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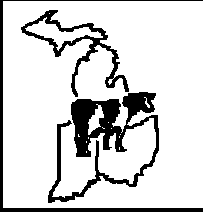
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Controlling Metabolic Diseases

David I. Byers, D.V.M.¹

Abstract

A healthy cow will give more milk and have better reproduction. Controlling metabolic diseases is necessary for optimum performance. Metabolic diseases are complexes (e.g., one condition leads to another, and to another, etc.). Fatty liver, hypocalcemia, and rumen acidosis are major metabolic complexes that adversely affect dairy cattle performance. Transition management and feeding programs that successfully reduce their incidence will generate greater lactational and reproductive performance

Introduction

The basic tenet of this paper is that cows that have fewer health disorders have greater milk production and better reproductive performance. Conversely, unhealthy cows do not produce or reproduce well. Controlling metabolic diseases, then, is paramount for good lactational and reproductive performance (Shearer and Van Horn, 1992).

Also, noting that metabolic diseases in the dairy cow are complexes is important (Gerloff, 1988; Risco, 1992; Risco, 1995; Van Saun, 1991). That is, one condition leads to another. For example, a cow that has milk fever (**MF**) is four times more likely also to have a retained placenta (**RP**) and 16.4 times more likely to develop ketosis (Van Saun, 1991).

This paper focuses attention on controlling three metabolic diseases. They are fatty liver (**FL**), hypocalcemia, and rumen acidosis. It is this individual's conviction that they are key diseases hindering lactation yield and reproductive performance in dairy cattle today.

Fatty Liver Disease

Description. Some misconceptions exist about FL. One, FL disease develops after calving when the cow is mobilizing large amounts of body fat. Recent research (Bertics et al., 1992; Grummer, 1993; Grummer and Carroll, 1991) shows that FL often develops prepartum or at parturition. Thus, it is a periparturient disease. Two, FL disease was the result of obesity. These cows are more susceptible, but some surveys show that all cows have some degree of fatty liver (Herdt, 1988b).

Cows with FL show depression, lack of appetite, and general weakness. Also, there are generally complicating conditions such as MF, RP, displaced abomasum (**DA**), metritis, or mastitis. The outstanding clinical feature of this disease is the poor response to treatment of the accompanying diseases. For example, a cow with metritis may die or recover slowly and milk poorly.

Etiology. Fatty liver begins with mobilization of body fat. Many factors stimulate lipolysis of adipose tissue, including negative energy balance (**NEB**), hypoglycemia, low serum insulin

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concentrations, and relatively high serum concentrations of lipolytic hormones, such as growth hormone, placental lactogen, and prolactin (Bell et al., 1992; Herdt, 1988a, 1988b). Estrogen, a potent regulator of hepatic fatty acids (FA) metabolism in nonruminants, may play a key role in FL development (Chandler, 1995; Grummer et al., 1990). Mobilization of fat from adipose tissue results in an increased level of serum nonesterified fatty acids (NEFA) and increased uptake by the liver. High concentrations of FA are toxic to tissues. Once in the liver, they are subject to two metabolic pathways: oxidation or esterification (Herdt, 1988a). Re-esterification leads to triglyceride synthesis. Triglyceride is a source of energy for body tissues and the mammary gland. For triglycerides to be exported from the liver, the liver must package them into lipoprotein particles. When hepatic production of triglycerides exceeds lipoprotein export, FL results (Bertics et al., 1992; Grummer, 1993; Herdt, 1988b).

Fetal Dynamics. Understanding the dynamics of fetal growth is helpful to our understanding of the development of FL. Key factors include the following:

- *Nutrient Partitioning.* Competition among organs for nutrients also affects the development of FL. Fetal needs receive top priority in advanced pregnancy. This can be detrimental to the cow.
- *Gestational Nutritional Requirements.* Fetal growth during the last trimester is exponential (Bell et al., 1992; Chandler, 1995; Gerloff, 1988; Van Saun, 1991). This creates a very large increase in the gestational requirement before parturition. Providing the nutrients required during this period of rapid

growth is imperative. Researchers (Bell et al., 1992; Ferrell and Ford, 1980; McNeil et al., 1994) showed that this is a significant nutritional requirement.

- *Paradoxical Decline in Feed Intake.* Unfortunately, DMI begins to decline around three weeks before calving. Feed intake declines about 30% (Bertics et al., 1992). It begins to decline around five weeks with twins. The increased gestational requirement coupled with a decline in DMI make it necessary to feed a nutrient dense ration for three weeks before calving. Cows carrying twins should receive a greater supply of nutrients for five weeks.
- *Use of Maternal Energy.* The conversion of maternal energy into energy deposited into the gravid uterus is poor. Earlier work (Ferrell and Ford, 1980) reported a 14% conversion of dietary metabolizable energy (ME) into energy retention of the gravid uterus. This compares with a conversion of ME to NE_L of 60% (National Research Council, 1989).
- *Fuel for the Fetus.* The fetus has very specific metabolic needs. Chandler (1995) shed light on this subject:
 - Use of ME from the dam is exceedingly low (i.e., 14%).
 - The fetus has a very high metabolic rate. There is a temperature gradient of 0.50 to 1.0 °C over the dam. This high metabolic requirement results in 60% or greater of the energy being dissipated as heat.

- The placenta has an oxidative requirement equal to or exceeding that of the fetus.
 - The primary substrates for achievement of this condition via oxidative metabolism are glucose, lactate, and amino acids. Since lactate originates from glucose, we can state that the fetus runs on glucose and amino acids.
 - The amino acid role is significant, with data showing that almost 60% of the nitrogen uptake are lost in oxidative forms.
- *Fuel for the Dam.* With the fetus dominating the use of glucose for energy, the dam must rely largely on the volatile fatty acids (VFA), acetate, and long chain FA. Fatty acid mobilization occurs to supply energy for the dam. No doubt, this predisposes her to FL. Also, if there is any additional depression in feed intake or if the ration lacks proper nutrient balance, an exacerbation of FL and other metabolic problems may occur.

Treatment and Prevention. No treatment is effective. Prevention is the best course of action. Because FL develops by day 1 after calving, strategies to prevent metabolic disorders must start before calving (Grummer, 1993). The key is to avoid excessive FA mobilization from body fat. Plausible strategies include the following:

- *Body Condition Management.* Cows should not lose body condition during the dry period. Dairy farmers should score dry cows each week. Cows losing weight may have twins. Move these cows to a higher energy ration. Increasing body condition

minimally is possible (i.e., 0.25- to 0.50-point) during the dry period. Avoid getting cows over conditioned (i.e., > 4.0). Fat cows have reduced appetites after calving. Though few, if any, studies show that overconditioned cows have greater depression of DMI before calving (Grummer, 1993), anecdotal evidence suggests that this is the case. The best way to avoid fat cows is to manage energy balance during the latter half of the lactation (Chandler, 1995).

- *Properly Balanced Close-Up Dry Cow Rations.* Provide 6 to 10 lb of grain daily to promote growth of the rumen papillae and to allow the rumen microflora to acclimate to grains. Feed some silage or haylage, if the milking rations contain them, to allow adaptation to fermented feeds before calving. Provide a protein balance of 15 to 16% CP that is 25 to 30% soluble protein and 35 to 40% rumen undegradable (McNeil et al., 1994; Van Saun, 1991). High-quality protein supplementation (e.g., blood meal, fish meal, meat meal, etc.) that provides a good supply of essential amino acids is critical. This is necessary to support gluconeogenesis.
- *Provide Glucose Precursors.* Feed 4 to 8 oz of propylene glycol or 8 to 12 oz of calcium propionate if ketosis is a problem. Provide fermentable carbohydrates (e.g., corn meal, high moisture corn, barley, etc.). Corn meal is the ideal choice because it ferments slowly.
- *Prompt Treatment of Fresh Cow Problems.* Do not allow a fresh cow to get "lost in the herd." Treat health problems promptly. Encourage fresh cows to eat. Force feed cows that are

off-feed to prevent excessive loss of body weight.

- *Optimize Dry Matter Intake.* Provide feed *ad libitum* to maximize feed intake during the transition period. Energy intake follows feed intake (i.e., DMI). Dry matter intake depends on many variables. They fall into three general categories (Table 1): 1) environment, 2) cow, and 3) ration.

Hypocalcemia

Description and Etiology. With the initiation of lactation, most cows experience some degree of hypocalcemia (i.e., low blood Ca) (Beede, 1995; Risco, 1995). There are two types of hypocalcemia: clinical and subclinical (Risco, 1995). Hypocalcemia results from the sudden flow of Ca from blood into colostrum. There is an influx of 23 g of Ca from blood during the first 24 hours after calving. This is 9x the available Ca pool in plasma (Risco, 1995; Van Saun, 1991).

In most cows, activation of Ca homeostatic mechanisms restores normal blood Ca early in the postpartum period (Goff, 1992; Risco, 1992). If the system malfunctions, however, increases in severity and duration of hypocalcemia occur. This predisposes the cow to periparturient disorders (Beede, 1995; Risco, 1995). Milk fever is the clinical manifestation of hypocalcemia. There is an accentuation of the degree and duration of hypocalcemia in milk fever. Clinical symptoms reflect changes in neuromuscular function (Oetzel, 1988), and initial symptoms are tremors. Subsequent neuromuscular dysfunction leads to sternal recumbency and lateral recumbency. Death generally results if not treated; it occurs in about 5 to 10% of cows (Oetzel, 1988).

Calcium homeostasis functions to maintain normal Ca concentration. These mechanisms maintain blood Ca by adjusting the supply and loss of Ca. The supply side of Ca is gut absorption and bone resorption. When compared with normal cows, milk-fever cows are the result of a breakdown on the supply side. The problem is inefficient Ca absorption from the gut and poor Ca resorption from bone (Oetzel and Barmore, 1992).

Relation to Other Diseases.

Parturient hypocalcemia is a risk factor for several metabolic diseases that negatively affect postpartum health and performance (Beede, 1992a, 1992b; Beede et al., 1991a, 1991b). Cows with milk fever are 3 to 9x more likely to develop other calving disorders (e.g., dystocia, RP, ketosis, DA, mastitis, and uterine prolapse) (Risco, 1992; Van Saun, 1991). Risco (1992, 1995) showed a significant relationship between MF, dystocia, and RP.

Subclinical hypocalcemia is generally a greater problem than clinical hypocalcemia. Therefore, greater economic losses occur due to the non-obvious form of hypocalcemia. The uterus, rumen, and abomasum have significant smooth muscle function. Subclinical hypocalcemia can adversely affect their performance. Beede (1995) described a hypocalcemia cascade that illustrates the association of hypocalcemia to other health disorders. Several studies confirm the relation of subclinical hypocalcemia to metabolic disease (Beede, 1992a, 1992b; Beede et al., 1991a, 1991b; Sanchez et al., 1992).

Treatment and Prevention. The aim of treatment is to correct the paresis and to sustain the cow until the reestablishment of normal Ca levels in the blood. Calcium deficits are generally in the amount of 8 g.

Giving 500 ml of 23% calcium gluconate intravenously provides 10.8 g of calcium (Risco, 1995). It is common to provide an additional 500 ml subcutaneously to reduce the incidence of relapses. This commonly alleviated clinical signs, but hypocalcemia remains for 2 to 3 additional days.

Cows generally respond favorably to a single Ca treatment. Other results include the following (Oetzel, 1988):

- Incidences of relapse 12 to 48 hours after treatment range from 25 to 40%,
- 10% will remain recumbent for 24 hours but eventually return, and
- 10% will die or become downer cows.

Programs for prevention of clinical hypocalcemia and correction of subclinical hypocalcemia usually revolve around: 1) manipulating the Ca and P content of the diet, or 2) manipulating the ionic balance of the diet. Two programs commonly encountered in the field are as follows:

- *National Research Council (NRC)*. The NRC (National Research Council, 1989) recommendation for a mature dry cow during the prepartum period is 36 to 43 g of Ca per day (i.e., 0.39% of ration DM). This is below maintenance requirements. This recommendation assumes a positive Ca balance at the beginning of the dry period. Field experience reveals two basic problems with this approach: 1) this level is commonly not low enough to reduce the incidence of milk fever; and 2) achieving low levels of Ca using feedstuffs most desirable for dry cows is generally not possible. Therefore, the frequently suggested

compromise is to feed < 100 g of Ca and < 50 g of P daily. Typically, this approach is effective in preventing clinical hypocalcemia; however, in other incidences, it has been completely ineffective (Gerloff, 1988).

- *Dietary Cation-Anion Difference (DCAD)*. This scheme is a more reliable method of preventing milk fever when the Ca intake exceeds NRC requirements (Beede, 1992a, 1992b, 1992c; Beede et al., 1991a, 1991b; Gerloff, 1988; Goff, 1992; Risco, 1995). It is a method that balances rations for cations and anions. Synonymous names are dietary cation-anion balance, dietary electrolyte balance, cation-anion balance, strong ion balance, and fixed ion balance. It has become popular in recent years. Cows are fed an anionic ration (i.e., a negative DCAD) the last two to three weeks before calving. A negative DCAD causes mild acidosis, resulting in increases in mobilization of Ca from bone and possible absorption of Ca from the gut (Beede, 1995). This increases the cow's ability to maintain normal blood Ca concentrations and reduces the incidence of clinical and subclinical hypocalcemia (Beede, 1995). This method also calls for Ca, 120 to 180 g/day (Beede, 1992c). The most common formula used for DCAD is as follows:

$$\text{DCAD (mEq/100g/DM)} = [(\% \text{Na}/0.023) + (\% \text{K}/0.039)] - [(\% \text{Cl}/0.0355) + (\% \text{S}/0.016)]$$

For example, if the DM content of a ration is 0.10% Na, 1.5% K, 1.0% Cl, and 0.45% S, calculation of DCAD is as follows:

$$\text{DCAD} = [(0.10/0.023) + (1.5/0.039)] - [(1.0/0.0355) + (0.45/0.016)] \text{ mEq/100 g DM}$$

$$\text{DCAD} = [(4.35) + (38.46)] - [(28.17) + (28.13)] \text{ mEq/100 g DM}$$

$$\text{DCAD} = -13.49 \text{ mEq/100 g DM}$$

Rumen Acidosis

Description. Rumen acidosis is the result of acids accumulating in the rumen (Nocek, 1995; Nordlund, 1995; Schultz et al., 1993). It generally occurs early in lactation with a shift to high-grain rations. There are few symptoms in mild cases and the condition often goes undiagnosed. Severe overfeeding of grain causes overt clinical signs.

There are several causes of rumen acidosis. Basically, they all relate to excessive grain feeding (Nocek, 1995; Nordlund, 1995; Schultz et al., 1993). It can result from feeding too much grain too quickly to fresh cows. Another cause is feeding grain before forage in component herds. It can develop from feeding forages that are cut so fine that they lack sufficient effective fiber (i.e., the ability to stimulate cud chewing).

The basic course is that grain ferments into VFA in the rumen. When production exceeds absorption of VFA, these acids accumulate in the rumen, causing the pH to drop to 5.5 or lower (Nordlund, 1995).

There are three types of rumen acidosis based on degree of acidosis (Schultz et al., 1993). They are subacute, acute, and peracute.

- *Subacute (Mild) Acidosis.* Indigestion and off-feed problems characterize the

mild form. It is a common underlying factor for ketosis and DA. It may also produce laminitis and foot problems. Consequently, it results in fresh cows with reduced feed intake, accentuated body condition loss, and delayed return to estrus.

- *Acute (Moderate) Acidosis.* Weight loss, poor milk production, chronic lameness, and inferior reproduction characterizes this form. Also, there is damage to the ruminal lining (i.e., ulceration). This results in bacteremia and bacterial localization in the liver, lungs, and other target tissues (e.g., heart valves, joints, and kidneys). Liver and lung abscesses are common findings in cows that suffered an attack of acute acidosis.
- *Peracute (Severe) Acidosis.* This form results from extreme over consumption of grain. Death is common without prompt veterinary intervention.

Treatment and Prevention. The difficulties of diagnosing the subacute and acute forms at the time of the insult make treatment enigmatic. Peracute acidosis demands immediate and drastic action. Rumenotomy and removal of rumen contents, followed by intensive fluid therapy is a common practice.

Prevention is always better than treatment. The following two-pronged approach is recommended:

- *Prepare the Rumen.* The transition period is a time to equip the rumen for moderate grain feeding after parturition. Feeding 6 to 10 lb of grain during the close-up dry phase promotes growth of the rumen papillae (i.e., finger-like projections of rumen epithelium). This increases the ability of the rumen to take

up VFA. Also, feeding a modest amount of grain allows the rumen microflora to adapt to highly fermentable feeds (e.g., high moisture shelled corn, ground shelled corn, barley, etc.). In addition, introducing small amounts of any silage or haylage that are being fed to the milk cows is advisable. Remember: during the transition period, we are trying to provide the feeds that will help the dairy cow to make the transition as smoothly as possible into the milking herd.

- *Protect the Rumen.* There are two major considerations:

1) Introduce grain slowly in early lactation. This is a time when DMI is lagging, and the rumen papillae are continuing to elongate. The transition fresh-cow feeding program should not hinder either of these. There is, however, the tendency to get as much grain into the cow as quickly as possible to reduce NEB in early lactation (Nordlund, 1995). This usually results in decreased DMI and even greater NEB. Consequently, we must strive for a balance between adequate fiber and energy. With TMR-fed herds, this is just simply a matter of a properly balanced ration. Component fed herds present a difficult task. My recommendation is to increase grain slowly, 1.0 lb/day until the cow reaches peak grain level. Some recommend a more conservative approach (Schultz et al., 1993). They advocate feeding cows no additional grain the first week after calving. Afterwards, increase grain 0.50 to 0.75 lb/day until the peak grain level is achieved. This results in weekly grain increases of 3 to 5 lb. Anecdotal experience is that this is a very conservative approach and may cause excessive weight loss, ketosis, and FL.

2) Reduce the acid produced after each meal. Feeding a properly formulated TMR is the best way to accomplish this (Schultz et al., 1993). This permits a constant ratio of forage to grain; however, even with a TMR, providing adequate effective fiber (i.e. fiber that promotes cud chewing) is absolutely necessary. This requires the feeding of forages that have adequate particle length. Fifteen to 20% of the pieces should be greater than 1.5 inches long. With component-fed herds, avoid slug feeding of grain, and divide grain into three or four daily feedings. Always feed forage before grain, and buffers may also help to maintain pH. Use buffers as aids, not as substitutes for good nutritional management.

Summary

- The transition period is from three weeks before to three weeks after calving.
- It is a critical time in the life of the dairy cow. During this time, the modern dairy animal makes a great metamorphosis. She moves from a dry cow with marginal nutrient requirements to a lactating cow with massive metabolic needs.
- How well she makes this transition affects her health, production, and reproduction.
- Our challenge is to feed and manage the modern dairy cow so that she makes this progression smoothly.
- Fatty liver, hypocalcemia, and rumen acidosis are metabolic diseases that adversely affect reproduction.

- Transition management and feeding programs that successfully reduce their incidence will generate greater lactational and reproductive performance.

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Table 1. Variables that influence dry matter intake.

ENVIRONMENT	COW	RATION
Temperature	Milk production	Physical texture
Ventilation	Body size	Palatability
Humidity	Hormonal status	Fiber content
Feedings per day	Breed	Nutrient balance
Water	Body condition	Moisture content
Sprinklers, fans, etc.	State of health	Forage quality

Effect of Level and Source of Energy During the Periparturient Period on Reproductive Performance

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Abstract

The financial loss due to poor reproductive performance is substantial. Poor energy nutrition during the transition period will predispose dairy cattle to poor reproductive performance later in lactation when it is critical for them to become pregnant to optimize financial returns. Dairy cattle should consume diets higher in energy than recommended by NRC (1989) during the late dry period to stimulate dry matter intake (DMI) and to offset decreases in energy intake due to decreasing DMI. Care must be taken to avoid over feeding energy throughout the dry period because this can result in fat cows and poor postpartum reproductive performance. Propylene glycol can be added to transition cow diets to increase plasma insulin and glucose concentrations and perhaps improve reproductive performance. Dietary fat appears to improve reproductive performance independent of energy status in many studies when fed for several months during early lactation. However, it is not recommended for use during the transition period because of concerns regarding decreased DMI and the long-term management of body condition in high producing cows, which hasn't been studied in cows fed fat during consecutive dry periods.

Introduction

The cost of poor reproductive performance in dairy cattle is determined by many factors, including cow age, milk production, rebreeding policies, and the costs of veterinary services, semen, and replacement animals (DeLorenzo, 1994; Marsh et al., 1987; Plaizier et al., 1998). Reproductive failure is the primary reason for culling cows from a dairy herd (Bascom and Young, 1998); excessive culling is also costly to the producer (Marsh et al., 1987). A 5% decrease in conception rate can cost from \$13 to \$52 per cow per year (DeLorenzo, 1994); a 1% decrease in estrus detection rate can cost as much as \$14 per cow per year (Plaizier et al., 1998). Clearly, improvements in nutrition and management practices that improve reproductive performance can yield financial returns.

Although strong numerical trends exist, analysis of variance provides limited statistical evidence of dietary effects on important reproductive endpoints (e.g., pregnancy rate, conception rate, and services per conception). Butler and Elrod (1991) suggest that this is due to inadequate numbers of animals being used in attempts to demonstrate treatment effects on an "all or none" variable; ultimately, either the animal does or does not become pregnant. The large numbers of animals that are required to detect what could be financially significant treatment effects results in an increased cost of experimentation, which

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limits this area of research. For example, to determine that a 5% change in conception rate (e.g., from 60 to 63%) is statistically significant ($P < 0.05$) would require over 4000 animals per treatment (Berndtson, 1991). This explains why conception rates that are declared significantly different ($P < 0.10$) often differ by more than 20% (Burke et al., 1997; Garcia-Bojalil et al., 1998a; Son et al., 1996).

Because of limited direct statistical evidence that nutrition affects important reproductive endpoints, nutritional recommendations are often derived indirectly. For example, several metabolic signals have been associated with decreased energy status (Table 1). Decreased postpartum energy status has been associated with increased days to first estrus, days to first ovulation, and days open (Staples et al., 1990). Therefore, nutritional strategies to manipulate the metabolic signals or postpartum energy status may be recommended to improve conception rates. Another paper presented during this conference will address the impact of energy balance on ovarian function (Pate, 1999), which will provide further insight into the mechanisms by which nutrition influences reproductive performance. The objectives of this paper are: 1) to briefly describe the changes in energy intake, metabolism, and metabolic signals (Table 1) that occur during the periparturient period of dairy cattle, 2) to describe the relationship between these changes and postpartum reproductive performance, and 3) to suggest ways to influence these changes with nutritional programs that have the potential to improve subsequent reproductive performance.

Intake and Requirements of Energy during the Periparturient Period

The periparturient period has been defined to include three weeks prior to calving through three weeks postpartum (Grummer, 1995). The energy status of dairy cows, which is variable during this period, is often evaluated based on the balance of energy intake and energy requirements (i.e., energy status = energy intake – energy requirement). During the three weeks prior to parturition, NRC (1989) estimates that the energy requirement of the transition cow changes only slightly. This is probably an over simplification; the energy requirement of the fetus will increase during this period, and the energy required for gestation can be as much as 30% of the energy requirement for maintenance (Grummer, 1995). However, due to decreased DMI, energy intake will decline during this period and most dairy cattle fed to provide ad libitum intake experience some degree of negative energy status prior to calving (Grummer, 1995), especially during the final week before calving (Bertics et al, 1992; Studer et al., 1993).

High producing dairy cattle also experience a negative energy status during the early postpartum period. However, a sudden increase in milk production is the cause of this negative energy status rather than a decrease in DMI. Both DMI and milk yield increase throughout the postpartum transition period of dairy cows that maintain an acceptable health status (Beam and Butler, 1997; Bertics et al., 1992). However, the energy requirements for milk production (0.34 Mcal NE_L/lb of 4% fat corrected milk; NRC, 1989) increase more rapidly than

energy intake until a negative energy status nadir (i.e., low point) is reached (Beam and Butler, 1997). Following the energy status nadir, energy intake will increase more rapidly than energy requirements, resulting in an increasing energy status; although the energy status is increasing, it generally remains negative throughout the transition period for high producing cows (Kertz et al., 1991; Staples et al., 1990).

Energy Metabolism during the Transition Period

Several changes occur in the energy metabolism of dairy cows during the periparturient period. These changes may be related to the stress of calving, to hormonal changes that occur prior to calving, to increased demand for glucose by the fetus or the mammary gland, or to the negative energy status of the cow (Bell, 1995; Grummer, 1995). One change that occurs is a gradual increase in plasma nonesterified fatty acid (NEFA) concentration prior to parturition. A spike in plasma NEFA concentration is observed at calving followed by a gradual decline; concentrations of NEFA during the post calving periparturient period do not become as low as precalving concentrations (Grum et al., 1996; Rukkwamsuk, 1999; Studer et al., 1993). These changes indicate that increased mobilization of adipose tissue is characteristic of the changing energy metabolism of periparturient dairy cattle; increased plasma concentrations of β -hydroxybutyrate are often observed when adipose tissue mobilization is increased (Bell, 1995).

Plasma glucose concentrations gradually decrease during the prepartum transition period (prior to day 2 precalving) and may peak suddenly around the time of calving; this peak is followed by a sudden decline and then a gradual increase as the days in milk increase (Grum et al., 1996; Vazquez-Anon et al., 1994). Similarly, plasma insulin concentrations decrease prior to calving and gradually increase following parturition as the stage of lactation advances (Grum et al., 1996). Insulin-like growth factor-1 (IGF-1) decreases during the prepartum period (Grum et al., 1996) and then increases following parturition (Grum et al., 1996; Spicer et al., 1990).

Energy Status and Reproductive Performance

Several of the metabolic changes that occur during the transition period may affect ovarian activity (Pate, 1999) and have been implicated as links between energy status and reproductive performance (Table 1). Although elevated concentrations of plasma NEFA or β -hydroxybutyrate and decreased plasma insulin or IGF-1 concentrations are indicative of negative energy status, they are not routinely measured in an applied setting. Body condition scoring (BCS) is a common management tool that has been used as an indicator of energy status in applied settings; a 5-point scoring system is generally used for dairy cattle (Wildman et al., 1982). The management of body condition throughout the lactation cycle (including the periparturient period) can have considerable effects on postpartum reproductive performance.

Body condition should be managed so cows are not too thin at parturition; thin cows will lack the necessary energy reserves to support maximum milk production during the early postpartum period. Dietary energy density during late lactation should be adjusted to ensure that cows dry off in moderate body condition (BCS of 3.5 to 3.75; Britt, 1992). To maximize DMI and avoid severe and prolonged negative energy status during the periparturient period, fat cows should also be avoided. Cows that are obese at parturition may show symptoms of "fat cow syndrome", which has been associated with an increased occurrence of metabolic, infectious, digestive, and reproductive disorders (Butler and Smith, 1989). However, in some studies, BCS of dairy cows at parturition did not affect number of days to first observed estrus, conception rate (Wolfenson et al., 1988), number of days to first artificial insemination, number of services per conception, or number of days open (Pedron et al., 1993).

It has been suggested by some authors (Butler and Smith, 1989; Staples et al., 1990) that the decrease in postpartum BCS, which would be indicative of the degree of negative energy status, may be more closely related to reproductive efficiency than the actual BCS at parturition. An increased loss of body weight following parturition coincided with decreased ovarian activity (Staples et al., 1990) and increased number of days to conception (Heinonen et al., 1988). An increase in body condition score loss from 0.8 to 1.05 units resulted in approximately 5.5 more days to first artificial insemination (Pedron et al., 1993). Burke et al. (1997) also noted a negative

relationship between the magnitude of the postpartum change in BCS and pregnancy and conception rates on two large dairy farms in Florida. Many of the relationships between reproductive performance and BCS have been established under controlled experimental conditions. If adequate BCS field data are not collected, BCS at calving and change in BCS during the transition period may appear unrelated to reproductive parameters (e.g., calving interval, and services per conception; Heuer et al., 1999). However, BCS can be determined regularly in the field; when this is done, the relationship between early postpartum changes in BCS and reproductive performance can be demonstrated in field situations (Burke et al., 1997; Domecq et al., 1997).

The nadir of early postpartum energy status can be reached quickly if cows increase DMI (and energy intake) at a rapid rate. Researchers at Cornell University have established a relationship between the energy status nadir and an early resumption of postpartum ovarian activity, which is necessary to optimize reproductive performance (Lucy et al., 1992). In the study of Butler et al. (1981), energy status during the first 20 days postpartum was correlated negatively ($r = -0.60$) with the number of days to first ovulation. In this study, cows ovulated an average of 10 days after negative energy status nadir; during this time most cows were still experiencing negative energy status. In another study (Canfield and Butler, 1990), negative energy status nadir, but not average daily energy status during the first 14 days postpartum, was correlated with the number of days to first postpartum ovulation. Finally, Canfield

and Butler (1991) and Beam and Butler (1997) reported correlations ($r = 0.85$ and $r = 0.55$, respectively) between the number of days postpartum to negative energy status nadir and the number of days to the first ovulation.

Managing DM and energy intake prepartum, so that postpartum increases in DMI are large and occur rapidly, should be emphasized in transition cow feeding. This will help to ensure that cows do not lose excessive body condition during the early postpartum period and that energy status nadir is obtained quickly and is of limited magnitude. Subsequently, reproductive performance should be improved.

Nutritional Manipulation to Support Improved Reproductive Performance

The energy consumed by a dairy cow will be a function of both the energy density of the diet and the amount of DM consumed; we can attempt to manipulate each of these. Also, the source of energy provided to transition cows may influence reproductive performance independent of energy status, which will also be discussed below.

Dry matter intake. Optimal management of cows during the transition feeding period is necessary to maximize DMI. Management factors to optimize DMI of transition cows have been reviewed (Drackley, 1997; Grant and Albright, 1995). Briefly, competition among transition cows for feed should be minimized (adequate bunk space and grouping strategies can help minimize competition) and bunks should be cleaned and fresh feed provided often.

Changes in DMI by cows fed *ad libitum* are often related to changes in dietary source and concentration of energy. Generally, the goal of transition cow management programs has been to maximize DMI (Drackley, 1997; Grummer, 1995). However, some recent research suggests that this approach should be critically evaluated with regard to effects on energy status and change in energy status (and subsequent BCS) during the periparturient period, which can be related to reproductive performance as discussed above. Grum et al. (1996) attempted to increase the energy status of prepartum cows by including fat in the diet for the entire dry period (approximately 60 days). All cows were adapted to their lactation diet during the final week prepartum. Cows fed fat actually consumed less DM than cows fed an isocaloric control diet (0.65 Mcal NE_L/lb of DM) or a control diet designed to maintain prepartum BCS (0.58 Mcal NE_L/lb of DM). As a result of the decreased DMI, cows fed fat experienced a gradual loss of body condition during the prepartum period, indicating that they were experiencing negative energy status. However, compared with cows not fed fat, cows fed fat during the dry period did not experience as rapid a decline in DMI during the 2 to 3 days prior to calving. Also, DMI numerically increased between the day before parturition and the day after parturition for cows fed fat; DMI numerically decreased during this period for all animals not fed fat. Finally, plasma concentrations of NEFA did not increase as much around the time of parturition for cows fed fat compared with those of cows not fed fat. Each of these measurements suggest that although cows fed fat experienced negative energy status during

the dry period due to low DMI, they experienced a higher energy status during the days immediately pre and post calving. This may have helped these cows avoid a severe negative energy status nadir, which could improve their subsequent reproductive performance. It should be noted that the cows that lost body weight were not obese at the beginning of the dry period (BCS \approx 3.25). Therefore, they do not represent fat cows that were fed to reduce BCS during the dry period, which should be avoided (Nocek, 1995).

Results from the study of Grum et al. (1996) could be attributed to the reduced DMI of cows fed fat or to the fat in the diet. In a subsequent study, researchers at the University of Illinois (Douglas et al., 1998) limited intake of diets that did not contain fat to 80% of the NE_L requirements during the dry period; cows were fed ad libitum following parturition. The diets contained 0.65 Mcal NE_L /lb of DM and were fed to cows that were not obese at dry-off (BCS \leq 3.5). Cows that were limit fed prior to calving experienced a less dramatic decrease in DMI prior to parturition (J. Drackley, Univ. of Illinois, personal communication), greater DMI during the first 21 days postpartum, and a decreased rate of decline in BCS postpartum than did cows fed ad libitum prepartum. This suggests that early postpartum energy status was improved by limit feeding during the prepartum period.

Although limit feeding during the dry period appears to have the potential to improve early postpartum energy status, the long-term effects of this practice require further research. In the study of Grum et al. (1996), cows that ate less DM and

experienced a more negative energy status during the dry period did not decrease milk yield. How would cows that were obese or thin at dry-off respond to restricted intakes? Would high producing cows be able to maintain adequate body condition over a lifetime if they were not allowed to gain weight during the dry period? Could some of these possible negative aspects of limit feeding negate any positive effects on postpartum reproductive performance that might be expected due to an increased energy status early postpartum?

Rukkwamsuk et al. (1999) published a study that clearly demonstrates the potential for negative responses to maximizing DMI in dry cows. Although BCS at dry-off and at calving were not reported for this study, cows were fed ad libitum a diet containing 0.72 Mcal/lb of DM to gain body condition or were restricted to 31 lb/day of DMI of a diet containing 0.48 Mcal/lb of DM to maintain body condition. Cows were fed the treatment diets throughout the dry period. Cows fed to increase body condition gained 176 lb during the dry period; this would correspond to approximately 1.5 BCS points on a 5-point scale. Cows that were fed to maintain body condition gained 40 lb during the dry period, which would correspond to less than 0.5 BCS points on a 5-point scale. During the dry period, cows that were limit fed consumed less DM (23.8 lb/day; note that they were offered 31 lb/day of DM) than cows fed the high energy diet ad libitum (38.8 lb/day). However, during the first 5 weeks postpartum, cows that were fed to gain body condition during the dry period consumed less DM (43.7 lb/day) than cows fed to maintain body condition (50.9 lb/day).

Cows fed the high energy diet during the dry period had higher plasma NEFA and β -hydroxybutyrate concentrations and increased loss of body weight during the early postpartum period, suggesting that they were experiencing a more severe negative energy status.

Dietary nonfiber carbohydrate. The examples discussed above demonstrate that prepartum DMI has the potential to influence reproductive performance by altering energy status during the transition period independently (Douglas et al., 1998) and dependently (Grum, 1996; Rukkwamsuk et al., 1999) of changes in diet composition. Dietary nonfiber carbohydrate (NFC) is often increased and dietary forage to concentrate ratio decreased in an attempt to increase dietary energy density and improve energy status. This practice does not always have the negative effects that were observed by Rukkwamsuk et al. (1999) and discussed above. For example, in the study of Grum et al. (1996) that is described above, BCS and body weight loss during the early postpartum period were not affected by decreasing the forage to concentrate ratio in diets that contained no supplemental fat.

Minor et al. (1998) fed standard (23.5%) or high (43.8%) NFC diets to cows for 19 days prepartum, followed by standard (41.7%) or high (46.5%) NFC diets for the first 30 weeks postpartum. The prepartum diets contained 0.61 or 0.74 Mcal NE_L/lb of DM for the standard or high NFC diets, respectively. Cows fed the high NFC diet prepartum had a more dramatic decrease in DMI (approximately 5.5 lb) during the final three days prepartum than cows fed the standard NFC diet (approximately 2.0 lb). However, cows fed the high NFC diet

prepartum were in positive energy status throughout the prepartum period; cows fed the low NFC diet experienced negative energy status the final six days prepartum. The NFC level did not affect postpartum DMI. However, because milk yield tended to increase more rapidly early postpartum for cows fed the high NFC diet postpartum, these cows experienced a decreased energy status. If the positive energy status during the late dry period in cows fed the high NFC diet will improve reproductive performance enough to offset any negative effects on reproductive performance resulting from the decreased energy status of these cows during the early postpartum period is not known. Perhaps the decreased energy status in the early postpartum cows could have been avoided if they were not fed a diet containing minimal (21.8%) NDF immediately postpartum; adequate fiber is critical for transition cows (Drackley, 1997).

Boisclair et al. (1986) fed cows to provide 100, 130, and 160 % of their energy requirements (as estimated by NRC, 1978) for eight weeks prior to parturition. Energy intake was manipulated by adjusting the amount of DM offered and the forage to concentrate ratio of the diet. The amount of body condition gained (estimated by BCS) during the dry period increased linearly as energy intake increased. All cows started the dry period at similar BCS (i.e., 3.35) BCS at the end of the dry period were 3.38, 3.73, and 3.99 for cows eating 100, 130, and 160 % of their energy requirement. Cows fed 100% of their energy requirement lost body condition until four weeks postpartum and then began to gain body condition; all other cows lost body condition until at least eight weeks postpartum. This suggests that

overfed cows reached a negative energy status nadir later than control cows following parturition. These results may differ from those of Miner et al. (1998) because Boisclair et al. (1986) fed the treatment diets throughout the dry period. This may have allowed these cows (Boisclair et al., 1986) to become too fat prior to parturition.

Propylene glycol is a source of NFC that is often used in dairy cattle to treat ketosis; propylene glycol may stimulate reproductive performance because of its effects on plasma insulin and insulin-like growth factor-1 (**IGF-1**) concentrations. Both insulin and IGF-1 can influence ovarian function (Pate, 1999; Poretzky and Kalin, 1987) and are positively correlated with energy status in early postpartum cows (Beam and Butler, 1998; Spicer et al., 1990).

Formigoni et al. (1996) fed 10.6 oz of propylene glycol with a diet containing 0.64 Mcal NE_L/lb of DM to dairy cattle from 10 days before the expected calving dates until parturition. In another treatment group, cows received 10.2 oz of propylene glycol in a 1.0 L drench on days 3, 6, 9, and 12 postpartum; the postpartum diet contained 0.77 Mcal NE_L/lb of DM. Compared to control cows (given no propylene glycol), treated cows experienced a less rapid decline in BCS during the first 15 days postpartum, higher IGF-1 and similar insulin concentrations in plasma during the first 50 days postpartum, and a lower percentage of acyclic cows at 96 days in milk. Unfortunately, these authors (Formigoni et al., 1996) did not report DMI. Burhans and Bell (1998) dosed cattle with 17.6 oz/day of propylene glycol in 2 equal oral drenches

from 21 days before expected calving to 21 days after calving; the prepartum and postpartum diets contained 0.72 and 0.76 Mcal NE_L/lb of DM, respectively. During this periparturient period, DMI was not reduced and plasma NEFA concentrations were reduced by propylene glycol; plasma insulin concentrations were not reported. These authors (Burhans and Bell, 1998) also attempted to feed a mixture of soluble sugars and Ca-propionate (5.6 lb/day as part of a TMR) as glucose precursors and did not see any response in plasma NEFA concentrations.

Researchers at the University of Wisconsin have actively studied the use of propylene glycol in transition cows. Studer et al. (1993) reported that a 1.0 L oral drench of propylene glycol given daily for approximately 10 days before calving did not affect DMI. Plasma insulin concentrations were higher and similar during the prepartum and early postpartum periods, respectively, for treated cows relative to control cows. However, plasma NEFA concentrations were lower for the treated cows during both the prepartum treatment period and the early postpartum period. Because daily drenching with propylene glycol is inconvenient, Christensen et al. (1997) investigated the effect of propylene glycol delivery method on plasma NEFA and serum insulin concentrations in feed-restricted cattle; cattle were not in the transition period (average 82 days from expected calving). Propylene glycol (approximately 11.8 oz/day) was administered once each day for 7 days as an oral drench, as a component of a concentrate mixture that was fed separately from forage, or as part of a total mixed ration. The

authors concluded that oral drenching and mixing propylene glycol with the concentrate portion of the diet were more affective at increasing serum insulin and reducing plasma NEFA concentrations than mixing propylene glycol with the TMR. However, these conclusions were based on short term (320 min) responses after feeding and may not represent effects over the entire transition period.

