	33.2	56.3	44.7	11.5
RUP dig	66.9	65.8	97.7	92	91.9	93.1	51
%Lys in RUP	2.9	3.2	2	1.9	1.9	1.9	3.5
%Met in RUP	1.9	1.4	3.2	2	2.4	2.3	1.6
Lys/Met	1.5	2.3	0.6	1.0	0.8	0.8	2.2
Dig RUP (% of DM)	10.9	8.9	46.1	27.7	26.6	27.8	13.6
Dig RUP Lys (% of DM)	0.32	0.28	0.92	0.53	0.50	0.53	0.48

Broin products

- Dakota Bran:
  - 17.5%CP, 21.7%NDF, 20.2% Fat(??), .65%P
- Germ
  - 16.9%CP, 23.9%NDF, 18.9% Fat, 1.37%P
- Dakota Gold HP
  - 44.8%CP, 22.1%NDF, 3.9%Fat, .38%P

Solaris-QTI initial estimates (90% DM basis)

	nutra fiber	probran	glutenol	energia	common DDGS
CP	6.8	9.5	45.0	30.0	26.4
Fat	1.5	2.0	3.3	2.5	8.8
Fiber (Crude)	17.1	16.6 72ndf	3.8 15ndf	8.2	8.3
P				lower	higher

Cereal Process Technologies

- Bran
  - 9%CP, 40%NDF, 4% Fat, .3%P
  - 30% Starch!
- Germ
  - 16%CP, 23% NDF, 21% Fat,1.4%P
  - 20% Starch!
- No 'DG' products yet

What is the National Feed Management Project All About?

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Introduction

In this paper we will focus on dairy feed management and: 1) overview the importance of feed management and it's relationship with whole farm nutrient management, 2) share a few examples of how feed management can reduce the import of nitrogen and phosphorus to the farm, and 3) describe an opportunity that is developing for consulting nutritionists to play a major role in the development of Feed Management Plans for livestock producers.

Whole Farm Import of Nutrients

Figure 1 depicts the concept of whole farm nutrient management. Ideally the goal is for the input to equal the output from the farm. This is rarely the case because only ~ 13 to 27 % of feed input of N, P, and K are exported in milk and animals (Figure 2). The remainder of the N, P, and K are excreted. The import/export imbalance is further impacted by the increase in cows density at the farmstead. From 1954 to 1987 there was a continual increase in cow density on dairy farms across the US (Lanyon, 1992). Coincident with this increase in cows per acre was an increased importation of feedstuffs to the farm to achieve higher levels of milk production. Data shown in Table 1 indicate that the amount of concentrate (assumed to be imported) fed to dairy farms increased ~ 10 to 50 fold between 1954 and 1987.

Feeding for Reduced Crude Protein

The transition from feeding the dairy cow for her crude protein requirement has clearly progressed today to a more sophisticated approach of formulating for the estimated requirement of amino acids (NRC Recommendation for Dairy Cattle – 2001 - http://bob.nap.edu/books/0309069971/html/). While this transition has been occurring there has been a simultaneous progression of a greater awareness of the interrelationship of diet formulation and feed management on whole farm nutrient management. The focus of this example will be to develop the concept of ration balancing for increased profit <u>and</u> reduced environmental impact as it relates to nitrogen. In particular, the merits of formulating for estimated amino acid requirements with the use of ruminally undegraded protein sources (RUP) sources.

Amino Acid Formulation

Amino acid formulation for dairy cattle has been common practice since the availability of the CNCPS (Fox et al., 1990) model and CPM model. We have used both models successfully to strategically formulate diets to evaluate the merits of sources of RUP, ruminally protected amino acids, and free lysine-HCL (Xu, et al.,1998; Harrison, et al., 2000). Others (VonKeyeserligk et al., 1999; Dinn et al., 1998) have had positive experiences with use of the model to formulate diets to reduce the CP level in the diet while maintaining milk productivity.

More recent studies (Harrison et al., 2002, and Harrison et al., 2003) continue to provide evidence that formulating diets for available amino acids can provide the opportunity to reduce CP levels in the diet and reduce on-farm import of nitrogen. A field study (Harrison et al., 2002) was conducted with a high producing herd in WA state to compare their general herd diet formulated at ~ 18 % CP to a diet that was reformulated at ~ 17 % CP (Tables 2 and 3). Results showed that milk production could be maintained while decreasing nitrogen import to the farm (Tables 4 and 5). In addition, the diet reformulation resulted in an increase in IOFC (Table 6).

The Phosphorus Feeding Myth?

A major reason for overfeeding P to dairy cows is concerns related to reproductive efficiency (Hristov, 2004). Past research has related P deficiency to health and reproductive problems (failure to conceive, reduced calving rates). Extensive reviews on the topic were published (Satter and Wu, 1999; Wu and Satter, 2000; Ferguson and Sklan, 2004; and Lopez et al., 2004). In retrospect, it appears that low P intake was linked to impaired reproductive performance in cattle through a series of confounded and misinterpreted experimental data reported in the late 1920s through the 1950s.

Recent P Research

A summary of 13 trials with lactating dairy cows (392-393 cows) and heifers (116-123 heifers) showed no effect of dietary P on reproductive performance (Satter and Wu, 1999). Levels of P in the cow diets varied from 0.32 to 0.40 (low-P groups) and from 0.39 to 0.61% of DM (high-P groups). Heifers were fed 0.14-0.22 and 0.32-0.36% dietary P, respectively. Days to first estrus, days open, services per conception, days to first artificial insemination, and pregnancy rates were not different between the low- and high-P cows. Similarly, services per conception and pregnancy rates were not affected by dietary P level in the heifer groups (Table 7).

More recently, Lopez et al. (2004) conducted an experiment with lactating dairy cows assigned to recommended (0.37%) or excess (0.57% of DM) dietary P. Cows were fed the respective diets after calving and reproductive parameters were monitored. The percentage of the anovular cows (29.9 vs 27.1%, recommended and excess P, respectively), days to first progesterone increase (53 vs 53 d, all cows), days to first recorded estrus (68 vs 67 d, all cows), days to first service (89 vs 90 d, all cows), the duration of estrus (8.7 vs 8.7 h), total mounts (7.4 vs 7.8), total mounting time (25.8 vs 24.5 s), conception rates, pregnancies lost, days open for pregnant cows (112 vs 116 d), services per conception, and the estrous cycle length (23 vs 23 d) were not different between the recommended and excess P groups. The authors concluded that feeding P in excess of NRC (2001) requirements (0.37% of DM for the cows involved in this trial) did not improve reproductive performance.

Phosphorus and Whole Farm Balance

A quick way to get an estimate of farm balance for P in a dairy operation is to compare milk export of P to farm import of P in feeds. If feed import of P = milk export of P, the farm theoretically is in balance. Milk export can be calculated by multiplying the % P in milk (0.09%). An example would be 500 cows x 85 pounds of milk/day x 0.09% P in milk = 38.25 pounds/day. For the farm to be in balance, the import of P would need to approximate 38 pounds per day.

A number of factors are associated with import of P in feeds. Since P can vary amongst feedstuffs and vary from load to load, often times the target P level is raised so as not to limit P in the formulated diet. The P availability in feedstuffs also varies with forages having a lower availability compared to grains. If the facilities and management are capable of grouping cows by age and stage of lactation, there is more of an opportunity to reduce import of P in feeds. In addition, home-grown forages have different abilities to remove P from the soil. Grass will remove almost twice as much P when compared to corn silage. Some producers choose to have their heifers raised off-farm and this can help with farm balance.