Dietary fat. Feeding fat during the prepartum period has received recent attention; the study of Grum et al. (1996), which was discussed above, suggested that this might improve the energy status of the transition cow. However, Douglas et al. (1998) fed dry cows isocaloric diets with or without supplemental fat and containing 0.65 Mcal NE_L/lb of DM at ad libitum or restricted (80% of NE_L requirement) intakes during the entire dry period. These authors reported that DMI had a greater effect on the energy status of the transition cow than did the inclusion of supplemental fat. In a study at Cornell University (Burhans and Bell, 1998), cows were assigned to a high fat diet (approximately 1.8% of dietary DM as supplemental fat) or a control diet at 21 days before expected calving. Diets were adjusted regularly to maintain a constant energy intake and energy status across both treatments. When energy status was kept constant across treatments, supplemental dietary fat during the late dry period did not affect DMI or plasma NEFA concentrations during the transition period. These data support the conclusion of Douglas et al. (1998) that effects due to supplemental fat during the dry period are more likely a result of changes in DMI than a direct effect of fat per se.

Providing supplemental fat in rations for lactating dairy cattle is a common practice today. Fat contains approximately three times more NE_L than corn grain (NRC, 1989); fat is included in the rations in an attempt to improve energy status. Although fat is more energy dense than concentrates, a depression in DMI (Andrew et al., 1991; Harrison et al., 1995; Jerred et al., 1990) or an increase in milk yield (Schneider et al., 1988; Sklan et al., 1989; Sklan et al., 1994) is often observed when fat is fed; this often results in no change in the energy status of the cow (Staples et al., 1991, Staples et al., 1998). However, feeding supplemental fat has changed reproductive variables independent of body weight change (Holter et al., 1992) or energy status (Lucy et al., 1992). Improved reproductive performance was observed when body weight loss was greater (Sklan et al., 1989, 1991) or energy status was lower (Sklan and Tinsky, 1993) in postpartum cows fed supplemental fat. Other studies (Carroll et al., 1990; Ruegsegger and Schultz, 1985; Schneider et al., 1988) have reported reproductive responses to supplemental fat that could at least partly be explained by changing energy status.

Staples et al. (1998) recently reviewed the effects of supplemental dietary fat during lactation on reproductive performance. Their review included reports of positive reproductive responses to feeding various supplemental fats in 11 of 18 (61%) studies; other studies cited by these authors reported no effects or negative effects of feeding fat. Most of these studies were designed to consider effects of fat on production and fat was fed for long periods of time. Therefore, these studies provided

limited direct information regarding the use of dietary fats during the early postpartum transition period as a means to enhance subsequent reproductive performance.

Energy status or change in BCS during the postpartum transition period of cows fed fat was not changed (Beam and Butler, 1998; Garcia-Bojalil et al., 1998b; Komaragiri et al., 1998; Scott et al., 1995) or was worsened (Sklan et al., 1989; Son et al., 1996). Therefore, it does not seem likely that feeding supplemental fat during this period will improve reproductive performance subsequent to a less severe, or shorter days to, negative energy status nadir. However, feeding fat to early postpartum cows has occasionally lessened the loss of body condition during the first 30 days postpartum (Beam and Butler, 1997) and can influence ovarian dynamics, which is discussed in another paper included in this conference (Pate, 1999).

Several mechanisms by which fat can influence reproductive performance independently of energy status have been proposed. Feeding fat increases plasma cholesterol concentrations in dairy cattle and cholesterol is a precursor for progesterone synthesis (Staples et al., 1998). Feeding fat increased plasma concentrations of progesterone in dairy cattle (Sklan et al., 1991), which suggests altered ovarian function or decreased progesterone clearance from the plasma. Elevated plasma progesterone concentrations have been associated with improved reproductive performance in ruminants (Staples et al., 1998). However, the effect of supplemental dietary fat during the three weeks following parturition on plasma progesterone

concentrations during this same time period has not been elucidated.

Arachidonic acid and its precursor, linoleic acid, are found in many fat sources (Staples et al., 1998). These fatty acids are precursors for the synthesis of the two series prostaglandins, including prostaglandin $F_{2\alpha}$ (**PGF_{2α}**), which may stimulate ovarian activity during the early postpartum period (Guibault et al., 1987), decrease intervals to the second and third postpartum ovulation and to conception (Benmrad and Stevenson, 1986), and decrease the time needed to complete uterine involution (Lindell et al., 1982; Madej et al., 1984). Prostaglandin $F_{2\alpha}$ production needs to be suppressed to maintain the corpus luteum and allow for the maintenance of pregnancy; this is a highly regulated process in the lactating dairy cow (Thatcher et al., 1994). Several fatty acids (e.g., arachidonic, linoleic, oleic, linolenic, eicosapentaenoic, docosahexaenoic, and eicosatetraenoic acids) can influence the production of prostaglandins (Gurr and Harwood, 1991; Jenkins, 1988; Oldick et al., 1994; Smith and Marnett, 1991).

Limited data from cattle have demonstrated that supplemental fat can influence $PGF_{2\alpha}$ or 13, 14 dihydro-15 keto prostaglandin $F_{2\alpha}$ (**PGFM**) production; PGFM is the primary metabolite of $PGF_{2\alpha}$. Oldick et al. (1997) found that cows receiving abomasal infusions of yellow grease, which is about 17% linoleic acid, produced less PGFM than cows infused with water, glucose, or tallow. Rice bran, which is approximately 15% fat, was used to add fat to the diet of Brahman cows; cows receiving rice bran tended to have greater peak concentrations of PGFM than cows fed

the control diet (Lammoglia et al., 1997). Each of the above studies (Lammoglia et al., 1997; Oldick et al., 1997) used cows that were not experiencing the transition period of a lactation cycle. When calcium soaps of long chain fatty acids were fed to cows for the first 60 days postpartum, no effect of fat on PGFM dynamics was reported (Lucy et al., 1991). Other researchers fed diets varying in the ratio of linoleic to linolenic acid (0.35 versus 2.22) from four weeks before parturition to one week after parturition (Kemp et al., 1998); plasma PGFM concentrations were not affected by treatment.

Summary and Conclusions

To optimize reproductive performance in dairy cattle, negative energy status during the transition period must be limited in magnitude and duration. Feeding diets that contain higher concentrations of energy than recommended by the NRC (i.e., > 0.57 Mcal NE_L /lb DM) to prepartum cows during the final three weeks before calving can help to achieve this goal. Dietary energy concentrations as high as 0.73 Mcal NE_L /lb of DM have been fed successfully. Concentrations of energy greater than this (Cameron et al., 1998) and long term feeding (i.e., > 3 weeks) of these diets during the dry period should be avoided to avoid over conditioned cows at calving. The magnitude of negative energy status can be limited during the transition period by limit feeding cattle or by adding a dietary fat source throughout the dry period during the close-up dry period to reduce DMI for the entire dry period. However, this approach is not recommended because the implications

of this approach on the long-term health of the cow have not been investigated.

Based on a limited amount of research, the addition of glucose precursors to transition diets may reduce the magnitude of the decline in plasma insulin concentrations around parturition and improve early postpartum reproductive performance. Glucose precursors also have the potential to decrease the risk of other health disorders (e.g., ketosis and fatty liver; Burhans and Bell, 1998; Drackley, 1997). Therefore, it seems prudent to include propylene glycol in transition cow diets. Glucose precursors other than propylene glycol require further research; a link between other glucose precursors and potential improvements in reproductive performance has not been established. Positive responses to propylene glycol are observed when dietary energy levels are higher than NRC recommendations (Burhans and Bell, 1998; Formigoni et al., 1996; Studer et al., 1993). Therefore, responses to propylene glycol may be observed when dietary NFC levels are increased, which would increase ruminal propionate production; propionate is a glucose precursor.

Feeding fat during the first few weeks postpartum generally does not improve the energy status of dairy cattle. Although mechanisms of action for effects of feeding fat immediately postpartum on reproductive performance have been developed, data from the transition period to support these hypotheses are lacking. For these reasons, and because of the potential to decrease DMI by adding fat to diets, feeding fat to cows immediately postpartum is not

recommended as a means to improve reproductive performance.

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Table 1. Metabolic signals that have been suggested as links between negative energy status and reproductive performance.

Metabolic Signal	Comments	Reference
NEFA ^a	Negatively correlated with energy status.	Canfield and Butler, 1991 Beam and Butler, 1998
Glucose	Relationship may be better explained by related insulin responses.	Butler and Smith, 1989
Insulin	Positively correlated with energy status. May act synergistically with LH ^b or FSH ^c .	Canfield and Butler, 1990 Beam and Butler, 1998 Poretsky and Kalin, 1987
IGF-1 ^d	Positively correlated with energy status. Propylene glycol administration increased plasma IGF-1 and decreased the duration to resumption of estrous activity.	Spicer et al., 1990 Beam and Butler, 1998 Formigoni et al., 1996
Opioids	Increased as part of the mechanism to increase appetite. Suppressed LH secretion in some but not all studies.	Butler and Smith, 1989 Mahmound et al., 1989 Canfield and Butler, 1991
Leptin	Leptin or leptin receptor deficient rodents have low fertility. Plasma leptin is decreased when cattle are underfed.	Houseknecht et al., 1998 Chilliard et al., 1998

^aNon-esterified fatty acids.

^bLuteinizing hormone.

^cFollicle stimulating hormone.

^dInsulin-like growth factor

Effects of Energy Balance on Ovarian Function

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Abstract

During the postpartum period, the reproductive system is in a state of rapid change. Immediately after calving, the uterus must begin the process of involution and the hypothalamic-pituitary-gonadal axis must be 're-set'. When the corpus luteum of pregnancy regresses, the ovaries may become somewhat quiescent until significant follicular development takes place. As lactation increases, the metabolic demands for energy are elevated, causing high producing cows to enter a state of negative energy balance. This state may be detrimental to ovarian function, either via direct effects of metabolites on the ovaries or via alteration in release of pituitary gonadotropins. In this paper, the effects of negative energy status on development and ovulation of ovarian follicles, as well as on function of the corpus luteum, will be discussed. An important aspect of this relationship is the time of the most negative energy balance, called the nadir. The correlation between the energy balance nadir, ovarian function, and fertility will be reviewed.

During the second half of this century, there has been a considerable increase in average milk production by dairy cows in the U.S. This can be attributed to genetic selection for high producing cows, improved nutrition for milk production, and new management practices. Unfortunately, the positive effects on milk production have coincided with a decline in fertility. Conception rates in dairy cows prior to about 1970 averaged 55% but have dropped to the present average conception rate of 45%. Although lower fertility is correlated to high milk production, reproductive performance seems to be more directly influenced by energy balance (**EB**) status in the transition cow. Thus, it is important to understand both nutrient balance and reproductive events in high producing dairy cows during the postpartum period, as well as how nutritional and reproductive management systems can be integrated to optimize fertility.

Introduction

Endocrine and Ovarian Events in the Postpartum Cow

The development and function of ovarian structures (follicles and corpora

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lutea) are primarily under the control of the gonadotropins, follicle stimulating hormone (**FSH**) and luteinizing hormone (**LH**). These glycoproteins are released from the anterior pituitary gland in response to the hypothalamic hormone, gonadotropin releasing hormone (**GnRH**). The initiation or resumption of ovarian cyclicity is characterized by increased pulse frequency and amplitude of FSH and LH releases, resulting in development of follicles on the ovary. As follicles mature, they produce estradiol, which can further modulate FSH and LH release from the pituitary. When threshold concentrations of estradiol are reached, there is a positive feedback to the hypothalamus which results in a surge release of GnRH and LH. The LH surge causes ovulation of the dominant ovarian follicle and differentiation of the follicular cells into the corpus luteum (**CL**). The CL produces progesterone, which is necessary to maintain pregnancy. When the CL is fully active, the high concentrations of progesterone will suppress gonadotropin release and thus inhibit further follicular maturation. If a viable embryo is not present, the uterus will produce large amounts of prostaglandin (**PG**) $F_{2\alpha}$, which causes regression of the CL, allowing a new follicle to mature and ovulate. The coordinated release of gonadotropins and ovarian steroids results in repeated estrous cycles, until the presence of a viable embryo alters $PGF_{2\alpha}$ release and prevents regression of the CL. It is important to understand that metabolic changes associated with nutritional parameters may affect reproduction at any of these levels, and it is difficult to determine whether effects are exerted directly on the ovary or indirectly via alteration of gonadotropin release.

The ovary of the cow contains hundreds of small, primary follicles. At any given time, a small number of primary

follicles may begin to develop and differentiate into secondary, then tertiary follicles. This early development of follicles is independent of gonadotropins, and little is known about the factors that initiate follicular growth at these stages. It takes many weeks for a primary follicle to eventually reach ovulatory size. Thus, a follicle that ovulates 1 to 3 months postpartum (at the preferred time for insemination) would have initiated early development during the period of severe negative EB. This has led Britt (1992) to hypothesize that metabolic factors associated with negative EB during early follicular development may have adverse effects on that follicle when it reaches the ovulatory stage.

Tertiary follicles are characterized by the presence of a fluid-filled antrum, allowing one to visualize them using ultrasonography. Once follicles reach 3 to 5 mm in size, they are dependent upon FSH for continued growth, while LH is primarily necessary for maintenance of the dominant follicle and stimulation of steroidogenesis (Fortune, 1994). Using ultrasonography, it has been possible to examine the dynamics of follicular development *in vivo*, and this has led to the recent understanding that in the cow, follicles develop in 'waves' (Pierson and Ginther, 1988; Savio et al., 1988; Sirois and Fortune, 1988). Shortly after ovulation, another cohort of follicles reach the tertiary stage and grow together until one of these is selected to be the dominant follicle. This dominant follicle achieves its maximum size about day 6 of the estrous cycle, and it suppresses continued development of other follicles in the cohort. Because there are increasing concentrations of progesterone produced by the CL at this time, the dominant follicle of this first wave will ultimately regress by day 7 or 8. However, a new wave of follicles

will replace the first one very quickly and a similar pattern of follicular selection and dominance is observed. In some estrous cycles, the dominant follicle of this second wave may become the ovulatory follicle when luteal regression occurs. In other cycles, this follicle will regress and the ovulatory follicle will result from a third or perhaps even fourth wave of follicular growth.

At the time of parturition, there are essentially no follicles > 5 mm on the ovaries. While gonadotropin concentrations will gradually increase to support follicular development, Canfield and Butler (1990) demonstrated that LH concentrations remain low until the EB nadir is reached. As EB begins to move in a positive direction, LH begins to increase. The period of negative EB is also characterized by low concentrations of plasma insulin and insulin-like growth factor-1 (**IGF-1**), and high concentrations of non-esterified fatty acids (**NEFA**). Metabolic status typical of the transition period has been discussed in detail elsewhere in this Proceedings by Dr. Bradley Oldick.

Follicular Development and Function

In vitro cultures of granulosa and theca cells have been used to determine factors that directly influence the steroidogenic capacity of follicles. Using these models, it is clear that insulin is a potent stimulator of both proliferation and function of follicular cells (Spicer et al., 1993a). In the same study, it was found that IGF-1 had stimulatory effects similar to insulin. Thus, one may extrapolate that optimal follicular development would only occur in the presence of adequate concentrations of insulin and/or IGF-1. Indeed, as mentioned above, both of these

compounds are low during the postpartum period.

A number of studies in various laboratories have been conducted in an attempt to sort out the metabolic parameters that influence follicular development and function in postpartum dairy cows. Beam and Butler (1997) found that in all cows examined, a wave of follicular development commenced during the second week postpartum that was characterized by emergence of a large dominant follicle. The fate of the dominant follicle fell into one of three categories. In 42% of the cows, the dominant follicle of the first follicular wave postpartum ovulated. However, in 40% of the cows, the first dominant follicle regressed, and this was followed by continued development of nonovulatory dominant follicles. The third category was characterized by persistence of the first dominant follicle, which developed into a cyst. This occurred in 18% of the cows. The days from parturition to first ovulation were increased in the latter two groups of cows from an average of 20 to 50 days. The dominant follicles in ovulating cows produced more estrogen and reached a larger maximum diameter than the dominant follicles in non-ovulating cows. One of the most interesting findings was that the number of days to the EB nadir was significantly less in cows that ovulated the first dominant follicle than in those that did not. In fact, 75% of dominant follicles that matured after the EB nadir ovulated, whereas only 24% of those maturing prior to the EB nadir ovulated. Therefore, it appears that the number of days to the EB nadir is an important factor in determining return to cyclic ovarian function.

Development of ovulatory follicles is also related to insulin and IGF-1 concentrations in postpartum cows. Plasma

concentrations of insulin and IGF-1 were both higher, but growth hormone was lower in cows that had ovulatory follicles versus cows that did not ovulate the first dominant follicle (Beam and Butler, 1997; 1998). These findings support those from other laboratories where it was shown that higher concentrations of plasma IGF-1 were associated with earlier occurrence of CL development (Thatcher et al., 1996) and total progesterone concentrations in postpartum cows (Spicer et al., 1990). Plasma concentrations of IGF-1 are positively correlated to energy status (Spicer et al., 1990; Spicer et al., 1993b), and an acute reduction in energy status is associated with a decrease in IGF-1 and reduced follicular growth rate (Lucy et al., 1992). It is possible that insulin and/or IGF-1 are necessary for maximal responsiveness of follicles to the stimulatory effects of FSH and LH.

There have been a number of studies to determine if feeding supplemental fat to dairy cows would result in enhanced follicular development and/or fertility. Although the results have varied, there generally seems to be a positive effect of fat supplementation on number and size of large ovarian follicles, even though high fat diets can decrease plasma insulin (Choi and Palmquist, 1996). This has been recently reviewed in detail by Staples et al. (1998). Beam and Butler (1997) fed three levels of fat, 3.3 (control), 5.2, and 7.1% of dietary DM. They found that the interval to first ovulation was decreased for cows fed 5.2% fat but not for those fed 7.1%. It is possible that there is a narrow margin of fat supplementation that will enhance follicular development. Lucy et al. (1991) fed Ca soaps of long chain fatty acids to cows and observed an increase in the diameter of the largest and second largest follicles but no change in LH secretion. This may be

evidence for a direct role of nutrition on the ovary (independent of gonadotropins), but neither FSH nor IGF-1 was measured in that experiment. In contrast, Beam and Butler (1998) were unable to affect follicle diameter or ovulation by feeding prilled fatty acids but did demonstrate that ovulation failure is related to a delayed EB nadir and lower plasma IGF-1. The reported positive or negative effects of feeding supplemental fat on ovarian function may be related to whether or not there is an alteration in IGF-1 or the time to the EB nadir.

Nutritional effects on follicular development and function may be dependent on prior body condition and energy status of the cow, as well as the stage of follicular development in which feed supplements are administered. Jolly et al. (1995) have proposed that moderate levels of undernutrition, analogous to moderate negative EB in the postpartum cow, may affect final maturation of dominant follicles, rendering them less than maximally functional and often preventing ovulation. More severe and prolonged undernutrition may affect earlier development of follicles. In this case, few or no follicles greater than 5 mm in diameter would be present on the ovaries. This latter effect is developmental, rather than an effect on the steroidogenic capacity of those follicles. It seems logical that animals representative of these two situations would respond very differently to nutritional treatments.

Corpus Luteum Function

The corpus luteum in the cow is dependent upon LH for maximal development and progesterone output. Luteal cells are some of the most

metabolically active cells in the body, requiring large amounts of precursor and ATP for steroidogenesis. There is little evidence that energy sources and precursors are normally limiting for luteal function, perhaps because of the high rate of blood flow to this tissue. However, *in vitro* studies have shown that continued steroidogenesis by luteal cells requires both insulin and an exogenous source of cholesterol. Luteal cells require insulin in order to respond to LH with an increase in progesterone (Poff et al., 1988). Similarly, steroidogenesis is enhanced by IGF-1 (Sauerwein et al., 1992), but it is difficult to discern the effects of circulating IGF-1 from locally produced IGF-1, because IGF-1 mRNA and protein are expressed in the bovine CL and are in highest concentrations during mid-cycle (Einspanier et al., 1990.).

Progesterone is synthesized in luteal cells from the precursor, cholesterol. Luteal cells can synthesize cholesterol *de novo* from acetate, derive cholesterol from cholesteryl ester stores within the cell, or acquire cholesterol from circulating lipoproteins. Pate and Condon (1982) demonstrated that bovine luteal cells could use either low density lipoproteins (**LDL**) or high density lipoproteins (**HDL**) as a source of cholesterol, and that maximal progesterone production required the presence of lipoproteins. The majority of the cholesterol used for progesterone production is derived from serum lipoproteins, and since HDL is the predominant source of lipoprotein in the cow, it is likely that HDL is the major source of substrate for luteal steroidogenesis (reviewed by Grummer and Carroll, 1988). Since HDL is rarely limiting in healthy cows, small increases in serum cholesterol due to feeding supplemental fat have only minor effects on serum progesterone (reviewed by Staples et al., 1998). Little to no effect on progesterone

synthesis would be expected to occur in response to acute decreases in serum cholesterol, because luteal cells can use stored cholesterol for immediate conversion to steroid. However, prolonged depletion of circulating cholesterol would likely have a negative impact on progesterone production.

Energy balance and/or body condition may affect the function of the CL in postpartum cows. Cows that lost body condition during the first 5 weeks postpartum had lower plasma progesterone during the third to fifth estrous cycles than cows that had gained body condition (Britt, 1992). Similarly, cows in more severe negative EB had lower plasma progesterone in the second and third cycles than cows in less severe negative EB (Villa-Godoy et al., 1988). Finally, cows that consumed diets supplemented with selenium exhibited significantly higher progesterone concentrations in the postpartum period than selenium deficient cows (Kamada and Hodate, 1998). Although the majority of studies on nutritional effects have focused on the follicle, there may be significant effects of nutrients on the function of the CL. Given the pivotal role of the CL in support of pregnancy and that pregnancy rates are correlated to progesterone concentrations, this is an area of investigation that may warrant further attention.

Relationship of Ovarian Responses to Fertility

In most studies where nutritional effects on follicular or luteal function are observed, there is also a positive influence on fertility. The first postpartum ovulation usually results in the formation of a short-lived CL and a short estrous cycle. These cycles are essentially infertile. Fertility increases with an increased number of

estrous cycles postpartum, perhaps due to a progesterone priming effect. Therefore, it is advantageous for the animal to have completed a number of estrous cycles prior to the time of insemination. This is most likely to occur if the first dominant follicle postpartum ovulates. From the studies previously discussed, it seems that this will most likely be accomplished if the EB nadir is reached very early or if the metabolism of the cow can be altered to produce metabolic changes similar to those observed after the EB nadir.

Drs. Miyoshi and Palmquist at The Ohio State University used propylene glycol administration on days 7 to 42 postpartum to increase circulating concentrations of insulin, which would otherwise occur after the EB nadir (Miyoshi et al., 1995). Although average insulin was not significantly altered by treatment, there were transient rises in plasma insulin shortly after each treatment. In this study, there were few significant differences in reproductive parameters because of low numbers of animals (18 per treatment group), but there was a trend toward earlier days to first ovulation in the treated animals. Perhaps most interesting was the finding that the treated animals did not experience a short luteal phase during the first estrous cycle, as did the controls, providing longer progesterone priming. The conception rates at first artificial insemination were 25% in the control cows and 57% in the propylene glycol-treated cows. This study has led to current experiments at this institution that are aimed at altering metabolites during defined periods of follicular development and determining subsequent effects on fertility.

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Supplemental Biotin for Dairy Cattle

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Abstract

Biotin, a water-soluble vitamin, is essential for normal formation and integrity of skin, hair, hooves, and fingernails. Biotin is a co-factor in several important enzymes involved in carbohydrate, fat, and amino acid metabolism, including the rumen synthesis of propionic acid. Fiber digesting bacteria of the rumen require, but do not synthesize, biotin. Ruminal bacteria involved in the synthesis of biotin appear to be sensitive to low pH; therefore, high grain levels in the ration reduce rumen synthesis of biotin. Supplementary biotin has been shown to reduce the incidence of several common hoof disorders in swine, horses, and cattle. Feeding 20 mg/day of supplemental biotin to dairy and beef cows has resulted in reduced incidence of hoof lesions and increased milk production.

Introduction

Functions and Bioavailability of Biotin. Biotin, a water soluble ("B") vitamin, is essential for the formation and integrity of the keratinized tissues (skin, hair, fingernails, hooves, and footpads) in mammals and birds (Maynard et al., 1979). Originally, biotin was named "Vitamin H" after "Haut", the German word for skin. Biotin exists in both the D- and L-isomers, but only the D- isomer is biologically active.

High grain (> 50% of DM) rations reduce ruminal synthesis of biotin in vitro

(DaCosta-Gomez et al; 1998). Feeding supplemental biotin to dairy cattle increases biotin levels in blood and milk in relation to biotin intake (Steinberg et al., 1994; Steinberg et al., 1995).

The bioavailability of supplemental biotin in dairy heifers was estimated at 48% with a half life in the body of 5 to 18 hours (Frigg et al., 1993). In a subsequent study with mature cows, these authors reported a bioavailability of 50 to 60% from a single oral dose of biotin and a half-life of 8 hours for intravenous administration (Frigg et al., 1994). This study also estimated a net uptake of 2.5 mg/day of biotin from both feed and ruminal synthesis. Net biotin absorption of 0.5 to 2.0 mg/day was estimated in studies with steers (Miller et al., 1986). Both plasma biotin concentration ($R^2=0.91$) and milk biotin output ($R^2=0.92$) are linearly related to supplemental biotin intake (Klunter and Steinberg, 1993). Serum biotin is higher in dry cows than in lactating cows (Klunter and Steinburg, 1993).

Varying proportions of biotin in feedstuffs is covalently bound and unavailable for digestion and absorption (Bonjour, 1991, Mock, 1990). Typically lactating cows consume 2 to 5 mg/day of total biotin from common feedstuffs, with varying bioavailability. Biotin is also bound by strepavidin, a glycoprotein produced by Streptomyces bacteria and some species of Saccaromyces yeast associated with spoiled

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or contaminated feedstuffs. This compound closely resembles avidin, the glycoprotein of egg-white long known to produce biotin deficiency symptoms when fed to animals in large amounts. Rancidification of dietary fat destroys biotin activity. High intakes of unstable, unsaturated fats can produce biotin deficiency in monogastric animals (McDowell, 1989). Several antimetabolites of biotin exist in nature. One of the more potent anti-biotin compounds is alpha-dehydrobiotin, produced by strains of *Streptomyces* bacteria and the yeast, *Saccharomyces lydicus* (Bonjour, 1991).

Biotin is a required co-factor in several important carboxylase enzymes. Biotin is required for the conversion of dietary carbohydrates to propionic acid by ruminal bacteria (Milligan et al., 1967) and for the re-conversion of propionic acid to glucose by the ruminant liver. Biotin also plays a key enzymatic role in fatty acid synthesis, including the production of the essential fatty acids and is required for metabolism of branched-chain amino acids and protein synthesis. Supplemental biotin is effective in normalizing blood glucose concentrations in human diabetics, probably through a stimulation of glucokinase activity in the liver (Mock, 1990). Rapidly growing broiler chicks can develop a fatty liver and kidney syndrome (FLKS) which is responsive to supplementary biotin (McDowell, 1989).

Biotin is required for the differentiation and keratinization of epidermal tissues that produce hoof horn, fingernails, and skin. Biotin deficiency was first recognized by a progressive loss of skin and footpad integrity. Biotin deficiency in calves results in production of soft, weak hooves due to a loss of both keratinization and cementing of the hoof horn (Budras et al., 1997). Supplemental biotin (2.5

mg/day) has been used successfully to treat human patients with brittle fingernails (Hochman et al., 1993).

Biotin and Hoof Integrity

Biotin has been shown to be a limiting nutrient for hoof horn integrity in swine (Bryant et al., 1985), horses (Geyer and Schulze, 1994; Josseck et al., 1995; Zenker et al., 1995) and most recently in dairy and beef cattle. In the last six years, a total of 10 controlled research trials have been completed with dairy and beef cattle showing a 30 to 80% reduction in the incidence of several common hoof lesions in response to feeding 10 to 20 mg/day of biotin. Biotin was fed continuously and significant changes in hoof lesions were reported after 3 to 12 months depending on the type and location of the lesions. For example, the hoof wall, or casing, grows from the coronary band downward, a process that takes 12 months in dairy cows (Blowey, 1992). The white line, the junction between the hoof wall and sole horn, is regenerated every 60 to 90 days (Budras et al., 1996). Sole horn is renewed in 4 to 6 months and heel horn in 6 to 8 months. In general, the response time of hoof disorders in the research studies has corresponded to the approximate growth rate of the hoof region affected when 20 mg/day of biotin was fed. Digital dermatitis lesions were reported to be reduced in two studies. The response time varied from 2 to 8 months which points out the complex nature of this infectious disease (Shearer et al., 1998). The effect of biotin on this disorder would be on skin integrity and not an antibacterial role or "treatment".

Hoof lesions are largely the result of the production of poor quality hoof horn (Budras et al., 1997). The production of normal horn by the epidermis is dependent on the supply of essential nutrients. This in turn depends on the concentration of

nutrients in the blood supply and the normal circulation of blood within the hoof. Compounds produced during rumen acidosis (lactic acid, histamine, and endotoxins) appear to disrupt the normal blood flow in the hoof (Blowey, 1992), although a direct relationship between rumen pH and the incidence of hoof lesions has not been demonstrated (Nocek and Young, 1998). Biotin is essential for two key processes in hoof horn formation by the epidermis: 1) the differentiation of horn cells with production of the full complement of keratin proteins that give the horn cells internal structure and stability and 2) the production of the intracellular cement that is secreted by the epidermal cells to cement together the hoof horn cells like bricks in a wall (Budras et al., 1997). Both of these are critical factors in hoof horn integrity and its function as a semi-waterproof barrier.

How Serious are Hoof Disorders?

The dairy industry has been reluctant to accept the magnitude of hoof disease, although digital dermatitis (hairy heel wart) has brought the issue to a head on many farms. Economic figures provided by Dr. Chuck Guard of Cornell University show that actual treatment costs amount to only 6.7% (\$23) of the total cost of \$346 per case of lameness. The major costs of lameness are increased culling (51% of total cost), followed by milk loss (20%), and increased days open (16%). A 10% incidence of lameness translates into a cost of \$.10 per milking cow per day over an average of 346 milking days per calendar year. A 30% incidence equates to a cost of \$.30 per milking cow per day. Put this way, it is clear that the cost of doing nothing about hoof health is high. There is clearly great potential economic return from adopting a comprehensive hoof health management program, including preventative hoof trimming by a professional hooftrimmer and

the active participation of the herd manager, veterinarian, and nutritionist. Hoof health is clearly related to cow comfort and environment, sanitation, nutritional and feeding management, and overall herd health. Managing hoof health provides a means of integrating these key areas of herd management using the hoof as a "barometer".

Response of Hoof Disorders to Supplemental Biotin

Sole Ulcer and Heel Horn Erosion.

A controlled field study of 180 dairy cows (Hagemeister and Steinberg, 1996) reported that cows fed 10 mg/day supplemental biotin exhibited a significant reduction in the incidence of sole ulcer and heel horn erosion over a 2-year period. Days open were reduced in the biotin group during the second year. As will be discussed below, response time of similar hoof disorders was more rapid (6 to 10 months) when 20 mg/day of biotin was fed continuously.

White Line Separation. A controlled clinical study was conducted using 100 first-lactation heifers on a large, commercial dairy herd in Ohio (Midla et al., 1998). Heifers were fed either 0 or 20 mg/day of supplemental biotin from calving through the first lactation. Biotin supplementation resulted in a significant reduction in white line separation by 100 days in lactation and a significant increase in 305-day milk production (693 lb).

Digital and Interdigital Dermatitis (Hairy Heel Warts and related disease). A controlled, clinical trial with 56 dairy cows over 11 months found that 20 mg/day supplemental biotin resulted in a significant reduction in the incidence of digital

dermatitis and sole bruising (Distl and Schmid, 1994). Similar results were found in a randomized clinical field trial with 40 dairy cows where 20 mg/day of biotin resulted in a reduction in the incidence of digital dermatitis over an 8 to 12 month period (Hochstetter, 1998).

Healing of Sole Ulcer. A clinical field study of 236 claw lesions with exposed corium in 160 cows in 82 dairy herds found that cows fed 20 mg/day of biotin experienced significantly better healing of the lesions (Lischer et al., 1996). A regression analysis of the data found a highly significant linear relationship between serum biotin concentration and the rate of new horn formation over the lesions. A recent study (Hochstetter, 1998) reported that supplemental biotin resulted in increased keratinization and cementing hoof horn and an increase in biotin concentration in the live epidermis (horn forming) tissue layer of the hoof.

Vertical Fissures and Horizontal Ridging of the Hoof Wall. A controlled field study of 265 purebred Hereford cows with a 37% incidence of vertical fissures (sand cracks) of the hoof wall found that supplementing a balanced mineral program with 10 mg/day of biotin resulted in a 50% reduction in the incidence of new vertical fissures (Campbell et al., 1999). A controlled study of 100 dairy cows in Washington State reported that 20 mg/day of supplemental biotin reduced the incidence of horizontal ridging and sole hemorrhage over a 12-month period (Bergsten et al., 1999).

General Lameness in Seasonally Calved Dairy Cows. One of the larger and more recent trials (Fitzgerald et al., 1999) took place with pastured dairy cows in the Atherton region of northern Australia. Lameness is a problem in this region due to

factors such as: seasonal calving during the wet season, the diet of high quality pasture with supplemental grain, and the long walking distances to and from milking by way of partially paved/partly mud cow lanes. A total of 20 farms (10 control and 10 biotin supplemented) with a total of 2700 cows participated in the study. Both the farmers and the evaluators were blind to the treatments to prevent bias. The net result after 4 months was that the cows fed 20 mg/day of biotin had a significant reduction in overall lameness, antibiotic treatments, and application of hoof shoes (Cowslips[®]; American Giltspur, Inc., Sarasota, FL). The participating farmers kept track of lameness during the trial. The economics of biotin were favorable at the Australian milk price of ~\$9.30/cwt. These results revealed that, besides a beneficial effect of biotin on hoof health, hoof disorders are not limited to confinement housing systems. Hoof disorders are more related to the overall level of "hoof stress" in a herd. Increased hoof stress increases the need to rebuild hoof horn and therefore the need for essential nutrients.

Milk Production Response to Supplemental Biotin

Supplemental biotin has been found to increase milk production in three research trials. This effect may have been due to a reduction in hoof lesions, a stimulation of metabolic pathways by biotin, or a combination of both factors. In the study of Bonomi et al. (1996) 10 mg/day of biotin was fed from calving through 150 days of lactation. An increase in milk production occurred within the first 2 to 3 weeks of supplementation, suggesting a metabolic effect of biotin. The overall milk response was +4.4 lb/day. In the study of Midla et al. (1998) at Ohio State, 305-day milk production was increased in biotin

supplemented first-calf heifers, while the same animals also had a significant reduction in white line separation after 100 days into the lactation. In this trial, the milk production response may have been due to improved hoof health, or to a combination of hoof health and metabolic factors, because the study herd was very high producing, milked 3X/day, and used bovine somatotropin. In the most recent trial from Washington State (Bergsten et al., 1999), 100 cows were fed either control or biotin (20 mg/day) supplemented grain mixes through a computer feeding system for one year. This allowed all cows to share a common environment. Hoof lesions and lameness were not a major problem at the outset of the trial; however, significant reductions in sole hemorrhage and hoof wall ridging were found in response to biotin. Over the course of the 1-year trial, the biotin supplemented cows had a significant increase in milk production. In this study, metabolic factors appear to have been involved in the milk response to supplemental biotin. Further research is being conducted on biotin and milk production.

Application

1. Biotin status of dairy cattle appears to be marginal as evidenced by the response of hoof lesions to supplemental biotin in controlled research trials. The strong relationship between biotin intake, serum biotin, and reduction in hoof lesions supports the concept that biotin is a limiting nutrient for normal hoof horn integrity and renewal in dairy and beef cattle. Supplementation with biotin at 20 mg/day is recommended for optimal hoof health in dairy cattle. For beef cattle or dairy heifers, 10 mg per day is recommended.
2. Biotin is not a cure-all for hoof disorders, nor a substitute for hoof health management. From the nutritional standpoint, the adequacy of effective fiber in the ration and the supply of other nutrients essential for hoof formation, such as vitamins A and D, calcium, phosphorus, zinc, copper, manganese, and sulfur-containing amino acids, must also be addressed and optimized in the diet.
3. The milk production observed in response to supplemental biotin may occur due to improved hoof health or stimulation of metabolic pathways related to propionic acid and glucose metabolism. Further research is being carried out in this area.

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Phosphorus: Nutritional Management for Y2K and Beyond

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Consider These Key Points

Maximizing efficiency of phosphorus (**P**) utilization, while optimizing performance and health of dairy cattle and minimizing P excretion, will be crucial economically and environmentally for Y2K and beyond.

- It is the obligation for dairy nutritionists and producers to implement nutritional management practices to achieve efficient utilization of feed P imported into farms and reduce excretion. Feeding dietary P in excess of requirements is costly and unnecessary.
- The major source of imported P into dairy farms is from purchased feeds. Feed P is 45 to 80% of total P inputs. Only 19 to 32% of feed P are exported as animal products (e.g., milk and marketed animals).
- Typically, greater than 95% of total P excretion is in feces. The high amount of feed P remaining in dairy farms (mainly in manure), requires effective recycling for crop fertilization and feed production.
- Full crediting of manure nutrients as fertilizer will necessitate a P standard (instead of a N standard), because the ratio of P-to-N in dairy manure is about 2-to-1; in contrast, crops need P-to-N in a ratio of about 1-to-2. The P standard for fertilizer credits will reduce the risk of P build-up in the soil and run-off from farms.
- Phosphorus has more known biological functions in animals than any other mineral element. Homeostasis of P in large part is maintained by salivary recycling and endogenous fecal excretion, which are related directly to the amount of dietary P consumed and absorbed.
- True (net) requirement for P is the amount (g/day) of absorbed P required for maintenance, growth, pregnancy, and lactation. The dietary requirement is the true requirement divided by the true absorption coefficient (**AC**).
- An AC of 0.70 is appropriate to compute the dietary P requirement (g/day). This is different than 0.50 used by NRC (1989).
- Based on available research, supplying P in greater concentrations than needed to meet the dietary requirement does not increase dry matter intake (**DMI**) or milk yield.

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- Milk yield was maximized with dietary concentrations of 0.32 to 0.42% P for the whole lactation and no additional benefits occurred with greater than 0.42% in any short- or long-term studies.
- Daily dietary requirement is expressed as grams per cow per day and not as a percentage of the diet! Diets should be formulated based on grams required. This requires a reasonably accurate estimate of actual DMI.
- Increasing the amount or concentration of P in the diet in excess of the requirement in late pregnancy or early lactation will not correct hypophosphatemia in the periparturient period. Hypophosphatemia appears to be a metabolic problem, not a problem of supplying sufficient absorbable P to the lumen of the digestive tract.
- Virtually all phytate P in many commonly used feedstuffs is hydrolyzed to the inorganic form in the rumen and is available for absorption.
- Variation in actual P content within and among types of feeds is large. Wet chemistry analyses of feeds are essential for precise and accurate information for diet formulation to meet requirements. Relying on current book values results in over-feeding of P relative to requirements.
- Based on available research, feeding P at concentrations in excess of that needed to meet dietary requirements does not improve reproductive performance. This is a common misconception among many.
- It will be critically important in the

future to accurately and precisely predict P excretion for nutrient budgets and tracking flow of P through the whole farm system.

- Several models (equations) to estimate P excretion from dairy cattle were evaluated. Models from the American Society of Agricultural Engineers were imprecise and inaccurate in predicting actual P excretion from an independent data set with measured P excretions.
- Amount of P consumed was by far the largest determinant of the amount of P excreted. The relationship: $P \text{ excretion (g/day)} = \text{feed P intake} - \text{milk P output}$ was the most accurate model with the greatest relative precision in estimating measured P excretion. Because of its simplicity, this model may be most useful in dairy farms to quantify P excretion for nutrient management.

Introduction

In 1998, Maryland's General Assembly passed a Water Quality Improvement Act. Under the law, livestock farms must have a certified animal waste nutrient management plan (NMP) based on P and nitrogen (N) in place by July 1, 2005 (Marbery, 1998). A companion commercial fertilizer NMP must be in place in farms by December 31, 2002. Similar laws are being discussed in other states and nationally.

The major source of P and N imported into dairy farms is from purchased feeds. Feed P was 45 to 80% of total P inputs, whereas comparable values for N were 62 to 86% (Klausner, 1993). Between 68 to 81% of the P and 64 to 76% of N imported remained in the farm. Thus, by difference only 19 to 32% feed P was exported as animal products (e.g., milk and

marketed animals); for N comparable figures were 24 to 36%. The high amount of feed P remaining in dairy farms (mainly as manure), requires that it be captured effectively and used (recycled) for other purposes (e.g., crop fertilization and feed production). If this is not done, excess P will be released into the environment, contaminating surface waters and causing eutrophication. This is not sustainable and will not be acceptable to the general public, nor should it be.

To effectively recycle manure P and N and reduce risk of nutrient overloading and pollution, nutrients must be applied in quantities and proportions that crops can utilize effectively. Livestock production areas (or individual farms) will need crop land areas capable of utilizing all of the manure nutrients produced. Full fertilizer credits for manure P and N will be required. Full crediting of manure nutrients necessitates that a P standard be used (instead of a N standard), because the ratio of P-to-N in dairy manure is about 2-to-1. In contrast, crops need P-to-N in approximately a ratio of 1-to-2. The P standard for fertilizer credits will reduce risk of P build-up in the soil and run-off from the farm.

Using P as the standard for manure nutrient application to cropland will double the land area need, compared with a N standard. As much as 2 to 3 acres per lactating cow and her replacement may be needed to maintain zero P balance in the farm (Alocilja et al., 1997). This, of course, is influenced by the amount of manure P produced by the animals.

Therefore, it is incumbent for dairy nutritionists and producers to implement nutritional management practices that will enhance the efficiency of utilization of feed

P imported into farms and reduce excretion by cattle. Additionally, being able to quantify and predict the amount of P excreted by cattle will be crucial as nutrient management plans are implemented. Additionally, P is the third most expensive nutrient supplemented in dairy diets. Maximizing efficiency of P utilization, while optimizing performance and health of dairy animals, and minimizing P excretion will be crucial economically and environmentally for Y2K and beyond.

Objectives of this paper are: 1) to review and discuss P nutrition and requirements of lactating cows, 2) to examine why P is over-fed in many dairy herds by reviewing available research on lactational and reproductive performance of dairy cattle fed varying concentrations of dietary P, and 3) to present an evaluation of P excretion models for lactating dairy cows, which may be useful tools in the future to quantify and monitor P excretion when whole-farm P inputs and outputs must be tracked and recorded.

Function and Metabolism of Phosphorus

Physiological roles

Phosphorus has more known biological functions in animals than any other mineral element. About 80% of P in the animal's body is present in bones and teeth. It also is found in cell walls and cell contents as phospholipids, phosphoproteins, and nucleic acids. Located in every cell of the body, P is involved in almost all energy transactions as part of ATP. It also is involved in acid-base buffer systems of blood and other bodily fluids and is involved in cell differentiation.

Blood plasma P concentrations normally are 6 to 8 mg/dl in growing cattle

and 4 to 6 mg/dl in adult animals. Whole blood contains 6 to 8 times as much P as plasma. In the last trimester of gestation, the conceptus requires between 2 and 5 g/day of P from maternal pools (House and Bell, 1993).

Phosphorus also is required by ruminal microorganisms for digestion of cellulose (Burroughs et al., 1951) and synthesis of microbial protein (Durand and Komisarczuk, 1988). Phosphorus from salivary recycling and from diets meeting the animal's requirement typically is sufficient for ruminal microbes.

Absorption and homeostasis

Net absorption of P occurs mainly in the small intestines (Grace et al., 1974; Reinhardt et al., 1988). Presumably, absorption is by a saturable active transport system, separate and distinct from the active transport mechanism for Ca. In animals fed low P diets resulting in low plasma P, synthesis and action of 1,25-dihydroxyvitamin D stimulates more efficient absorption (Horst, 1986). Passive absorption predominates when normal to high amounts of dietary P are consumed. Absorption is related directly to amount of P in the lumen of the small intestine and to plasma concentrations (Care et al., 1980; Wasserman and Taylor, 1976).

Homeostasis of P in large part is maintained by salivary recycling and endogenous fecal excretion, which are related directly to the amount of dietary P consumed and absorbed. Concentration of P in saliva can be 4 to 5 times the concentration found in blood plasma. Between 30 and 90 g/d of P is secreted in saliva of cows and is mostly inorganic (Goff, 1998; Reinhardt et al., 1988; Scott, 1988). Abundant flow of saliva contributes

70 to 80% of total endogenous P (Horst, 1986). The amount secreted in saliva appears to be controlled by parathyroid hormone (Wasserman, 1981). Inorganic salivary P is absorbed with equal or greater efficiency than dietary P (Challa et al., 1989).

In the past, the Ca-to-P ratio was held as an important nutritional consideration in diet formulation and proper utilization of both elements. This is important only if dietary P or Ca is deficient. However, with sufficient dietary P, wide ranges of the ratio can be tolerated (ARC, 1980; NRC, 1989). The Ca-to-P ratio in blood is about 1.7-to-1, in bone it is nearly 2-to-1, and in milk it is about 1.3-to-1. The ratio is very low in saliva because very little Ca is present.

Amount of salivary recycling depends largely upon the amount of P absorbed and plasma concentrations. Mixing of recycled endogenous P with that directly from the diet certainly changes the Ca-to-P ratio in the lumen of the small intestine compared with the ratio that is supplied by the diet. This, taken with the fact that the efficiencies of absorption of P and Ca can vary depending upon feed sources of the elements, suggest no need for recommending a specific dietary Ca-to-P ratio. No differences in milk yield, persistency of milk production, milk composition, or reproductive performance were found with early lactation cows fed diets with Ca-to-P ratios of 1-to-1, 4-to-1, 8-to-1, or 8-to-8 for 20 wk (Smith et al., 1966), or 3-to-1 or 1.5-to-1 (Stevens et al., 1971). Nonetheless, it is important to insure that the dietary requirements of both P and Ca are met.

Phosphorus Requirements for Lactating Dairy Cows

Worldwide, the commonly accepted approach to determine the P requirement is the factorial method (ARC, 1980; AFRC, 1991; GEH, 1986; Gueguen et al., 1989; Kirchgeßner, 1993; NRC, 1978; 1989; NRLO, 1982).

True requirement for phosphorus.

The amount (grams) of absorbed P required for bodily functions is the true (net) requirement. It is factorially derived by summing estimates of requirements for maintenance (M), growth (G), pregnancy (Pr), and lactation (L):

$$\text{true requirement (g/day)} = M + G + \text{Pr} + L$$

In general, the various international working groups agree on estimates of the true requirements for growth and pregnancy, and this also is true for lactation (Table 1). However, approaches for determination of and estimates of true maintenance requirement differ. Maintenance requirement estimates have been expressed as a function of body weight (**BW**) by most working groups including NRC (1989). With new research (Spiekers et al., 1993), a different approach is possible.

Maintenance. True maintenance requirement by definition is the amount of obligatory endogenous P excreted (inevitable loss) in feces and urine when P supply is less than the true requirement. Typically, greater than 95 to 98% of total P excretion is in feces. Under normal conditions, excretion of P by the bovine kidney is small compared with fecal excretion. Kleiber et al. (1951) noted that the secretion rate of endogenous P was correlated positively with the amount of feed intake or the rate of fecal excretion. Other

workers suggested that metabolic (endogenous) fecal P was a function of total fecal DM excretion in ruminants (Conrad et al., 1956; Preston and Pfander, 1964). Therefore, it follows that metabolic fecal P also is related to DMI. The AFRC (1991) hypothesized that inevitable fecal loss is influenced mainly by DMI, and not by live weight. More recent research in Germany with lactating dairy cows (Spiekers et al., 1993), illustrated that a conceptually more sound and repeatable approach than expression as a function of BW is to express true maintenance requirement as a function of DMI when, by definition, dietary P is fed and absorbed very close to true requirement.

In their study, a low P (0.21%) diet was fed to two groups of dairy cows of very similar BW but with different daily milk yields (stage of lactation effect) and DMI. Phosphorus balance was similar and slightly negative (-1.6 or -0.8 g/d) for cows at high or low intake rates, respectively, indicating that animals were fed very near the true requirement. Total fecal P excretion differed between groups (20.3 vs. 13.3 g/cow/day). Fecal P excretion was 51% greater per unit of live weight for cows at high versus low DMI. However, calculated as a function of DMI, fecal P excretion averaged 1.20 and 1.22 g/kg DMI per day for the two groups. The German workers suggested that true maintenance requirement for lactating cows be set at 1.2 g/kg of dry diet consumed.

To account for the small amount of endogenous P excreted in urine which is part of the true maintenance requirement, an additional 0.002 g/kg BW (ARC, 1980) is included.

Pregnancy. For pregnant lactating dairy cows, the requirement for P for gestation is low until the last trimester.

Using slaughter data of Ellenberger et al. (1950), NRC (1989) estimated that about 75% of the 300 g of P in the fetus at term was deposited in the last 2 months of pregnancy. However, new information is available on accretion of P in conceptuses (fetus, fetal fluids and membranes, placentomes, and uterine tissues) of 18 multiparous Holstein cows slaughtered at varying times from 190 to 270 days of gestation to more accurately define the true pregnancy requirement (House and Bell, 1993). The true requirement to meet demands of the conceptus for any day beyond 190 days of gestation is described by the exponential equation:

$$P \text{ (g/day)} = 0.02743e^{(0.05527-0.000075t)t};$$

where t = day of gestation (House and Bell, 1993).

Prediction estimates of rates of P accretion in the conceptus increase from 1.9 and 5.4 g/day at 190 and 280 days of gestation, respectively. This equation should not be used to predict P accretion of the conceptus prior to 190 days of gestation.

Lactation. True requirement (g/day) for lactation is equal to daily milk yield multiplied by the percentage of P in milk. Flynn and Power (1982) reported a range of 0.09 to 0.10% P in bovine milk. An average value of 0.09% is assumed appropriate to compute true lactation requirement and to estimate milk P output (AFRC, 1991; Gueguen et al., 1989; NRC, 1989; NROL, 1982).

In the NRC (1989), the true requirement of P for lactation was adjusted depending upon fat content of milk. However, the P in cows milk is distributed as: 20% esterified to casein, 40% as colloidal inorganic calcium phosphate, 30% as phosphate ions in solution, and only about

10% associated with the lipid fraction (Jenness and Patton, 1959; Renner, 1983). Therefore, it does not seem important to adjust the true P requirement based on milk fat content. As illustrated in Table 1 there is good agreement among working groups about the true requirement for P for lactation.

Dietary requirement and efficiency of absorption of phosphorus. To derive the dietary requirement, the true requirement is divided by the AC (e.g., 0.70). The AC represents the true (as opposed to apparent) efficiency of absorption of dietary P:

$$\text{Dietary requirement (g/day)} = \frac{M + G + Pr + L}{AC}$$

The AC value as the denominator of the factorial equation potentially has great influence on the final computed dietary requirement. The smaller the AC, the greater will be the calculated dietary requirement. The NRC (1989) used an AC of 0.50. Other working groups established overall values of 0.58 (AFRC, 1991), 0.60 (NRLO, 1982), 0.60 (Gueguen et al., 1989), and 0.70 (Kirchgeßner, 1993) (Table 1).

Of course, the AC of P cannot be determined by a simple apparent digestibility trial because the vast majority (> 95%) of endogenous P in excess of the true requirement is excreted in feces. Therefore, the apparent digestion coefficient will be much lower than the true AC. If used in the factorial equation, the dietary requirement will be over-estimated greatly.

Experimentally determined true AC for most common feed ingredients for dairy cattle are not available. To accurately determine the true AC of P in a particular feedstuff or mineral source, P must be fed in an amount less than the animal's true requirement. This will insure maximum efficiency of absorption of all potentially

absorbable P from that particular source. Additionally, the amount of endogenous P recycled via saliva must be taken into account. This only can be done appropriately by quantifying recycling of P with a tracer (e.g., radioactively labeled P^{32}). Most studies do not satisfy this specification.

Furthermore, the efficiency of absorption of dietary P (e.g., the overall actual AC) is influenced by such factors as physiological state of the animal (e.g., growing versus lactating), amount of P intake, amounts of other mineral elements present in the diet or lumen of the gut (e.g., Ca), feed ingredients in the diet, and the supplemental mineral sources.

In general, quantity of P absorbed from the upper small intestine is related directly to the quantity of P in the lumen (potentially absorbable P from the diet and from saliva), and in most instances, it is not related to need for P (Braithwaite, 1985; Challa et al., 1989). An exception may be the early lactation dairy cow in which demand for P is greater and stimulation of active transport by 1,25 dihydroxyvitamin D may play an important role in absorption (Horst, 1986).

Evidence suggests that the efficiency of and absolute amount of P absorbed increases when physiological demands increase, such as during lactation compared with the nonlactating state in ewes (Braithwaite, 1983). Huffman et al. (1930) showed that efficiency of assimilation of dietary P increased with the heightened demand of peak lactation compared with the nonlactating state.

Because studies with lactating cows using appropriate tracers are very expensive (high cost of the tracer or its analysis, or

disposal of radioactive animals) an alternate approach to the estimation of the AC would be useful. One possibility utilizes P balance data and assumes that an accurate estimate of the true maintenance requirement is endogenous fecal output (1.2 g/kg DMI; as suggested by Spiekers et al., 1993) plus endogenous urine output (0.002 g/kg BW; ARC, 1980). Using P intake (I, g/day), milk P output (L, g/day), P balance (B, g/day) data from actual P balance determinations plus the assumed true requirement for maintenance (M, g/day) one can obtain a "calculated" absorption coefficient (CAC) as:

$$CAC = \frac{M + L + B}{I}$$

The fecal output value from the balance determination is ignored because it represents excess endogenous P excreted in feces plus unabsorbed dietary P.

Using this approach, the CAC obtained from results of four different P balance studies with lactating cows are shown in Table 2 (Brintrup et al., 1993; Morse et al., 1992b; Spiekers et al., 1993; Wu et al., 1998). Two or three different concentrations of P were fed in each study. Within experiment, the CAC declined as the dietary P concentration increased, as expected (Challa et al., 1989). Also, among all studies, the CAC values at dietary P concentrations (0.39 to 0.42%) near the dietary P requirement for lactating cows are similar [0.67, Brintrup et al. (1993); 0.74, Morse et al. (1992b); 0.72, Wu et al. (1998)] to the recent AC (0.70) used by the German working group (Kirchgeßner, 1993). All of these CAC values are greater than the NRC (1989) AC value. Additionally, in the case of Spiekers et al. (1993) in which cows were fed diets with 0.2%P (P-deficient diet which resulted in slightly negative P balance), the

CAC was 1.0, as would be expected. This approach for estimating AC appears useful and deserves further evaluation with other balance data and various diet types. Overall, an AC of 0.70 is appropriate to compute the dietary P requirement from the true requirement.

Intake of phosphorus. In studies with P³²-tracer, efficiency of absorption of P declined as intake of P reached high amounts in cattle (Challa et al., 1989). However, over a considerable range of P intakes within recommended amounts, the efficiency of absorption from inorganic sources remained high and relatively constant in cattle (AC = 0.83; Challa et al., 1989) and in sheep (AC = 0.74; Braithwaite, 1986). Because salivary P typically supplies appreciably more (e.g., at least two-fold greater amounts) P to the lumen of the small intestine than does the diet, the efficiency of absorption of salivary P is important. Salivary P is in the inorganic form. The AC of endogenous P recycled to the small intestine of 300 lb BW bull calves was 0.68, 0.81, and 0.80 with 0.13, 0.33 and 0.48% dietary P, respectively. Additionally, very low or excessive dietary P reduced the efficiency of absorption of salivary P (Braithwaite, 1986). Similar studies with tracer data are not available for lactating dairy cows.

Feed sources of phosphorus. The true AC of P of most common feedstuffs are unknown, and likely vary as affected with other factors cited previously. Martz et al. (1990) measured true absorption of P in corn silage and alfalfa hay by dosing lactating Holstein cows intravenously with P³²-tracer to quantify endogenous fecal loss of P. True AC of P in alfalfa hay was 0.67 and 0.80 in corn silage. Using a tracer technique, Lofgreen and Klieber (1953; 1954) reported that the true AC of P in alfalfa hay fed to

lambs ranged from 0.81 to 0.96, whereas apparent digestibility of dietary P was only 22% due to the large amount of endogenous P in feces.

Supplemental mineral sources of phosphorus. More data are available on the AC of P in mineral sources. Generally, these are primary sources of supplemental P in diets for dairy cattle. Dicalcium phosphate (calcium phosphate dibasic) had an AC of 0.75 and monosodium phosphate had an AC of 0.90 in cattle (Challa et al., 1989). The AC of P in other mineral sources also are in this range (Soares, 1995; Peeler, 1972).

Effect of dietary calcium. At higher than recommended supplemental Ca, greater depression of P absorption occurs (ARFC, 1991). Phosphorus deficiency was exacerbated in lambs by high Ca intake (Sevilla and Ternouth, 1982), likely a result of reduced soluble P in ruminal fluid (Wan-Zahari et al., 1990). This may be an important practical consideration in dairy rations with supplemental fat in which Ca is supplied in excess of requirement, presumably to compensate for potential soap formation in the intestine. Evidence to support this formulation practice is scanty and not supported well by research results. Phosphorous availability may be reduced by Ca supplementation in excess of requirement.

Based on available data, AC for most feedstuffs commonly fed to dairy cattle of various physiological states range from 0.90 for calves consuming milk or milk replacer, 0.78 for young ruminating calves at less than 440 lb live weight, and about 0.70 for lactating and non-lactating animals consuming diets with P concentrations needed to meet dietary requirements (Tables 1 and 2). The AC value of 0.70 is

recommended to derive the dietary requirement of P from the true requirement for lactating dairy cows.

Phosphorus Is Fed in Excess of Requirements. Should It Be?

Phosphorus often is fed to lactating dairy cows at dietary concentrations in excess of the amount needed to meet dietary requirements at typical feed intake rates (Shaver and Howard, 1995). Frequently, lactation diets in the upper Midwest have P concentrations 25 to 50% in excess of the dietary requirement (Beede, personal observation). Several reasons and concerns are given for this aggressive over-supplementation:

1. A safety margin is used in formulation because the accuracy of the published requirements is questioned.
2. Increasing dietary P content in excess of that needed to meet the requirement improves milk yield.
3. Hypophosphatemia sometimes occurs in fresh or high producing cows; it is assumed that the P requirement (or P content of the diet) is too low, resulting in low blood P and downer cows.
4. A safety margin is included because of the presumed unavailability of P from phytate P in feeds and the variable and (or) unknown P concentrations in commonly used feeds.
5. Increasing dietary P content in excess of that needed to meet the dietary requirement improves reproductive performance.

Subsequently, we reviewed evidence to support or refute each stated reason or concern.

Accuracy of published phosphorus requirements.

Table 1 presents an example of the true and dietary P requirements determined by various scientific working groups. The groups agree on the true requirements for lactation. Requirements for growth and pregnancy of lactating cows are relatively small (values not shown in Table 1) compared with those for lactation and maintenance. The largest differences among the various working groups in deriving the dietary requirement is in the determination of the true maintenance requirement and the AC which are used to compute the dietary requirement. With the new approach and data supplied by Spiekers et al. (1993), more recent working groups (AFRC, 1991; Kirchgeßner, 1993) agree on the true maintenance requirement. Previously in this paper, discussion was presented for using an AC of 0.70 to compute the dietary requirement.

Total dietary requirement for P (Kirchgeßner, 1993; NRC, 1978; 1989; NRLO, 1982) was supported by results of experiments with Holstein cows in early lactation and in a full lactation in Wisconsin (Table 3; Studies 9 and 8, respectively). The calculated dietary requirement for 87 lb of milk plus maintenance is 84 g/cow/day. During the first 8 wk of lactation, supplying 84 g/cow/day of dietary P (0.42% dietary P, dry basis) supported maximum milk yield (87.3 lb/cow/day). More P (106 g/cow/day; 0.52% dietary P) did not increase milk yield (Wu et al., 1998). In a full lactation study, supplying 72 g/cow/d of P (0.35% P, dry basis) maximized milk yield (69.7 lb/cow/day) (Wu and Satter 1998a,b).

Increasing dietary P to 92 g/cow/day did not further increase milk yield (64.9 lb/cow/day). The calculated dietary requirement for 70 lb milk yield per day plus maintenance is about 72 to 74 g/cow/day (Kirchgeßner, 1993; NRC, 1978; 1989; NRLO, 1982).

Based on these experiments and others reported in Table 3, there is no good evidence to feed diets with dietary P concentrations greater than needed to meet dietary requirements set by several scientific working groups around the world. The dietary requirements are correct.

Lactational responses to vary dietary P concentrations

Very often, P is fed at dietary concentrations greater than the requirement established by various scientific working groups (e.g., Kirchgeßner, 1993; NRC, 1989). Does feeding P in excess of requirement improve lactational performance?

In early research in Michigan, Huffman et al. (1930) reported that the efficiency of assimilation of dietary P was enhanced by greater requirements in peak milk production, and increasing dietary P in excess of requirement reduced the efficiency of assimilation. Phosphorus balances were conducted with 20 Holstein cows at peak, medium, or low milk production and during the dry period. Negative P balances were observed only during peak milk production in 12 of 20 cows, and positive balances were found during most of the lactation and nonlactating period. Cows were able to replenish P stores after peak milk production.

A thorough search of the literature found results of nine more recent studies

available to assess lactational responses of dairy cows to varying concentrations of dietary P concentrations. Summary of experimental circumstances and results of DMI, milk yield and composition, and blood P as available from these reports are presented in Table 3. Among these nine studies, treatments represented a range of dietary P concentrations (0.24 to 0.65% of dietary DM), length of feeding varying concentrations of dietary P ranged through the first 8 wk of lactation to as long as three consecutive lactations, feeding systems ranged from all confinement with harvested feeds to a combination of confinement feeding and grazing within the same lactation, and average milk yields ranged from 33 to 87 lb/cow/day during the time of study.

Overall, supplying dietary P percentage above that needed to meet the dietary requirement did not increase DMI or milk yield. The reported analyses of results in the study of Kincaid et al. (1981) suggested that increasing dietary P may have increased DMI and 3.5% FCM yield; however, the data were not properly analyzed. Based on the description of the analysis of variance in the paper, the correct test term (cow within treatment) was not used to test mean differences among treatments, thus invalidating interpretation. Feed intake and milk yield were lower ($P < 0.05$) for cows fed 0.24 versus 0.32 or 0.42% P in one study (Call et al., 1987). Within none of the other seven studies was DMI or milk yield increased by increasing dietary P from its lowest concentration to a higher concentration (Table 3).

Milk fat and protein percentages were not affected by dietary P percentage in most studies. In the study of Call et al. (1987), milk protein percentage increased when P was 0.32 or 0.42% compared with

0.24%. Protein content of milk was higher with 0.45 versus 0.35% P in the study of Wu and Satter (1998a). Milk fat percentage was higher in year 1 of the study of Brodison et al. (1989) with 0.44 vs. 0.35% P but lower in the study of Brintrup et al. (1993) with 0.33 versus 0.39% P. There does not appear to be any consistent effects of dietary P concentration on milk composition across studies.

Blood P concentrations were evaluated in seven of the nine studies (Table 3). Plasma inorganic P of 4.0 to 6.0 mg/dl is considered normal for adult cattle (Goff, 1998). In only one case among all of the studies was blood P below the normal range (3.6 mg/dl for cows fed 0.24% dietary P; Call et al. 1987); 0.24% did not provide the dietary requirement. In several other cases among the studies, increasing dietary P increased blood P. But, all of these increases were within or above the normal range and not considered beneficial to lactational performance.

Dry matter intake and milk yield of early lactation cows was maximized with 0.40 to 0.42% dietary P (dry basis) and greater concentrations did not increase DMI or milk yield (Carstairs et al., 1981; Wu et al., 1998). In the study of Carstairs et al. (1981), milk yields were not different due to dietary P concentration during the first month of lactation. From wk 5 through 12 of lactation, milk yield tended to be greater with 0.40 compared with 0.50% P. For the entire 84-day treatment period, cows fed 0.40% P yielded 8% more milk than those fed 0.50% P ($P < 0.10$). Authors suggested that it should not be assumed that P concentrations 30 to 50% in excess of requirements are not without negative effects.

In the early lactation study of Wu et al. (1998), feeding 0.42% P maximized milk

yield, positive P balance, and normal blood serum P concentrations. Feeding 0.52% dietary P resulted in no additional benefits compared with 0.42%. In early lactation, Ca is mobilized from bone, and substantial quantities of P also are released. Increased lactational demands for P increase P absorption, while concurrently the need for additional Ca increases P mobilization from bone. This results in a surplus of P in the extracellular pool, which is then secreted in saliva and excreted in feces.

As long as the dietary requirement is met after peak milk yield, replenishment of P reserves in bone and other tissues occurred in ewes with more efficient assimilation (Braithwaite, 1983). Feeding early lactation cows in excess of the factorially derived P requirement for milk yield plus maintenance is not necessary and does not benefit P assimilation. Certainly provision of P in excess of the requirement would seem unnecessary and costly.

Based on the results of nine available studies, a concentration in the range of 0.32 to 0.42% P for the whole lactation was sufficient, obviously depending upon milk production potential of cows and nutritional plane supplied in various studies. No benefits on lactational performance of dietary concentrations greater than 0.42% were reported in any short- or long-term studies which were properly analyzed.

It is important to remember that daily dietary requirement as determined by the factorial method is expressed as g/cow/day, and not as a percentage of the diet. Diets should be formulated based on grams required. This of course, requires a reasonably accurate estimate of actual DMI.

Free-choice phosphorus. A possible practical consideration is whether dairy

cattle will consume free-choice P-containing supplements to satisfy their requirements when fed diets low or marginally deficient in P or Ca. This was evaluated in growing yearling heifers (Coppock et al., 1972) and lactating dairy cows (Coppock et al., 1972; 1975). With heifers, there was little relationship between need for the mineral elements and free-choice consumption of dicalcium phosphate or defluorinated phosphate. In lactating cows offered basal diets providing P and Ca below requirements for 9 and 12 wk, there was no evidence that cows consumed free-choice dicalcium phosphate to correct the deficiency. Overall, there was no indication that appetite for P and Ca supplements coincided with the animals' nutritional requirements. Thus, free-choice feeding of P and Ca supplements represents an inaccurate and imprecise method to provide requirements and other approaches should be used if practically possible.

The concern about hypophosphatemia

Phosphorus deficiency. Detailed description of the occurrence, etiology, clinical pathology, diagnosis, treatment, and prevention of P deficiency in cattle was reviewed (Goff, 1998). Nonspecific chronic signs of deficiency include unthriftiness, inappetence, poor growth and lactational performance, and unsatisfactory fertility; but, signs are often complicated by coincidental deficiencies of other nutrients, such as protein or energy. Animals may be chronically hypophosphatemic (blood plasma P of 2 to 3.5 mg/dl), but the concentration of P in milk remains within normal range.

Severe clinical manifestations of P deficiency may include acute hypophosphatemia (less than 2 mg/dl plasma P) in periparturient and high yielding

cows. This may occur if cows are fed marginally low dietary P and challenged by extra demand for P in late pregnancy with accelerated fetal growth, especially with twin fetuses, and with colostrum and milk formation in early lactation. The disease usually is complicated with concurrent hypocalcemia, hypomagnesemia, and possibly hypoglycemia. In some cows with severe cases of clinical milk fever, protracted hypophosphatemia (plasma P less than 1 mg/dl) occurs with recumbency; even with successful treatment for hypocalcemia, blood P remains low. This condition is not well understood.

Normally low blood P rapidly stimulates physiological correction as P absorption is responsive to renal production of 1,25-dihydroxyvitamin D. Increased plasma P also may be partially an indirect result of correction of hypocalcemia, facilitated by parathyroid hormone and vitamin D. However, in some cases correction of hypophosphatemia may not occur. The condition may be further complicated if the cow is developing or has severe hypocalcemia because parathyroid hormone is secreted, increasing urinary and salivary losses of P. Secretion of cortisol around parturition also may depress plasma P concentrations.

Intravenous Ca to correct hypocalcemia usually results in a rise in plasma P because parathyroid hormone secretion is reduced, reducing urinary and salivary loss of P which stimulates resumption of gut motility, recycling of salivary P, and absorption.

For treatment of low blood P, intravenous or intraruminal administration of a soluble form of P, such as sodium monophosphate, can help correct hypophosphatemia. The solution containing

P must be prepared and administered separately from that with Ca and Mg, or insoluble precipitants will form. Phosphorus in hypophosphite salts, while soluble with Ca and Mg, is not biologically functional and should not be used.

The periparturient dairy cow represents a unique situation with respect to P homeostasis. Conservation of Ca facilitated by the endocrine system at the kidney, mobilization of Ca from bone, and increased absorption from the digestive tract have high physiological priority during hypocalcemia (Horst, 1986). During the mobilization of 10 ions of Ca from bone, six phosphate ions also are released into the blood circulation. Indirectly, this serves to increase the blood P pool. Bone stores would be replaced later in lactation as long as P intake was sufficient.

In this physiological circumstance, increasing supply of potentially absorbable P via the diet may be of little benefit. In late pregnant and early lactation ewes, that also have an accentuated demand for blood Ca and P, increasing dietary P did not increase net retention or utilization of P (Braithwaite, 1983). Instead, the increased amount of P supplied was absorbed with lower efficiency and that which was absorbed appeared as a net increase in salivary P and endogenous fecal P in excess of the animal's requirement. Similar studies were not found for periparturient dairy cows, but physiological events are presumed similar.

It is unlikely that increasing the amount or concentration of P in the diet in excess of the requirement in late pregnancy or early lactation will correct hypophosphatemia in the periparturient period. Hypophosphatemia appears to be a metabolic problem, not a problem of supplying sufficient absorbable P in the

lumen of the digestive tract. Nonetheless, oral or intravenous P administration will help increase blood P once the condition has occurred.

In the field. Low blood P in periparturient and high yielding cows and related health problems are a source of concern in the field. Often the typical conclusion is that the dietary P requirement (e.g., NRC, 1989) is too low. However, in drawing this conclusion the assumptions most often are that affected cows are consuming adequate amounts of a diet able to provide the dietary requirement (g/cow/day). However, actual DMI of a group of cows may be unknown, and rarely is DMI of individual cows known, especially for those cows that are affected. Also, laboratory analysis to determine actual dietary P concentration is often not performed. For example, these were not known (or not reported) in a case study of hypophosphatemia of high producing cows (Gerloff and Swenson, 1996).

Phytate phosphorus and feed phosphorus concentrations

Two-thirds or more of P in cereal grains, oilseed meals, and grain by-products is bound organically in phytate. Phytate P almost exclusively is found in seeds. Hays or fresh samples of alfalfa, brome grass, bermudagrass, orchardgrass, fescue, and sudangrass silage contained no detectable phytate P (Nelson et al., 1976).

Phytate P is only slightly or totally unavailable to nonruminants (NRC, 1998; Soares, 1995). However, inherent phytase activity of ruminal microorganisms renders most of the phytate P available for absorption (Clark et al., 1986; Morse et al., 1992a; Nelson et al., 1976; Reid et al., 1947). As a percentage of total P, phytate P

contents ranged from 32 to 81% for some concentrate feeds commonly used in diets for dairy animals: cottonseed meal (69%), peanut meal (57%), soybean meal (69%), ground corn grain (64%), hominy feed (73%), dried distillers grains (32%), rice bran (81%), and wheat middlings (78%) (Morse et al., 1992a). When these feeds were incubated in an artificial rumen system with live ruminal microbes for 12 and 24 hours virtually all of the phytate P disappeared. In a digestion trial in which the total diet contained 0.17% phytate P, digestibility of phytate P was greater than 99% (Morse et al., 1992a).

About 98% of phytate P in a diet (47% grain, grain by-products, and soybean meal, plus 50% corn silage, dry basis) was hydrolyzed to inorganic P when fed to high producing dairy cows during the first 10 wk of lactation (Clark et al., 1986).

Similar results were found with young bulls (56 days of age) consuming a diet composed of corn grain, crimped oats, and soybean meal, or steers (9 months of age) consuming sorghum grain and soybean meal (Nelson et al., 1976). Phosphorus availability from canola meal was similar to that from soybean meal or inorganic P when fed to Holstein bull calves starting at 6 wk of age (Ingalls and Okemo, 1994). Apparent digestibility of P was not different when supplemented as wheat bran or mono- and dicalcium phosphate to dairy cows during the first 120 days of lactation (Herbein et al., 1996).

Based on available research, essentially all phytate P in many commonly used concentrates for dairy diets is hydrolyzed to the inorganic form and should be considered totally available for absorption. Therefore, in diet formulation no discounting or compensation for phytate

P is needed to meet requirements. More research may be useful to determine if hydrolysis of phytate P is adequate in situations where animals may have transiently compromised rumen microbial function. Also, measuring release of P from phytate P in other feeds, such as corn gluten feed, corn gluten meal, brewers grains, wheat grain, and whole soybeans, would prove useful.

Variation in P content of feeds.

Laboratory analyses of feeds for P content is critically important for precise and accurate diet formulation to meet requirements. There is considerable variation in actual P content within types of forages and concentrates fed to dairy animals. Adams (1974) reported that the mean coefficient of variation in forage samples (n = 16,844) for concentration of P was 25%, whereas that of corn grain (n = 221) was 22%. In general, variation was greater for grasses compared with legumes (26 versus 17% coefficient of variation), and there was a 10-fold difference in P content among legume-grass forage samples. There were two- to twenty-fold differences in P content of 16 concentrates evaluated.

In a more recent report, the coefficient of variation of P content of forages ranged from 20 to 30% (Kertz, 1998). Phosphorus content of grasses was more variable than that of legumes, but there was little difference in variability between hay and silage of the same forage type.

Berger (1995) compared the P concentrations of feeds listed as "book" values (NRC, 1982) with values determined by actual laboratory analyses. In most cases, the average actual analytical value was greater than the book value. For example with alfalfa, actual values from laboratory analysis were 38% greater than

book values. Doubtless, relying on book values results in over-feeding of P relative to animal requirements in many dairy farms.

Inherent variation in P content within feed types and among different feeds, and under-estimation of actual P concentrations with book values, emphasizes the importance of obtaining laboratory analyses, especially for concentrates which typically contain greater concentrations of P than forages, to accurately and precisely formulate diets and supply requirements. Analysis of P using wet chemistry analysis is required to obtain accurate values and near infrared reflectance spectroscopy (NIRS) is not reliable (Shenk and Westerhaus, 1994).

Phosphorus and reproduction

Feeding P to virgin heifers or lactating cows at concentrations to provide excess of dietary requirements is claimed empirically by some to improve reproductive performance. To examine this belief, published research reports with cattle from 1923 through 1998 were examined. Results of more recent reports (1971 to 1998) with lactating dairy cows are summarized subsequently and in Table 4. Based on review of the research literature, increasing dietary P concentration in excess of that needed to meet requirements to improve reproductive performance is a misconception.

During severe deficiency. In some studies, severe deficiency of dietary P caused reduced reproductive performance (Alderman, 1963; Hignett and Hignett, 1951; McClure, 1994; Morrow, 1969). Typically, P concentrations were less than 0.20% of dietary DM and the P-deficient diet was fed for 1 to 4 years. When measured, feed intake was depressed,

presumably causing coincidental deficiencies of energy, protein, and other nutrients. Palmer et al. (1941) showed that reproductive performance of dairy heifers was compromised much more when both dietary protein and P were deficient compared with P singularly. Little (1974) demonstrated that deficiencies of P and protein were additive on failure to exhibit first postpartum estrus in grazing multiparous beef cows.

Virgin heifers. In virgin heifers, experimentally induced reproductive failure by dietary P deficiency was very difficult to produce. Huffman et al. (1933) found no reproductive problems in dairy heifers fed a diet with 0.20% P. In two trials with growing dairy heifers (n = 52), increasing dietary P from about 0.22 to 0.32% (dry basis) resulted in no improvement in reproductive performance (Noller et al., 1977). In another study, with 76 dairy heifers fed diets with 0.13 to 0.22 versus 0.40% P for 5.5 months, no differences in estrus exhibition, services per conception, or pregnancy rates were detected (Hecht et al., 1977). Beginning at 7-months of age, 96 Hereford heifers fed 0.16 or 0.40% dietary P for 2 years had similar pregnancy rates (96 versus 100%) and percentages live calves (91 versus 93%) (Call et al., 1978). Hurley et al. (1982) examined intensity of estrus in 12- to 16-month old dairy heifers fed diets containing 73, 138, or 246% of NRC (1978) requirements. Estrous behavior, ovarian activity, and blood serum progesterone and luteinizing hormone concentrations were not different among heifers fed different amounts of P. Because heifers are still growing and bone P is readily available, they apparently can compensate to short-term (e.g., less than 2 years) dietary deficiency, thus reproductive performance is not affected.

Early studies with lactating cows. Eckeles et al. (1935) fed eight dairy cows 0.17 or 0.22% P, depending upon rate of milk production, through two gestations and found no abnormal effects on frequency or duration of estrus. They suggested that results of earlier reports of impaired reproductive performance due to P deficiency (Hart and Guilbert, 1928; Theiler et al., 1924), were more likely a complicated multiple nutrient deficiency. Previously, these same researchers used severely anestrus cows and over a period of 3 to 9 months supplied a diet which was sufficient in all nutrients except P. Cows came into estrus; therefore, authors assumed that P was only a contributing factor in an complicate multi-factorial dietary deficiency (Eckeles et al., 1926).

More recent studies (1971 to 1998). In more recent studies with lactating dairy cows, evidence to support feeding P in excess of requirements to improve reproduction is not compelling. Table 4 summarizes six experiments with lactating dairy cows examining the effects of dietary P concentration on reproductive performance. These were all of the studies found in the literature. Table 4 is included to give the reader the opportunity to review experimental conditions and results of each study in more detail.