Feed Management Plan Development – An Opportunity for Nutrition Consultants

The US Environmental Protection Agency (EPA) released new guidelines for Concentrated Animal Feeding Operations and Animal Feeding Operations (CAFO/AFO) in 2003. Under the new guidelines, CAFO/AFO's will be required to develop a Nutrient Management Plan (NMP). One form of a NMP is a Comprehensive Nutrient Management Plan (CNMP) as defined by the Natural Resources Conservation Service (NRCS). There are six core elements of a CNMP: 1) Feed Management, 2) Manure and Wastewater Handling and Storage, 3) Nutrient Management, 4) Land Treatment, 5) Record Keeping, and 6) Other Manure and Wastewater Utilization Options.

Feed represents the largest import of nutrients to the farm, followed by commercial fertilizer (Klopfenstein at al.,2002). Feed Management opportunities currently exist to reduce imports of nutrients, particularly nitrogen and phosphorus, to most animal livestock and poultry operations.

In 2005, a group of Universities (Washington State University, University of Idaho, Oregon State University, Texas A&M, University of California – Davis, University of Nebraska, Purdue University, Iowa State University, Cornell University, Virginia Tech, and the University of Georgia) were funded by the NRCS for an implementation project entitled "Development and Integration of a National Feed Management Education Program and Assessment Tool into a CNMP".

The goal of the project is to increase the understanding of agricultural professionals about the area of Feed Management, with an emphasis on Environmental and Financial Sustainability of Livestock and Poultry Operations. The primary audience for the education program will be: 1) Animal Nutritionists, and 2) NRCS staff and Technical Service Providers and advisors. The NRCS and ARPAS have established a memorandum of understanding which identifies ARPAS members as the appropriate professional to develop a feed management plan.

The national version of the NRCS 592 Feed Management Practice Code can be found at http://www.nrcs.usda.gov/technical/efotg/. The primary purposes of the 592 Standard are: 1) supply the quantity of available nutrients required by livestock and poultry for maintenance, production, performance, and reproduction; while reducing the quantity of nutrients, especially nitrogen and phosphorus, excreted in manure by minimizing the over-feeding of these and other nutrients, and 2) improve net farm income by feeding nutrients more efficiently.

The Feed Management project team is in the process of developing species-specific tools and education materials to provide training across the US for both consulting nutritionists as well technical service providers and NRCS staff (see Figures 3 and 4). A key outcome that will be used by nutritionists will be species-specific on-farm implementation checklists which can be used to gather the information needed to develop a Feed Management Plan. We are working closely with NRCS to develop payment rates for implementation of the 592 Feed Management Standard so that there is both an incentive for the consultant as well as the livestock and poultry producer.

Summary

Development of Feed Management Plans is a new opportunity for consulting nutritionists. We encourage you to embrace this opportunity and assist livestock and poultry producers to remain economically viable and environmentally responsible.

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Table 1. Changes in dairy farm numbers, cow numbers, and the concentrate consumed for three US dairy states from 1954 to 1987. Source: Lanyon (1992).

	California	
	1954	1987
No. dairy farms	34,031	3,631
Milk cows	790,730	1,070,366
Concentrate use		
lb/yr per cow	1,899	7,542
lb/100 lb milk	23.98	42.02
lb/yr per farm	43,747	2,223,069
	Florida	
	1954	1987
No. dairy farms	16,738	1,073
Milk cows	158,877	176,993
Concentrate use		
lb/yr cow	3,216	9,469
lb/100 lb milk	62.92	75.9
lb/yr per farm	30,523	1,562,323
	Pennsylvania	
	1954	1987
No. dairy farms	82,708	15,096
Milk cows	875,631	673,054
Concentrate use		
lb/yr per cow	2,248	5,643
lb/100 lb milk	35.9	40.0
lb/yr per farm	23,793	251,123

Table 2. Chemical composition for control and treated diets (Harrison et al., 2002)

Item	Control	Treated
CP, % DM	17.8	16.95
Available CP, % DM	16.4	15.35
Unavailable CP, % DM	1.4	1.55
Neutral Detergent CP, % DM	2.3	2.65
Adjusted CP, % DM	17.8	16.95
Soluble Protein, % DM	6.4	6
Soluble Protein, % CP	35.7	36.95
ADF, % DM	22.55	22.65
NDF, % DM	32.45	32.7
NFC, % DM	39.05	39.8

Table 3. Composition of diets (Harrison et al., 2002).

Item	Control - % DM	Treated - % DM
Alfalfa Hay	29.32	26.23
Corn Silage	19.55	19.99
Corn grain, flaked	16.15	18.01
Whole cottonseed	8.26	8.49
Corn Distiller Grains	4.35	–
Beet pulp pellets	2.10	6.22
Molasses	1.74	1.94
Ener GII	1.48	.63
Soybean Meal	–	3.45
Bakery Mix*	14.28	–
Bakery Waste	–	7.97
Soy Pass	–	3.95
Std Mineral/Vit	2.77	–
Std Minerals +		
Novus Premix**	–	3.12

*Bakery mix = Canola – 28.8% (as fed), soybean meal – 32.9% (as fed), and bakery waste – 32.8% (as fed).
**contained Alimet and lysine HCL at a5.7% and 24%, respectively.

Table 4. Treatment response to diet reformulation (Harrison et al., 2002).

Item	Control	Treated	SE	P<
DMI,lb	56.7	55.2	–	–
CP Intake, lb	10.1	9.35	–	–
Milk, lb	99.9	101.9	0.53	.007
3.5% FCM, lb	96.0	96.6	0.46	.32
Fat, %	3.28	3.21	0.014	.001
Milk Fat, lb	3.26	3.23	0.018	.63
Protein, %	2.90	2.93	0.006	.0009
Milk Protein, lb	2.88	2.95	0.015	.0004
MUN, mg/dl	17.5	14.5	–	–
Ratio Milk True Protein: Intake				
Protein Ratio	.285	.316	–	–
BW, lb	1396	1395	1.80	.88
Change in BW, lb	34	36	4.3	.70

Table 5. Environmental Characterization (Harrison et al., 2002).

Item	Control	Treated	% Change
Nitrogen Intake, gms/d	734	680	-7.4
Milk total N, gms/d*	240	246	+2.5
Predicted Urinary N, gms/d**	289	239	-17.3
Calculated Fecal N, gms/d***	205	195	-5.0

*(Milk True protein - gms/6.38**)** X 1.17
**Estimated per J Dairy Sci.85:227-233. Urinary nitrogen (gm/d) = 0.026 X BW (kg) X MUN (mg/dl)
***Intake N- Milk N- Urine N

Table 6. Economic Evaluation. (Harrison et al., 2002).

Item	Control	Treated
Feed Costs, $/day/cow	4.82	4.88
Milk Income, $/day/cow	11.92	12.10
IOFC*, $/day/cow	7.10	7.22

*IOFC = Income over feed cost.

Table 7. Reproductive performance of heifers and lactating dairy cows fed varying levels of dietary P (from Satter and Wu, 1999)

Animal Type	Dietary P (% of DM)	Number of animals	Days to 1st estrus	Days open	Services conception	Days to 1st AI	Pregnancy rate
Cows	0.32-0.40	393	46.8	103.5	2.2	71.7	0.92
	0.39-0.61	392	51.6	102.1	2.0	74.3	0.85
Heifers	0.14-0.22	116			1.5		0.98
	0.32-0.36	123			1.8		0.94

*Means not different at $P < 0.05$. Measurements based on most, but not all, of the animals.

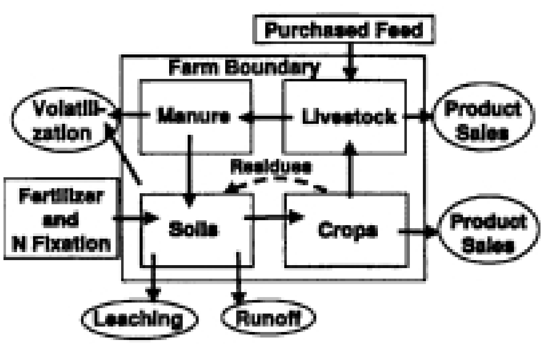

Figure 1. Schematic depicting the concept of whole farm nutrient management. Ideally, inputs = outputs.