Results of the six studies can be summarized very succinctly. All of the various measures of reproductive performance compared within each study were not different ($P > 0.05$) due to dietary P concentration with one exception. In the study of Stevens et al. (1971), services per conception were greater in the second year for cows fed 0.40 vs. 0.55% P.

Among these six studies, treatments represented a range of dietary P

concentrations (0.24 to 0.62% of dietary DM), length of feeding varying concentrations of dietary P ranged through the first 12 wk of lactation to as long as three consecutive lactations, feeding systems ranged from all confinement with harvested feeds to a combination of confinement feeding and grazing during the same lactation, and average milk yields ranged from 33 to almost 70 lb/cow/day for a full lactation. Surveying the reproductive performance results of all of these studies, it appears that as long as dietary P was greater than or equal to 0.32%, reproductive performance was normal and not improved with greater concentrations of P. There were no advantages to reproductive performance of feeding dietary P above 0.32 to 0.40%, dry basis. Of all the studies, only 0.24% dietary P in the study of Call et al. (1987) negatively affected feed intake and milk production (Table 3); however, pregnancy rate and services per conception tended to numerically favor cows fed 0.24% P compared with those fed 0.32 or 0.42% P.

Cows in some of the studies would not be considered high producing cows by modern standards. However, 48 Holstein cows (28 multiparous) in the study of Wu and Satter (1998a) yielded an average of 69.7 and 64.9 lb/cow/day for the full lactation when fed 0.35 or 0.45% total dietary P. No supplemental P was fed in the low P treatment. Days to first estrus tended (non-significant) to be more for cows fed the lower dietary P concentration. Days postpartum to first insemination, days not pregnant, and services per conception were not different by dietary P concentration. Pregnancy rates at the end of the first 120 days of lactation (50.0 versus 45.8%) and for the entire lactation (87.5 versus 79.2%) tended to be greater for cows fed 0.35 compared with 0.45% P, respectively.

Overall, evidence from the research literature does not support feeding dietary P at a concentration in excess of that needed to meet the dietary requirement as determined by the factorial method. Certainly, additional studies with more higher yielding cows would be useful.

Predicting P Excretion By Dairy Cows

In addition to the obligation and management objectives of the dairy industry to maximize efficiency of utilization of P by dairy animals and to feed accurately to meet dietary requirements, it will be critically important in the future to accurately and precisely predict P excretion by cattle. This will be necessary for nutrient budgets and for tracking flow of P through the whole farm system. A reliable and relatively simple on-farm method to estimate P excretion from animals is needed and will be very advantageous as defined nutrient management plans are implemented.

Several models (equations) have been developed to estimate P excretion from dairy cattle. We evaluated six models using an independent data set from the scientific literature in which actual P balance (and excretion) was quantified experimentally by measuring P intake minus P output. A short description of each of these six models is below and in Table 5. Additionally, another simple and seemingly reliable relationship (Model 6, Table 5) was developed from all of the available data which could be very applicable at the farm level to manage P nutrition and monitor P flow from animals in the farm.

P excretion models

Models (1) and (2). The American Society of Agricultural Engineers Standards Engineering Practice Data (ASAE, 1980;

1996) provide estimates of P excretion in which P excretion is expressed as a function of BW of animals (Table 5). These models currently are used in planning dairy start-ups, manure management systems, and whole farm nutrient management. The ASAE (1980) standards (P excretion as a percentage of total solids excreted per 1000 lb BW) and the ASAE (1996) standards (P excretion lb/day/2200 lb BW) were based on published and unpublished data about excretion and composition of dairy manure. However, it was not possible to determine the origins or amount of data included in the individual estimates of total P excretion from the publications. The estimates changed in 1988, compared with estimates in the original publication in 1976. The major change in the standards was to increase the estimate of fecal DM excretion from 22.77 to 26.4 lb/day per 2200 lb BW. Also, the estimated P in manure was changed from 0.70 to 0.78% between the 1980 and 1996 publications.

Other nutritional factors and variation in such factors as concentration of and absolute intake of P from diets, P availability from feeds, and P utilization by the animal may alter P excretion more so than BW. Including these factors in models to predict P excretion from dairy cows may improve the ability to more accurately estimate P excretion in order to better manage nutrients at the whole farm level. Therefore, we evaluated four other models which had been developed assessing other nutritional factors.

Models (3) and (4). Models of Morse et al. (1992b) and VanHorn et al. (1994) were developed from data collected in Florida in experiments measuring P intake and output of individual cows fed varying amounts of P (Table 5). In each model, intake of P (g/day) and milk yield were

significant variables in the prediction of P excretion.

Model (5). We also used data (46 treatment means from 13 separate balance trials) of Hibbs and Conrad (1983) in which actual P excretion was quantified in lactating Jersey cows fed diets varying in several factors. Among these trials, factors studied included vitamin D supplementation, rate of grain feeding, cutting of forage, type of alfalfa pellets, type of concentrate, and dietary inclusion of starch. None of these variables were significant in our initial regression analysis across the entire data set. To develop a P excretion prediction model, variables tested in the subsequent multivariate regression analysis included: BW, DMI, MY, P as a percentage of dietary DM, intake of P (g/day), Ca as a percentage of dietary DM, intake of Ca (g/day), milk P percentage, and milk P output (g/day).

Using statistical methods, the most appropriate model (H and C Model) to describe P excretion from the data set included dietary P (percentage of dietary DM), BW, and grams of milk P output per day [Model (5); Table 5]. This model accounted for 78% (R^2) of the variation associated with P excretion ($P < 0.01$).

Model (6). Van Horn et al. (1994) suggested that perhaps prediction of P excretion using the simple relationship of intake P (g/day) minus milk P (g/day) might provide the best estimate of P excretion.

Evaluation of prediction models comparing predicted versus. measured P excretion

An independent data set was used to assess accuracy of prediction of each model. The data set (11 treatment means from 85 intake-output balances with individual lactating cows) was from five reports (Martz

et al., 1990; Brintrup et al., 1993; Spiekers et al., 1993; Wu et al., 1998; Rodriguez, 1998; Table 6).

The bias or accuracy (predicted P excretion minus measured P excretion) was determined for each model. The bias was determined statistically to be different from zero by t-test (Table 7). The H and C Model (Model 5) and the intake P minus milk P relationship (Model 6) were not significantly different from zero, which indicates good agreement between the predicted P excretion and the actual measured excretion in the independent data set. Models 1, 2, 3, and 4 were biased in their prediction of P excretion compared with the measured P excretion in the independent data set ($P < 0.01$; Table 7).

To estimate the relative precision of the models to predict P excretion compared with measured excretion of the independent data set, the relative over- or under-prediction was computed as [(predicted - measured) / measured] x 100%. The relative precision of each model was computed over the total range of the measured P excretion, low P excretion (13.6 to 22.2 g/day), and high P excretion (40.4 to 62.7 g/day) of the independent data set. Coincidentally, the independent data set could be categorized logically according to low and high measured P excretion; there were no measured P excretion data between the low and high ranges. Therefore, all percentages reported indicate the relative precision of the prediction model compared with the measured P excretion.

Models (1) and (2). Prediction based on the ASAE (1980) relationship (Model 1) had a mean relative over-prediction of 68% over the full range of measured P excretion (Figure 1). Model 1 greatly over-predicted P excretion at low measured P excretion

(155%), whereas at high measured P excretion, the relative precision of prediction was 18% (Table 8). Prediction based on the ASAE (1996) (Model 2) had a mean over-prediction of 106% over the full range of measured P excretion (Figure 1). Model 2 greatly over-predicted at lower measured P excretion (230%) and was more precise in prediction at higher measured P excretion (35%) (Table 8).

Models (3) and (4). The models of Morse et al. (1992b) and Van Horn et al. (1994) over-predicted P excretion approximately 65% over the full range of measured P excretion (Figure 1). Models (3) and (4) had greater over-prediction for low measured P excretion (81% and 93%, respectively) compared with high measured P excretion (57% and 49%, respectively) (Table 8).

Model (5). Overall, the H and C Model had a relative precision for predicting P excretion within 39% of measured P excretion in the independent data set (Figure 1; Table 8). For lower measured P excretions, Model 5 over-predicted 54%, but for higher measured P excretions, the precision of determination of P excretion was 31% (Table 8). This occurred even though P intake, MY, and DMI of the independent data set were above the range of data that were used to develop the H and C Model (Hibbs and Conrad, 1893).

Model (6). The prediction using the simple calculation of intake P (g/day) minus milk P (g/day) proposed by Van Horn et al. (1994) provided the best estimate of measured P excretion. The difference between measured and predicted P excretion was within 18% of measured P excretion over the total range of measured values in the independent data set (Figure 1, Model 6). However, greater over-prediction (on a

relative basis) occurred with measured P excretion within the low range than within the high range of measured P excretion (Table 8).

Further evaluation of the (intake P minus milk P, g/day) model. The prediction of P excretion expressed as “intake P (g/day) - milk P (g/day)” was then evaluated using all of the available data including the independent data set and data of Hibbs and Conrad (1893) and Morse et al. (1992b) (71 treatment means). The model, on average, over-predicted P excretion approximately 39% over the full range of measured excretion (Figure 2). Additionally, the mean bias (predicted - measured P excretion) was 14.5% and different from zero ($P < 0.01$, t-test). This over-prediction may be caused by experimental error in measured P excretion or not accounting for P retained in bone and soft tissues.

To determine if the prediction of P excretion using (intake P - milk P, g/day) could be improved, an additional linear regression weighted for number of observations per treatment mean was performed using all data (71 treatment means) in the independent data set, and data sets of Hibbs and Conrad (1893) and Morse et al. (1992b). The regression model was $Y = (5.92 \pm 1.54) + X(0.741 \pm 0.034)$, where $Y =$ P excretion (g/day) and $X =$ intake P (g/day) minus milk P output (g/day) (Figure 3). This model accounted for 87% (R^2) of the variation in measured P excretion ($P < 0.01$). It appears based on the data used and the models evaluated that the simple model (intake P - milk P, g/d) used to estimate P excretion may be the most appropriate. Obviously, this linear regression model should be evaluated with another independent data set. Additional, independent data are not available currently in the literature.

Summary: Predicting P Excretion of Lactating Dairy Cows

Model 5 developed from balance data of lactating Jersey cows (Hibbs and Conrad, 1983) resulted in better prediction of measured P excretion than Models 1 and 2 using ASAE (1980; 1996) standards. In estimating P excretion, Model 5 had more relative error in prediction at lower ranges of P excretion than higher ranges. Phosphorus (percentage of dietary DM) accounted for 66% (partial R^2) of the variation in P excretion in the data set. The range of P (percentage of dietary DM) in the independent data set was similar to the range of data used to develop Model 5. However, the independent data set was still quite different from the data used to develop Model 5. The independent data set was collected from Holstein cows with higher milk production during 1990 through 1998 (Table 6). The ability of Model 5 to accurately predict P excretion may be less useful for cows at higher milk yield (MY), DMI, and BW, such as the contemporary lactating Holstein cows of the independent data set. However, Model 5 was more accurate than Models 3 and 4 previously reported (Morse et al., 1992b; Van Horn et al., 1994). Models 3 and 4 also tended to have greater relative difference in predicted P excretion from the measured P excretion compared with Model 5. Additionally, their overall ability to predict P excretion in the independent data set was lower than Model 5, even though cows and their milk yields to develop Models 3 and 4 were more similar to that of the independent data set. Models 3, 4, 5, and 6 all greatly improved the estimation of P excretion over the full range of data compared with the estimations from Models 1 and 2 (ASAE, 1980; 1996).

Compared with all other models evaluated, Model 6, the intake P minus milk

P (g/day) relationship, suggested by Van Horn et al. (1994) was the most accurate model and had the greatest relative precision in estimating measured P excretion for lactating dairy cows of the independent data set. Of all the models evaluated, this model likely has the most usefulness in the field to improve estimation of P excretion to manage nutrient balance in the farm. This is a relatively simple calculation and demonstrated best predictive ability of P excretion.

Data to estimate intake P and milk yield are reasonably easy to obtain in farms. Calculation of P intake would simply be the weighted summations of the product of the DMI times the P content of the various diets fed to lactating cows. Because the variation in milk P percentage is quite low, the amount of P in milk is simply the product of the amount milk shipped times the P content of milk (approximately 0.09%). The calculation of P excretion (intake P - milk P) can then be performed easily. This would improve the ability to estimate P excretion greatly over the current standards, such as ASAE (1996). All of the models improved prediction of measured P excretion compared with the ASAE standards. However, intake P minus milk P had the best prediction over the entire range of data. Intake P was by far the largest determinant in the amount of P excreted by the animal in all the models tested, except Models 1 and 2 which use BW only in prediction (ASAE, 1980; 1996).

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Table 1. Phosphorus requirements (true and dietary, g/d) determined by different working groups for a 1320 lb non-pregnant cow, consuming 44 lb DM and yielding 66 lb of 3.5% FCM.

Source	True Requirement			AC ^a	Total Dietary Requirement
	Maintenance	Lactation	Total		
USA					
NRC (1978)	9.4	28.9	38.3	0.55	69.6
NRC (1989)	8.6	27.5	36.1	0.50	72.2
UK					
ARC (1980)	7.2	27.0	34.2	0.58	59.0
AFRC (1991)	22.1	27.0	49.1	0.58	84.7
France					
Gueguen et al. (1989)	17.5	27.0	44.5	0.60	74.2
Germany					
GEH (1986)	14.4	30.0	44.4	0.60	74.0
Kirchgeßner(1993)	20.0	30.0	50.0	0.70	71.4
The Netherlands					
NRLO (1982)	15.1	27.0	42.1	0.60	70.2
Proposed					
Beede (1999)	24.0 ^b	27.0 ^c	51.0	0.70 ^d	72.8

^aAC = absorption coefficient.

^bTrue maintenance requirement (g/d) = 1.2 x DMI (kg/d) + 0.002 x BW (kg); terms on the right hand side of the equation represent obligatory endogenous fecal (Spiekers et al., 1993) and urine P excretion (ARC,1980).

^cTrue lactation requirement (g/d) = milk yield (kg/d) x 0.09% P in milk. Requirement not influenced by milk fat content (see text).

^dAbsorption coefficient derived from literature data (see text) plus computations from balance data and assumption for P required for true maintenance as in footnote "b" above.

Table 2. Calculated absorption coefficients (CAC) from balance data with lactating cows consuming diets with different dietary phosphorus concentrations (average milk yield also shown).^a

Source	% dietary P, dry basis		
Morse et al. (1992b)	<u>0.30</u>	<u>0.41</u>	<u>0.56</u>
CAC	0.81	0.74	0.59
MY,lb/day ^b	44.1 ^c	48.0	48.0
	% dietary P, dry basis		
Spiekers et al. (1993)	<u>0.20</u>	<u>0.21</u>	
CAC	1.03	1.02	
MY,lb/day	22.0	45.8	
	% dietary P, dry basis		
Brintrup et al. (1993)	<u>0.33</u>	<u>0.39</u>	
CAC	0.78	0.67	
MY,lb/day	73.5	70.6	
	% dietary P, dry basis		
Wu et al. (1998b)	<u>0.32</u>	<u>0.42</u>	<u>0.52</u>
CAC	0.76	0.72	0.67
MY,lb/day	85.6	87.3	82.3

^a CAC = (M + L + B)/I; computed using P intake (I, g/day), milk P output (L, g/day), P balance (B, g/day) from actual P balance determinations and an estimation of true requirement for maintenance (M, g/day) as endogenous fecal output (1.2 g/kg DMI, as suggested by Spiekers et al., 1993) plus endogenous urinary output (0.002 g/kg BW; ARC, 1980).

^bMY = mean milk yield during balance.

^cActual value not reported; value computed from reported daily milk P output and assuming 0.09% P in milk.

Table 3. Lactational performance responses to varying dietary phosphorus concentrations (all values are on a per cow basis, unless otherwise noted).

Study 1. Stevens et al. (1971) (Oklahoma)

Experimental

Animals: 48 cows (27 Holstein, 15 Ayrshire, 6 Guernsey) first and second lactation; blocked to treatments by breed, season of calving, initial milk yield, and parity.

Length of study: from 3 wk of initial lactation through 16 wk of next lactation.

Basal diet: grain-to-hay ratio = 50-to-50 throughout lactation; amounts fed varied through lactation to meet requirements.

Dietary treatments: initial lactation: 0.41 or 0.62% dietary P, dry basis
next lactation: 0.40 or 0.55% dietary P, dry basis.

Results¹:

Item	% dietary P, dry basis		
Initial lactation (3-43 wk)	<u>0.41</u>	<u>0.62</u>	<u>P<</u>
DMI, lb/day	29.7	28.4	NS
SCM yield, lb/day	34.1	32.7	NS
Milk fat, %	3.6	3.6	NS
	% dietary P, dry basis		
Next lactation (0-16 wk)	<u>0.40</u>	<u>0.55</u>	<u>P<</u>
DMI, lb/day	33.7	33.0	NS
SCM yield, lb/day	46.6	44.0	NS
Milk fat, %	3.40	3.55	NS

¹NS = not statistically different ($P > 0.05$); SCM = solids-corrected milk.

Table 3 continued next page.

Table 3. (continued)

Study 2.		Carstairs et al. (1981) (Michigan)					
Experimental							
Animals: 48 first-lactation Holstein cows.							
Length of study: parturition through 12 wk of lactation.							
Basal diet: ammonia-treated corn silage, alfalfa-brome hay, corn grain, soybean meal, molasses, mineral-vitamin mix.							
Dietary treatments: 2 x 2 factorial: 0.4, 0.5% P x low, high energy ² .							
Results: (pooled across dietary energy levels)							
		% dietary P, dry basis					
Item		0.40	0.50	P<			
DMI, lb/day		33.9	34.0	NS ³			
Milk yield, lb/day		51.5	47.7	NS			
Milk composition		-----no differences-----		NS			

² Results pooled across dietary energy concentrations [85 or 135% of net energy requirement (NRC, 1978)]; no interactions of dietary P by energy.							
³ NS = not statistically different (P > 0.05).							
Study 3.		Kincaid et al. (1981) (Washington)⁴					
Experimental							
Animals: 40 Holstein cows (each treatment group had 3 first, 3 second, and 4 third and greater parity animals).							
Length of study: full lactation.							
Basal diet: forage-to-concentrate ratio = 1-to-1 throughout lactation; forage = alfalfa hay ad lib, grass-alfalfa silage (10.3 lb DM/day); concentrate = corn, beet pulp with molasses, cull peas, soybean meal, appropriate mineral and vitamin mix.							
Dietary treatments: 2 x 2 factorial: 0.31, 0.54% P x 1.0, 1.8% Ca, dry basis.							
Results:							
			Treatments				
		P, %	0.31	0.31	0.54	0.54	
Item		Ca, %	1.0	1.8	1.0	1.8	P<
DMI, lb/day ⁵			47.5 ^a	48.8 ^{ab}	49.3 ^b	49.3 ^b	0.05
3.5% FCM yield, lb/day ⁵			59.4 ^a	61.4 ^{ab}	65.1 ^b	62.7 ^b	0.05
Blood plasma inorganic P, mg/dl			5.46 ^a	5.32 ^a	6.44 ^b	6.37 ^b	0.05

⁴ Based on description of ANOVA in the paper, the correct test term (cow within treatment) was not used in statistical analysis of dietary treatment effects; nonetheless, treatment mean differences were compared by Duncan's multiple range test.							
⁵ Authors indicate significant P x Ca interaction on DMI and 3.5% FCM yield (P<0.05).							
^{a,b} Means within row with different superscripts were different according to the report; however, see footnote "4" above.							

Table 3. continued next page.

Table 3. (continued)

Study 4.		Call et al. (1987) (Utah)			
Experimental					
Animals: 34 second parity Holstein cows; blocked by previous milk yield and season of calving.					
Length of study: 24 cows full third lactation; 10 cows first 5.5 months of third lactation.					
Basal diet: alfalfa hay, corn, molasses, dried beet pulp, soybean hulls, urea (< 1.0% of dietary DM), plus appropriate mineral-vitamin supplement.					
Dietary treatments: 0.24, 0.32, or 0.42% total dietary P, dry basis.					
Results:					
		% dietary P, dry basis			
	Item	0.24	0.32	0.42	P<
	Digestible energy intake, Mcal/day	50.3 ^a	65.3 ^b	66.1 ^b	0.05
	FCM yield, lb/day	38.1 ^a	48.8 ^b	46.6 ^b	0.05
	Milk protein, %	3.15 ^a	3.35 ^b	3.38 ^b	0.05
	Milk fat and P, %	-----no differences-----			NS
	Blood serum inorganic P, mg/dl	3.6 ^a	5.0 ^b	5.1 ^b	0.05

^{a,b}Means within row with different superscripts were different.

Table 3 continued on next page.

Table 3. (continued)

Study 5. Brodison et al. (1989) (Northern Ireland)**Experimental**

Animals: 70 to 90 British Friesian type cows in one herd; seasonal calving December-April; 14, 24, 8, and 54%, first, second, third, and fourth and greater parities.

Length of study: 3 years (results presented separately for each year).

Basal diet: winter (6 mo) indoor feeding – ad lib grass silage, 17.6 lb concentrate/day (electronic feeder) during first half of lactation; summer (6 mo) perennial ryegrass pasture, plus 4.4 lb concentrate/day (electronic feeder).

Dietary treatments: 0.35 or 0.44% total dietary P, dry basis.⁶

Results:

Item	% dietary P, dry basis		P<
	<u>0.35</u>	<u>0.44</u>	
<i>Year 1</i>			
Milk yield, lb/lactation	11,400	10,688	0.05
Milk fat, %	3.49	3.67	0.05
Milk protein, %	3.11	3.08	NS ⁷
Milk P, % ⁸
Blood P, mg/dl ⁹	4.83	4.96	NS
<i>Year 2</i>			
Milk yield, lb/lactation	11,442	11,262	NS
Milk fat, %	3.70	3.76	NS
Milk protein, %	3.11	3.14	NS
Milk P, % ⁹	0.095	0.095	NS
Blood P, mg/dl ⁹	5.20	5.73	0.01
<i>Year 3</i>			
Milk yield, lb/lactation	10,971	11,037	NS
Milk fat, %	3.90	3.82	NS
Milk protein, %	3.11	3.12	NS
Milk P, % ⁹	0.081	0.092	0.0001
Blood P, mg/dl ⁹	4.52	5.57	0.001

⁶Once assigned, cows remained on the same P treatment for 3 yr.

⁷NS = not statistically different (P > 0.05).

⁸Milk P% not available in year 1.

⁹From samples taken during indoor feeding period.

Table 3 continued on next page.

Table 3. (continued)

Study 6. Brintrup et al. (1993) (Germany)
Experimental
Animals: 52 multiparous cows; blocked to dietary treatments based on parity, previous milk yield, and month of calving.
Length of study: two full lactations (104 wk of lactation, with 42-d dry period in between).
Basal diet: grass silage ad lib; corn silage (1/3 of grass silage DMI); mineral mix blended into corn silage to create two dietary treatments; concentrate by electronic feeder (1.0 lb/2.2 lb milk yield per day when milk yield exceeded 26.4 lb/day) = 20% wheat, 19% sugar beet pulp, 15.2% soybean meal; 15% horse beans, 10% corn, 6.3 % corn germ meal, 5% citrus pulp, 4.7% molasses, 3.5% premix, and 1.3% mineral mix.
Dietary treatments: 0.33 or 0.39% total dietary P, dry basis.
Results:

Item	% dietary P, dry basis		P<
	0.33	0.39	
DMI, lb/day ¹⁰	39.8	38.3	...
Milk yield, lb/day	55.9	53.9	NS ¹¹
Milk fat, %	4.38	4.21	0.05
Milk protein, %	3.31	3.27	NS
Milk P, %	0.091	0.088	NS
Blood serum P, mg/dl ¹²			
Less than 100 DIM	4.34	4.65	NS
Greater than 100 DIM	5.27	5.57	NS

¹⁰Measured on group basis, therefore not analyzed statistically.

¹¹NS = not statistically different (P > 0.05).

¹²Median value of samples taken 30, 60 and 90; or, 150, 200, and 300 days of lactation; DIM = days in milk.

Table 3 continued on next page.

Table 3. (continued)

Study 7. Dhiman et al. (1996) (Wisconsin)

Experimental

Animals: 46 mid to late lactation Holstein cows; blocked to dietary treatments based on pre-study (10 days) milk yield.

Length of study: 84 days.

Basal diet: 45% alfalfa silage, 10% corn silage, 19% high moisture ear corn, 12% barley, 10% roasted soybean, 3% soybean meal, plus minerals and vitamins, dry basis.

Dietary treatments: 0.39 or 0.65% total dietary P, dry basis.

Results:

Item	% dietary P, dry basis		P<
	0.39	0.65	
DMI, lb/day ¹³	48.4	48.6	...
Milk yield, lb/day	52.6	53.7	NS ¹⁴
3.5% FCM yield, lb/day	54.8	55.4	NS
Milk fat, %	3.88	3.97	NS
Milk protein, %	3.48	3.60	NS
Blood serum P, mg/dl ¹⁵	5.64	6.52	0.01
Blood serum P, mg/dl ¹⁶	5.29	6.54	0.01

¹³Measured on group basis, therefore no statistical comparison made.

¹⁴NS = not statistically different (P > 0.05).

¹⁵Sampled wk 7 of study.

¹⁶Sampled wk 12 of study.

Table 3 continued on next page.

Table 3. (continued)

Study 8. Wu and Satter (1998a) (Wisconsin)**Experimental**

Animals: 48 Holstein cows calving in September-October; dried-off the following end of August.

Length of study: full lactation.

Basal diet: September-mid May, TMR = corn silage, alfalfa silage, high moisture ear corn, roasted soybeans, plus mineral vitamin supplement; mid May-August, forage as pasture, plus supplemental concentrate (15.4 lb/cow/day; 40% of total feed intake).

Dietary treatments: 0.35 or 0.45% total dietary P, dry basis

Results: Item	% dietary P, dry basis			P<
	0.35	0.45		
DMI, lb/day ¹⁷	45.5	44.9		...
Milk yield, lb/day	69.7	64.9		NS ¹⁸
Milk fat, %	3.41	3.61		NS
Milk protein, %	3.05	3.17		0.02
Blood serum P, mg/dl	6.0	6.7		0.01

¹⁷Measured on group basis during confinement feeding (TMR), therefore no statistical comparison made.

¹⁸NS = not statistically different (P > 0.05).

Study 9. Wu et al. (1998) (Wisconsin)**Experimental**

Animals: 26 multiparous Holstein cows.

Length of study: first 8 weeks of lactation.

Basal diet: not defined in abstract.

Dietary treatments: 0.32, 0.42, or 0.52% total dietary P, dry basis.

Results:

Item	% dietary P, dry basis			P<
	0.32	0.42	0.52	
DMI, lb/day	47.1	44.2	44.9	NS ¹⁹
Milk yield, lb/day	85.6	87.3	82.3	NS
Milk P, %	0.083	0.085	0.083	NS
Blood serum P, mg/dl ²⁰	5.8	5.9	6.0	NS
P balance, g/day	-5.6	2.7	15.3	0.01

¹⁹NS = not statistically different (P > 0.05).

²⁰Blood samples taken 5 days postpartum.

Table 4. Reproductive performance of lactating dairy cattle fed varying dietary phosphorus concentrations.

Study 1. Stevens et al. (1971) (Oklahoma)

Experimental

Animals: 48 cows (27 Holstein, 15 Ayrshire, 6 Guernsey) first and second lactation; blocked to treatments by breed, season of calving, initial milk yield, and parity.

Length of study: from 3 wk of initial lactation through 16 wk of next lactation.

Basal diet: grain-to-hay ratio = 50-to-50 throughout lactation; amounts fed varied through lactation to meet requirements.

Dietary treatments: initial lactation: 0.41 or 0.62% dietary P, dry basis; next lactation: 0.40 or 0.55% dietary P, dry basis.

Results:

Item	% dietary P, dry basis		
Initial lactation (3-43 wk) ¹	<u>0.41</u>	<u>0.62</u>	<u>P<</u>
Days to first estrus	43	37	NS ²
Services per conception	2.6	2.4	NS
	% dietary P, dry basis		
Next lactation (0-16 wk) ³	<u>0.40</u>	<u>0.55</u>	<u>P<</u>
Days to first estrus	32	38	NS
Services per conception	4.4	2.4	0.05

¹During the initial lactation four of 16 cows fed 0.4% P and two of 32 cows fed 0.62% P required hormone therapy to correct apparent ovarian dysfunctions before becoming pregnant.

²NS= not statistically different ($P > 0.05$).

³During the next lactation, six of 16 cows fed 0.40% P and three of 32 cows fed 0.55% required hormone therapy because of extended anestrus or other evidence of ovarian dysfunction. In seven of nine cases, an ovarian cyst was detected.

Table 4 continued on next page.

Table 4. (continued)

Study 2. Carstairs et al. (1980) (Michigan)**Experimental****Animals:** 48 first-lactation Holstein cows.**Length of study:** parturition through 12 wk of lactation.⁴**Basal diet:** ammonia-treated corn silage, alfalfa-brome hay, corn grain, soybean meal, molasses, mineral-vitamin mix.**Dietary treatments:** 2 x 2 factorial: 0.4, 0.5% P x low, high energy.⁵**Results:** (pooled across dietary energy levels):

Item	% dietary P, dry basis		P<
	0.40	0.50	
Days to first ovulation	27	27	NS ⁶
Days open	123	114	NS
Pregnancy rate, % ⁷	79	75	NS
Services per conception	2.3	2.5	NS

⁴Different dietary P concentrations fed through 12 wk of lactation. All cows fed a common P-adequate diet from wk 12 through 21 of lactation while measurement of reproductive performance continued.

⁵Results pooled across dietary energy concentrations [85 or 135% of net energy requirement (NRC, 1978)]; no interactions of dietary P by energy.

⁶NS = not statistically different ($P > 0.05$).

⁷Through 21 wk of lactation.

Table 4 continued on next page.

Table 4. (continued)

Study 3.		Call et al. (1987) (Utah)		
Experimental				
Animals: 34 second parity Holstein cows; blocked by previous milk yield and season of calving.				
Length of study: 24 cows full third lactation; 10 cows first 5.5 months of third lactation.				
Basal diet: alfalfa hay, corn, molasses, dried beet pulp, soybean hulls, urea (< 1.0% of dietary DM), plus appropriate mineral vitamin supplement.				
Dietary treatments: 0.24, 0.32, or 0.42% total dietary P, dry basis.				
Results:				
Item	% dietary P, dry basis			P<
	0.24	0.32	0.42	
Days to first estrus				
Pregnant cows	45(12) ⁸	66(7)	50(10)	NS ⁹
Nonpregnant cows	45(1)	75(1)	84(3)	NS
Days to first breeding				
Pregnant cows	77	91	72	NS
Nonpregnant cows	117	168	104	NS
Days open	82	135	87	NS
Pregnancy rate, %	92	87	76	NS
Services per conception	1.3	1.9	1.5	NS

⁸Number in parenthesis = number of cows in treatment by pregnancy status category.

⁹NS = not statistically different (P > 0.05).

Table 4 continued on next page.

Table 4. (continued)

Study 4. Brodison et al. (1989) (Northern Ireland)			
Experimental			
Animals: 70 to 90 British Friesian type cows in one herd; seasonal calving December-April; 14, 24, 8, and 54%, first, second, third, and fourth and greater parities.			
Length of study: 3 years (results presented separately for each year)			
Basal diet: winter (6 mo) indoor feeding – ad lib grass silage, 17.6 lb concentrate/day (electronic feeder) during first half of lactation; summer (6 mo) perennial ryegrass pasture, plus 4.4 lb concentrate/day (electronic feeder).			
Dietary treatments: 0.35 or 0.44% total dietary P, dry basis. ¹⁰			
Results:			
<u>Item</u>	<u>% dietary P, dry basis</u>		<u>P<</u>
	<u>0.35</u>	<u>0.44</u>	
<u>Year 1</u>			
Days to first service	74	74	NS ¹¹
Days to conception	95	90	NS
Calving interval, days	368	376	NS
Conception rates, %			
First service	52	59	NS
All services	59	68	NS
Services per conception	1.7	1.5	NS
Total cows conceiving, %	89	88	NS
<u>Year 2</u>			
Days to first service	75	80	NS
Days to conception	85	95	NS
Calving interval, days	372	377	NS
Conception rates, %			
First service	60	57	NS
All services	76	76	NS
Services per conception	1.3	1.3	NS
Total cows conceiving, %	86	77	NS
<u>Year 3</u>			
Days to first service	79	83	NS
Days to conception	89	103	NS
Calving interval, days	372	385	NS
Conception rates, %			
First service	63	63	NS
All services	76	59	NS
Services per conception	1.3	1.7	NS
Total cows conceiving, %	81	96	NS

¹⁰Once assigned, cows remained on the same P treatment for 3 yr.

¹¹NS = not statistically different ($P > 0.05$).

Table 4 continued on next page.

Table 4. (continued)

Study 5. Brintrup et al. (1993) (Germany)¹²

Experimental

Animals: 52 multiparous cows; blocked to dietary treatments based on parity, previous milk yield, and month of calving.

Length of study: two full lactations (104 wk of lactation, with 42-day dry period in between).

Basal diet: grass silage ad lib; corn silage (1/3 of grass silage DMI); mineral mix blended into corn silage to create two dietary treatments; concentrate by electronic feeder (1.0 lb/2.2 lb milk yield per day when milk yield exceeded 26.4 lb/day) = 20% wheat, 19% sugar beet pulp, 15.2% soybean meal; 15% horse beans, 10% corn, 6.3 % corn germ meal, 5% citrus pulp, 4.7% molasses, 3.5% premix, and 1.3% mineral mix.

Dietary treatments: 0.33 or 0.39% total dietary P, dry basis.

Results:

Item	% dietary P, dry basis		P<
	0.33	0.39	
Days to first AI	55	47	NS ¹³
Days open	99	109	NS
Services per conception	2.1	2.3	NS
Calving interval, days	381	393	NS
Cows pregnant in second lactation, %	90	79	NS

¹²Six cows were replaced in each treatment group between the two successive lactations.

¹³NS = not statistically different ($P > 0.05$).

Table 4 continued on next page.

Table 4. (continued)

Study 6. Wu and Satter (1998b) (Wisconsin)**Experimental**

Animals: 48 Holstein cows calving in September-October; dried-off the following end of August.

Length of study: full lactation.

Basal diet: September-mid May, TMR = corn silage, alfalfa silage, high moisture ear corn, roasted soybeans, plus mineral vitamin supplement; mid May-August, forage as pasture, plus supplemental concentrate (15.4 lb/cow/day; 40% of total feed intake).

Results:

Item	% dietary P, dry basis		P<
	0.35	0.45	
Days to first estrus	51.3	42.5	NS ¹⁴
Days to first AI	74.3	75.5	NS
Days open	112.4	120.1	NS
Conception rate to first AI	29.2	37.5	...
Pregnancy rate ¹⁵			
Before 120 DIM, %	50.0	45.8	...
Entire Lactation, %	87.5	79.2	...
Services per conception ¹⁶	2.4	2.6	NS

¹⁴NS = not statistically different ($P > 0.05$).

¹⁵Results of statistical analysis not reported; DIM = days in milk.

¹⁶Includes only cows that ultimately became pregnant: 21/24 and 19/24 for 0.35 and 0.45% P, respectively.)

Table 5. Models evaluated with the independent data set (Table 6) to predict P excretion of dairy cows (note that values are in metric units).¹

Model and Source	Equation (Y = P excretion, g/day)
(1) ASAE, 1980	$Y = \text{BW (kg)} \times 0.0724$
(2) ASAE, 1996	$Y = \text{BW (kg)} \times 0.094$
(3) Morse et al., 1992b	$Y = 14.67 + 0.6786 \times \text{intake P (g/day)}$ $+ 0.00196 \times [\text{intake P (g/day)}]^2 - 0.317 \times \text{MY (kg/day)}$
(4) Van Horn et al., 1994	$Y = 9.6 + 0.472 \times \text{intake P (g/day)}$ $+ 0.00126 \times [\text{intake P (g/day)}]^2 + 0.323 \times \text{MY (kg/day)}$
(5) H & C Model ^a	$Y = -24.06 + 81.67 \times \text{diet P (\% of dietary DM)} + 0.07 \times \text{BW (kg)}$ $- 0.45 \times \text{milk P (g/day)}$
(6) Intake P - milk P ^b	$Y = \text{intake P (g/day)} - \text{milk P (g/day)}$

¹ BW = body weight and MY = milk yield.

^a The H and C model was developed from data of Hibbs and Conrad (1983).

^b Van Horn et al. (1994) proposed that P excretion could be estimated by the simple difference between intake P (g/day) and milk P secretion (g/day) which assumes P retention is constant or non-consequential.

Table 6. Summary of variables and treatment means of the independent data set from the literature used to evaluate prediction models for P excretion.¹

Data Source	n	BW, kg	DMI, kg/day	MY, kg/day	Dietary P, % of DM	Intake P, g/day	Milk P, g/day	Milk P, %	P Excretion^a, g/day
Martz et al., 1990	4	645	20.6	32.01	0.15	31.8	26.6	0.083	16.96
	4	645	22.7	35.21	0.21	48.0	31.2	0.089	21.90
Brintrup et al., 1993	10	633	20.8	32.10	0.41	86.0	29.0	0.090	56.10
	10	645	21.4	33.40	0.34	73.0	30.0	0.090	43.86
Spiekers et al., 1993	5	603	16.9	20.80	0.22	37.0	18.0	0.087	20.71
	5	597	10.9	10.00	0.20	21.5	8.7	0.087	13.57
Wu et al., 1998	8	638	21.4	38.90	0.32	70.5	32.2	0.083	45.49
	9	643	20.1	39.70	0.42	86.7	33.9	0.085	50.90
	9	609	20.4	37.40	0.52	108.4	31.2	0.083	62.73
Rodriguez, 1998	11	763	14.17	39.63	0.62	87.3	38.5	0.097	40.36
	10	701	14.23	38.40	0.60	85.7	37.8	0.098	40.47

¹ BW = body weight, DMI = dry matter intake, and MY = milk yield.

^aBecause urinary P excretion data were not reported in most data sets, they were estimated as 2% of measured fecal P excretion. Martz et al.(1990) and Rodriguez (1998) reported actual urinary P excretion and these data were used.

Table 7. Accuracy (bias) of prediction models to predict P excretion (g/day) in lactating dairy cows based on the difference between predicted and measured P excretion (g/day).

Model and Source	Predicted P Excretion - Measured P Excretion, g/day.		
	Mean	SE^a	P^b
(1) ASAE, 1980	-9.37	5.00	0.0900
(2) ASAE, 1996	-23.31	5.03	0.0090
(3) Morse et al., 1992b	-22.38	2.83	0.0001
(4) Van Horn et al., 1994	-20.66	2.18	0.0001
(5) H & C Model ^c	-1.49	4.24	0.7324
(6) Intake P - milk P ^d	-0.525	2.25	0.8205

^a SE = standard error of mean.

^b Significant bias (e.g., mean different from zero) was analyzed by t-test statistic (n=11).

^c The H and C model was developed from data of Hibbs and Conrad (1983).

^d Van Horn et al. (1994) proposed that P excretion could be estimated by the simple difference between intake P (g/day) and milk P secretion (g/day) which assumes P retention is constant or non-consequential.

Table 8. Precision of models to predict measured P excretion (g/day) of lactating dairy cows in the independent data set based on percentage difference from measured P excretion (g/day).^a

Item	Percentage of Measured		
	All Data	Low ^b	High ^b
Measured P Excretion (g/day)	13 to 62.7	13.6 to 22.2	40.4 to 62.7
Measured Intake P (g/day)	21.5 to 108.4	21.5 to 48.0	70.5 to 108.4
Model and Source	Mean \pm SEM	Mean \pm SEM	Mean \pm SEM
(1) ASAE, 1980	67.8 \pm 22.7	154.8 \pm 26.1	18.15 \pm 5.0
(2) ASAE, 1996	106.0 \pm 32.4	230.4 \pm 33.8	34.9 \pm 10.2
(3) Morse et al., 1992b	65.5 \pm 6.8	80.8 \pm 7.3	56.7 \pm 8.5
(4) Van Horn et al., 1994	64.8 \pm 9.2	92.8 \pm 11.7	48.8 \pm 8.2
(5) H & C Model ^c	39.1 \pm 9.6	53.9 \pm 25.0	30.7 \pm 5.6
(6) Intake P - milk P ^d	17.5 \pm 5.8	26.6 \pm 14.8	12.21 \pm 3.6

^a Percentage difference calculated as predicted P excretion minus measured P excretion divided by measured P excretion multiplied by 100; SEM = standard error of mean

^b For simplicity, Low (13.6 to 22.2 g/day) and High (40.4 to 62.7 g/day) categories of measured P excretion were used to compare the precision of prediction models over the range of measured P excretion in the independent data set.

^c The H and C model was developed from data of Hibbs and Conrad (1983).

^d Van Horn et al. (1994) proposed that P excretion could be estimated by the simple difference between intake P (g/day) and milk P secretion (g/day) which assumes P retention is constant or non-consequential.

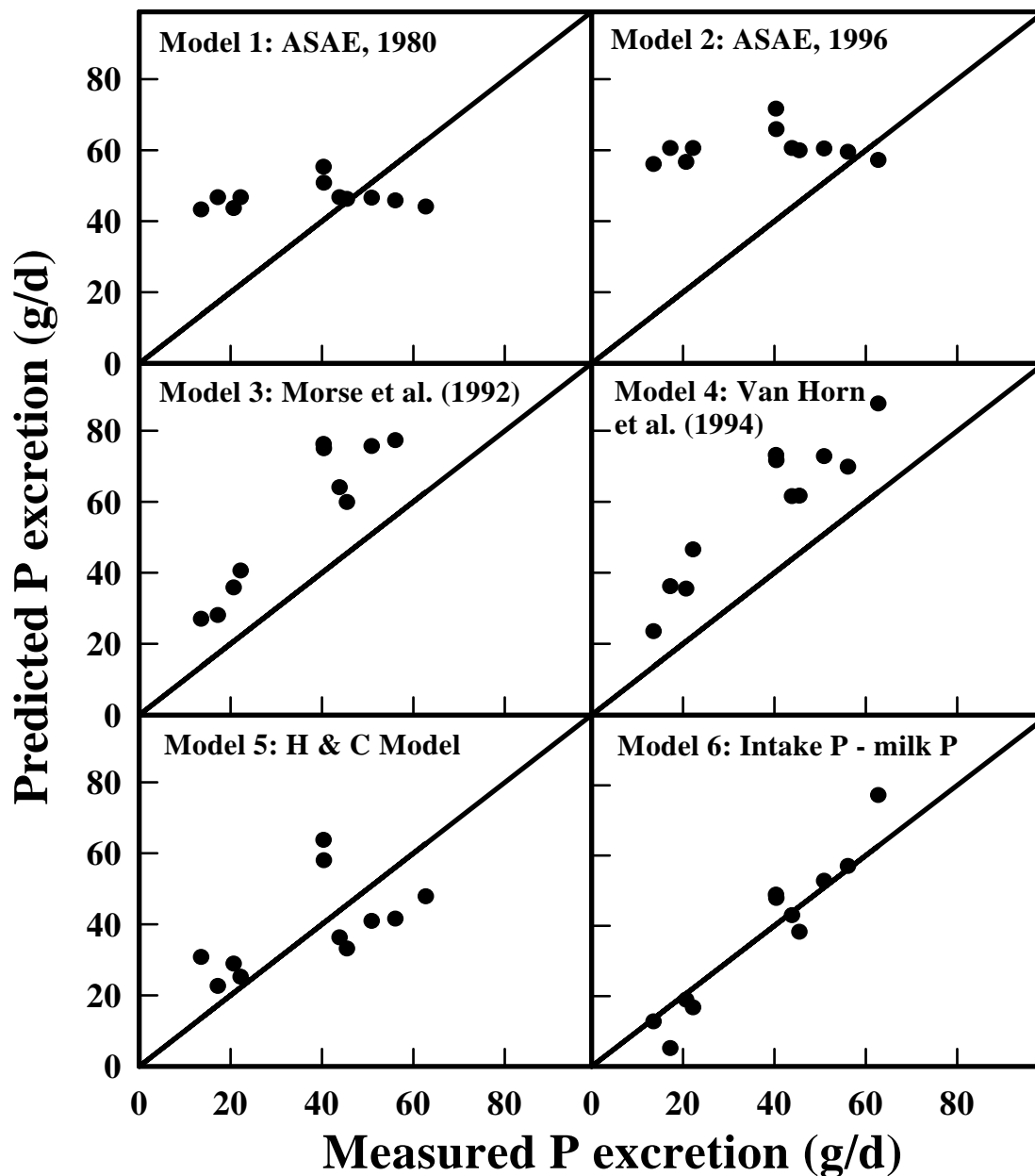


Figure 1. To indicate precision of the models to estimate P excretion, predicted P excretion (!) is plotted versus the measured P excretion of the independent data set for the following models. (1) Model 1 from ASAE (1980); (2) Model 2 from ASAE (1996); (3) Model 3 from Morse et al. (1992b); (4) Model 4 from Van Horn et al. (1994); (5) Model 5 was developed from data in Hibbs and Conrad (1983); and (6) Model 6: intake P (g/day) minus milk P (g/day). The diagonal line is unity where predicted P excretion equals measured P excretion (e.g, 1-to-1).

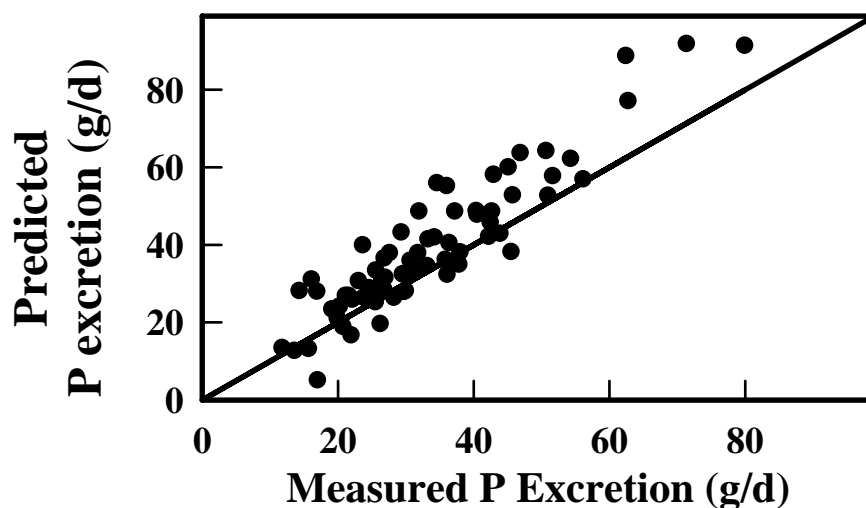


Figure 2. All the data included in the independent data set, data from Hibbs and Conrad (1983), and data from Morse et al. (1992b) were used to further evaluate the relationship of intake P minus milk P to predict P excretion. The predicted P excretion (!) from the model versus the measured P excretion is shown. The diagonal line is unity where predicted P excretion equals measured P excretion (e.g, 1-to-1).

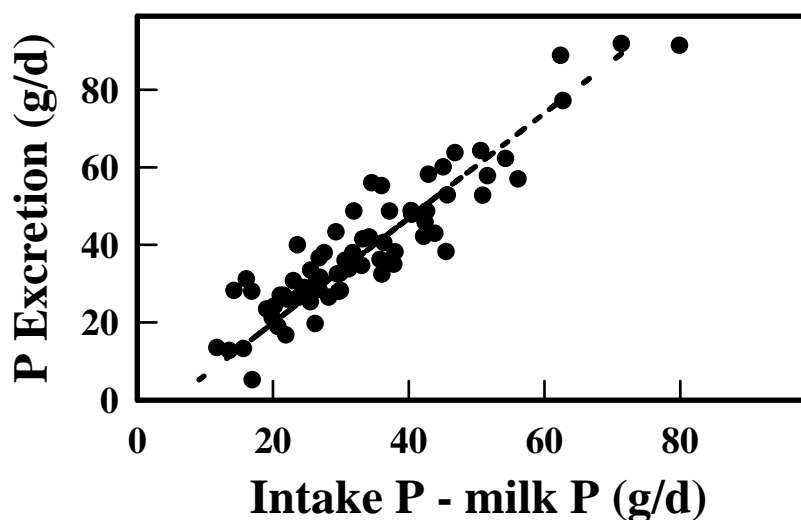


Figure 3. All the data (!) included in the independent data set, and data from Hibbs and Conrad (1983), and Morse et al. (1992b) were used to describe the linear relationship (---) between the dependent variable, measured P excretion, and the independent variable of (intake P – milk P, g/day). The regression accounted for 87% (R^2) of the variation.

Managing During Heat Stress

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Abstract

Heat stress negatively impacts performance and health of dairy cattle. During the prepartum period, heat stress is responsible for lower calf birth weight and reduced milk yield in the subsequent lactation. Postpartum hyperthermia depresses dry matter intake and reduces milk yield. Reproductive performance decreases in hot weather as a result of poorer conception rates, alterations in the length and expression of estrus behavior, and increased early embryonic death. Hot and humid weather conditions, along with wet and muddy conditions, are also responsible for higher rates of mastitis and poorer milk quality, particularly in the southeastern United States. Improper ration formulation, intermittent feeding behavior, a lack of cud-chewing, elevated respiratory rates,

excessive losses of saliva from drooling, and an overall reduction in the buffering capacity of cows may interfere with the normal buffering of rumen contents. This is believed to be a significant contributor to rumen acidosis, laminitis, and other lameness conditions that seem to be particularly prevalent during periods of hot weather. Feeding the lactating cow is particularly challenging during periods of intense heat. The objective is to maintain some level of performance and homeostasis yet not add to the internal heat load or tendency toward rumen acidosis. Without doubt, the most effective way to reduce heat stress and maximize performance and health is to develop an integrated environmental management system. Depending upon climatic conditions, such systems may include one or more of the following environmental modifications: shade in the

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form of trees and/or artificial or permanent shade structures, high pressure foggers and fans, misters, sprinklers and fans, exit lane sprayers, and possibly cooling ponds.

Introduction

Normal physiological processes require that the body's temperature be maintained within fairly narrow limits. When environmental temperatures are moderate (41° to 78°F) physiologic demand for body cooling or warming is minimal and optimal performance can occur. However, in the face of environmental temperature extremes, thermoregulatory activities increase and performance is proportionally reduced.

The primary sources of heat gain from the environment are solar radiation and elevated ambient air temperature. These are complicated by high relative humidity and a lack of air movement. Primary methods for altering the environment include the provision of shade, evaporative cooling with water in the form of fog, mist, or sprinkling with natural or forced air movement, and in some regions, possibly cooling ponds. The incorporation of these methods into an integrated environmental management system, which protects cows from the sources of heat gain from the environment and takes advantage of opportunities to enhance evaporative heat loss, have the best potential for successful reduction of heat stress on dairy cows.

In addition to heat gain from the environment, sources of heat gain include those derived internally from the cow's body. These include the heat from metabolism associated with basal body functions, daily maintenance, physical activity, and performance. In lactating dairy cows, increases in body heat load are

primarily associated with increases in feed consumption and metabolism (rumen fermentation and nutrient metabolism) related to milk production. In the face of rising environmental temperatures, the cow's primary mechanism for lowering the amount of internally derived heat is to reduce dry matter intake.

There are several nutritional strategies and/or supplements that may be used to help compensate for reduced dry matter intake in cows during periods of heat stress. Decreasing forage to concentrate ratios, supplementing fat, elevating dietary protein, encouraging or facilitating water intake, increasing dietary concentrations of potassium, sodium, and magnesium, and feeding buffers are among some of the more common types of adjustments made during hot weather conditions. The primary objectives of these nutritional strategies are to maintain performance and homeostasis. Although such adjustments in nutrition and feeding management can alleviate some of the negative effects of heat stress on health and performance, compared with environmental modification, manipulation of the cow's diet specifically for heat stress has little effect on comfort or productivity (Beede and Shearer, 1991). The following is a brief review of some of the more significant effects of heat stress on performance and health with emphasis on environmental management strategies.

Impact of Heat Stress on Performance and Health

Heat stress during the prepartum period reduces blood flow to the uterus and thus the developing fetus. The result is the birth of calves which are smaller (Collier et al., 1982; Wolfenson et al., 1988), less viable, and frequently subject to failure of passive transfer. Milk production of cows

during the lactation following parturition heat stress is also reduced by as much as 10 to 12% as a result of reduced placental mass and altered placental and maternal endocrine functions (Collier, et al, 1980; Wiersma and Armstrong, 1988; Wolfenson, et al., 1988). In lactating cows, studies have documented reductions in milk production ranging from 10 to 25% (Roman-Ponce et al., 1977; Schneider et al., 1984; Thatcher et al., 1974). Effects on reproductive performance include lowered conception (Ingraham, 1974), increased early embryonic death, and reductions in the length and intensity of estrus behavior (Thatcher and Collier, 1985). Heat stress also impacts milk quality and mastitis (Shearer and Beede, 1990a). Bacteria and somatic cell counts in milk tend to increase during the summer months, particularly in the southeastern United States. Exact cause for this is unknown but presumed to be associated with a stress-related depression in immunity combined with the exposure of cows to a pathogen-rich environment. The effects of heat stress on performance and health have been more thoroughly reviewed elsewhere (Shearer and Beede, 1990a).

Heat Stress, Rumen Acidosis, Acid-Base Balance, and Lameness

Decreasing the forage-to-concentrate ratio of diets during periods of hot weather may help to maintain dry matter intake. However, since such strategies often predispose cows to rumen acidosis, they are generally ill advised. Feeding behavior of cows is altered during periods of heat stress. For example, where concentrates and forages are offered separately, the consumption of forages tends to decline more rapidly and to a greater extent than the intake of concentrate feeds. In addition, intake is less consistent as cows tend to eat fewer meals but more at each feeding

session. This is often referred to as "slug feeding" and in itself encourages rumen acidosis. Consistent intake is a primary objective of feeding in hot weather conditions. The combination of energy dense rations and intermittent feeding patterns increases the risk for acidosis problems and consequently, laminitis in hot weather.

Another significant contributor to rumen acidosis during periods of heat stress relates to changes in the cow's acid-base balance (Shearer and Beede, 1990b). The primary avenues for evaporative heat loss during periods of hot weather are sweating and panting. As temperatures rise, both sweating and respiratory rates increase. In severe heat, panting progresses to open-mouth breathing, characterized by a lower respiratory rate and a greater tidal volume. The consequence is respiratory alkalosis as a result of the rapid loss of carbon dioxide. The cow compensates by increasing urinary output of bicarbonate (HCO_3). Simultaneously, the salivary HCO_3 pool for rumen buffering is decreased because of the loss of saliva which occurs from drooling in severely stressed cows. The end result is less rumen buffering and a reduction in total buffering capacity.

Rumen pH is largely determined by the balance between the acids generated from the fermentation of feedstuffs and the bicarbonate and phosphate buffers in saliva which neutralize these acids. Physically effective fiber stimulates chewing, and chewing stimulates saliva secretion. Consequently, consistent intake of feedstuffs with effective fiber and cud-chewing are essential for rumen buffering. Saliva flow rates in beef and dairy cattle are estimated to be in the range of 108 to 308 liters (28 to 81 gallons) per day (Erdman, 1988). At these rates of saliva flow, it is estimated that the

cow can contribute in the range of 390 to 1115 grams (0.86 to 2.5 lb) per day of disodium phosphate and 1134 to 3234 grams (2.5 to 7.1 lb) per day of sodium bicarbonate for rumen buffering. Reduced feed intake, a preference for concentrates rather than forage, a loss of salivary buffering from increased respiratory rates and drooling, and a reduction in the total buffering pool all contribute to a greater potential for rumen acidosis during periods of hot and humid weather and may explain in part why some herds experience more acidosis and lameness despite being fed properly formulated rations.

Environmental Modification for Management of Heat Stress

Successful abatement of heat stress generally requires environmental modification. Critical components include shade, water in the form of fog, mist, or sprinkling, and air flow either natural or by forced air movement with fans. The primary objectives are to reduce direct solar radiation, lower air temperature, improve or assist air movement, or in some cases, increase the natural evaporative cooling from skin surfaces.

Natural Shade. Trees are an excellent source of shade. They are not only effective blockers of solar radiation, but the evaporation of moisture from leaf surfaces cools the surrounding air without appreciably interfering with air circulation. In addition, animals acquire very little radiant heat load from the shade of a tree compared with a metal roof. Therefore, trees are a highly desirable natural resource in the environment of the dairy cow.

Unfortunately, and particularly in large herds, trees have a short life span. In fact, most last only about 1 to 2 summers

after the onset of cow exposure where stocking rates are high. As cows congregate to seek protection from the summer sun, they quickly develop mud holes at the base of trees. This soon leads to death of the tree and loss of this natural shade source. While some advocate fencing around the perimeter of the tree to protect the root system, doing so usually results in effectively fencing cows outside of the zone of shade.

Pasture rotation and management strategies can also be used to provide relief for trees as well as pastures. For example, one may rotate cows through pastures with shade trees during the hot summer months. During moderate times of the year, avoid use of these pastures and instead concentrate on filling-in low areas with topsoil and re-seeding with grass. Grass prevents soil erosion, utilizes nutrients and moisture, saves the trees, and with continued management, provides a cooler, cleaner, and drier place for cows to be during periods of hot weather.

Another option for taking advantage of the natural shade of trees is tree-lined fences. These work best when tree lines are situated on the southern and western borders of corrals or pastures. While not an immediate solution, it should be considered in the long-term design of facilities. Two potential problems, of course, are loss of animals from lightning strike and toxicity that may occur subsequent to ingestion by cows of the wilted leaves of certain types of trees (e.g. wild cherry).

Artificial Shade. Solar radiation is a major factor in heat stress and increases heat gain by direct as well as indirect means. Blocking its effects through the use of properly constructed shade structures alone increased milk production by 10 to 19% in studies conducted in Florida (Collier et al.,

1981; Roman-Ponce, 1977; Schneider et al., 1984). Options include permanent or portable shade structures. In the following sections are factors to be considered with respect to design and maintenance of shade structures.

Permanent Shade Structures. Major design parameters for permanent shade structures include: 1) orientation, 2) floor space, 3) height, 4) ventilation, 5) roof construction, 6) feeding and water facilities, and 7) waste management system (Beede et al., 1987; Bucklin et al., 1988; Bucklin et al., 1991; Buffington et al., 1983; Collier and Buffington, 1979).

The preferred orientation of a shade structure depends upon whether or not cows are confined to the structure. In the southeast, for example, alignment of the long-axis in an east-west direction achieves the maximum amount of shade under the structure and is therefore the preferred orientation for confined animals. On the other hand, where cows are free to move with the shadow of the structure, a north-south orientation is better because this orientation will allow sunlight to dry out as much as 35 to 50% of the area beneath the shade structure during both the morning and afternoon hours. This is particularly important for shade structures with earthen floors.

Some prefer concrete slab floors. A reinforced concrete slab at least 4 inches thick, with a smooth finish and grooved for good footing, is recommended. If a flush system is to be used, the floor should be sloped 1.5 to 2%. Many operations in Florida and the southeast incorporate a flushing system with dump tanks or pop-up valves. Water availability, space, and environmental concerns have interested some of late in floor scraping and removal

of manure solids from the premises. Various other waste handling facilities incorporate settling basins, liquid-solid separators, pumping, and gravity-flow systems.

Guidelines regarding size of shade structures vary according to climatic conditions. Hahn (1985) recommends 19 to 27 square feet of floor space per cow. However, for environments that are particularly hot and humid (such as Florida), floor space equivalent to 60 to 65 square feet per cow is recommended (Collier and Buffington, 1979). Space requirements are essentially doubled in hot and humid climates to provide additional open area for improved air movement.

Natural air movement under a shade structure is affected by its height and width, the slope of the roof, and the presence of, or size of, the ridge opening. Air movement may occur naturally as breezes through the open sides of structures or by the concept of thermal buoyancy in which air warmed by the presence of animals and radiation through the roof creates air flow toward the ridge opening. A steady flow of air through a shade structure requires the following design specifications:

- 1) Shade structures of 40 feet or less require a minimum eave height of 12 feet. Structures wider than 40 feet should have eave heights of at least 16 feet or more.
- 2) There should be at least 50 feet of clearance between adjacent buildings or other obstructions.
- 3) Gable roofs should have at least a 4:12 slope (6:12 is acceptable but difficult to work on) and a continuous open ridge. Ridge caps if desired should have a

minimum of one foot of clearance between the cap and the roof peak.

4) Ridge openings should be a minimum of one foot wide plus two inches for each 10 feet of structure width over 20 feet.

5) Painting metal roofs white and adding insulation directly beneath the roofing will reflect and insulate from effects of solar radiation and will reduce thermal radiation on cows.

Thermal radiation from the roof of shade structures can add significant heat load to cattle, particularly in low structures without a ridge opening. In these types of structures, thermal radiation can be reduced by cooling the roof with water, adding insulation, or painting the roof with a reflective type of paint. However, it should be remembered that these additions to the structure do not cool air, reduce humidity, or augment the natural evaporative cooling mechanisms of cows beneath the shade structure. Furthermore, proper design of the shade structure (adequate eave height and an open ridge) will naturally limit thermal radiation effects. When faced with the need to retrofit cooling into an ill-designed existing structure, the priorities should be directed to cooling the cows rather than the roof. Roof cooling (beyond painting with a reflective paint), while beneficial, is a secondary consideration.

Portable Shade Structures. Portable shades offer some advantages over permanent structures in their ability to be moved as needed to cleaner and drier locations. However, protection from solar radiation is less than that achieved in permanent structures. Shade cloth patterns come in various weaves providing 30 to 90% shade. One of the more common types is a woven polypropylene fabric which provides 80% shade. While longevity is

considerably less than that expected of permanent structures, shade cloth if properly maintained (kept tight) can last five years or longer (Beede et al., 1987; Bray, 1986; Bucklin, 1991).

Cooling by Reducing Ambient Air Temperature

As temperatures rise above the upper critical temperature threshold of 78°F, the dairy cow begins to increase heat loss via the respiratory tract and skin surface. However, despite the remarkable efficiency of these thermoregulatory responses to dissipate heat, as temperatures continue to rise, these natural mechanisms are overwhelmed leading to hyperthermia and reduced performance. In these circumstances, efforts to minimize additional heat gain and provide supplemental cooling become necessary. Water and air movement become the agents by which the micro-environment is cooled and evaporative cooling by the cow is augmented.

Evaporative Cooling Pads and Fans.

Air temperatures can be lowered by air conditioning or refrigeration, but the expense of such types of mechanical air cooling make these impractical for cooling dairy cows. A more economically feasible method to cool the micro-environment is the evaporative cooling pad (corrugated cardboard or similar material) and fan system which uses the energy from air to evaporate water. This process cools the air and raises its relative humidity. Although these systems are most effective in arid climates, such as the southwestern United States, they have been observed to reduce air temperature in humid climates like Florida as well (Taylor, 1985).

High Pressure Foggers. In recent years, however, there has been more interest in high pressure foggers. Foggers disperse a very fine droplet of water which quickly evaporates, cooling the surrounding air and raising the relative humidity in the process. The typical design incorporates a ring of fogger nozzles attached to the exhaust side of a fan. As fog droplets are emitted (200 psi), they are immediately dispersed into the fan's air stream where they soon evaporate. Animals are cooled as the air is blown over their body and they inspire the cooled air. Fogger systems are most effective in areas of low humidity. However, even in the southeast where humidity is normally quite high, daytime humidity is still low enough to allow for effective cooling with fogger systems. On the other hand during overnight hours, the relative humidity increases to near 100%. When the air is saturated with moisture, evaporation is reduced and cooling stops. Consequently, high pressure foggers are designed to operate during the daylight (less humid) hours only (9:00 AM to 8:00 PM). Fans, however, run continuously for nighttime cooling.

High pressure foggers are becoming more popular in Florida and elsewhere. While they are advantageous in the fact that they use far less water (3 to 5 gallons/cow/day) compared with sprinkler systems (30 to 50 gallons/cow/day), they require more maintenance. Water filters must be cleaned or checked daily to prevent clogging of fogger nozzles. High pressure foggers should be used only in open-sided, ridge-vented, tall (greater than 12 feet) barns. Low barns with side walls restrict air flow and fog droplet evaporation. This reduces cooling and makes for excessively wet conditions in the barn.

Misters. A mist droplet is larger than a fog droplet but cools air by the same principle. These systems do not work well in windy conditions or in combination with fans in humid environments. In warm humid environments, mist droplets are too large to fully evaporate before settling to the ground. The consequence is wet bedding and feed. A further complication with misters is the formation of an insulating layer of air that can form between the droplets of water on hair shafts and the skin. When this occurs, it impedes natural evaporative heat loss from the skin and can result in body heat buildup.

Enhancing the Cow's Natural Mechanism of Heat Loss

Protecting the cow from solar radiation with shades and reducing ambient air temperatures through the process of water vaporization and controlled ventilation are important considerations in cooling dairy cattle. Various combinations of these techniques have proven to be particularly useful in arid climates. Cooling in hot and humid climates, on the other hand, can be more challenging. Instead of attempts to lower ambient air temperature, another technique is to provide shade, wet the skin, and move air to enhance the cow's primary mechanism for the dissipation of heat - evaporative cooling from the skin.

Sprinklers and Fans. Sprinkling systems utilize a larger size water droplet that is able to wet the hair coat to the skin. Cooling is accomplished as water evaporates from the hair and skin. In combination with forced-air, sprinkling substantially increases the loss of body heat over that possible by sweating alone. Several studies have demonstrated upper body sprinkling followed by forced-air ventilation to be an effective means to reduce body temperature

(Igono et al., 1987; Turner et al., 1989), increase feed intake (Igono et al., 1987; Strickland et al., 1989; Turner et al., 1989), and boost milk yield (Flamenbaum et al., 1986; Igono et al., 1987; Strickland et al., 1989; Turner et al., 1989). This combination has been applied to holding areas, shade structures, feed barns, and free-stall barns with good success.

The typical configuration for a sprinkler and fan (or high pressure fogger and fan) cooling system for either a feed barn or freestall barn is shown in Figure 1. It requires a properly sloped concrete floor with facilities to handle water run off at rates of somewhere between 50 to 100 gallons of water per animal per day depending upon sprinkling rates. In early Florida studies, water use amounted to 120 gallons/cow/day (sprinkling for 30 seconds every 5 minutes when ambient air temperatures exceeded 80°F). Later work has shown that rates of 50 gallons/cow/day or less will provide effective cooling (Bray et al., 1991). Consequently, in addition to plans for water run-off and containment, some determination of the water supply is advised.

Sprinklers should be located above the cows with nozzles directed as shown in Figure 1. The type of nozzle one chooses to use depends upon the volume of water and sprinkling rate desired. Generally, low pressure (10 psi), 180° spray nozzles, capable of delivering the equivalent of 0.05 inches of rainfall per sprinkling cycle are used. Nozzles are spaced approximately every 8 feet or as far apart as necessary to provide overlapping coverage.

Fans (0.5-1.0 hp) capable of air flow rates of 11,000 cfm or greater are recommended. Thirty-six inch fans rated as such can be hung above the sprinklers every 30 feet (every 40 feet for 48 inch fans).

They should be tilted downward at a 20 to 30° angle (from vertical) to direct the flow of air onto the cows. An air velocity of 400 to 600 feet per minute over the cow is desired. The system combines fans and sprinkling with cows being sprinkled for 1 to 2 minutes at 15 minute intervals. Fans should be run continuously. The entire system should be thermostatically controlled to operate automatically when ambient air temperatures reach or exceed 80°F.

Sprayers in Parlor Exit Lanes. Exit lane sprayers are available commercially and designed to automatically spray water onto cows as they pass through. Fan nozzles and timing of the spray are designed to spray only onto the cow's back and sides. Fan spray nozzles must have a flow rate of least 8 gallons per minute at 40 psi. These systems would seem to have greatest appeal in operations where cows travel some distance from the milking parlor to feed and loafing areas. A less complex system can be made by simply locating an ordinary shower nozzle above cows in the parlor exit lane. Cows can be showered as they leave the parlor.

Cooling Ponds. Tradition has held that it is better to limit or exclude access of cows to streams and farm ponds, and with good reason. Experience has shown that free access to streams and ponds may predispose cows to a number of infectious diseases and some toxicities. Most notable of these are *Leptospirosis* and mastitis caused by a variety of organisms, particularly *Protheca* species (achlorophyllic algae). As a result, most advise that cows be fenced away from streams and ponds. Cooling ponds, therefore, represent a controversial method for the management of heat stress. However, in Florida, studies have found that cooling ponds not only effectively reduce body temperature but

have no apparent adverse effect on udder health (Beede et al., 1987; Shearer et al., 1987).

The primary mode of heat loss in cooling ponds is conduction with a small amount lost by evaporative cooling during the 5 to 10 minutes after exiting the pond. Water temperature of the cooling ponds generally ranges from 75 to 86°F, or occasionally higher. At this temperature, there is a favorable heat transfer gradient between the cow's body and the pond water.

In addition to its effect on animal cooling are its potential effects on animal health, particularly mastitis. This was evaluated by comparison of clinical mastitis cases occurring in cows exposed to ponds versus cows with no exposure to ponds (Shearer et al., 1987). Herd records of clinical mastitis on 1400 Holstein cows divided into 12 lactating groups were monitored. Seven of the 12 lactating groups of cows were located in lots with cooling ponds and permanent shade structures. The no-pond groups were assigned to lots with permanent shade structures only. During the period of July to September, the incidence of clinical mastitis for cows exposed to ponds was half that observed for cows with no access to ponds. A follow-up study during the following year found no increase in clinical mastitis associated with pond use (Bray and Shearer, 1988).

Possible explanations for the observed results include: 1) an improved pre-milking hygiene afforded by cleaner cows at milking, and 2) enhanced resistance to mastitis as a result of reduced heat stress. All cows entered a cow wash in the milking parlor holding area and were pre-dipped as part of the pre-milking udder hygiene routine. Despite an effective wash system, cows from the lots without ponds were much dirtier upon entering the parlor. This

occurred because cows from the lots without ponds were prone to wallow in mud in an effort to cool themselves. Cows from the lots with cooling ponds were cleaner, and accordingly milkers preferred to milk them. The possibility of enhanced resistance due to the abatement of heat stress is conjectural.

Major questions remain as to how cooling ponds should be designed or maintained. Some operations relying on ponds for cooling cows maintain them by providing a constant in-flow of water with an overflow at one end of the pond. They also drain and dredge them every 1 to 2 years. Although total bacterial content does not appear to be appreciably affected, there is less build-up of organic material. There is some evidence that allowing cows access to stagnant or natural ponds may negatively affect milk quality and the incidence of mastitis (Bray et al., 1989). Cows from herds with man-made ponds, which were maintained regularly, produced milk with lower bacteria and somatic cell counts compared with cows from herds which had no ponds or natural ponds. Thus, we would conclude that the use of ponds for heat stress management should be accompanied by plans for pond maintenance.

Summary

Dietary manipulation for the purpose of reducing the effects of heat stress has relatively little impact on performance compared with environmental modification. The management of heat stress and its effects through environmental modification involves reducing heat gain via solar and thermal radiation and high ambient air temperatures. This may be reasonably accomplished with shade and evaporative air cooling. Elevated temperatures combined with high humidity limit the opportunity for cooling air by evaporative methods. In such

conditions, methods which augment the cow's natural mechanism of heat loss (sweating) are more effective. This can be effectively achieved with a combination of shade, sprinkling, and air movement, which in many areas requires forced ventilation with fans. In some areas like Florida, cooling ponds may be a part of the heat stress management scheme. In the end, what's best is a combination of components that can be used throughout the day in various locations. The goal is to keep the cow's body temperature as close to normal for as much of the day as possible. If successful, one can minimize losses in performance and health.

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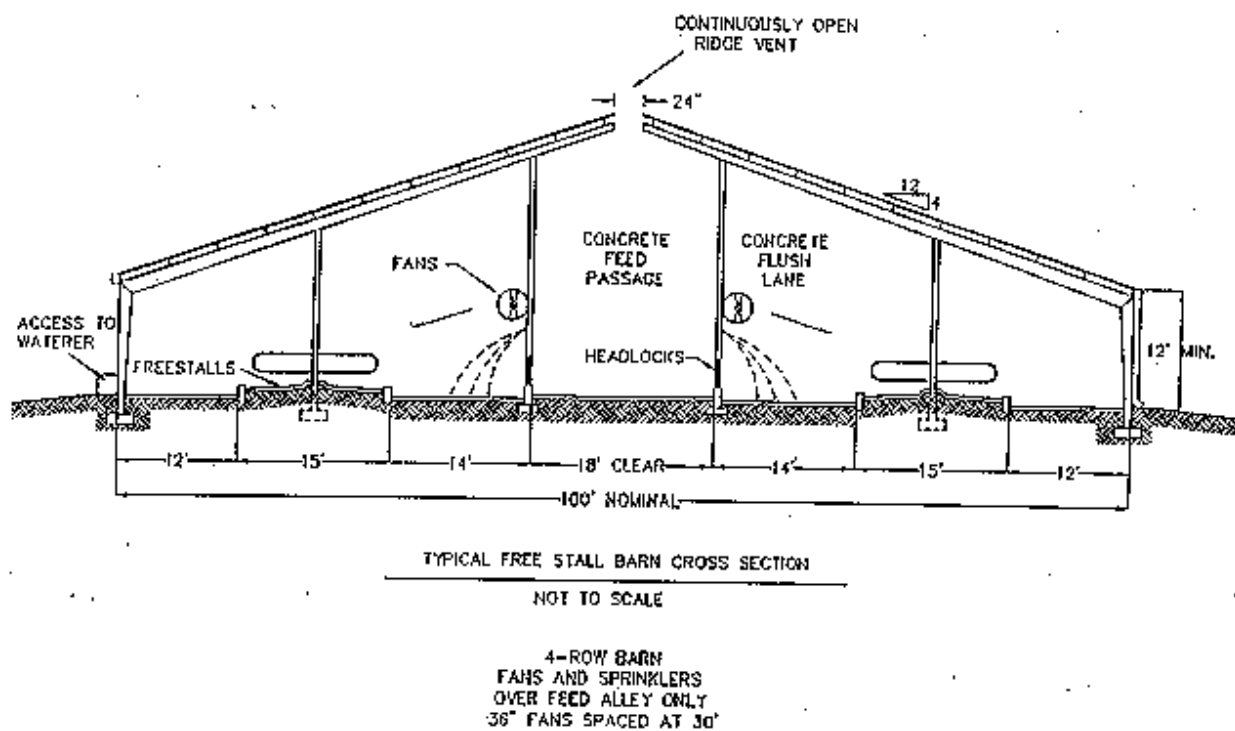


Figure 1. Typical configuration for a sprinkler and fan (or high pressure fogger) cooling system.

Protein Nutrition of Dry Cows

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Veterinary treatment and lost milk income from metabolic and infectious diseases and fertility problems cost the US dairy industry several billion dollars a year. Most metabolic diseases and even most cases of mastitis occur in the periparturient period (30 days before calving to 30 days after calving). Even in above-average Michigan dairy herds, incidence rates are 8% for dystocia, 12% for retained placenta, and 7% for milk fever. Furthermore, 12% of cows experience ketosis and 6% have displaced abomasum in the first 3 wk after calving, and 8% of cows exhibit at least one case of clinical mastitis in the first 10 days after calving.

Proper feeding and management of the cow around the time of calving will impact not only cow health, but also cow performance, comfort, longevity, and fertility and overall farm profitability. Therefore the objectives in feeding dry cows, particularly in confined feeding systems, should be to minimize health problems around calving and in early lactation and to ensure that the cow is optimally prepared for high milk production in the following lactation. This review will focus on the current state of knowledge of dry cow protein nutrition and propose a recommendation for feeding protein to dry

cows based on our present knowledge (and lack thereof).

Biology of the Peripartum Cow

Several changes, occur or, are desired in the biology of the cow as she goes through the transition of the last month of pregnancy and the first month of lactation. These changes must accommodate the demands of the maturing fetus, the maintenance requirements of the cow as well as increases in gut tissue capacity and mammary growth. Dietary protein is either degraded in the rumen or it passes down to the abomasum and small intestine where much of it is digested. If it is degraded in the rumen, it is lost as ammonia or incorporated into microbial protein, which can then be digested later in the tract. The undigested protein will be lost in feces, but some absorbed protein is required for normal digestive function and is also lost in feces as endogenous fecal N. This endogenous fecal N can be considered part of the cow's maintenance requirement for protein, although it is directly related to the amount of undigested feed eaten by the cow. Other maintenance components of protein requirements include the replacement of damaged and worn muscle proteins and synthesis of hair, skin, blood and regulatory proteins. Turnover of body proteins is never

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completely efficient and thus some amino acids will be deaminated and no longer useful as protein; these deaminated amino acids can certainly be considered part of the maintenance requirement for protein. However, some of this inefficiency also may be caused by metabolic needs for amino acids that require their deamination. For example, glutamine is used as a fuel source for gut tissues, and many amino acids are used as glucogenic substrates when glucose is in short supply. Whether these deaminated amino acids should be considered part of the maintenance requirement is less clear. In some cases, skeletal growth may be necessary for pregnant heifers. There are two distinct uses of amino acids in the systemic blood that are unique to the cow in late gestation and deserve further discussion; namely, the requirements for support of the gravid uterus and for preparation of the mammary gland for lactation. Amino acids also may play unique roles relative to the glucose and lipid metabolism that influence health of the peripartum cow. Furthermore, any discussion of protein requirements in late gestation must include a discussion of changes in feed intake that occur prepartum.

Requirements of the gravid uterus.