Source: Nelson (1999)

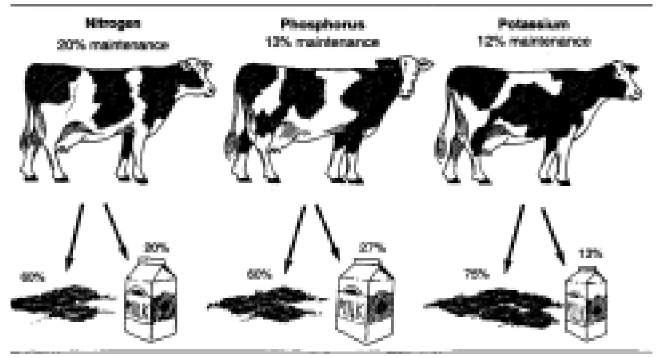

Figure 2 - Fate of nutrients in feed.

Source: Hart et al. (1996).

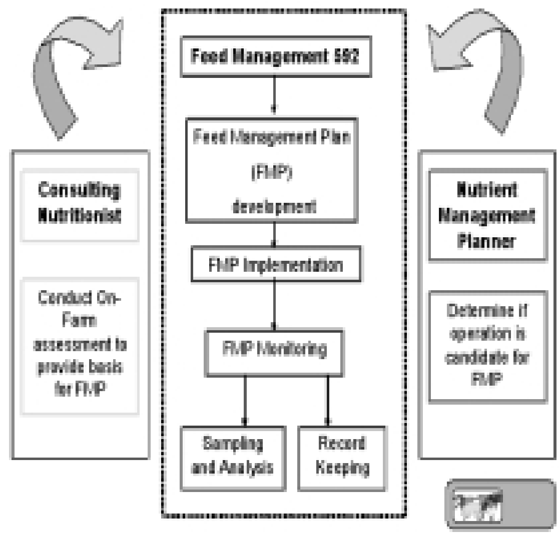

Figure 3 – Roles of nutrient management planner and consulting nutritionist in implementing Feed Management practice standard 592.

Activity	Who is Involved with Activity
Step 1) Determine the Purpose Specific to the Farm	Step 1) Nutrient Management Planner and Producer
Step 2) Identify where Practice Applies and Assess the Opportunity for Adoption of 592 Standard	Step 2) Nutrient Management Planner and Producer
Step 3) Evaluate the Economics of Making a Ration Change vs Transporting Manure	Step 3) Nutrient Management Planner, Producer, and Nutritionist

*USDA-NRCS – United States Department of Agriculture – Natural Resources

Step 4) Feed Management Plan Development	Step 4) Producer, and Nutritionist
Step 5) Feed Management Plan Implementation and Monitoring	Step 5) Producer, and Nutritionist

Figure 4 – Feed Management Development and Implementation Flow Chart for Adoption of USDA-NRCS* Feed Management 592 Practice Standard.

Practically Dropping Protein of Diets to Reduce Nitrogen Excretion

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Key Points

1. Nutrient management is increasingly on the "radar screen" of dairies in the US.
2. Reducing nitrogen excretion is critical in the southeast US, particularly Florida.
3. Nitrogen excretion is a function of protein feeding.
4. Reducing dietary protein decreases nitrogen excretion, and it may reduce milk yield.
5. Curbing milk yield does NOT have to be the result of lower-protein diets.
6. Reducing dietary protein, while concomitantly balancing for amino acids, can result in an equivalent or greater milk yield.
7. Formulating diets for specific target levels is a fundamental and practical approach for achieving efficient and economical milk production.

Introduction

The majority of this consultant's work is in the Southeast US, primarily Georgia and Florida. I work with approximately 25,000 cows with herd sizes ranging from 500 – 5000. It is a challenging environment due prolonged periods of hot, humid weather. And if you have ever been to Disney World in July or August, you know it is the toughest place in the country to feed dairy cows. As shown in Table 1 and Figure 1, there are, typically, 5 – 6 months of heat stress annually.

Evironmental regulations in the Southeast are stringent, particularly in the Florida. In the Ocheechobee section of south Florida, reducing phosphorus is a major environmental concern. On the other hand, containing nitrogen excretion in the environment is problematic for dairies in the northern section of the "Sunshine State." These dairies have test wells that are monitored for N and if they do not remain below acceptable levels, they have to reduce cow numbers and are subject to fines. This paper focuses on feeding and management practices for controlling nitrogen levels in dairies in north Florida.

Table 1. Monthly climatic records for Orlando, FL (30-year average).1

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Av max. temp (F)	75.9	74.1	79.4	83.2	88.3	91.2	92.2	91.2	89.8	85.8	77.0	76.2	83.9
Av min. temp (F)	54.8	51.6	56.5	60.8	**67.8**	**73.0**	**74.5**	**74.0**	**73.2**	**68.7**	58.1	56.3	64.3
Av precip (in.)	2.31	2.98	2.84	2.61	4.21	5.85	6.74	8.85	5.47	2.82	1.81	2.07	48.56

[1]Source: Southeast Regional Climate Center

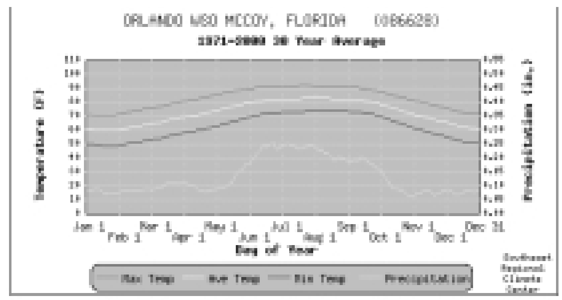

Figure 1. Monthly climatic records for Orlando, FL (30-year average).[1]
[1]Source: Southeast Regional Climate Center

Nitrogen Efficiency

Nitrogen excretion is simply a function of dietary crude protein. Consequently, reducing crude protein decreases nitrogen excretion and improves nitrogen efficiency. This biological phenomenon is classically demonstrated by recent work of Maryland researchers (Table 2).

Consultants and dairymen alike often lament, "I know I should reduce the crude protein in my diets, but I am afraid I will lose milk." This may result, but it does not have to be the case. Balancing amino acids is paramount for maintaining or increasing milk yield when lessening dietary protein (Broderick, 2003 and 2005; Ishler et al., 2005; Reynal and Broderick, 2005).

Table 2. The effects of lowering dietary crude protein on milk yield, milk components, and nitrogen efficiency (Kalscheur et al., 2006).

	------------ Diet (% RDP) ----------			
Parameter	6.80	8.20	9.60	11.00
CP, % DM	12.30	13.90	15.50	17.10
MUN, mg/dL	9.50a	11.60b	14.10c	16.40d
4% FCM, lb/day	66.80c	67.90bc	70.99ab	72.97c
Milk CP, %	2.95c	3.06b	3.09ab	3.11a
Milk CP yield, lb/day	2.07c	2.16b	2.25ab	2.31a
N efficiency, %	36.50a	32.80b	30.40c	28.20d

Balancing for Amino Acids

The Southeast US is a 100% fluid market; consequently, we do not get paid for milk protein. This generally prompts the question, "Why do you concern yourself with balancing for amino acids?" The answer is twofold. One, we feed diets of lower protein content to conform to environmental regulations, and by balancing for amino acids we are able to feed diets lower in crude protein that will support economical and efficient milk production (Broderick, 2003 and 2005; Ishler et al., 2005; Reynal and Broderick, 2005).

Second, another reason for balancing for amino acids is that the scientific literature clearly shows increased milk yield when balancing for amino acids. Garthwaite et al. (1998) summarized a group of studies where either MET, MET + LYS, or LYS were used to supplement lactating dairy cows. They also separated the studies where RPAA were imposed both prepartum and continued postpartum or only postpartum (Table 3). Two points are obvious: 1) milk yield and protein % are generally both improved in early lactation when rations are balanced for LYS and MET at freshening or shortly thereafter, and 2) the improvements in milk yield can be enhanced if rations are also properly balanced for LYS and MET in the pre-fresh ration as well as in early lactation.

Table 3. Summary of milk response to rumen protected amino acids were supplemented both prepartum and continued postpartum or only postpartum (Garthwaite et al., 1998).

		Postpartum Only		**Pre + PostPartum **	
	Units	Control	Response[3]	Control	Response[3]
LYS/MET	**%EEA[1]**	**14.2/4.7**	**14.9/5.3**	**14.5/4.5**	**15.4/5.2**
Diet CP	%DM	16.6	16.6	17.6	17.6
MP/ME[2]	**-**	**11/102**	**-**	**103/100**	**-**
DMI	lb/d	45.6	+1.1	45.9	+1.1
Milk	**lb/d**	**76.9**	**+1.1**	**81.1**	**+3.7**
Prot	%	3.02	+0.15	3.07	+0.06
Prot	**lb/d**	**2.29**	**+0.15**	**2.57**	**+0.17**
Fat	%	4.04	+0.06	3.87	+0.10
Fat	**lb/d**	**3.03**	**+0.10**	**3.25**	**+0.19**

[1]EAA = essential amino acids
[2]MP/ME = ratio of metabolizable protein to metabolizable energy
[3]Response is the change of treated (supplemented) opposed to control

Target Formulation Levels

I formulate for specific nutrients . . . nutrients that can be measured in a laboratory. Table 4 summarizes these nutrients and recommended levels; Following is a brief explanation of this individual's rationale:

1. Fiber Carbohydrates. The most important nutrient to formulate for in dairy rations is the fiber. It is necessary for the health of the rumen, the health of the animal, and the efficiency of fermentation. I formulate for 32 – 34% NDF. This is higher than many recommendations and slightly higher than the NRC (2001). Furthermore, I want to be sure that it is effective NDF. In this regard, I adhere to the guidelines outlined in the NRC (2001), chapter 4.
2. Nonfiber Carbohydrates. After meeting the fiber requirement, the objective is to liberally feed glucose precursors, primarily starches and sugars, to drive milk production. This produces the following cascade of events: starches & sugars >>> propionate (rumen) >>> glucose (liver) >>> lactose (mammary gland). Milk production varies directly with the production of lactose, because it is the osmotic regulator of milk yield. Optimizing the levels of starch and sugars is necessary for the best possible milk performance (Broderick and Radloff, 2004; Hoover and Stokes, 1991; Vallimont et al., 2004.)
3. Protein. I don't formulate for crude protein in lactating diets. On the other hand, I balance for three protein fractions. First, I balance for RDP, which is based on work by West Virginia researchers (Hoover and Stokes, 1991). It is as follows: RDP = NFC (lb) / 3.30. I target for a balance of -0.30 to -0.50 lb/d. The reason for a negative balance is that it permits feeding diets lower in crude protein. Second, I formulate for the amino acid LYS. The target level is a balance of +4.0 to +8.0 g/d. Lastly, I formulate for the amino acid (MET). The target level is a balance of -2.0 to -4.0 g/d. The typical strategy is to formulate diets with feeds that are relatively rich in rumen undegraded LYS, and if necessary or beneficial, supplement with rumen protected MET.
4. Fat. Since fats are not sources of fermentable energy for rumen bugs, I try to feed minimal levels of fat. There is, however, a level of fat needed to support reproductive efficiency. My experience is that 3.0 – 5.0% is adequate, and this seems to be in agreement with the literature. Where possible, I tend to feed fat levels in the lower part of this range (3.0 – 4.0%). The literature does tend to show two

disadvantages of liberally fat feeding (>5.0%). One, DMI is generally depressed, especially with Ca salts of FA. This seems to be the result of unsaturated fat increasing satiety and reducing gut motility. Two, protein test is generally depressed 1 – 2 points.

5. Ash. I try to restrict the level of ash below 7% in rations. The reason is that I want to "create ration space" in order to feed extra fermentable carbohydrates.

Table 4. Ration target formulation levels of selected nutrients for lactating (phase one) Holstein dairy cows.

Holstein dairy cows

Priority	Group	Nutrient	Units	Milk level 70-100 lbs.
#1	Fiber carbs	**NDF**	**% DM**	**32.0-34.0**
			% BS	1.1-1.3
			% forage	70-85
		fNDF	% DM	24.0-28.0
		eNDF	% DM	24.0-28.0
		Lignin	% DM	3.0-4.0
#2	Nonfiber carbs	NFC[1]	% DM	36.0-40.0
		Starch	**% DM**	**24.0-26.0**
		fermStarch[2]	% DM	16.0-19.0
		Sugar	**% DM**	**4.00-6.0**
		Soluble NDF	**% DM**	**8.5-11.5**
		Glu precursors[3]	% DM	20.0-22.0
#3	Protein	**RDP balance[4]**	**lb**	**-0.30 to -0.50**
		MET balance[5]	**g**	**-2.0 to -4.0**
		LYS balance[6]	**g**	**+4.0 to +8.0**
#4	Fat	**Total fat**	**% DM**	**3.0-5.0**
#5	Minerals	**Ash**	**% DM**	**7.0-8.0**

[1]NFC = 100 – (NDF + CP + Ash + Fat)
[2]Fermentable starch is a measure of the amount of starch that is available for fermentation
[3]Glucose precursors is an estimate of the total of the sugars plus the amount of starch that is fermented in the rumen
[4]RDP requirement calculated as follows: NFC/3.3
[5]MET requirement is factorial: METmain + METmilk + METgain
[6]LYS requirement is factorial: LYSmain + LYSmilk + LYSgain.

Summary

Nitrogen excretion is a function of protein feeding. Reducing dietary protein decreases nitrogen excretion, and it may—but does not have to—reduce milk yield. Reducing dietary protein, while concomitantly balancing for amino acids, can result in an equivalent or greater milk yield. Formulating diets for specific target levels is a fundamental and practical approach for achieving efficient and economical milk production.

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Making Starch Work in the Rumen

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As corn grain prices remain high (compared to the typical $2 a bushel), dairy managers and nutritionists raise questions and concerns on optimizing starch levels in the rumen. Corn can be used in the following roles in the U.S.

- Food for human consumption or human products
- Fuel as a source of stable and renewable ethanol
- Feed for livestock use

Ruminant animals have the ability to convert forages and fibrous by-products such as distillers grain (DG) to energy and protein resources. In 2006, 20 percent of 10.5 billion bushel U.S. corn crop was used for ethanol production. As corn prices passed $3.50 per bushel, feed cost increased by $1.20 cents per 100 pounds of milk (cwt). The price of corn silage (increased from $30 to $40 per wet ton) as well as alfalfa, barley, and by-product feeds has increased. Milk price has increased to cover higher corn grain and silage costs. Dairy nutritionists recommend 21 to 26 percent total starch in the total ration dry matter with a range from 18 to 32 percent reported in the field. Starch and sources of rumen fermentable carbohydrate are critical to optimize rumen microbial fermentation producing microbial amino acid (can supply over 60 percent of amino acid needed and over 80 percent of needed energy as volatile fatty acids). Several strategies can be considered by dairy managers with current corn grain prices.