The most obvious change during the peripartum period is the growth and expulsion of the fetus. Estimates for protein accretion of the gravid uterus (fetus, uterus, placenta, and associated tissues) based on slaughter data are shown in Figure 2 (Bell et al., 1995). For the last 3 wk of gestation, Bell et al. (1995) have estimated that accretion of energy is 830 kcal/day and accretion of protein is 120 g/day. These values for protein accretion are less than those used by the 1996 Beef NRC, which predicts a value of 167 g/day. Furthermore, Ferrell et al. (1976) determined protein accretion if the gravid uterus to be 156 g/day

for beef heifers. Fetal growth is associated with considerable turnover and remodeling of tissues, so the fetus has high requirements for maintenance as well as growth. The fetus uses amino acids with relatively low efficiency, and Bell et al. (1995) have estimated that the gravid uterus must be supplied with 3 times more amino acids than it incorporates. Thus, the gravid uterus must be supplied with ~300 g of absorbed or metabolizable protein per day when averaged over the entire dry period and 360 g/d in the last 3 wk of gestation. The work of Bell et al. was based on multiparous cows, and the values may be slightly lower for heifers, perhaps about 320 g/day in the last 3 wk. Work by Moe and Tyrrell (1972) suggests that the combined requirement for growth and maintenance of the fetus is 3 to 5 Mcal of NE_L per day. Thus, the protein to energy ratio required by the gravid uterus is substantially higher than that needed by most other tissues or body functions.

Requirements of the developing mammary gland and lactogenesis.

Next to the actual process of calving, the process of lactogenesis, or initiation of lactation, is the major transition that occurs in the peripartum period. During this time, the number of mammary cells almost doubles, as indicated by DNA content of the gland 10 days before and after calving, and the cells increase in size as they become more metabolically active (Akers et al., 1981). Based on data from Akers et al. (1981) and Capuco et al. (1987), the amount of mammary tissue deposited in the last 3 wk before calving likely is ~500 g/day or 1.1 lb/day (see figure 3). Assuming the composition of parenchyma is 8 to 10% lipid (Akers et al., 1981) and 20% protein, the mammary parenchyma would be retaining ~1 Mcal of energy and 100 g of protein per day. This much tissue retention likely would require ~2 Mcal of NE_L and 200 g of

absorbed protein per day. Coupled with the beginning of milk secretion in the last days before calving, lactogenesis increases the energy and protein requirement of the dry cow.

Role of dietary protein in fatty liver.

Intake and endocrine changes that accompany the transition period act to promote adipose tissue mobilization and decrease protein catabolism. When mobilization of adipose tissue exceeds the ability of liver to oxidize fatty acids then liver lipids accumulate. This situation is exacerbated by the decline in prepartum feed intake (Bertics et al., 1992). Therefore, in order to avoid the problems associated with liver lipid accumulation, it is necessary to either a) maintain energy (non-lipid) intake or b) enable the dairy cow to metabolize the nonesterified fatty acids (NEFA) mobilized by adipose tissue or c) maintain (or enhance) the response of adipose tissue to insulin in an attempt to decrease net lipolysis or d) enhance the capacity of liver to package and export lipid as triglyceride rich lipoprotein.

Studies conducted using goat hepatocytes in culture and sheep liver indicate that secretion of triglyceride (TG) as part of very low density lipoprotein (VLDL) is tenfold lower in ruminants than other species (reviewed by Grummer 1995). Apolipoprotein B100 (Apo B) is a protein synthesized by liver and is the rate limiting component for assembly of the VLDL particle, furthermore, the abundance of this protein in liver is lowest during the first 30 days of lactation especially when hepatic steatosis is greatest (Gruffart et al., 1997). L-methionine added to milk fed to calves stimulates VLDL synthesis (Auboiron et al., 1994) and feeding the hydroxy analog form of methionine increases circulating lipoproteins in the lactating dairy cattle and milkfat percent. Furthermore, methionine

and lysine infusions in lactating dairy cows reduced plasma ketones during the second week of lactation (Durand et al., 1992). Work by Durand et al. (1992) also suggests a role for additional methionine and lysine to increase the ability of liver to export TG as VLDL, perhaps in the formation of apolipoprotein B. The benefits of additional protein on lipid clearance must outweigh the action of dietary protein to decrease liver glycogen in order for additional prepartum protein to benefit the transition cow. The reduction in plasma NEFA in cows with BCS greater than 3.25 supports the potential actions of additional amino acids on lipid metabolism (Putnam and Varga, 1998). Additionally, strategic supplementation with protected amino sources or protein sources rich in certain amino acids may target lipoprotein formation specifically and serve to alleviate the risk of fatty liver in certain cows.

A high ratio of glycogen to lipid in liver during early lactation may reduce the risk of ketosis during early lactation (Smith et al., 1997). Glycogen breakdown in liver can serve as a source of oxaloacetate carbon to couple with acetyl-CoA generated through lipid mobilization that favors oxidation of fatty acids and reduces ketogenesis in liver. The effects of specific amino acid feeding may increase lipid clearance from the liver it may also decrease glycogen storage and decrease glycogen to lipid ratio. Protein feeding in excess of requirements may act to reduce glycogen synthesis by more than 50% (Moundras et al. 1993) and place transition dairy cows at risk for ketosis.

Role of amino acids in glucose synthesis. To support the increased fetal growth in late gestation, and to prepare for early lactation, the dam undergoes a number of metabolic adjustments. These adjustments

serve to spare glucose and possibly amino acids for use by the fetus. Glucose production, mostly from hepatic gluconeogenesis, is increased in pregnant ewes compared to nonpregnant ewes (Steel and Leng, 1973) indicating increased hepatic uptake of gluconeogenic substrates such as amino acids, glycerol, and lactate (Bell et al., 1995). The use of amino acids as gluconeogenic precursors may be spared in late gestation in favor of glucose synthesis from other sources. Increased lactate utilization and Cori cycling has been observed in animals as a result of lactate release from the gravid uterus (Comline and Silver, 1976; Baird et al., 1983; Reynolds et al., 1986), and from skeletal muscle during pregnancy (Hough et al., 1985).

Impact of amino acids in adipose tissue mobilization and insulin resistance.

Plasma insulin concentrations decrease as the dairy cow progresses from late gestation into early lactation, with a transient increase occurring at parturition (Hart et al., 1978; Kunz et al., 1985). Along with decreased concentrations, the insulin resistance previously observed in humans and laboratory animals also occurs in sheep (Pettersen et al., 1993, Pettersen et al., 1994). Thus in sheep, goats, and probably in cattle, fat mobilization during late pregnancy is facilitated by the decreased ability of insulin to promote lipogenesis and oppose lipolysis (Bell, 1995). Insulin resistance seems to carry over into early lactation, and is associated with almost total suppression of lipogenesis in adipose tissue (McNamara and Hillers, 1986). The uptake of glucose by skeletal muscle of sheep in early lactation as affected by insulin is attenuated (Vernon et al., 1990) but is not attributable to any change in insulin binding by adipocytes, which implies a postreceptor effect (Bell, 1995).

Low dietary protein (8 versus 20% CP) in isocaloric diets decreases peripheral (adipose and muscle) insulin sensitivity but enhances insulin action on liver in rats (Sugden and Holness, 1995). A significant portion of the insulin desensitizing effect of amino acids on adipose tissue can be linked to elevated glutamine and is linked to elevated cellular glucose-6-phosphate (Marshall et al., 1991). These adaptations spare amino acid use by liver, reduce amino acid use for muscle synthesis, ensure fetal amino acid supply is not compromised and promote hepatic glycogen storage. Low protein diets may serve to increase adipose tissue mobilization in animals that are already at risk to develop fatty liver. However the action of insulin to enhance liver glycogen storage and reduce amino acid catabolism may counteract the negative effects of low protein feeding. Furthermore any negative effects of low protein feeding may be overcome if the amino acid complement of the diet stimulates lipoprotein synthesis and hepatic triglyceride clearance.

Inducing amino acid breakdown and nitrogen excretion.

The ornithine cycle, also called the urea cycle is an enzyme system that converts ammonia generated by the deamination of amino acids to urea nitrogen, a nontoxic excretory product. Liver is the only tissue that contains the full complement of five enzymes necessary for complete conversion of ammonia to urea. Changes in the activity of the urea cycle are closely linked to the changes in amino acid catabolism. During pregnancy there is a striking decline in urea cycle enzymes and plasma urea concentrations and the enzymes that control amino acid breakdown in liver which serves to spare amino acids for fetal growth (Naismith, 1973). The activity of the urea cycle enzymes is closely linked to mRNA expression, which is regulated by

amino acid supply and hormones. The enzymes of the urea cycle are induced by feeding a high protein diet but require 3-5 days for half-maximal induction and conversely require 4 to 5 days for half-maximal repression (Schimke, 1964). Therefore feeding a high protein diet in late gestation may induce the urea cycle which requires as much as 8 to 10 days to readjust. The carryover effects of increased amino acid catabolism as a result of excess protein supply during the prepartum period coupled with the fact that absorbed nutrients must first pass through liver before distribution to other tissues may negatively impact the efficiency of amino acid use in the early lactation cow and shortchange the needs of the mammary gland for milk production. The adaptations to increase protein catabolism in late gestation may act to decrease the efficiency of amino acid use for milk production after calving.

Changes in voluntary feed intake.

During the last 2 wk of gestation, voluntary feed intake gradually decreases, as shown in figure 4 (Hayirli et al., 1998). This decrease in feed intake can lead to negative energy balance and mobilization of body fat stores to meet the energy deficit. Body fat stores are mobilized as NEFA. As a cow approaches calving, plasma NEFA concentration increases in a manner that is inversely related to changes in feed intake. The NEFA in plasma are used by tissues as energy sources and are generally taken up proportional to their concentration in blood. Liver takes up NEFA and oxidizes them completely, converts them to ketones, or reesterifies them into triglycerides. Because ruminant liver exports only small amounts of very low-density lipoproteins, the reformed triglycerides accumulate (Grummer, 1993). Thus, mobilization of body fat stores before calving can lead to pathologic accumulation of triglyceride in

the liver, known as "fatty liver". This is further supported by work of Gerloff and colleagues (1986) showing that cows that have severe fatty liver after calving already had the problem before calving. Serum NEFA will remain elevated after calving as the cow continues to mobilize body fat stores to support the high energy demands of lactation.

Although some cows may be in negative energy balance, most dry cows, even in the last few weeks before calving, are in positive protein balance. Extra protein during the late dry period, however, even if it is deaminated, may benefit the cow by serving as glucose precursor and helping to prevent fatty liver (Putnam and Varga, 1997). Furthermore, positive protein balance in late gestation does not mean that a cow is not mobilizing body muscle proteins to help meet the needs of the gravid uterus, mammary gland, and normal body maintenance. Based on the above discussion, a normal cow in the last 3 week of gestation should be retaining 120 to 170 g/day as fetal and uterine tissues. This should be subtracted from total protein balance to determine if maternal protein balance is positive. However, another 100 g/d of protein should be retained as mammary tissue. Thus, the real test of whether a cow has been fed adequate protein seems more likely to be whether or not she is in positive N balance with respect to maternal (nonuterine, nonfetal), nonmammary tissues. Using a value for protein accretion of the gravid uterus at 150 g/day, Putnam and Varga (1998) determined maternal N balance at three different protein intakes (Figure 5). Based on their results, maternal protein balance would be greater than 100 g/day when multiparous cows are fed at least 1250 g of CP per day. At the lower protein intake, mobilization of carcass

protein likely occurred to support gain of uterine and mammary protein.

Not only does feed intake drop as calving approaches, but as with any group of animals, there can be considerable variation in voluntary feed intake before calving (Figure 6). This can have important implications when designing diets to meet protein requirements of cows in the last weeks of gestation.

Dietary Protein Guidelines For “Close-Up” Dry Cows

The NRC and many nutritionists commonly recommend that cows be fed more grain in the last 3 weeks so that the NE_L density of close-up cows be 0.67 to 0.72 Mcal/lb. This level of energy with ad libitum feeding is generally sufficient to keep most cows from mobilizing body tissues and liver lipid content at a minimum (VandeHaar et al., 1999). While some may disagree with this level of energy, there is even less agreement on the level of protein that should be included in diets for dry cows, particularly those in the last 3 wk of gestation. While more data would be helpful, the problem is not entirely a lack of research. Rather the problem is that research has provided inconsistent results. Future research in this area must focus on answering more basic questions.

Choosing a target function for determining dietary protein recommendations. The 1989 NRC estimates nutrient requirements for dairy cows including those in the dry period. The NRC, however, does not categorize cows in the last 3 weeks of the dry period (“close-up” dry cows) separately from those earlier in the dry period. Furthermore, NRC gives estimates of nutrient requirements rather than recommendations or guidelines for

nutrient density of diets or daily nutrient intakes. Nutrient recommendations may be different that nutrient requirements for several reasons. First, requirements are not easily defined. For example, as a cow is fed increasing amounts of protein, the point at which the “requirement” is met is not usually clear-cut, and responses to nutrient additions often follow the law of diminishing returns. Secondly, requirements for nutrients vary among individual animals, so if dry cows are fed to meet the average requirement, then some cows would be eating significantly less and others significantly more of the nutrient than required. And thirdly, choosing the correct response to determine when a requirement is met is not always a simple decision. Nutritionists typically have used body nutrient balance or blood nutrient concentrations as indicators for setting requirements. However, in some cases, nutrients might have beneficial effects on health that occur when fed above their requirement for growth or maintenance as traditionally defined. For example, feeding vitamin E or selenium or chromium above “requirements” seems to improve health (Mowat, 1997; Weiss et al., 1997).

Thus, when considering the proper level of protein to feed a cow in the last 3 wk prepartum, there are several possible target functions one could emphasize:

- Maternal protein balance > 0 for the average cow
- Maternal protein balance > 100 g/day (to account for mammary growth) for the average cow
- Maternal protein balance > 150 g/day (to account for mammary and body growth) of the average cow

- Maximum body protein gain to give a "protein reserve" for use in early lactation
- Excess dietary protein < 200 g/day (to prevent negative effects from too much protein)
- Maximum milk yield in subsequent lactation
- Minimum health problems based on metabolic effects of amino acids

Furthermore, when group-feeding cows, we must decide what percentage of the cows in the group we want to achieve our selected target. Given the variation in feed intake before calving, this is an important consideration. If, for example, we decide that we want 80% of the cows to achieve a maternal protein balance of greater than 100 g/day, then we might expect at least 50% of the cows to eat far more protein than required.

Recommendations

The case for 12% CP in diets for late gestation. Available experimental evidence does not support increasing the dietary protein amount or profile to prepartum dairy cows during the last three weeks of gestation. In one experiment where a beneficial effect of addition protein was observed (Van Saun et al., 1993) (Table 2) the energy density of the diets were less than 0.67 Mcal/lb of DM during the close up period. If the energy density of the diets is maintained then 12% CP will meet the needs of transition cows. The negative impact of increased protein feeding above 12% CP cannot be ignored. If the energy of the diet is adequate (i.e. 0.68 Mcal/lb) then the need for additional protein is reduced.

The case for increasing the protein content in late gestation. Requirements for CP in the last 2 to 3 wk of gestation are 1000 to 1400 g/day for heifers and 1100 to 1600 g/day for cows, depending on which set of equations and requirements one chooses to use (Table 1). To meet these requirements using intakes predicted by Hayirli et al. (1998; Figure 4), the percentage of CP needed in diets for groups of heifers in the last 2 wk of gestation varies between 10 and 17%, and the percentage of CP needed in diets for groups of cows in the last 2 wk of gestation varies between 8 and 13% (Table 1). Moreover, the voluntary feed intake of cows and heifers before calving varies considerably (Figure 6). To ensure that 83% of all heifers receive the predicted protein requirement, groups of heifers should be fed 14 to 22% CP using the target feed intake of Hayirli et al. (1998) minus one unit standard deviation. Equivalent values for groups of cows are 11 to 17% CP.

Results of actual experiments testing various protein concentrations do not necessarily support higher protein but neither is there overwhelming evidence suggesting that higher protein is detrimental. About 30% of reports show a negative effect of feeding protein higher than 12%; these negative effects occurred at 15% CP (Crawley and Kilmer, 1995), 16% CP (Greenfield et al., 1997), and 14% CP (Hartwell et al., 1999). None of these studies had enough cows to detect differences in health. And studies in which both energy and protein are increased together show no detrimental effect. VandeHaar et al. (1999) found that increasing both energy and protein decreased liver fat at calving, whereas Hippen et al. (1999) reported that feeding prepartum cows very high energy with only 12% CP caused severe fatty liver. An

increase in both starch and protein might negate some of the potential metabolic problems of replacing starch with protein. Furthermore, management to prevent fatty liver (minimize number of fat cows, feed adequate energy) should be a high priority because high liver triglyceride content may decrease the capacity for ureagenesis (Zhu et al., 1998). Decreased ureagenesis might explain some of the negative effects of high protein prepartum diets in some studies.

One of the major problems with current nutrition modeling efforts is that we have become very precise at estimating requirements that may in fact not be very accurate. Furthermore, we have failed to account for the large variation in voluntary feed intake of animals. The cost of the extra protein in a close-up dry cow diet is insignificant (~\$3 per cow per 3-wk-period), and the potential risks of over or underfeeding protein are far more important when choosing which protein level to feed. Currently, many (perhaps most) farms feed protein concentration to dry cows greater than NRC recommends (12%). Before we recommend to the industry that it make a major change in feeding practices, we need solid evidence that such a change is warranted.

One reasonable approach would be to ensure that 83% of animals are able to eat enough protein to meet our current estimates of protein requirements for maintenance, pregnancy, and lactogenesis. Depending on which prediction equations one uses, this would require a diet of ~14% CP for cows and 17% CP for heifers

Final recommendations.

Late lactation. Goal is to dry the cow off at a body condition score of 3.0.

Fat cows may be more susceptible to the risks of excess protein.

Early dry period. If most cows have a body condition score of 3.0 or more at dry-off, this group should be fed a diet containing 0.60 Mcal of NE_L per lb and 11 to 12% CP. If most cows have a body condition score less than 3.0, the diet can be slightly more energy-dense but the protein density need not be increased. The goal should be for cows at the end of the early dry period to be at a body condition score of 3.0 to 3.5 and in excellent health. Cows should be moved to the close-up group at 3 weeks before expected date of calving.

Close-up dry period. The diet should contain ~14% CP with true protein sources used as the supplement. Caution should be used particularly if there is inadequate starch in the diet as a nonprotein source for glucose and glycogen precursors in liver. Bypass protein sources are not needed in most cases. Supplemental rumen-protected methionine may be beneficial, but data are not conclusive. These recommendations assume that a TMR will be fed containing 0.67 to 0.72 Mcal of NE_L/lb with 25 to 40% easily fermented grains. Feed should be available all day long and cows should be encouraged to eat. Heifers may need diets higher in energy and protein than cows to support body growth as well as pregnancy and lactogenesis. A separate group for close-up heifers may be beneficial.

Fresh cows. The goal is to maximize the daily intake of carbohydrate and protein while at the same time providing adequate fiber for good rumen function. Fresh feed should be available all day long. Cows

should be fed a TMR that contains ~28% NDF with high-quality silage of adequate length, ~40% nonfiber carbohydrate with easily digested starch as the major source, 4 to 5% total fat, and 18-20% CP. Some bypass protein sources are desirable, but palatability should be a major concern. Fresh water should be available all day long.

Summary

Proper nutrition and management of the cow before parturition are necessary for optimal functioning of the digestive system, immune system, major metabolic organs, and mammary gland. Currently-available data are inconclusive in establishing the optimal concentration of protein to include in diets for the last 3 wk of gestation. Predicted daily requirements for metabolizable protein are ~400 to 600 g for maintenance, 240 to 360 g for support of the gravid uterus, and ~200 g/day for support of mammary tissue development and lactogenesis. Additionally, 50 to 100 g may be needed if skeletal growth is desired in heifers or if support for a labile protein reserve is targeted. Amino acids may also serve to prevent fatty liver and minimize lipid mobilization. Excess amino acids may decrease liver glycogen content and put the animal at risk for some metabolic diseases. Feeding a diet with ~14% CP to dry cows in the last 3 wk prepartum likely will ensure that at least 83% of cows will be in positive protein balance in regards to nonuterine, nonmammary, maternal tissues. Heifers may require an even higher protein concentration to ensure the same.

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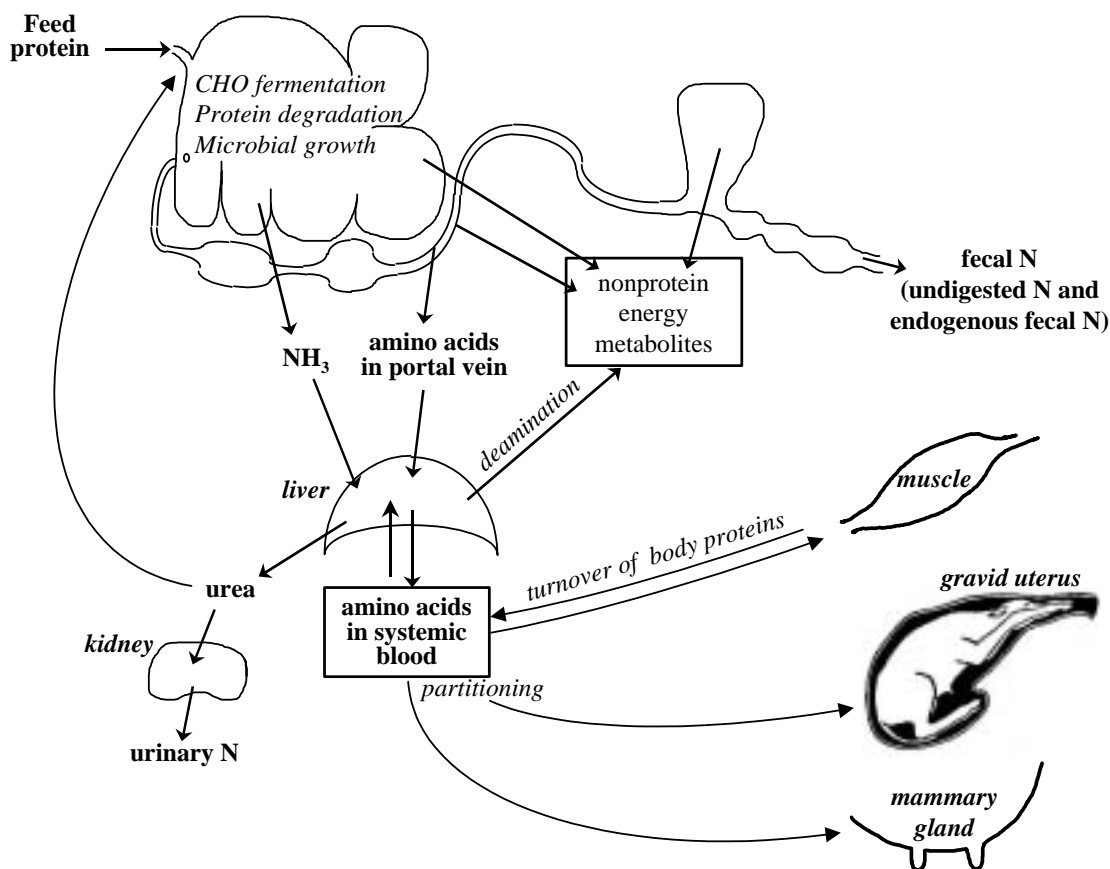


Figure 1. The flow and use of dietary protein in cows before calving.

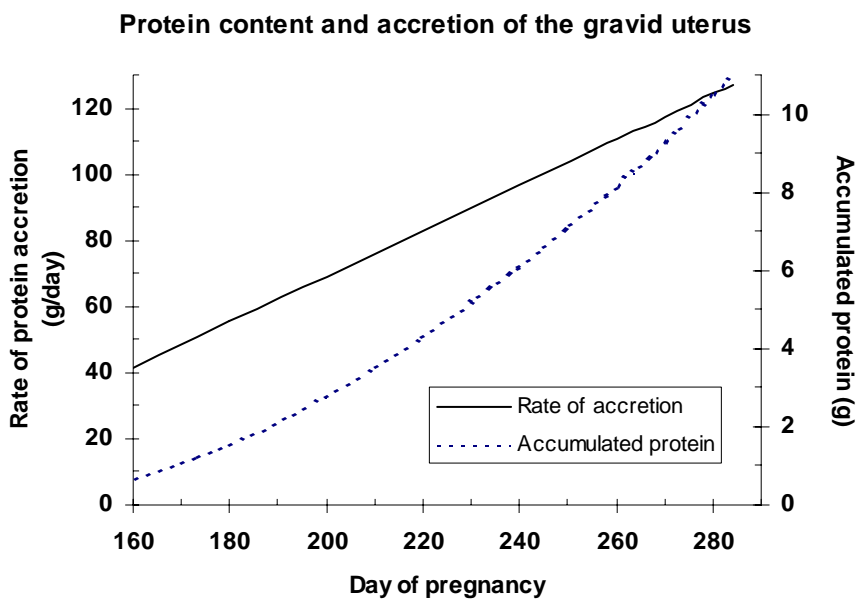


Figure 2. Daily accretion and accumulated content of protein in the gravid uterus (from Bell et al., 1995).

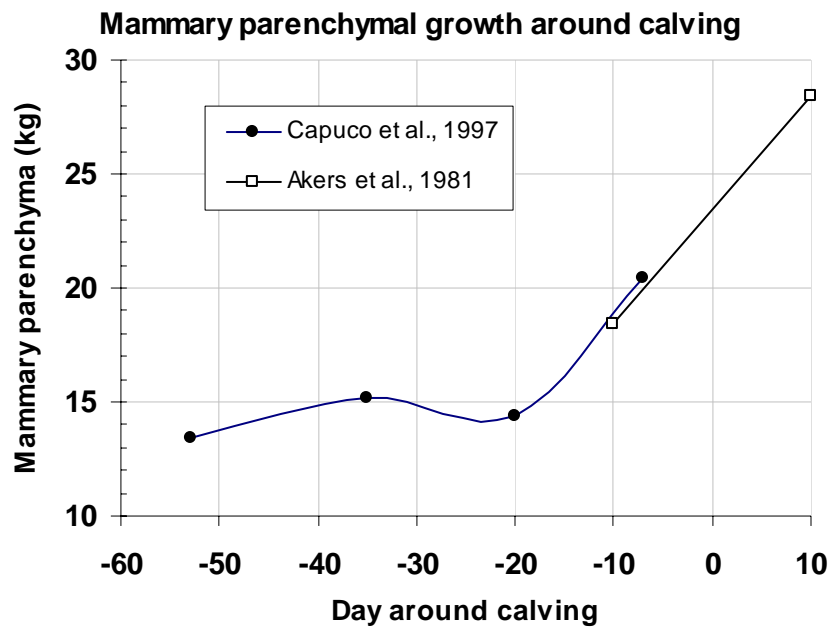


Figure 3. Changes in mass of mammary parenchymal tissue around the time of calving. Data from Akers et al. (1981) are adjusted to a whole gland basis.

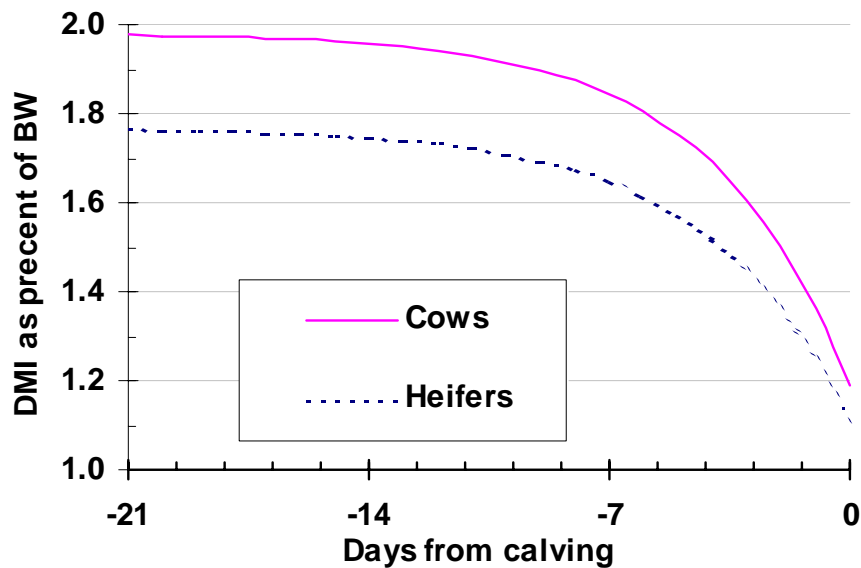


Figure 4. Predicted intake of cows and heifers before calving based on data from several university studies (Hayirli et al., 1998).

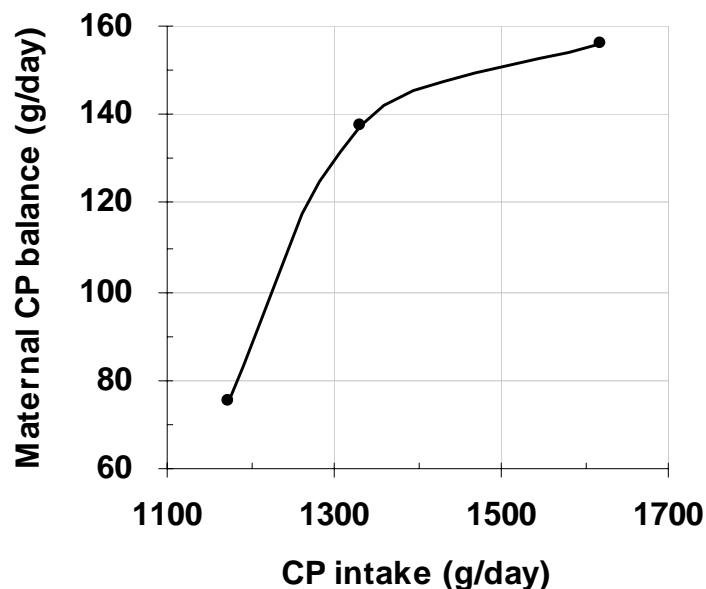


Figure 5. Mean maternal N balance from day 12 to 7 prepartum of multiparous Holstein cows fed 10.5, 12.6, or 14.5% CP diets at ~11 kg of feed DM per day (Putnam and Varga, 1998).

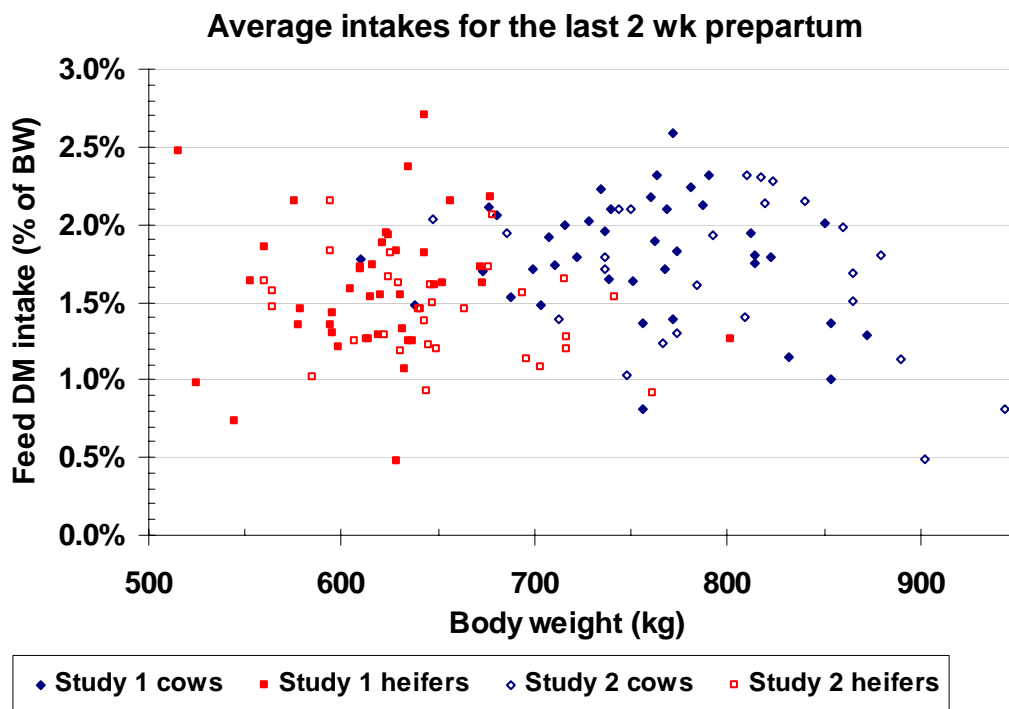


Figure 6. Actual daily dry matter intake of individuals cows and heifers averaged over the last 2 wk prepartum from two MSU studies (VandeHaar et al., 1999; Moore et al., 1997). Animals were fed TMR individually in tie-stalls.

Table 1. Requirements for metabolizable protein (MP) and crude protein (CP) in the last 3 wk of gestation and the CP concentrations needed to meet those requirements.

	heifer	heifer	heifer	cow	cow	cow
Body weight, kg	550	550	650	650	750	850
Gain of maternal skeletal tissues, g/day	0	250	0	0	0	0
Calf birth weight, kg	40	40	40	45	45	45
Average DM intake, % of BW	1.57	1.57	1.57	1.75	1.75	1.75
Standard deviation for DM intake, % of BW	0.39	0.39	0.39	0.42	0.42	0.42
Average DM intake, kg/d	8.63	8.63	10.20	11.36	13.11	14.85
Average DMI - 1 standard deviation	6.49	6.49	7.67	8.63	9.96	11.28
Average DMI + 1 standard deviation	10.78	10.78	12.74	14.09	16.26	18.42
Using the 1996 Beef NRC for maintenance and pregnancy¹						
MP for maintenance, g/d	432	432	489	489	545	598
MP for gravid uterus, g/d	240	240	240	271	271	271
MP for body gain, g/d	0	54	0	0	0	0
Total MP requirement, g/d	672	726	729	760	815	869
CP requirement, g/d²	959	1037	1042	1086	1165	1241
%CP needed	11.1	12.0	10.2	9.6	8.9	8.4
%CP needed - for low DMI	14.8	16.0	13.6	12.6	11.7	11.0
%CP needed - for high DMI	8.9	9.6	8.2	7.7	7.2	6.7
Add requirement for mammary development						
MP for mammary gain, g/d	200	200	200	200	200	200
Total MP requirement, g/d	872	926	929	960	1015	1069
CP requirement, g/d	1245	1323	1327	1371	1451	1527
%CP needed	14.4	15.3	13.0	12.1	11.1	10.3
%CP needed - for low DMI	19.2	20.4	17.3	15.9	14.6	13.5
%CP needed - for high DMI	11.6	12.3	10.4	9.7	8.9	8.3
Using Bell et al. (1995) requirement for pregnancy						
MP for gravid uterus, g/d	322	322	322	362	362	362
Total MP requirement, g/d	754	808	812	851	907	960
CP requirement, g/d	1077	1155	1159	1216	1295	1372
%CP needed	12.5	13.4	11.4	10.7	9.9	9.2
%CP needed - for low DMI	16.6	17.8	15.1	14.1	13.0	12.2
%CP needed - for high DMI	10.0	10.7	9.1	8.6	8.0	7.4
Add requirement for mammary development						
Total MP requirement, g/d	954	1008	1012	1051	1107	1160
CP requirement, g/d	1363	1441	1445	1502	1581	1658
%CP needed	15.8	16.7	14.2	13.2	12.1	11.2
%CP needed - for low DMI	21.0	22.2	18.8	17.4	15.9	14.7
%CP needed - for high DMI	12.6	13.4	11.3	10.7	9.7	9.0

¹ From pages 116-117 of 1996 Beef NRC. A gain of 250 g of BW per day above maternal and pregnancy gain is associated with a gain of 27 g of protein per day for a heifer at 550 kg.

² Assuming that CP is converted to MP at 70% efficiency.

Table 2. Summary of investigations of prepartum dietary protein on subsequent milk production and physiological measures

Reference	Prepartum Diet	Protein source	Response
VandeHaar et al., 1999 Cows (n=10 per treatment) Heifers (n=10 per treatment) starting ~26 days precalving	NE _L = .67 Mcal/lb 14.2% CP, 32% RUP vs. 16.2% CP, 39% RUP	Expeller soybean meal Blood meal	No effect on liver fat at calving or on milk production or dry matter intake.
Van Saun et al., 1993 Heifers (n=10 / treatment) starting 3 weeks precalving	NE _L = .62 Mcal/lb 12.4 vs 15.3 % CP	Soybean meal	Reduced postpartum losses in BCS Increased milk protein (%)
Huyler et al., 1997 Cows (n=12 per treatment) starting 6 weeks precalving	NE _L = not specified 11.7 %CP, 25% RUP vs 15 %CP, 43% RUP vs 20.5 %CP, 51.1 RUP	Blood meal	Increased milk production as protein and RUP increased. No effect on BCS. Increased blood urea nitrogen.
Crawley and Kilmer, 1995 Cows (n=10 per treatment) Heifers (n=4 per treatment)	NE _L = not specified 12 %CP, 33% RUP, vs 15 %CP, 39% RUP (blood meal) vs 15 %CP, 39% RUP (soybean meal)	Soybean meal Blood meal Protected soybean meal	Decreased prepartum intake. Decreased milk production with increased protein and RUP.

Table 2. continued.

Greenfield et al., 1997 Cows (n =10 per treatment)	NE _L = .68 Mcal/lb 12 %CP, 26% RUP, vs 16 %CP, 26% RUP vs 16 % CP, 33% RUP vs 16 % CP, 33% RUP.	Soybean meal Urea Protected soybean meal	High protein (16%CP) exacerbated postpartum losses in BCS. High prepartum protein decreased postpartum feed intake and milk production (cows fed a common postpartum diet).
Hartwell et al, 1999 Cows (n = 8 per treatment)	NE _L = .69 Mcal/lb 12 %CP, 30% RUP, vs 14 %CP, 40% RUP	Soybean meal Urea Protected soybean meal Corn gluten meal	Higher protein decreased prepartum intake, decreased postpartum intake and reduced milk production.
Carson et al., 1998 Cows (n=26 per treatment)	NE _L = .not specified 13.8 %CP, 35% RUP, vs 15.6 %CP, 42% RUP	Soybean meal Protected soybean meal Roasted soybeans	No effects on milk production or BCS.
Putnam and Varga, 1998 Cows (n =8 to 16 per treatment)	NE _L = .70 Mcal/lb 10.6 %CP, 38% RUP, vs 12.7 %CP, 38% RUP, vs 14.5 %CP, 38% RUP	Soybean meal Expellers soybean meal	No effects on milk production or postpartum intake. No effect on BCS. Increased N excretion and efficiency of absorbed N utilization.
Chew et al., 1984 Cows (n= 15 per treatment) Heifers (n= 4 per treatment) Beginning 60 days prepartum	NE _L = not specified 12% CP vs 9.6% CP	not specified	Compared to low protein, feeding NRC protein increased prepartum intake diet and increased milk production.

Biosecurity – The Role of the Feedsperson/Nutritionist

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The Concept of Biosecurity

It is becoming unusual to open a journal or magazine dealing with the dairy industry without finding a reference to biosecurity, usually accompanied by advice on implementing biosecurity measures on farms. The concept of biosecurity provides a framework for controlling the transmission of infectious disease between herds and between groups of livestock within herds. The essence of biosecurity is to break the transmission of infection from one group of animals to another either by preventing contact with infected animals or with infective material such as manure, bodily secretions, or other infected materials, including in some cases (e.g. salmonellosis), contaminated feeds. People who have regular contact with groups of animals are capable of carrying infected material from one farm to another or from one group of animals to another, if proper precautions are not taken. Feedspersons and nutritionists who provide services to dairy farms and who visit them regularly need to be aware of the disease

threats to dairy farms, and the role which traffic between farms can play. The observance of proper sanitary practices when moving between farms helps to control disease transmission. The demonstration of this concern when visiting a farm conveys respect for the biosecurity and integrity of the farm operation and enhances one's professional image.