Strategy 1. Reduce starch level

If the target level is 25 percent starch for high producing cows, can starch levels be lowered by 1 to 5 percentage points while maintaining performance? The key factor is to evaluate the level and rate of fermentable carbohydrate that is currently available including forage quality, dry matter intake, digestibility of neutral detergent fiber (NDF), availability of starch for rumen fermentation and lower gut enzymatic digestion, rate of feed passage, use of monensin (an ionophore), and feed additive that can impact the rumen environment. Each herd may have a different starch optimal level, but if a dairy manager lowers starch levels, the signs of "cheating" starch levels too low (listed below).

- Decline in milk peak milk production
- Lower milk yield in the herd in general, especially early lactation cows
- Drop in milk protein test and yield (drop in microbial amino acid yield)
- Lower milk fat test (less rumen volatile fatty acids or VFA)
- Increase in milk urea nitrogen (MUN) by more than 3 mg/dl from the herd's normal baseline value
- Increase in manure scores (over 3.5 or "stiff" manure)
- Decline in dry matter intake
- Thinner cows (less energy available)
- Lack of response to bovine somatotropin (bST)

Strategy 2. Increase current starch availability in the rumen

Plant processing of corn silage can reduce the passage of partial or whole kernels of corn allowing for improved rumen fermentation of starch. The corn plant is also reduced in particle size increasing surface area for microbial fermentation of fiber. Guidelines of plant processing are chopping at 18 cm or 0.75 inch theoretical length of chop (TLC) with 2 to 3 millimeter openings between rollers. The processed corn silage should have 10 to 15 percent on the top box of the Penn State Particle Size Box, over 40 percent in the second box, and less than 35 percent the bottom two boxes (all values on expressed on a wet or as-is basis).

Processing corn grain to an optimal particle size, heat treatment, and/or high moisture content (over 25 percent moisture) can increase rumen fermentation and availability. Table 1 lists the energy values of corn with different processed corn grain (NRC 1989). Table 2 illustrates the impact of three different particle sizes of corn grain milk performance and rumen parameters. Finely processed corn (900 to 1100 microns), stream flaking (26 pound bushel weight), and high moisture corn (over 25 percent moisture at 1500 to 2000 microns) can increase energy content and rumen fermentation.

Table 1. Energy content of shelled corn related to processing effects (NRC, 1989).

Corn process	Mcal / kg (lb) dry matter
Cracked corn	1.85 (0.84)
Ground corn	1.96 (0.89)
High moisture corn	2.05 (0.93)
Steam flaked corn	2.05 (0.93)
High lysine corn	2.07 (0.94)
Finely ground corn	2.11 (0.96)

Table 2. Impact of corn degradation rate on milk production and rumen characteristics (Hutjens, 2000).

Component	Slow	Moderate	Fast
Degradation rate (%/hr)	6.04	6.98	7.94
Rumen pH	6.43	6.30	6.19
Rumen acetate: propionate	3.12	2.90	2.60
Total VFA (umol/ml)	134	135	138
Blood urea nitrogen (mg/dl)	14.6	14.2	12.8
NEFA (umeq/liter)	128.2	115.8	103.4
Milk kg (lb) / day	42.9 (94.4)	43.3(95.3)	45.6 (100.4)
Milk fat (%)	3.49	3.42	3.37
Milk protein (%)	2.83	2.86	2.89
4% fat-correct milk kg (lb)	39.3(86.5)	39.2(86.2)	41.3(90.8)
MUN (mg/dl)	16.2	15.4	13.7
Dry matter intake kg (lb)	26.5(58.3)	26.6(58.5)	26.3(57.8)

Strategy 3. Reduce fecal starch losses

Starch levels on manure can vary from 5 to 20 percent of dietary starch. Fecal starch losses could occur for two general factors. ***Factor one*** could be physical presence of corn starch in fecal droppings due to improper processing of corn grain or corn silage. Proper plant processing of corn silage (kernels crushed), ensiling at the proper dry matter level (28 to 33 percent for bunker silos, piles, or bags; 33 to 36 percent of tower silos, and 35 to 40 percent for oxygen limit structures), and selection of softer textured corn grain should be evaluated. ***Factor two*** is the chemical (analytical) presence of starch related to poor fermentation or fermentation in the digestive tract. Adjusting rate of passage to allow adequate time for rumen fermentation and maintaining an optimal rumen fermentation environment, and avoiding rumen acidosis could improve this aspect of chemical starch loss. Data in Table 3 were collected from early lactation cows (less than 60 days in milk) fed the same ration and in the same environmental conditions at the University of Illinois. Free manure samples were sent to a lab to be analyzed for pH and starch content. Fecal starch levels were not statistically related to dry matter intake, milk yield, or days in milk. Multiple samples over three weeks did not indicate cow changes as cows progressed in early lactation. Rumen pH and starch were correlated. While the results were interesting, analyzing fecal starch content remains variable and is not routinely used in the field.

Table 3. Fecal measurements in thirteen early lactation cows (Meier et al, 2002)

Measurement	Range
pH	5.44 to 6.63
Fecal starch (% dry matter)	2.3 to 22.4
Manure dry matter (%)	14.8 to 19.2
Dry matter intake (lb (kg) / day)	44 (20) to 61 (27.7)
Dry matter (% of body weight)	3.1 to 4.5
Milk yield (lb/day (kg)/day	77 (35) to 119 (54.1)

Strategy 4. Consider starch alternatives

As corn prices increase, other feed ingredients can be economically attractive replacing corn grain. Table 4 lists typical starch and sugar content of feed ingredients. Sugar can replace starch, but dairy managers must consider the rate of fermentation and limit the total level of sugar to 6 to 8 percent of the ration dry matter. Nutritionists recommend 22 to 26 percent starch and 4 to 6 percent added sugar.

Table 4. Comparison of starch and sugar levels of various feed ingredients

Feed ingredient	Starch	Sugar
	———— % ————	
Wheat grain	64	2
Barley grain	58	2
Bakery waste	45	8
Corn distiller grain	3	4
Corn gluten feed	20	2
Hominy	49	4
Wheat midds	22	5
Molasses	0	61
Whey	0	69

Strategy 5. Strategic use of feed additives

Optimizing rumen fermentation can improve total starch and ration digestibility. Favorable rumen pH (over 6.0), microbial VFA pattern (over 2.2 part rumen acetate to 1 part propionate), and low levels of lactic acid in the rumen can improve microbial yield and cow performance. Sodium bicarbonate fed at the rate of 0.75 percent of the total ration dry matter can stabilize rumen pH near 6.2 while maintaining dry matter intake. Yeast culture and yeast products can stimulate fiber digesting bacteria, volatile fatty acid production, and reduce lactic acid levels. Direct fed microbial products (DFM) can encourage favorable microbial growth and maintain a desired rumen environment. Mycotoxin binders can reduce the negative effects of mycotoxins in the digestive tract. Ionophores (monensin or Rumensin) can favor the production of propionic acid in the rumen and reduce methane production increased energy yield and efficiency in the rumen. Recommended levels of Rumensin (300 milligrams) in lactating dairy cow rations can replace one and one half pounds of corn equivalents. Review research results to determine which additive(s) may be beneficial in specific rations.

Strategy 6. Optimize corn distillers grain (DG)

Corn DG continues to be available while prices depend on competition in the area, alternative feeds, wet vs. dry corn distillers, and the price of corn grain. Several guidelines should be considered when adding DG to the feeding program.

- Corn DG is a protein source for dairy cattle, not corn grain.
- The recommended levels are 10 to 20 percent of the total ration dry matter for high producing cows (Table 5). Distillers grains are a source of rumen undegraded protein (RUP) that is low in lysine and should be positioned to replace other protein sources in the ration. One approach is to blend 50 percent heat treated soybean and 50 percent DG. For older heifers, dry cows, and low producing cows, DG could be the only source of supplemental protein.
- Several factors will impact the risk of feeding too much DG as dairy managers report drops in milk fat test of 0.3 point or more (for example from 3.8 percent to 3.5 percent). A lack of functional and/or total fiber, too much starch, rapidly fermentable starch, high levels of unsaturated fatty acids, and/or ionophores can lower fat tests.
- Quality of DG is critical. Risks that must be managed include the presence of mycotoxins in the orginal corn used, level of corn distillers added back, color of the DG (indication of heat damage), and storage of wet DG.
- Nutrient variation of DG can be large as corn nutrient content will be reflected in DG, amount of solubles added back, and processing effects.

A new process in ethanol plants can result in several new corn by-products and does not use supplemental sulfur dioxide (can affect feed palatability and cause corrosion). Table 6 lists several potential new products including corn germ, corn bran, modified corn gluten meal, and modified dried distillers grain (DG) compared to "typical DG" is listed for comparison. Corn germ could be a premium product that may be sold to corn oil processors. Corn bran is a feed that ruminants could ferment and digest (similar to citrus or beet pulp). For dairy producers, this product could be used to replace lower quality forages, soy hulls, and/or dilute starch found in corn silage based dairy rations. Modified corn gluten is more applicable as swine and poultry feed (source of pigmentation). Modified DG would be similar to typical DG, but it is lower in oil that can impact rumen fermentation challenges and lower milk fat test. "New" corn co-products could be a valuable feeding tool for dairy nutritionists and managers if economical for the following reasons.

- Lower levels of oil will allow higher inclusion levels
- Less phosphorous may allow higher manure application rates avoiding high soil levels of phosphorous
- A source of digestible fiber that is lower in protein compared to "typical" DG

Table 5. Dry matter intake (DMI), milk yield, and milk fat and protein percentages from cows fed diets containing various levels of DDG with solubles (Kalscheur, 2005)

Inclusion rate	DMI	Milk	Fat	Protein
(% DM)	--- kg (lb)/day ---		--- %---	
None	22.2(48.9)b	33.1(72.8)ab	3.39	2.95a
4 to 10	23.7(52.2)a	33.5(73.6)a	3.43	2.96a
10 to 20	23.5(51.6)ab	33.3(73.2)ab	3.41	2.94a
20 to 30	22.9(50.3)ab	33.5(73.9)a	3.33	2.97a
> 30	20.9(46.1)c	32.3(71.0)b	3.47	2.82b

Values within column followed by a different letter differ ($P < 0.05$)

Table 6. Nutrient profile of corn grain by-products (Lohrmann, 2006).

	Germ	Bran	Gluten meal	Modified DDG	"Typical" DDG
	-----------	(% as fed basis)	-------------		
Crude protein	17	10	45	30	27
Fat	45	2	3	3	9-15
Fiber	6	17	4	8	8
Starch	8	6	2	4	3
Ash	2	1	4	3	4

In Summary

Dairy managers should optimize corn grain starch fermentation in the rumen and digestion in the rumen. By-products and other starch sources can control feed costs and increasing nutrient availability. Additives such as yeast culture and rumen buffers that could enhance starch fermentation in the rumen and stabilize the rumen environment would be strategically important. Monensin can reduce starch levels. Increasing fiber digestion using enzymes and/or direct fed microbes would increase rumen VFA yields while not increasing starch levels. Dairy ration formulation in the future will focus on high digestible forage/fiber sources in diets while optimizing milk yield, milk components, and cow health.

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Field Comparison of Commercially-Available Lab Tests for Starch Digestibility

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Introduction

Starch, supplied by dry or high moisture corn grain and whole-plant corn silage, is an important source of energy in dairy cattle diets. The digestibility of corn starch can be highly variable (Nocek and Tamminga, 1991; Owens et al., 1986). Sources of variation in starch digestibility include: fineness of grind, processing method (i.e. grinding, dry rolling or steam flaking), and endosperm type for dry corn; fineness of grind, maturity, moisture content, length of time in storage, and endosperm type for high-moisture corn; maturity, moisture content, length of time in storage, kernel particle size as influenced by chop length and kernel processing, and endosperm type for corn silage. While in vivo digestion studies have been useful for elucidating the numerous factors that influence starch digestibility by ruminants, these types of trials are too time consuming and costly for use to assess variation in starch digestibility of samples collected across feed mills, silos, and (or) farms.

Techniques available through commercial feed testing laboratories to determine starch digestibility directly have been slow to evolve for several reasons which include: relatively little work on assay development, fine grinding of samples as typically done for lab procedures tends to mask differences in starch digestibility among samples, and little effort to validate in vitro starch digestibility measurements from the available assays with in vivo digestion data. However, there are currently a few procedures to assess starch digestibility of corn-based feeds being offered through commercial feed testing laboratories.

Methods of assessing variation in starch digestibility include: dry sieving of grain to determine mean particle size and particle distribution of dry and high-moisture corn, dry matter determination on high-moisture corn, dry sieving of corn silage to determine the percentage of starch passing a 4.75 mm sieve (Kernel Processing Score, KPS; Mertens, 2005; Ferreira and Mertens, 2005), enzymatic starch recovery on unground samples of dry and high-moisture corn and corn silage (Degree of Starch Access, DSA; Blasel et al., 2006), and ruminal in-situ or ruminal-fluid in-vitro degradations of coarsely-ground corn or corn silage samples either with or without a follow-up determination of in vitro enzymatic digestion on the incubation residue (Modified In Vitro Starch Degradation, MIVSD; Sapienza, 2002). There has been little work done to compare results from the various methods that are now available for assessing starch digestibility of corn-based feeds.

The MILK2000 corn silage evaluation model (Schwab et al., 2003; Shaver et al., 2001) uses whole-plant dry matter and kernel processing as regression equation variables to predict total tract starch digestibility. The MILK2006 corn silage evaluation model (Shaver et al., 2006) allows spreadsheet user's the option of using that regression or inputting results from assays to assess starch digestibility (KPS, DSA, or In vitro) to calculate energy content and milk per ton. There has been no work done to evaluate the impact of these various starch digestibility values on MILK2006 corn silage energy content and milk per ton estimates.

The objectives of this project were as follows:

- Evaluate variation in nutrient composition of corn grain (dry and high-moisture) and corn silage samples collected from dairy farms and analyzed at a commercial feed testing laboratory.
- Evaluate variation in starch digestibility of corn grain (dry and high-moisture) and corn silage across dairy farms as assessed by methods available though a commercial feed testing laboratory. Compare results from the various methods used to assess starch digestibility, and evaluate their impact on corn silage energy content and milk per ton estimates.

Methods

Dry corn, high-moisture corn (HMC), and corn silage samples were obtained from inventories that were being fed on twenty-five dairy farms during two separate farm visits in June and July, 2006. The samples were obtained from farms that were either clients of Five-Star Dairy Consulting or were located in close proximity to the University of Wisconsin-Madison; two of farms sampled in the latter group were UW-Madison Arlington and Campus dairies. Corn silages samples were collected from all farms, but dry corn and HMC samples varied depending upon whether or not they were being fed. Storage structures sampled were as follows: dry corn—upright bin (n = 8) and flat storage (n = 6); HMC—upright silo (n = 9), silo bag (n =1), and bunker silo (n = 5); corn silage— upright silo (n = 1), silo bag (n = 4), bunker silo (n =15), and drive-over pile (n =3).

Several sub-samples were taken from various areas of the exposed face of the feed in the storage structure and combined to make a larger sample. This sample was mixed thoroughly and reduced to a volume of 1 liter. These final samples were then placed in plastic sample bags and either mailed immediately to Dairyland Laboratories Inc. (DLI; Arcadia, WI) or frozen until they could be mailed for analyses. The replicate samples from individual farms were analyzed separately at the lab, and we then averaged the data by farm for presentation and data analysis; the data presented herein represents variation among the farms and should not be interpreted as variation among the individual samples or analytical error.