Mandated Programs for Biosecurity

Transmission of disease from farm to farm has always been a concern. International and national control programs have accomplished control of diseases with epidemic potential. Diseases such as foot and mouth disease and hog cholera have been eradicated from the United States, and freedom from these diseases is maintained by import regulation of animals and animal products, as well as surveillance for these diseases within the country. Diseases, which are of human health concern, such as brucellosis and tuberculosis, have been dealt with effectively by regional and national mandated programs for the testing and removal of infected cattle.

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Biosecurity Concerns on the Farm

Farm level biosecurity measures have been implemented for many years, particularly through the pre-purchase inspection and health certification of livestock. These measures have dealt most efficiently with diseases that are capable of causing outbreaks of acute disease, such as viral respiratory disease or hairy foot-warts. In these cases, introduction of infection into the herd can be prevented with some degree of certainty by combining health inspection of animals to make sure they are not already sick and quarantine of the purchased animals once they arrive at the farm. During the quarantine period, animals that were already infected at purchase and are incubating the disease can be detected during a suitable period of on farm quarantine.

Current Biosecurity Concerns

Biosecurity as a concept has been given a new lease of life with the increasing importance of diseases which are much less dramatic in their expression, less easy to detect by inspection of animals, but whose insidious spread within a herd may ultimately be devastating. These diseases, of which Johne's Disease is the most discussed example, are most often introduced to farms through the inadvertent purchase of infected animals, an event that may remain undetected for some years. But Johne's Disease, as well as the more dramatic infectious diseases mentioned above, may also be introduced to farms as a result of infectious material being carried from one farm to another on

vehicles, boots, contaminated clothing, or hands. Infected fecal material is the only means of transmitting Johne's Disease (apart from colostrum in a few cases), and it is unconscionable that with the rising level of awareness and importance of this disease that farm service professionals would carry visible fecal material on boots from one farm to another.

A short list of current biosecurity concerns on individual dairy farms would include, as well as Johne's Disease, bovine virus diarrhea (**BVD**), bovine leukosis virus (**BLV**), hairy foot warts, viral respiratory disease, *Staphylococcus aureus* mastitis, and salmonellosis.

Practical Steps

1. Understand the biosecurity concerns of your clients.
2. Understand the basic modes of transmission of the common infectious diseases.
3. Ask the producer with what procedures the farm wishes visitors to comply.
4. Wear clean rubber boots or robust disposable plastic boots.
5. Disinfect rubber boots on leaving the farm, and preferably on arrival at the next farm. The practical test of effective cleaning and disinfection is that no visible fecal material or mud is carried from one farm to the other.

Forage Harvester Crop Processors and Other New Hay and Forage Equipment

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Abstract

Like other segments of the agricultural equipment industry, hay and forage equipment of the future will become larger and operate at faster speeds. More animal feed will be harvested as silage and more forage will be purchased rather than produced on the farm. As livestock farms become larger, labor becomes scarce, and forage is sold as a commodity, there will be a need for greater productivity from forage harvesting equipment. This desire for greater productivity will mean increased sales of disk cutterbar mower-conditioners, self-propelled forage harvesters, and large square balers.

Animal producers will expect more from their forages. Greater field productivity during harvest will often result in higher forage quality. Another way to achieve more with forage is to mechanically process it prior to feeding. During the last few years, there has been an unprecedented explosion in interest in processing whole-plant corn silage on-board the forage harvester. Processed corn silage has the potential to improve dairy and beef cattle performance. However, the feed benefits of processed corn silage are

only realized if the forage harvester is first set-up properly.

Whole-plant corn silage was harvested at various stages of maturity with forage harvesters equipped with processing rolls. Variables considered were crop maturity, theoretical-length-of-cut (TLC) and roll clearance.

- Compared to unprocessed whole-plant corn silage cut at 3/8" TLC, corn silage cut at 3/4" TLC and then processed had greater whole-plant particle size, less whole cob fraction, fewer undamaged kernels, and smaller kernel fraction particle size.
- A forage harvester set at 3/4" TLC and 0.12 or 0.20" processing roll clearance required similar power and produced similar harvesting rates to the harvester without a processor set at 3/8" TLC.
- Based on crop physical properties, harvester power requirements, and dairy cattle lactation performance, recommended forage harvester settings when harvesting whole-plant corn silage would be 3/4" TLC and 0.04 or 0.12" processing roll clearance.

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Future of Dairy and Commercial Hay Industries

Annual sales of hay and forage harvesting equipment are over \$1 billion dollars, with the beef, dairy, and equine/miscellaneous segments accounting for about 45, 40, and 15% of the total, respectively. The North American (NA) dairy industry currently has fewer than 150,000 farms and will probably have less than 90,000 farms in five years (Figure 1). In the next five years, dairy cattle population will fall from about 10.5 to 9 million. However, the remaining cattle will be larger, better producing animals, so the forage requirements for the industry will probably remain flat. Dairy farm consolidation (Figure 2) will be fueled by economic efficiencies of larger herds and by new waste management regulations. Larger farms are also better able to manage the volatile milk price swings of the unregulated markets. Economic analysis has shown that larger herds can produce milk at lower cost than small herds. This is because larger herds have better labor efficiency (Table 1) and feed efficiency. For these reasons, milk production will continue to shift to more efficient producers, especially in the western US, where economies of scale are particularly practiced, while consolidation continues in the traditional dairy regions of the US and Canada (Table 2, Figure 2).

A trend in all dairy regions will be increasing specialization in milk production. Improved efficiencies will be achieved through investment in capital facilities and herd management. Increasingly, milk producers will become dairy farmers, concentrating on feeding, breeding, and milking larger herds. A major component

of milk production for these producers will be the procurement of high quality forage, either by contract production on their own land or by purchasing commercial hay. Dairy producers in humid climates will continue to be confronted with the problem of how to produce high quality forage. For this reason, it is expected that there will be an increasing emphasis on haylage and corn silage production in these climates, with more dry hay being purchased from arid regions in the west. Dairy farms located a great distance from the commercial hay growing regions of the west will be at a competitive disadvantage. It is expected that forage production will slowly and inexorably decline in Canada and the dairy crescent in the US, while growth in commercial hay production occurs in the west (Figure 3).

Farm consolidations, regional production shifts, dairy specialization, growth in commercial hay production, and growth in farm size all will have a profound effect on the hay and forage equipment industry for the next five years. Animal producers will demand greater forage quality in the future. Forage quality is linked in great part to speed of harvest. One thing will be certain, forage equipment will need to be more productive in the future.

Cutting and Conditioning

Through much of the last two decades, the sickle cutterbar mower-conditioner with intermeshing conditioning rolls has dominated the NA market. In Europe, where fine stem grasses predominate, impact cutting with high speed disks and abrasion type conditioning with impellers is the most common method

of cutting forages that are mainly harvested as chopped or round-bale silage. In the 1980's, the disk cutterbar mower-conditioner with intermeshing conditioning rolls started to make inroads into NA markets because of the ability of these machines to harvest at high speeds and to cut through the toughest crop conditions. A comparison of one manufacturer's specifications for similar size sickle and disk cutterbar mower-conditioners highlights some of the differences between these two configurations (Table 3). In the last 15 years, sales of disk cutterbar machines have steadily increased to where in 1997, these mower-conditioners outsold sickle cutterbar machines in NA for the first time. Concern had been expressed that cutting with a disk machine negatively affected stand persistence and yield, but research has shown this to be unfounded (Table 4).

Manufacturers are now offering disk cutterbar mower-conditioners for leafy legume crops with slow speed impeller conditioners at lower cost compared to intermeshing rolls (Figure 4). Although previous research had shown greater leaf loss with impeller conditioners in legume crops, new research has been conducted which shows that slow speed impeller conditioners produce only slightly higher leaf loss but slightly faster drying rates compared to intermeshing rolls (Table 5).

In the mower-conditioner market, simplicity and productivity are key. Productivity comes from speed (disk cutterbars), width, and maneuverability (center-pivot and self-propelled units). Center-pivot machines will dominate in

both the sickle and disk cutterbar market segments, with several manufacturers introducing 13' and 15' center-pivot disk machines in the last several years. Self-propelled cutting widths up to 18' are now available and the 12' market segment is rapidly shrinking. Self-propelled machines are sold mainly in alfalfa growing regions, so the sickle cutterbar had been the only configuration offered. There are now several 15' disk cutterbar self-propelled machines on the market.

Dairy producers and contact harvesters with large self-propelled forage harvesters (**SPFH**) are looking to increase cutting productivity to match their SPFH capacity. They are also looking for the ability to place windrows side-by-side when cutting so that the crop can be chopped without raking first. This practice not only improves productivity but also reduces the chances of rock contamination of the windrow. Some operators are using grain headers with shiftable draper tables that allow crop discharge to the left or right of the head that allows up to 72' of crop to be placed in a single massive windrow. Harvesting capacities of over 17 ac/h are possible. Of course, these headers use a sickle cutterbar and offer no crop conditioning. Another high capacity cutting option involves the use of a gang of three, mounted disc mower-conditioners. These units are either placed on a dedicated power unit, bi-directional tractor, or even on the chassis of a used SPFH (with head and cutterhead removed). With cutting widths as large as 30' and the typical high field speed of the disk cutterbar, harvesting capacities of over 25 ac/h are possible. Besides cost, these machines have the disadvantage of placing

the crop in three separate windrows, so that merging by raking is still required. One option to eliminate the raking operation is through the use of a grouper. This device will merge two windrows into one at cutting through the use of a shiftable conveyor located behind the windrow forming shields (Figure 5).

Although researchers have worked on "super-conditioning" and "maceration-mat making" techniques for almost 20 years, there has not yet been a successful commercialization of this technology. The problems associated with leaf loss, power requirements, machine cost and complexity, and the need to re-design almost the entire forage harvesting equipment scheme will tax any manufacturer hoping to commercialize this system.

Summing up the mower-conditioner market, efforts will be expended to develop wider and faster machines. The future does not look bright for sickle cutterbar mower-conditioners, as the disk cutterbar becomes more refined and widely marketed. As balers and forage harvesters become larger and more productive, look for cutting equipment to follow suit.

Manipulating Swaths And Windrows

Parallel-bar and wheel rakes have been the main machines used to manipulate forage crops in NA. Parallel-bar rakes are considered less aggressive than wheel rakes, but wheel rakes are less expensive and are available in wider widths. Recent trends in rake designs have emphasized frame configurations that allow two swaths or windrows from a 5.5-m (18.2') cut to be merged together in

order to provide sufficient crop for large capacity forage harvesters and balers. Rotary rakes, another innovation from Europe, have started to have greater importance in the NA market. Perceived advantages of this rake include its ability to rake wet swaths or windrows, produce less roping and twisting of the windrow, and form a taller, more open windrow which may improve crop drying after raking. Because this rake was originally designed for use with grass crops, its aggressive, sweeping action may lead to greater leaf loss and more stones in the windrow.

In the future, expect to see rakes and merging systems to get larger and more sophisticated as forage producers match the capacity of these implements to the cutting and harvesting capacity and also look to perform merging with fewer field passes.

Harvesting Forages as Silage

Forages to be stored as silage are harvested either as a chopped material (haylage or corn silage) or as wrapped bales (balage). The advantages of chopped material include high field capacity, harvester versatility, and mechanization of the feeding system. Potential disadvantages include high capital cost, difficulty in off-farm forage marketing, and difficulty in target feeding from large storage structures.

The advantages of balage include low capital costs, easier off-farm forage marketing, and high quality feed can be target fed to high producing animals. The disadvantages of balage include slow harvesting rates, feed cannot be handled as a bulk material, difficult material handling

and feeding in TMR, and difficulty in maintaining plastic integrity. As in the case with Europe, it may be that smaller NA dairy farmers will harvest grass/legume forage themselves as balage and hire a contractor to chop corn silage. Large NA dairy operations will continue the trend toward harvesting all forage as chopped silage. With so many different systems and schemes to harvest silage, equipment manufacturers will have to be nimble to react to the diverse needs of their customers.

Despite the trend toward more forage fed as chopped silage, sales of forage harvesters will remain relatively flat to declining in the next few years. This is due to increased sales of larger, higher capacity pull-type and large self-propelled machines at the expense of smaller machines. Sales of self-propelled machines will increase in line with larger dairy operations and the trend toward more contract harvesting

The kernel/crop processor on-board the forage harvester has taken the market by storm during the last several years. The crop processor is basically an on-board roller mill that crushes and shears whole-plant corn silage as the crop passes from the cutterhead to the blower (Figure 6). Much greater detail about the performance and set-up of crop processors will be given later in this manuscript.

Another interesting development is the non-row-sensitive row crop head (Figure 7). This device permits harvesting any row spacing in any direction in the field. These are important features for owners of self-propelled harvesters who have customers with varied row spacing and small, irregular fields. The only drawback to this crop unit

is cost. This crop unit costs about 50% more than an equivalent width conventional head.

Yield monitors are becoming more prevalent in grain harvesting machines, so expect that these systems will eventually become part of forage harvesters as well, although there are no commercially available systems on the market as of yet. It will be a challenge to develop yield monitors for forage harvesters considering the diverse crops and moistures they harvest.

Summing up the forage harvester market, expect to see fewer pull-type machines and more self-propelled units. No matter which configuration, new machines will have greater capacity and capable of greater power input. New features will include yield monitors and on-board crop processing systems.

Harvesting Forage as Dry Hay

Forage to be harvested as dry hay will be packaged in one of three forms - small square, large round, and large square bales. Small square baler sales have fallen dramatically during the 1990's but have likely stabilized because of the market for equestrian, commercial, and export hay. The reduction in small square baler sales is due primarily to the increase in farm size, the lack of available labor and its relatively low harvesting capacity. Round baler sales are driven extensively by the beef industry, so expect industry sales to remain flat to slightly down during the next five years as the beef industry continues to suffer from declining share of the meat market. The one bright spot in the baler business is sales of

large square balers where the market has increased an average of about 20% over the last five years. The drivers for this market surge are productivity and the growth of forage as a commodity.

There are two types of small square balers - bottom-fed and side-fed bale chambers. Bottom-fed balers typically result in lower pick-up and bale chamber losses than side-fed balers do. It has been almost 20 years since the introduction of the bottom-fed baler, and there hasn't been a significant new small square baler development since that time.

There are also two types of round balers - fixed and variable chamber. Fixed chamber balers are usually associated with fixed rollers around the bale chamber (Figure 8). These balers produce lower core densities and some designs will produce greater leaf loss when harvesting dry alfalfa. Variable chamber balers usually use a belt design and can be set-up to produce a high-density core (Figure 8). For years, the European market was dominated by the fixed-chamber design because these designs were felt to be superior when harvesting wet forage for silage. However, with variable chamber balers now having design features that improve performance with bale silage and the desire for greater core densities to maintain silage quality, there has been a shift toward variable-chamber designs in Europe. In NA, the variable-chamber design has always dominated and will likely continue that trend. However, there has been a growing interest in bale silage in NA and that has caused a fixed chamber market to grow slightly in NA.

Large rectangular bales will be the package of choice for those planning to market commercial hay in the future. Although these balers cost 2 to 3 times that of a round baler, their cost can be justified because these balers have tremendous capacity, lower losses, greater bale density, and the bales utilize shipping volume more efficiently than round bales. These balers were first used in the commercial hay growing regions of the arid western US over 20 years ago. The 4' x 4' baler was so large that it was generally confined to large farms which had sufficient sized handling equipment. However, the introduction of the 3' x 3' baler has pushed sales of the large square baler into the hay growing regions east of the Mississippi River. It is expected that the greatest growth in the large square baler market in the next five years will be in the 3' x 3' bale size.

Mechanisms that cut grass/legume forages into 3" to 6" segments before the bale chamber are starting to enter the market on both round and large square balers (Figure 9). These devices, which have been used for many years on self-loading forage wagons in Europe, help to increase bale density and thereby improve silage quality. They also make either wet or dry forage more easily processed in a TMR mixer.

Summing up the baler business, expect to see flatness to downsizing of the large round and small square baler segments. Large square baler sales will continue to increase as forage producers search for greater productivity and produce more commercial hay. Processing of hay in the baler with cutting systems will be more prevalent to make hay easier to mix and feed

to animals. Finally, expect to see yield monitors on round and large square balers.

In the Future

Although much has been made about single pass equipment that artificially dries forages from standing to baling moisture, do not expect to see this equipment anytime soon. These machines may use heated rolls or microwaves to drive off moisture, essentially a dehydration plant on wheels. The unfortunate fact is that it takes tremendous energy to remove water from forages, and in order for these machines to achieve acceptable field capacities, tremendous power is required. Therefore, capital and energy costs doom these systems from the start.

The best hope to improve drying rates, and hence quality, of forage crops is to develop new conditioning systems that improve the moisture migration properties of the crop and most effectively utilize solar energy for drying. Several new intensive conditioning systems have been introduced. These systems condition the crop by abrasion with a brush conditioner or flatten the stem with aggressive rollers. It will be interesting to see how these machines fair in the marketplace.

More forage will be grown for commercial and export sale in the future, and many producers will be operating with multiple machines at one time, often in remote locations. Producers will need more management information in order to keep efficiencies high and costs low. Therefore, such technology as geographical information systems (GIS), yield monitors and systems to measure crop moisture, and

quality on-the-go will certainly be part of tomorrow's hay and forage equipment.

Conclusions

Summing up the trends in hay and forage machinery industry, expect the following during the next five years:

1. Larger and faster equipment that is targeted at large farm operators and contractors.
2. In the dairy forage business, greater emphasis toward silage production and contract harvesting of that silage.
3. Greater specialization in the dairy business with more emphasis on purchased forages, both dry hay and silage.
4. Increased emphasis on commercial and export hay production.
5. Increased effort to improve forage-drying rate by intensive conditioning and improve forage feed utilization by greater processing at harvest.
6. Development of systems to integrate hay and forage equipment GIS.

Crop Processing Rolls On Forage Harvesters: Performance And Proper Machine Set-Up

In Europe, dairy producers' plant what is known as a "flint" corn, that has a harder kernel compared to NA "dent" corn. In the late 1970's, European dairy farmers expressed to forage harvester manufacturers their desire to inflict damage to the kernel at harvest to help

insure greater utilization by the dairy cow. Based on this customer requirement, harvester manufacturers developed the crop processor, basically placing a roller mill between the cutterhead and blower on the forage harvester. Although a common practice in Europe for years, this practice was virtually ignored in NA. This lack of interest could be traced to:

- Nutritional research with beef and dairy animals had not shown improved animal performance with processed corn silage diets. Often, both the control and processed crops were cut at TLC less than 3/8". The particle-size of the processed diet was then very short and masked any benefits of processing (Miller et al., 1969; Rojas-Bourrillon et al., 1987).
- A decade long decline in the total NA production of corn silage (Shinners, 1997).
- The lack of availability of processing systems on pull-type forage harvesters, the most common machine used to harvest most whole-plant corn silage in NA.
- Dairy producers typically used a short TLC to be compatible with upright silo unloaders. This short TLC caused considerable kernel damage, so the concern about incomplete kernel utilization was less.
- New nutrition research which showed the flaws of earlier research. Current researchers greatly increased the TLC of the processed crop and this led to improved animal performance compared to control diets comprised of short TLC unprocessed corn silage (Bal et al., 1998; Harrison et al., 1997; Straub et al., 1996).
- Renewed interest in producing and feeding corn silage as a means to maximize dry matter yield per unit area, important to dairy producers expanding their herd size on a limited land base.
- Introduction and heavy promotion of new self-propelled and pull-type harvesters with easy to remove crop processors.
- Dairy and beef producers began using bunk and bag silos to a much greater extent and these storage structures were more compatible with longer TLC whole-plant corn silage. Dairy producers became more aware of the nutritional benefits of coarse dietary fiber. Traditional, unprocessed corn silage cut at long TLC had too many intact kernels and whole cobs. Processed corn silage cut at a long TLC produced a feed with sufficient kernel and cob damage while yielding a long fiber fraction.

Recently, there has been an unprecedented explosion in the interest in processed corn silage. This reversal in opinion concerning processed corn silage can be traced to:

As more producers have become aware of crop processing on the forage harvester, questions have developed concerning the appropriate machine settings for TLC and processor roll

clearance. Concerns have also surfaced about the productivity and power requirements of the harvester when equipped with crop processing rolls.

Objectives

In order to help producers' set-up their machines to achieve the benefits of processing whole-plant corn silage, research was conducted with the following objectives:

- To measure the crop physical properties at a variety of stages of maturity and machine variables, such as TLC, roll speed differential, and roll clearance.
- To determine the power requirements and harvester capacities when processing whole-plant corn silage.

Description of Crop Processors

For decades, livestock producers had achieved greater feed utilization by processing grain crops with roller mills before feeding. Most of these roller mills used a pair of counter-rotating corrugated rolls operating at very small clearance. Typically, the pair of rolls was operated at the same speed, so that the grain crop was crushed but not sheared. To achieve a greater level of processing than the rasp bar processors produced, forage harvester manufacturers placed these roller mills between the cutterhead and blower on self-propelled harvesters. In this application, the rolls were operated at different speeds so that the resulting tip speed ratio also created a shearing action as the crop

passed through the roll nip. It is important to remember that these rolls will process the entire crop: stalk, cob, and kernel. The crushing and shearing action of the rolls will change the physical properties of all components of the plant, not just the kernel.

What are features to look for ...

Crop processors first appeared in NA on self-propelled harvesters in the 1980's. In 1997, pull-type harvesters were first offered for sale with these devices. Most of the crop processors on the market today have very similar roll diameter, tooth pitch, and speed ratio (Table 6). Large diameter rolls generally offer better feeding characteristics and are less likely to plug, all other factors being equal. Other features to look for when considering a crop processor are: 1) ease of removing or disabling the processor to harvest other crops, 2) ease of roll clearance adjustment, and 3) complexity of the drive system.

Details about the machines we used.

Unless noted otherwise, most of the research reported here was conducted with an experimental pull-type forage harvester equipped with crop processing rolls. A set of grooved counter-rotating rolls was placed after the cutterhead that was equipped with six knives. With a simple field adjustment, it was possible to direct the crop from the cutterhead toward either the processing rolls (processed treatment) or directly toward the blower (unprocessed treatment). The rolls were about 6" diameter, had a pitch of 4 teeth per inch, and a sharp tooth profile. Speed ratio was altered from 10 to 70% through the use of variable pitch sheaves. The harvester was equipped with a 2-row row-crop-harvesting unit and was operated

with a 200 PTOhp tractor. Harvesting ground speed typically was between 2.5 and 3.5 mi/h.

In 1998, two additional commercially available harvesters equipped with optional crop processors were used. A pull-type harvester was equipped with processing rolls between the cutterhead equipped with four knives and the cross-auger. The rolls were about 8.5" diameter, had a pitch of 4 teeth per inch, and a sharp tooth profile. Roll speed differential was 13%. The harvester was equipped with a 3-row row-crop harvesting unit and was operated with a 110 PTOhp tractor. Harvesting ground speed typically was between 2 and 2.5 mi/h. A self-propelled forage harvester was equipped with processing rolls between the cutterhead equipped with six knives and the cylindrical blower. The rolls were about 8.5" diameter, had a pitch of 4 teeth per inch, and a sharp tooth profile. Roll speed differential was 21%. The harvester was equipped with a 6-row non-row sensitive row-crop harvesting unit and a rated engine power of 365 hp. Harvesting ground speed typically was between 3 and 3.5 mi/h.

Procedures

How we determined crop physical properties in 1997. At harvest, stage of maturity was determined by visual observation of milk line progression. Kernel milk line is the visual line that separates the solid and liquid endosperm as the kernel reaches physiological maturity. Each time the forage harvester was operated with a different set-up, samples were taken for

determining dry matter (**DM**) content by oven drying and whole-plant particle size by sieving (ASAE, 1998). The coarse fiber fraction was defined as the fraction of the total particle size sample remaining on the top two sieves of the particle separator, expressed as a percentage. Whole, intact cob sections located on the top sieve were collected, weighed, and quantified as a percentage of the total mass on that sieve.

To determine the fraction of kernels damaged, a "coffee-can" sub-sample was collected and spread on a white surface. Identifiable whole or partial kernels were removed by hand and segregated as either damaged or undamaged. Each fraction was weighed and expressed as a percentage of the total kernel mass collected.

How we determined crop physical properties in 1998. Stage of maturity, crop moisture, whole-plant particle-size, and the coarse fiber fraction were determined using the same techniques as described above. However, it was felt that a more accurate method was needed for determining the extent of kernel damage. A modified technique based on a method for determining the fineness of ground feed material by sieving was developed to quantify the physical properties of the kernel fraction. A small sample of whole-plant corn silage was placed in a cascade of sieves and the sieve shaker operated for 2 minutes. The contents of each of the five sieves and the pan were then separated into five fractions: stalk and broken cob, whole cob, undamaged kernel, damaged kernel, and broken kernel. Undamaged kernels were defined as those that clearly had no physical damage. Damaged kernels were defined as

those that were basically intact, but that had a small nick or cut, probably from the cutterhead rather than the processing rolls. Broken kernels were defined as those whose physical shape was disrupted.

How we changed machine set-up in 1997. Tests were conducted with the experimental harvester at the University of Wisconsin West Madison Experimental Research Station harvesting Pioneer 3563 hybrid corn (103 day maturity, planted May 10) on September 23, October 2, and October 7, 1997. For these three dates, stage of maturity was about $\frac{1}{3}$, $\frac{1}{2}$ and $\frac{2}{3}$ milk line and moisture was 71, 64 and 61% wet basis (w.b.), respectively. Two roll clearances were used, 0.04 and 0.12". All processed treatments were harvested at $\frac{3}{4}$ " TLC. The two unprocessed controls were harvested at $\frac{3}{8}$ and $\frac{3}{4}$ " TLC.

How we changed machine set-up in 1998. Tests were conducted with the experimental harvester at the University of Wisconsin West Madison Experimental Research Station harvesting Pioneer 3563 hybrid corn (103 day maturity, planted May 11, 1998) on September 4, 11, and 18, 1998. For these three dates, stage of maturity was about $\frac{1}{3}$, $\frac{1}{2}$ and $\frac{3}{4}$ milk line and moisture was 69, 63 and 60% (w.b.), respectively. Three roll clearances were used, 0.04, 0.12, and 0.20". All processed treatments were harvested at $\frac{3}{4}$ " TLC. The two unprocessed controls were harvested at $\frac{3}{8}$ and $\frac{3}{4}$ " TLC.

In addition, on September 18th, 1998, the commercial pull-type and self-propelled harvesters described above were operated along side the experimental harvester. The commercial pull-type

harvester was operated at $\frac{3}{4}$ " TLC and 0.04, 0.12, and 0.20" roll clearances. The self-propelled harvester was operated at $\frac{13}{16}$ " TLC and 0.04, 0.12, and 0.20" roll clearances. Finally, the commercial pull-type harvester was operated on September 25th, 1998 at three TLC ($\frac{1}{2}$, $\frac{3}{4}$, and 1") and three roll clearances (0.04, 0.08, and 0.12"), values typical of practice in Wisconsin at the time. The Pioneer 3563 hybrid was at black layer maturity.

How we determined power requirements. Field measurement of experimental forage harvester power requirements was made on September 4, 11 and 18, 1998 using the experimental conditions described above. During field tests, all the chopped material from the forage harvester was collected in a side-dumping forage box with a weighed container (Kraus et al., 1993). The machine feed rate was determined by dividing the material mass collected during a test run by the test duration. The feed rate chosen was the maximum possible without plugging the harvester at the crop processor. Two torque transducers were used: one mounted between the tractor PTO and drive shaft of the forage harvester and another in the drive to the processing rolls. The former transducer allowed determination of the total machine power and the latter the power required by the processing rolls alone. A typical test run lasted about 70 seconds with about 1,300 lb harvested.

Results

First, does crop processing really work? There is no doubt that crop processing significantly alters the physical properties of not only the kernel fraction but

also the stalk and cob fractions as well. Data in Tables 7 and 8 show that the whole-plant particle size of the processed material ($\frac{3}{4}$ " TLC) falls somewhere between that of the unprocessed material cut at $\frac{3}{4}$ and $\frac{3}{8}$ " TLC. Processing also provides a significant quantity of coarse fiber to stimulate rumen function (Table 8). This long dietary fiber is an important constituent of the dairy cattle ration. Insufficient fiber length can lead to such problems as reduced milk fat content, displaced abomasum, laminitis and acidosis (Sudweeks et al., 1981). However, processing allows a significant quantity of coarse fiber to be achieved with almost no whole, intact cob slices in the processed material (Tables 7 and 8). Whole cob slices are often segregated and refused by cattle.

Of course, processing clearly affects the physical nature of the kernel fraction of whole-plant corn silage. Without processing, anywhere from 33 to 52% of the kernels were undamaged after harvest (Tables 7 and 9). The undamaged fraction for the processed material was only 0 to 12%. Processing also reduced the particle size of the kernels, which would imply they have greater surface area, which might lead to improved rate and extent of utilization.

What effect does roll clearance have? About the only adjustment that can be made to a crop processor is the clearance between the rolls, but this adjustment has a considerable effect of the processors performance. The greater the roll clearance, the lower the level of processing (Tables 7, 8, and 9). Increased roll clearance results in a reduced fraction of kernels damaged, greater whole-plant and kernel fraction particle size, and increased coarse fiber

fraction. It is obvious from the data that even a change of a few thousandths of an inch in roll clearance can greatly effect the physical properties of the crop material.

After separation of the kernel from the stalk and cob fractions, it was determined that the overall kernel mass fraction for the two control treatments was about 33%, but only about 27% for the processed treatments. The unidentified "loss" of six percentage units of kernel fraction in the processed treatments was probably due to the very small size of many of the kernel particles, which made collection difficult. Therefore, the physical properties of the processed treatments presented in Table 9 probably conservatively measure the degree of kernel processing.

What about as the crop matures? With whole-plant corn-silage, physical properties such as lignin content, kernel size, and mechanical strength of the stalk and kernel change as the crop matures. On grain combine harvesters, settings are routinely changed as the crop matures. Do operators of forage harvesters with crop processors need to make similar adjustments as the crop matures during harvest?

Independent of clearance or speed ratio, the level of processing of whole-plant corn silage appeared to increase as the plant matured (Table 10). Generally, there was not much difference in the processed crop physical properties between $\frac{1}{3}$ and $\frac{1}{2}$ milk line maturity. However, the processed crop at $\frac{3}{4}$ milk line had smaller whole-plant and kernel fraction particle size and fewer undamaged kernels

than when the crop was less mature. It was observed that the unprocessed kernels and cobs were physically larger at $\frac{3}{4}$ milk line than when the crop was less mature. These larger kernels and cobs might have been more likely to be damaged by the processing rolls. The results suggest that as the crop matures, changes to the configuration of the processing rolls are unnecessary and clearance could even be increased slightly to achieve the same level of processing found when the crop was less mature.

Were there differences between machines? Perhaps the biggest difference between the pull-type and self-propelled harvesters is their relative throughputs. In the study reported here, the self-propelled harvester was operated at roughly twice the feed rate, its crop processor was about the same width, and its cutting frequency (cutterhead knives past shearbar per unit time) was 18 to 50% greater than that of the two pull-type harvesters. Therefore, the thickness of the mat of material entering the crop processor was greater for the self-propelled harvester than the pull-type harvesters. How did these differences affect the final physical properties of the crop?

For a given roll clearance, there were generally very few differences in crop physical properties between different machines when harvesting whole-plant corn silage at $\frac{3}{4}$ milk line (Tables 11 and 12). At 0.04" roll clearance, all three machines produced a similar whole-plant and kernel fraction particle size. The self-propelled harvester produced a slightly greater change in physical properties of the kernel fraction than the pull-type

harvesters did as the clearance was increased from 0.04 to 0.20". At 0.20" roll clearance, the extra mat thickness mentioned above might have cushioned some of the material from the roll forces and contributed to a lower level of processing than the pull-type harvesters at this roll clearance. The data show that when properly set-up, both self-propelled and pull-type harvesters did an excellent job of processing whole-plant corn silage.

What about TLC other than $\frac{3}{4}$ "?

Many operators are using TLC other than $\frac{3}{4}$ " when processing whole-plant corn silage. What affect does a shorter or longer TLC have on the crop physical properties?

With a very mature, black layer crop, the $\frac{1}{2}$, $\frac{3}{4}$, and 1" TLC all produced a similar level of kernel processing (Tables 13 and 14). However, the longer TLC produced a crop that may be more beneficial to ruminant health because of greater whole-plant particle size and more coarse fiber. The longer TLC could also save power at the cutterhead, which could be used at the processing rolls (see below). It is unknown how well the processing rolls can withstand material longer than $\frac{3}{4}$ " TLC. Also unknown is the effect material longer than $\frac{3}{4}$ " has on silage packing and fermentation or handling in a TMR.

Clearly, processing improves the physical characteristics of whole-plant corn silage. Processing allows for a longer TLC to be used so that the processing rolls can utilize energy conserved at the cutterhead (see below). Harvesting with longer TLC and processing resulted in a

material with similar whole-plant particle-size, greater coarse fiber fraction, smaller kernel particle size, and fewer whole kernels and whole cobs than a control treatment that represented current practice (3/8" TLC).

How does processing effect power requirements and harvesting capacity?

Roll clearance had a significant effect on harvester power requirements (Table 15). The power required by the processor was reduced by 20 and 9% as clearance was increased from 0.04 to 0.12 and 0.12 to 0.20", respectively, indicating that the effect on power required was less as clearance increased. The power required when operating the harvester at 3/4" TLC and 0.12 or 0.20" roll clearance was similar to that required when operating the harvester without the processor at 3/8" TLC. Power required was greater when the processor clearance was set at 0.04". Also, the processed treatment at 0.04" clearance had numerically the lowest harvesting rate because frequent plugging at the rolls occurred at mass-flow-rates obtainable with other machine configurations. If roll clearance is set at 0.12", it appears that the physical property benefits of processing can be achieved with no loss of harvesting rate or additional power requirements compared to current practice of harvesting at 3/8" TLC without processing.

TLC and roll clearance recommendations.

At this time, a 3/4" TLC setting is recommended for the harvester when processing whole-plant corn silage for several reasons. Feed intake and lactation performances were excellent for

this coarsely cut and processed silage (Bal et al., 1998). Observed trends in particle size and rumen fiber-mat formation may prove beneficial in certain feeding situations (Bal et al., 1998). The physical property benefits of processing can be achieved with no loss of harvesting rate or additional power requirements if roll clearance is 0.12" or greater. If 100% kernel damage is desired, rolls should be set and maintained at about 0.04" clearance.

At this time, it is suggested that cutting at lengths greater than 3/4" TLC is not appropriate for several reasons. There is no evidence that coarse cutting and processing of corn silage greatly improves animal performance. In the absence of data, there is concern about adequate packing of coarsely chopped silage in the silo and the quality of the ensuing fermentation process. Also, there have been reports from the field about excessive crop processor wear when cutting and processing whole-plant corn silage at 1" or greater TLC.

Conclusions

- Unprocessed whole-plant corn silage cut at 3/8" TLC is a common harvesting strategy. Compared to this practice, whole-plant corn silage cut at 3/4" TLC and processed with crop processing rolls on-board the forage harvester had:

- Greater whole-plant particle size
- Fewer whole, intact cob sections
- Fewer undamaged kernels

-Smaller kernel fraction particle size

- Within the limits tested, the clearance between the processing rolls appeared to have greater effect on the level of kernel processing than roll speed differential. It is obvious from the data that even a change of a few thousandths of an inch in roll clearance can greatly effect the physical properties of the crop material.
- Independent of clearance or speed ratio, the level of processing of whole-plant corn silage appeared to increase as the plant matured. As maturity increased, the kernels and cobs were observed to be larger, and therefore, might have been more likely to be damaged by the processing rolls.
- The data showed that when properly set-up, both self-propelled and pull-type harvesters did an excellent job of processing whole-plant corn silage. The self-propelled harvester may be more sensitive to changes in roll clearance because of its harvesting rate and subsequent thickness of material flowing through the crop processor.
- With a very mature, black layer crop, the 1/2, 3/4, and 1" TLC all produced a similar level of kernel processing. However, the longer TLC produced a crop that may be more beneficial to ruminant health because of greater whole-plant particle size and greater quantity of coarse fiber.
- The processed treatments at 3/4" TLC and 0.12 or 0.20" roll clearance required similar power to the control unprocessed treatment at 3/8" TLC. It appears that the physical property benefits of processing whole-plant corn silage can be achieved with no loss of harvesting rate or additional power requirements
- Based on crop physical properties, harvester power requirements and dairy cattle lactation performance recommended settings when harvesting whole-plant corn silage would be 3/4" TLC and 0.04 to 0.12" processing roll clearance.
- Crop conditions and machine set-up can change throughout the harvesting day, so an operator should check the level of processing on every load and adjust the roll clearance to deliver the level of processing needed.
- Besides price, other factors to consider when comparing crop processors include roll diameter, tooth pitch and profile, robustness of the drive and bearings, ease of clearance adjustment and ease of processor removal.

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Table 1. Impact of dairy herd size on production costs.¹

	Herd Size	
	60 to 120	> 300
Output/cow, lb/lactation	15,069	17,243
Labor efficiency, h/cwt milk	0.36	0.13
Production cost, \$/cwt milk	17.34	12.55

¹Source: USDA Farm Cost and Returns Survey (1993).

Table 2. Impact of location on production costs.¹

	Midwest & Northeast US	Western US
Output/cow, lb/lactation	15,487	17,464
Labor efficiency, h/cwt milk	0.38	0.12
Production cost, \$/cwt milk	17.21	12.09

¹Source: USDA Farm Cost and Returns Survey (1993).

Table 3. Productivity comparison of sickle versus disk cutterbar mower-conditioners.

	Sickle Cutterbar	Disc Cutterbar
Approximate weight, lb	5,400	7,000
Cutting width, ft	14.3	14.5
Minimum tractor power, hp	70	115
Approximate retail cost	\$23,500	\$31,000
Productivity range, ac/h	5 - 6	8 - 11

Table 4. Effect of sickle versus disk cutterbar mower-conditioners on alfalfa stand and yield.¹

	Sickle Cutterbar	Disc Cutterbar
Stand after two years cutting, plants/ft ²	6.2	6.2
Yield, tons DM/ac	1.47	1.49

¹Source: Mueller et al., 1998.

Table 5. Effect of impeller versus roll conditioners on alfalfa and grass crop loss and drying rate.¹

	Drying constant, h ⁻¹			Crop loss, % of total DM
	First day	Second Day	Third Day	
Impeller	0.201 ^a	0.119 ^a	0.229 ^a	6.21
Roll	0.126 ^b	0.041 ^b	0.072 ^b	4.43
LSD ² (P = 0.10)	0.053	0.075	0.069	2.71

¹Source: Greenlees et al., 1999.

²LSD = least significant difference.

^{ab}Means in the same column with different superscripts differ (P < 0.05).

Table 6. General specifications of commercially available crop processors.¹

	Roll diameter, inches	Pitch, teeth per inch	Roll speed ratio, %	Retail list ² , \$
John Deere 6000 Series SPFH	8.5	4	21	~\$13,000
Claas 800 Series SPFH	7.7	3.3	20	~\$15,000
New Holland FX Series SPFH	7.9	4	9	~\$12,000
Gehl 1275 PTFH	8.5	4	13	~\$9,000
Gehl 1075 PTFH	8.5	4	13	~\$7,100
New Holland 900 PTFH	7.9	4	18	~\$7,000
Dion 1224	10.6	6	60	~\$7,800
Georgetown Crop Processor Kit ³	8.5	4	20	~\$8,300
LSC Crop Processor Kit ⁴	9	4	19	~\$11,500

¹SPFH = self-propelled forage harvester and PTFH = pull-type forage harvester.