Dry corn and HMC samples were analyzed for DM, CP, NDF, ADF, fat, and ash at DLI using NIRS; ash was determined using both NIRS and total combustion at 500 °C for 2 h. Energy values for dry corn and HMC samples were calculated using OARDC equations (Weiss et al., 1992). Corn silage samples were analyzed for DM, pH, CP, NDICP, NDF, ADF, lignin, fat, and ash at DLI using NIRS; acid detergent lignin (Goering, H. K., and P. J. Van Soest, 1970) and ash (total combustion at 500 °C for 2 h) were determined using both NIRS and wet chemistry methods. Energy and milk per ton values for corn silage samples were calculated using both MILK2000 (Schwab et al., 2003; Shaver et al., 2001) and MILK2006 (Shaver et al., 2006) equations. For dry corn and HMC samples and corn silage samples, starch was measured at DLI using wet chemistry during the DSA procedure (Blasel et al., 2006). Particle sizes of dry corn and HMC samples were determined at DLI by Ro-Tap shaker method. Corn silage particle size distributions were determined at DLI as part of the KPS procedure (Mertens, 2005) using a Ro-Tap shaker. The corn silage KPS (Mertens, 2005) and corn grain and silage DSA (Blasel et al., 2006) procedures were performed at DLI. The data from the DSA assay presented herein are the estimated starch digestibility values calculated from the starch recoveries in the DSA procedure using the following equation: Starch $\text{Digestibility}_{DSA}$, % of Starch = 78.6 + (.1928* DSA Starch Recovery , % of Starch). Corn grain and silage samples were sent by DLI to Sapienza Analytica, LLC (Johnston, IA) for determination of MIVSD as follows: samples were dried in 62 °C forced-air oven to a consistent weight, ground through 6 mm Willey Mill screen, and placed into Dacron bags incubated in flasks filled with mixed rumen fluid from four cows with 8 replicates per sample incubated in rumen fluid for 12 h and 4 of the replicates then incubated in intestinal enzymes for 8 h. The values were then added together to estimate ruminal plus intestinal starch degradation. The data from the MIVSD assay presented herein are in vitro ruminal starch degradation (MIVSD-R) and in vitro ruminal plus intestinal starch degradation (MIVSD-RI). Descriptive statistics were calculated using Excel®. Correlation coefficients and regressions were determined using SAS®.

Results and Discussion

Descriptive statistics (average, standard deviation, minimum, and maximum) are presented in the tables. The nutrient compositions of dry corn, HMC and corn silage samples are presented in Table 1. Variation in nutrient composition of corn grain samples was generally similar to that reported by NRC (2001). Variation in DM content of HMC samples was extensive, with two-thirds of the HMC samples falling between 70% and 77% DM and minimum and maximum values of 68% and 81% DM, respectively. This may partially be a reflection of the varying types of storage structures used for HMC on these farms.

Variation in DM content of corn silage samples was extensive, with two-thirds of the corn silage samples falling between 31% and 41% DM and minimum and maximum values of 30% and 52% DM, respectively. Wide variation in DM content was not unexpected considering differences in hybrids, growing conditions, grain yields, dry-down rates, harvest timing, and storage structures across the farms. But, it is surprising that half of the farms were feeding corn silage that contained ≥ 36% DM since the commonly recommended whole-plant corn silage harvest DM is 30% to 35% (Shaver et al., 2005). The average corn silage NDF content was lower than that reported by NRC (2001; 40.6 ± 2.8% vs. 45.0 ± 5.3%). This was likely related to a high proportion of grain in the whole-plant corn silage as reflected by an average starch content of 31.6%. Variation in starch content of corn silage samples was extensive, with two-thirds of the samples falling between 28% and 35% starch. The correlation coefficient between lignin determined by NIRS versus wet chemistry methods was only 0.67 ($P < 0.05$). Results from this relatively small sample set cause concern over the practice of using NIRS lignin data to calculate NDF digestibility and energy value of corn silage (NRC, 2001). The correlation coefficient between ash determined by NIRS versus total combustion was only 0.45 (P <

0.05). Results from this relatively small sample set cause concern over the practice of using NIRS ash data to calculate non-fiber carbohydrate (NFC) content and energy value of corn silage (NRC, 2001).

Presented in Table 2, are particle size data and results from assays to assess starch digestibility for dry corn and HMC samples. Mean particle size (MPS) was lower and percentage passing a coarse sieve (#16; 1180 microns) was higher for dry corn than HMC. The MPS and the percentage passing a coarse sieve data had a high negative correlation ($P < 0.05$) for both dry corn ($r = -0.94$) and HMC ($r = -0.96$) samples indicating that the % passing the #16 sieve was a good predictor of MPS. Variation in MPS of HMC samples was extensive, with two-thirds of the HMC samples falling between 1250 and 2000 microns and minimum and maximum values of 950 and 2500 microns, respectively. This may partially be a reflection of the varying types of processing used for HMC on these farms and also the variation in DM content when processed on the farms. The average MPS of HMC samples ground through a hammer-mill was 1208 microns, while samples processed through a roller-mill averaged 1780 microns. There was no relationship ($P > 0.10$) between MPS and the DM content of HMC samples. As expected (Blasel et al., 2006), DSA had a high negative correlation ($P < 0.05$) with MPS ($r = -0.72$) for HMC samples. But, DSA was not correlated ($P > 0.10$) to either MPS or the percentage passing a coarse sieve for dry corn samples. This may have been related to the MPS range for dry corn than HMC samples (642 versus 1531 microns) or the relatively small number of dry corn samples ($n = 11$) in this dataset. Dry matter content of HMC was negatively ($r = - 0.50$) correlated ($P < 0.05$) to DSA in HMC samples. The r-square value from multiple regression of DSA on DM content and MPS for HMC samples was 61% ($P < 0.0001$). This supports the data of Blasel et al. (2006) which showed that the DSA assay was sensitive to both particle size and moisture content of HMC samples. Dry matter content of HMC was negatively ($r = - 0.66$) correlated ($P < 0.05$) to both MIVSD-R and MIVSD-RI in HMC samples. For the HMC samples, correlations ($P < 0.05$) between MIVSD-R and MPS or the percentage passing a coarse sieve were only -0.39 and -0.43, respectively, and MIVSD-RI was unrelated ($P > 0.10$) to particle size. For dry corn samples, the MIVSD parameters were unrelated ($P > 0.10$) to particle size. This was not surprising since samples were ground to pass through a 6 mm screen prior to performing the in vitro starch degradation assays. Degree of starch access was unrelated ($P > 0.10$) to the MIVSD parameters in HMC samples, but was positively ($r = 0.71$) correlated ($P < 0.05$) to MIVSD-RI in dry corn samples. It is unclear why DSA was related to MIVSD-RI but not MIVSD-R. The MIVSD-RI values were low for both HMC and dry corn relative to published total tract starch digestibility values from in vivo experiments (Owens and Zinn, 2005), which may partially be explained by lack of measurement of hindgut fermentation with the MIVSD procedure (Owens et al., 1986).

Particle size data and results from assays to assess starch digestibility for corn silage samples are presented in Table 3. Particle size data are presented as the percentage of DM retained on 4.75 and 1.18 mm screens and the pan. On average, approximately equal parts DM were retained on the 4.75 mm and 1.18 mm screens with $11.2 \pm 4.9\%$ retained on the pan. Mertens (2005) suggested optimum, average, and poor KPS values of ≥70%, <70% and ≥50%, and <50% of starch passing through a 4.75 mm screen, respectively. Only 10% of the samples were in the "optimum" processing category. This agrees with the report of Visser (2005) where with sample sets of 252 and 55 corn silage samples only 10% and 7% of the samples, respectively, were in the "optimum" processing category. The consistent low percentage of samples categorized as optimally processed by the KPS procedure suggests that requiring ≥70% of starch passing through a 4.75 mm screen for designation as "optimum" kernel processing may be too rigid. It is also possible that viscous starch retained on coarse fiber particles may inappropriately reduce the starch that passes through a 4.75 mm screen or KPS for some samples (P. C. Hoffman personal communication). Kernel processing was categorized as poor (<50% of starch passing through a 4.75 mm screen) in 35% of the samples. This agrees closely with the Visser (2005) where 37% of the corn silage samples were in the poor processing category when averaged across the two sample sets evaluated in that report. There was variation in DSA of corn silage samples; two-thirds of the samples fell between 91% and 96% of starch. There was also variation in MIVSD-R for the corn silage samples; two-thirds of the samples fell between 84% and 95% of starch. The DSA and MIVSD-R average values of 94% and 90% of starch, respectively, may have been lower, and possibly the variation wider, had the corn silage samples evaluated not been in the silos for eight months or more since starch digestibility of corn silage has been shown to increase over time in storage (Newbold et al., 2006). The MIVSD-RI values varied minimally ($98.0 \pm 1.1\%$ of starch). Higher MIVSD-RI values for corn silage than HMC (refer to table 4) was not unexpected since corn silage is normally harvested at an earlier stage kernel maturity than HMC and the kernels in some corn silage samples may be processed finer than HMC. Degree of starch access was positively ($r = 0.43$) correlated ($P < 0.05$) to KPS. The KPS was unrelated ($P > 0.10$) to the MIVSD parameters. Here again this was not surprising since samples were ground to pass through a 6 mm screen prior to performing the

MIVSD procedure. Whole-plant DM was unrelated ($P > 0.10$) to DSA and the MIVSD-R parameters.

Corn silage net energy and milk per ton values calculated using MILK2000 (regression for starch digestibility) and MILK2006 (regression, KPS, DSA, and MIVSD-RI) are presented in Table 4. As expected, average net energy and milk per ton values were lower when using MILK2006 than when using MILK2000 due to changes in model equations (Shaver, 2006). Differences in average net energy and milk per ton values and their variance estimates within MILK2006 when using regression, KPS, DSA, or MIVSD-RI for starch digestibility were minimal for this sample set. Further, sample rank correlations between regression and KPS, DSA, or MIVSD-RI methods of calculating starch digestibility were highly positive ($P < 0.05$) for energy ($r = 0.081$ to 0.92) and milk per ton ($r = 0.82$ to 0.93) values.

Implications

Variation in nutritional and processing characteristics of corn grain and silage fed on dairy farms in the Upper Midwest is extensive. Recent advances in assays designed to assess starch digestibility of corn grain and silage and fiber digestibility of corn silage aide our evaluation of these feeds in the field. More comparative research of the assays designed to assess starch digestibility and research to validate their results relative to in vivo digestibility data is needed before these assays can be used with confidence in the field.

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Table 1. Nutrient composition of dry and high-moisture corn and corn silage samples measured using NIRS except for ash which was measured using both NIRS and total combustion methods, lignin (corn silage only) which was measured using both NIRS and acid detergent lignin (Goering and Van Soest, 1970) methods, and starch which was measured using wet chemistry during the DSA procedure (Blasel et al., 2006).

Dry Corn		Average	Standard Deviation	Minimum	Maximum
NIR DM %	% as fed	85.3	1.2	83.7	87.2
NIR CP		9.5	0.5	9.0	10.7
NIR NDF		9.9	1.1	8.4	12.2
NIR ADF		4.0	0.4	3.4	4.8
NIR Starch		66.2	1.8	62.6	68.2
NIR Fat	% of DM	3.9	0.5	3.2	5.1
NIR Ash		1.4	0.1	1.2	1.6
Wet Chem % Ash		1.3	0.1	1.1	1.5
TDN-OARDC		87.4	0.4	86.6	88.0
NEL-OARDC-Mcal/CWT	Mcal/lb	0.92	0.00	0.91	0.93
HMSC					
NIR DM %	% as fed	73.7	3.7	67.6	81.3
NIR CP		9.3	0.5	8.2	10.5
NIR NDF		7.5	1.1	5.6	9.2
NIR ADF		3.3	0.5	2.3	4.0
NIR Starch		67.4	1.7	64.9	71.6
NIR Fat	% of DM	3.9	0.4	2.8	4.7
NIR Ash		1.4	0.1	1.2	1.5
Wet Chem % Ash		1.3	0.1	1.0	1.5
TDN-OARDC		88.4	0.5	87.4	89.1
NEL-OARDC-Mcal/CWT	Mcal/lb	0.93	0.01	0.92	0.94
Corn Silage					
DM	% as fed	35.8	4.7	29.9	51.9
pH		3.9	0.2	3.5	4.2
CP		8.5	0.6	7.1	9.5
NDICP		1.4	0.1	1.1	1.5
NDF		40.6	2.8	34.1	46.3
ADF		25.0	2.0	20.1	28.5
NIR Lignin		3.4	0.3	2.7	4.0
Wet Chem Lignin	% of DM	3.1	0.4	2.5	4.1
Starch		31.6	3.6	25.5	37.8
Fat		3.6	0.3	3.2	4.2
Ash- NIRS		3.8	0.3	3.3	4.5
Ash- Furnace		4.1	1.0	2.4	7.6

Table 2. Particle size data and results from assays to assess starch digestibility for dry and high-moisture corn samples.

Dry Corn		Average	Standard Deviation	Minimum	Maximum
Mean Particle Size (Microns)	Microns	670	180	407	1049
Percent passing #16 Sieve	% as fed	69.1	13.8	41.5	91.4
DSA		96.4	3.4	86.9	98.9
MIVSD-R	% of Starch	64.3	9.3	48.7	74.3
MIVSD-RI		86.2	5.9	72.9	96.3
HMSC					
Mean Particle Size	Microns	1629	377	955	2486
Percent passing #16 Sieve	% as fed	25.0	11.7	4.7	54.9
DSA % of Starch	% of Starch	94.9	2.8	89.1	98.1
MIVSD-R		73.1	9.3	58.9	93.4
MIVSD-RI		87.9	8.4	74.3	98.6

Table 3. Particle size data and results from assays to assess starch digestibility for corn silage samples[1].

		Average	Standard Deviation	Minimum	Maximum
Remaining on Coarse screen	% of DM	47.1	9.4	22.0	61.0
Remaining on Medium screen	% of DM	41.7	5.3	31.5	53.5
Remaining on Pan	% of DM	11.2	4.9	7.0	28.5
KPS	% of starch passing 4.75 mm screen	54.4	12.7	32.0	88.0
DSA	% of starch	93.7	2.3	90.1	97.2
MIVSD-R	% of starch	89.7	5.4	75.8	98.8
MIVSD-RI	% of starch	98.0	1.1	96.1	99.5

[1]Sieving was done using the Ro-tap shaker method: Coarse screens were ≥ 4.75 mm, medium screens had openings <4.75 mm and >1.18 mm, and the pan retained material that passed through the 1.18 mm screen.

Table 4. Corn silage NE_L-3x and milk per ton and calculated using MILK2000 and MILK2006 corn silage evaluation models[1].

MPT			Average	Standard Deviation	Minimum	Maximum
MILK2000	Regression	lbs. Milk per ton of DM	3938	219	3631	4412
	Regression		3466	158	3136	3758
MILK2006	KPS		3412	170	3062	3738
	MIVSD-R		3404	162	3098	3727
	MIVSD-RI		3497	151	3106	3756
NEL						
MILK2000	Regression	Mcal per lb. of DM	0.79	0.03	0.75	0.85
	Regression		0.72	0.02	0.68	0.77
MILK2006	KPS		0.72	0.03	0.66	0.76
	MIVSD-R		0.71	0.02	0.67	0.76
	MIVSD-RI		0.73	0.02	0.67	0.77

[1]All calculations were done using 48-h IVNDFD data.