²Approximate retail price as of March, 1999.

³Kit for New Holland and Gehl PTFH.

⁴Kit for John Deere 3950/3970 PTFH and John Deere 5830 SPFH.

Table 7. Roll clearance effects on physical properties of whole-plant corn silage during 1997.¹

Treatment / TLC ²	Roll clearance (in)	Whole-plant particle size (in)	Fraction of total kernel mass damaged (%)	Whole, intact cob (% of material on top sieve)
Unprocessed, 3/4 in	-	0.63 ^d	48 ^a	30
Unprocessed, 3/8 in	-	0.40 ^a	59 ^b	25
Processed, 3/4 in	0.04	0.45 ^b	100 ^c	0
Processed, 3/4 in.	0.12	0.53 ^c	94 ^c	4
LSD ² (P = 0.05)		0.04	10	

¹Average values for crop harvested at about 1/3, 1/2, and 2/3 milk line.

²TLC = theoretical length of cut and LSD = least significant difference.

^{abc}Means in the same column with different superscripts differ (P < 0.05).

Table 8. Roll clearance effects on physical properties of the whole-plant during 1998.

Treatment /TLC ¹	Roll clearance (in)	Whole-plant particle size (in)	Whole cob fraction (% of total mass)	Coarse fiber fraction (%)
Unprocessed – ¾ in	-	0.77 ^d	8 ^c	55 ^e
Unprocessed – ⅜ in	-	0.45 ^a	4 ^b	15 ^a
Processed – ¾ in	0.04	0.47 ^{ab}	0 ^a	36 ^b
Processed – ¾ in	0.12	0.49 ^b	0 ^a	40 ^c
Processed – ¾ in	0.20	0.55 ^c	0 ^a	46 ^d
LSD ¹ (P = 0.05)		0.03	3	2

¹TLC = theoretical length of cut and LSD = least significant difference.

^{abcd}Means in the same column with different superscripts differ (P < 0.05).

Table 9. Roll clearance effects on physical properties of the kernel fraction during 1998.¹

Treatment/TLC ²	Roll clearance (in)	Kernel particle size (in)	Undamaged (% of kernel mass)	Damaged (% of kernel mass)	Broken (% of kernel mass)
Unprocessed - ¾ in	-	0.252 ^d	41.6 ^e	19.7 ^d	38.7 ^a
Unprocessed - ⅜ in	-	0.250 ^d	33.3 ^d	19.6 ^d	47.2 ^b
Processed 19 mm	0.04	0.181 ^a	0.2 ^a	3.5 ^a	96.3 ^e
Processed 19 mm	0.12	0.193 ^b	3.8 ^b	10.0 ^b	86.2 ^d
Processed 19 mm	0.20	0.200 ^c	12.0 ^c	15.3 ^c	72.8 ^c
LSD ² (P = 0.05)		0.004	3.0	2.8	3.8

¹Average values for crop harvested at about ⅓, ½, and ¾ milk line.

²TLC = theoretical length of cut and LSD = least significant difference.

^{abcd}Means in the same column with different superscripts differ (P < 0.05).

Table 10. Physical properties of whole-plant corn silage as affected by crop maturity.¹

	Harvested 9/4/98 (¹ / ₃ milk line)	Harvested 9/11/98 (¹ / ₂ milk line)	Harvested 9/18/98 (³ / ₄ milk line)	LSD ² (P = 0.05)
Whole-plant particle size, in	0.52 ^b	0.52 ^b	0.47 ^a	0.04
Coarse fiber fraction of whole-plant, %	44.1 ^c	41.5 ^b	36.2 ^a	0.9
Kernel fraction particle size, in	0.189 ^b	0.192 ^b	0.181 ^a	0.004
Undamaged kernels, % of kernel mass	6.4 ^b	4.3 ^b	3.0 ^a	1.4
Damaged kernels, % of kernel mass	8.1 ^b	7.7 ^b	5.9 ^a	1.7
Broken kernels, % of kernel mass	85.5 ^a	88.0 ^b	91.1 ^c	2.1

¹Average values for crop harvested at $\frac{3}{4}$ in theoretical length of cut and 0.04, 0.12, and 0.20 in roll clearance.

²LSD = least significant difference.

^{abc}Means in the same row with different superscripts differ (P < 0.05).

Table 11. Effect of pull-type versus self-propelled harvesters on physical properties of the whole-plant.¹

Treatment/TLC	Roll clearance (in)	Whole-plant particle size (in)	Whole cob fraction (% of total mass)	Coarse fiber fraction (%)
Ave. PTFH ² - 3/4 in	0.04	0.43 ^a	0 ^a	29.6 ^{ab}
“	0.12	0.45 ^a	0 ^a	32.2 ^{ab}
“	0.20	0.53 ^c	0 ^a	37.8 ^d
SPFH - 13/16 in	0.04	0.43 ^a	0 ^a	28.7 ^a
“	0.12	0.50 ^b	0 ^a	31.6 ^b
“	0.20	0.52 ^{bc}	2 ^b	35.3 ^c
LSD (P = 0.05)		0.02	0.7	2.6

¹Crop harvested at 3/4 milk line maturity; TLC = theoretical length of cut, PTFH = pull-type forage harvester, SPFH = self-propelled forage harvester, and LSD = least significant difference.

²Average values from crop harvested with experimental and commercial PTFH.

^{abcd}Means in the same column with different superscripts differ (P < 0.05).

Table 12. Effect of pull-type versus self-propelled harvesters on physical properties of the kernel fraction.¹

Treatment/TLC	Roll clearance (in)	Kernel particle size (in)	Undamaged (% of kernel mass)	Damaged (% of kernel mass)	Broken (% of kernel mass)
Ave. PTFH ² - 3/4 in	0.04	0.181 ^a	0.0 ^a	6.6 ^b	93.4 ^d
“	0.12	0.196 ^b	1.6 ^a	6.9 ^b	91.5 ^d
“	0.20	0.209 ^c	8.8 ^c	14.4 ^c	76.8 ^b
SPFH - 13/16 in	0.04	0.177 ^a	0.0 ^a	0.0 ^a	100.0 ^e
“	0.12	0.220 ^d	0.0 ^a	17.4 ^{cd}	82.6 ^c
“	0.20	0.228 ^d	5.8 ^b	19.5 ^d	74.7 ^{ab}
LSD (P = 0.05)		0.008	2.3	3.9	3.6

¹Crop harvested at 3/4 milk 1 in maturity; TLC = theoretical length of cut; PTFH = pull-type forage harvester, SPFH- self-propelled forage harvester, and LSD = least significant difference.

²Average values from crop harvested with experimental and commercial PTFH.

^{abcd}Means in the same column with different superscripts differ (P < 0.05).

Table 13. Effect of theoretical length of cut (TLC) on physical properties of the whole-plant.¹

TLC ²	Whole-plant particle size (in)	Whole cob fraction (% of total mass)	Coarse fiber fraction (%)
½ in	0.42 ^a	0.7 ^b	15.2 ^a
¾ in	0.49 ^b	0.0 ^a	34.2 ^b
1 in	0.52 ^c	0.0 ^a	38.3 ^c
LSD ³ (P = 0.05)	0.02	0.5	2.3

¹Crop was harvested at black layer of maturity.

²Average values for roll clearance of 0.04, 0.08, and 0.12 in for each TLC.

³LSD = least significant difference.

^{abc}Means in the same column with different superscripts differ (P < 0.05).

Table 14. Effect of theoretical length of cut (TLC) on physical properties of the kernel fraction.¹

TLC ²	Kernel particle size (in)	Undamaged (% of kernel mass)	Damaged (% of kernel mass)	Broken (% of kernel mass)
½ in	0.204 ^b	0.3	8.8	90.7
¾ in	0.193 ^a	0.0	6.5	93.5
1 in	0.197 ^{ab}	0.2	8.6	91.2
LSD ³ (P = 0.05)	0.2	0.3	4.0	3.9

¹Crop was harvested at black layer of maturity.

²Average values for roll clearances of 0.04, 0.08, and 0.12 in for each TLC.

³LSD = least significant difference.

^{ab}Means in the same column with different superscripts differ (P < 0.05).

Table 15. Power requirements for whole-plant corn silage harvested with an experimental pull-type harvester.¹

Treatment /TLC	Roll speed ratio (%)	Roll clearance (in)	Throughput (ton/h)	Total harvester power requirement (hp-h/ton)	Processor power requirement (hp-h/ton)
Unprocessed $\frac{3}{4}$ in	-	-	38.5	2.14 ^a	-
Unprocessed $\frac{3}{8}$ in	-	-	37.6	2.69 ^b	-
Processed $\frac{3}{4}$ in	21	0.04	35.7	2.99 ^c	1.01 ^b
Processed $\frac{3}{4}$ in	26	0.12	38.8	2.76 ^{bc}	0.80 ^a
Processed $\frac{3}{4}$ in	26	0.20	39.0	2.70 ^{bc}	0.74 ^a
LSD (P = 0.05)			3.7	0.26	0.09

¹Averages for crop harvested on September 4, 11, and 18, 1998; TLC = theoretical length of cut and LSD = least significant difference.

^{abc}Means in the same column with different superscripts differ (P < 0.05).

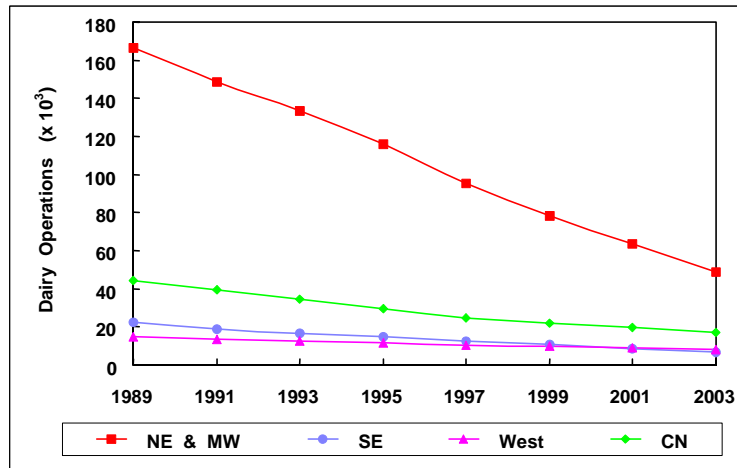


Figure 1. Number of dairy operations by region.

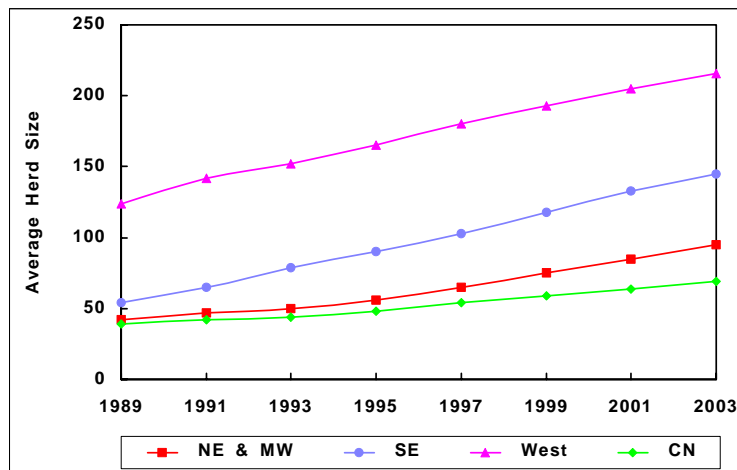


Figure 2. Average herd size (number of cows) by region.

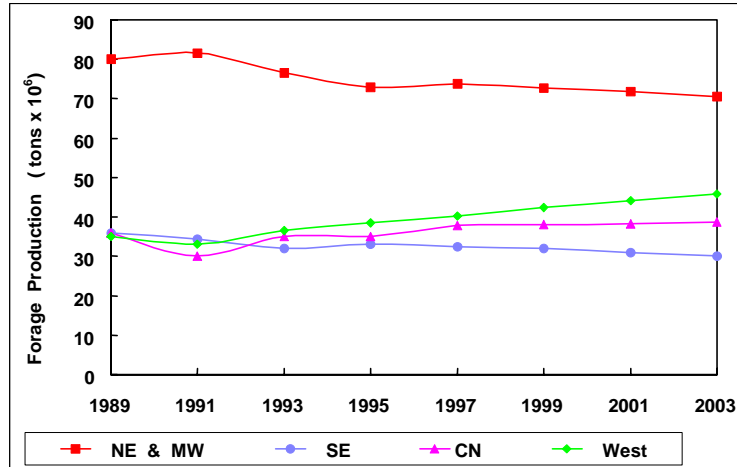


Figure 3. North American forage production by region.

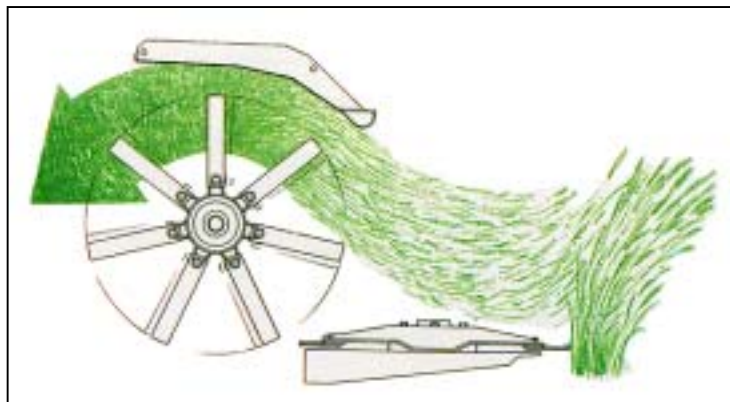


Figure 4. Impeller conditioner on disk mower conditioner.

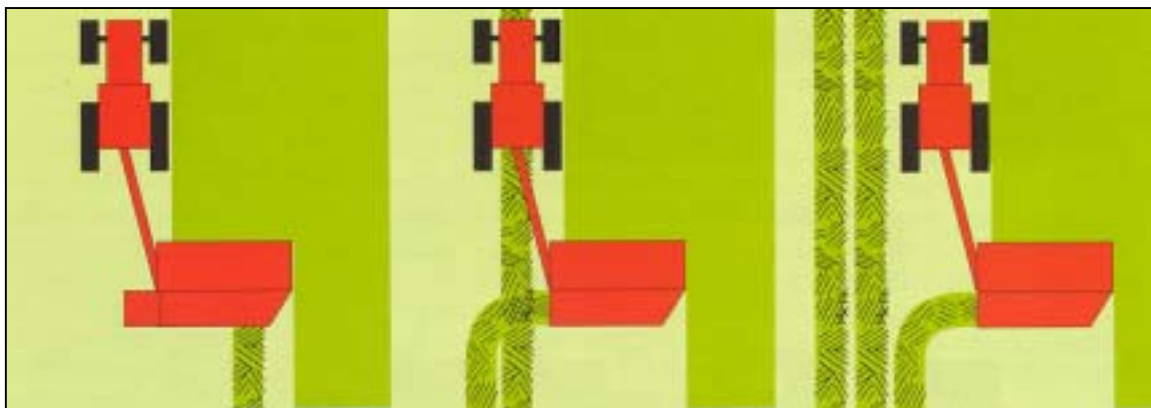


Figure 5. Schematic of mower-conditioner grouper merging windows.

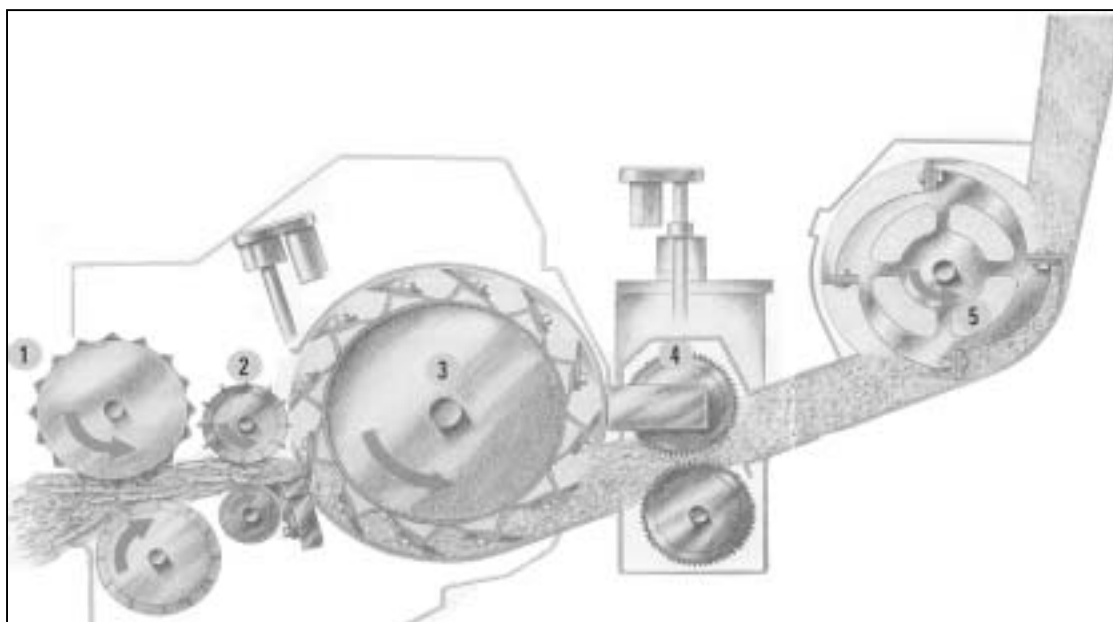


Figure 6. Schematic of harvester with feed rolls ① and ②, cutterhead ③, crop processor ④, and blower ⑤.

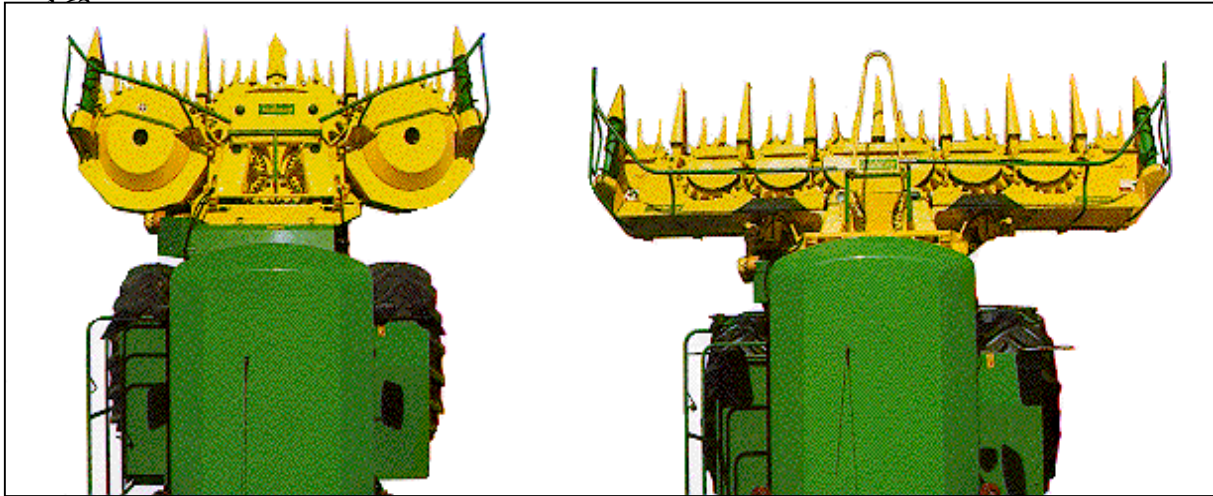


Figure 7. Non-row sensitive row-crop head on self-propelled forage harvester.

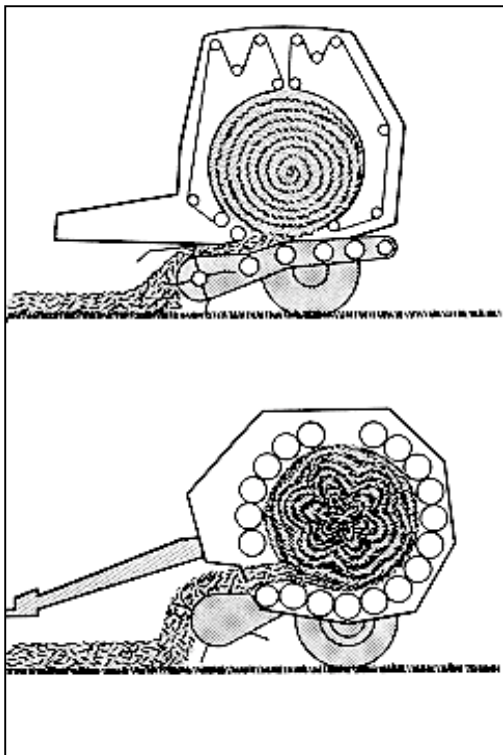


Figure 8. Schematic of variable (top) versus fixed (bottom) chamber large round balers.

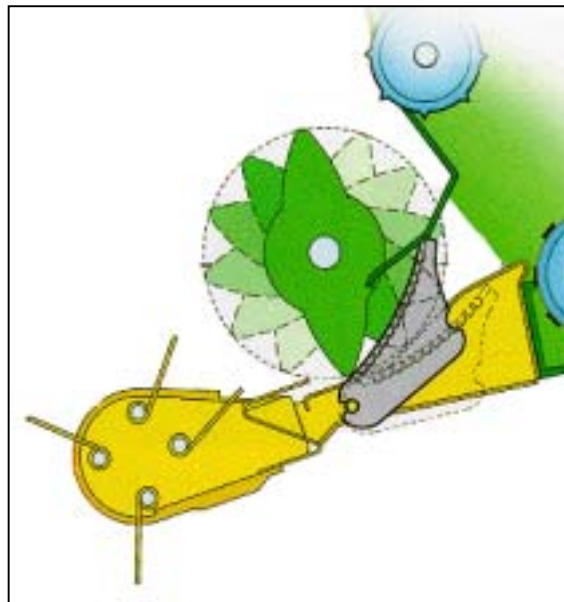


Figure 9. Crop cutter in large round baler.

Update on Predicting Harvest Time for Alfalfa

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Abstract

Knowing the chemical composition of alfalfa in the field would help producers to harvest, store, and inventory the feed resource based on its potential value in dairy rations. Use of conventional laboratory analyses to obtain forage quality status of individual fields for making harvesting decisions is impractical because of the time, labor, and expense required. Three methods of predicting or estimating alfalfa quality are currently generating significant interest: 1) actual forage sample collection and quality analysis (scissors-cut programs), 2) predictive equations of alfalfa quality (**PEAQ**) based on stem length and maturity, and 3) predicting alfalfa fiber content from growing degree days (**GDD**). Scissors-cut programs can provide general guidelines on the timing of first harvest but are too expensive to use routinely on individual fields. Based on research to date, GDD data from the start of the season may not by themselves produce a consistent, reasonably accurate estimation or prediction of alfalfa

neutral detergent fiber (**NDF**) in the spring, and GDD do not relate to forage quality in summer regrowth. Research to date with PEAQ indicates that this method has the greatest potential to provide fast, simple, inexpensive, and reasonably accurate estimates of alfalfa NDF across environments and across all harvests during the growing season. It may be the most practical system for adoption on individual farms and to monitor forage quality in individual fields. When significant forward planning is needed or desired during the spring, an early spring sample analyzed for NDF content coupled with the historic GDD accumulation can be used to predict (into the future) an optimal date for the first cutting. The PEAQ method could then be used to estimate NDF content of a given field as the predicted optimal date approaches.

Introduction

Dairy producers understand the importance of forage quality to profitability. Poor quality forages increase feed costs and

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limit milk production in high producing cows. Unfortunately, harvest and storage management decisions are often made without knowledge of alfalfa chemical composition. Knowing the chemical composition of alfalfa in the field would help producers to harvest, store, and inventory the feed resource based on its potential value in dairy rations. Use of conventional laboratory analyses to obtain forage quality status of individual fields for making harvesting decisions is impractical because of the time, labor, and expense required. Instead, producers often rely on calendar date or maturity to make the best guess of when to harvest high quality alfalfa. But these indices are not reliable. For example, under certain environmental conditions, morphological stage of alfalfa can remain nearly constant while quality continues to decline (Cherney, 1995). Chronological age of forage relates to quality in spring growth but is inconsistently related to quality in regrowth. Harvesting by calendar date can give very disappointing results as well. The NDF content of spring harvested alfalfa has been shown to vary by as much as 10 percentage units when harvested on the same date from one year to the next (Allen et al., 1992). Clearly, there is a need for simple and reliable methods of predicting or estimating forage quality of alfalfa.

Cherney and Sulc (1997) described the ideal method of estimating alfalfa quality in the field as one providing reasonably accurate results while being easy, quick, inexpensive, and consistent across all harvests during the season and across a wide range of environments. The ideal method would also allow for predictions into the near future and would require alfalfa producers to visit and personally assess their fields for individual differences in characteristics affecting both quality and

quantity of the forage produced. In the past few years, three methods of predicting or estimating alfalfa quality have generated the most interest: 1) actual forage sample collection and quality analysis (the scissors-cut program), 2) PEAQ based on stem length and maturity, and 3) predicting alfalfa fiber content from GDD. In this paper, we describe these methods and outline the pros and cons of each. We also discuss recent developments in the use of these methods in this region.

It is important to understand that any method used to predict or estimate forage quality will have some error in relation to wet chemistry analyses. We will discuss the relative accuracy of these different methods. When discussing the use of forage quality models as decision aids for harvest timing, it is also important to define the desired forage quality goal. In this discussion, our premise is that NDF is currently the best commercially available criterion for evaluating forage quality in alfalfa and that alfalfa NDF of approximately 40% usually optimizes profitability in a 50% concentrate ration fed to dairy cows.

Scissors-Cut Method

Scissors-cut programs have been successfully used for a number of years in Wisconsin and Minnesota. In these programs, alfalfa samples are collected 1 to 3 times per week during the spring growth in randomly selected fields. Samples are usually analyzed via near infrared reflectance spectroscopy (**NIRS**), and the decline in forage quality is monitored. Results are quickly distributed to clientele through various channels to help them adjust timing of the first harvest on their farms. Scissors-cut programs are restricted to the spring growth period, since widely differing first-harvest dates on farms preclude any

widespread use of scissors-cut results in subsequent growth cycles.

Pro-scissors cut. Through the publicity associated with these programs, forage quality is put on the front burner for alfalfa producers during the spring growth when forage quality is especially difficult to assess. This increased awareness of forage quality is significant because the spring growth typically produces more forage than any other growth cycle. The exact forage quality of a given field at the time of sampling is determined, and after several sampling dates, a trend in forage quality decline is established. This information helps producers judge how the current season is shaping up and when to consider initiation of spring harvest on their farms. Since sampling is real-time, the effect of current weather conditions on quality is accurately reflected in the results.

Cons – Scissors-cut. The accuracy of a forage quality sample is only as good as the sampler, and good sampling technique is imperative. If samples are not representative of the field, they will not accurately reflect the forage quality of the field. Results reflect only the actual field sampled. Elevation and slope aspect of the field can significantly affect alfalfa quality trends. For example in New York, alfalfa on a hill may mature over a week later than alfalfa in a nearby valley. The time and expense of NIRS analysis deters its use as a routine harvest decision aid on individual farms or specific fields on a farm. In addition, NIRS is subject to errors when compared with wet chemistry and might be no more accurate than other predictive methods when used as a harvest decision aid. In a Wisconsin study comparing NIRS and PEAQ with wet chemistry, the NDF and acid detergent fiber (ADF) values obtained through a commercial NIRS lab were about as

accurate as the PEAQ estimated values for the same sample set (Owens et al., 1995). Errors can occur with NIRS analysis of scissors-cut samples because equations for fresh alfalfa are not generally available.

PEAQ (Predictive Equations for Alfalfa Quality)

Hintz and Albrecht (1991) evaluated fifteen maturity and morphological characteristics of plants in developing mathematical models to estimate fiber content of alfalfa. Among the models tested were simple equations (referred to as PEAQ) based on length of the tallest stem and stage of the most mature stem in the sample. These were considered the best compromise between accuracy and ease of use for routine estimation of alfalfa fiber composition.

The PEAQ equations for NDF and ADF were first validated with 308 samples collected from several locations in Wisconsin during hot and dry 1992 and cool and moist 1993 (Owens et al., 1995). The PEAQ equations were further validated with a total of 488 samples collected from production fields in New York, Pennsylvania, Ohio, Wisconsin, and California between 1994 and 1996 (Sulc et al., 1997). Those samples represented a wide range of environmental and management conditions and a diverse set of alfalfa varieties. The PEAQ method was found to be robust across the wide range of environments sampled, and the equations performed as well in states outside Wisconsin as they did in Wisconsin, where they were originally developed. The equations also performed well across spring and summer growth cycles. Estimated NDF using PEAQ was within ± 3 percentage units of the wet chemistry value in 72 to 81% of the samples collected and within ± 4

percentage units in 84 to 89% of the samples (Sulc et al. (1997).

In 1998, additional samples were collected from all growth cycles (spring and summer) in Ohio, Wisconsin, and South Dakota to further validate the use of PEAQ in field settings and to compare it to other simpler equations. Subsamples were collected from five representative locations within each field on any given sampling date. The length of the tallest stem and stage of the most mature stem in each subsample were determined directly in the field before cutting the subsample. In the previous validation work (Owens et al., 1995; Sulc et al., 1997), these measurements were carefully made in the comfort of a lab after the sample had been cut and collected. In 1998, the five subsamples collected from each field on a given sampling date were composited, dried, and analyzed for NDF content via wet chemistry. Wet chemistry NDF was compared with the PEAQ estimate of NDF (average of the five subsample measurements). In addition, a simplified staging scale was evaluated for use in the PEAQ equation. This scale consisted of only three stages (late vegetative, bud stage, and flower stage) rather than the detailed staging system of Kalu and Fick (1981) used in previous PEAQ research. In the simplified system, the two bud stages are averaged into a single bud stage value, and the two flower stages are averaged into a single flower stage value. With this method, one does not need to differentiate between early and late bud stages, or between early and late flower stages. The sampling protocol and NDF values generated from the PEAQ equation with this simplified staging system are shown in Table 1. The NDF values listed in Table 1 are calculated assuming a 1.5-inch cutting height.

Typical statistics used to evaluate regression equations include the coefficient of determination (r^2), root mean square error (RMSE), the y-intercept, and the slope of the regression line. A good equation will give a high r^2 value ($r^2 = 1.0$ for a perfect 1:1 relationship), a low RMSE, a y-intercept not different from 0, and a slope not different from 1.0 (Fick and Onstad, 1988). In validating such models, the RMSE measures the error of the estimation and is in the same units as the trait being estimated. If RMSE = 3 for an NDF equation, then more than half the estimates are within ± 3 percentage units of NDF, and nearly all estimates are within ± 6 units of NDF ($2 \times$ RMSE).

Results obtained from samples collected in 1998 are shown in Figure 1. The PEAQ estimates of NDF (Figure 1, top panel) were calculated using the 3-stage scale and stem length measurements obtained directly in the field during sampling, only the stem length was corrected for an assumed constant 2-inch cutting height. Using the 3-stage scale in the PEAQ equations yielded NDF estimates that were just as accurate as those calculated using the more detailed staging scale (data not shown). The in-field PEAQ estimates were nearly always identical to the PEAQ estimates calculated from the measurements made on the cut samples in the lab (data not shown). Thus, PEAQ can be performed accurately and quickly right in the field. These data demonstrate once again that PEAQ performs well across spring and summer growth cycles. The PEAQ method (using the 3-stage scale) estimated NDF within ± 2 percentage units of the wet chemistry value in 63% of the samples collected, within ± 3 percentage units in 75% of the samples, and within ± 4 percentage units in 93% of the samples. This

agrees with previous data sets (Sulc et al., 1997).

In addition to the PEAQ equations based on maturity and stem length, Hintz and Albrecht (1991) also reported an NDF equation based only on length of the tallest stem, with no consideration given to the maturity stage. We used the 1998 data set to validate that equation. The data shows that the equation based only on stem length works quite well (Figure 1, bottom panel); however, the error of estimation was slightly higher and the y-intercept deviated further from 0 than for the equation based on both stem length and maturity stage (Figure 1, top panel). The equation based only on stem length estimated NDF within ± 2 percentage units of the wet chemistry NDF in 37% of the samples collected, within ± 3 percentage units in 56% of the samples, and within ± 4 percentage units in 82% of the samples. Preliminary evaluation of this stem length equation for other data sets showed similar or even slightly better results. This method deserves more careful study. If it proves to be reliable, it would have the advantage of being even easier than the simplified PEAQ method described in Table 1. Below are summarized the pros and cons of the PEAQ method for estimating NDF.

Pros – PEAQ. The PEAQ method of estimating alfalfa quality is simple, fast, and inexpensive. Alfalfa quality has been estimated reasonably well in a number of different locations across the USA. Thus, the method is robust across a wide range of environments. It also performs well across all growth cycles during a season, not just in the first growth cycle (Owens et al., 1995; Sulc et al., 1997). The PEAQ sampling forces alfalfa producers out into their fields for a close inspection of alfalfa development. This encourages and facilitates scouting for other concerns, such as winter injury, disease development, insect

damage, and weed encroachment. The PEAQ sampling is real-time, so the effect of current weather conditions on crop development is reflected in the results. This method requires no record keeping. Yardsticks with NDF markings based on stem length and maturity stage are being produced and distributed. These “Alfalfa Fiber Sticks” will eliminate the need to calculate NDF from the equation or to look it up in a chart (Table 1). Thus, the method will become even more streamlined and convenient.

Cons – PEAQ. As with scissors-cut sampling, results are highly dependent on good sampling technique. This includes careful attention to finding and measuring the length of the tallest stem in the sample and correctly identifying what is the most advanced maturity stage present in the sample. The equation is calibrated only for pure alfalfa stands, so estimates are less reliable for weedy fields and alfalfa-grass fields. It does not work well in fields with poor stands, or in alfalfa suffering from waterlogging stress. It does not provide reliable estimates of NDF in alfalfa that is very short (longest stem less than 16 inches) or very tall (longest stem more than 40 inches). Nevertheless, the 16- to 40-inch height limit represents a much broader range in growth than the normal harvest range for alfalfa.

GDD (Growing Degree-Days). Growing degree-days is a temperature-derived index representing the amount of heat to which plants are exposed. Growing degree-days have been used successfully with corn development but have had mixed success with perennial forages. Accumulated GDD are related to NDF content in the spring growth of alfalfa (Allen et al., 1992; Allen and Beck, 1996; Cherney, 1995) but are inadequate in predicting

alfalfa quality across cuttings (Fick and Onstad, 1988; Sanderson, 1992). As noted by Van Soest (1996), GDD relate reasonably well to forage quality in perennial forages when soil moisture is not limiting, but later in the season when moisture is typically limiting, GDD do not relate well to quality. This is presumably because forage growth is limited more by soil moisture than by heat units. Therefore, researchers have focused their efforts on using GDD to predict quality of alfalfa in the spring only.

For alfalfa, GDD are calculated by averaging the maximum and minimum temperature ($^{\circ}\text{F}$) for a given day (24-h period) and subtracting the base temperature of 41°F . For example, if the maximum temperature is 65°F and the minimum is 43°F for a given day, then 13 GDD accumulated that day $[\frac{(65 + 43)}{2} - 41]$. For days with an average temperature of less than 41°F , daily GDD are set equal to 0. The seasonal total is obtained by summing the daily GDD from a predetermined starting date. Different criteria have been used to determine the starting date for GDD accumulation in the spring. In New York, Cherney (1995) began GDD accumulation after air temperature during the day remained above 41°F for five consecutive days. The actual date when this occurred varied from late March to early April, depending on the year and site. Allen and Beck (1996) used a constant starting date (March 1) for GDD accumulation in their six-state study.

The GDD method offers the advantage of using historical weather records to forecast the date when alfalfa will reach 40% NDF in the spring, or whatever the quality goal may be. Two recent reports indicate that alfalfa was near 40% NDF when about 700 to 750 GDD were accumulated in the spring (Allen and Beck,

1996; Cherney, 1995). Thus, historical weather records for a given location can be used to predict the date when 700 to 750 GDD will be accumulated. Actual GDD accumulation up to the date of prediction can be substituted for the long-term average values, thus improving the prediction for the current year (Cherney, 1995). This method could potentially allow producers to plan well in advance for the target date of spring harvest.

Although GDD and alfalfa NDF content are highly related within an environment, GDD prediction equations have not been consistently accurate across environments. Cherney (1995) demonstrated that the relationship between GDD and NDF content of alfalfa in Iowa (Sanderson, 1992) was quite different from that in New York. A New York GDD equation was developed to predict the date of 40% NDF, but the equation gave variable results when tested on samples that were outside of the data set used to calibrate the equation. The predicted date for 40% NDF was 1 to 7 days earlier than the actual date of 40% NDF. Allen and Beck (1996) reported that prediction equations developed in one year resulted in biased predictions for another year (the equations were not stable across years). The bias was generally less for predicting across states than across years. It appears that GDD models must be developed for a relatively narrow range of environments and periodic re-calibration is probably required (Sanderson, 1992). Below are summarized pros and cons of the GDD method.

Pros-GDD. The GDD method eliminates the need to sample a field, and therefore eliminates the potential for alfalfa sampling error. It allows NDF estimation in a predictive mode, meaning we can predict NDF into the future by using a historic GDD database. Thus, it potentially enables more

forward planning than the scissors-cut or PEAQ methods. It is inexpensive, fast, and easy assuming weather data are available for the site. As with PEAQ, the GDD equations were developed for pure stands of alfalfa, so weeds or grasses in the stands are not accounted for in the estimates.

Cons-GDD. Equations to predict NDF based on GDD can be developed, but it is unlikely that one GDD equation will work across all environments. Validation of GDD equations in the literature is limited. Based on analysis of large data sets across many environments (Allen and Beck, 1996; Cherney, 1995), predicted NDF may vary from actual NDF by over six percentage units, which is unacceptable. This method does not require alfalfa producers to go out and assess their fields. From an agronomist's perspective, this is not always desirable because other problems may not be discovered until it is too late to take corrective action. The utility of the GDD method is limited to the first (spring) growth cycle.

The GDD method requires a weather station near the site where NDF estimates will be made. Alternatively, producers will have to monitor and keep records of the maximum and minimum daily temperatures, which has the advantage of reflecting conditions right on their farm. Inexpensive thermometers are available which record the daily minimum/maximum temperatures. It is imperative that these thermometers be placed 5 feet above the ground in an enclosure mounted in an open area (preferably near a field), providing good ventilation with free airflow around the sensors, and preventing direct sunlight from hitting the sensors. When using GDD equations to predict the date for a given NDF level, it is necessary to have long-term weather data (10+ years).

Possible Combinations of Methods

Since no single method will ever result in perfect predictions of alfalfa quality into the future, a combination of methods may be most acceptable. Allen and Beck (1996) suggested that GDD in combination with plant height and maturity stage might be more accurate for estimating alfalfa NDF than using GDD alone. In Michigan, spring harvest alert programs are being used which are based on the GDD method (R. Leep, Michigan State Univ., personal communication, 1999). Accumulation of GDD (base 41°F, beginning March 1) is reported through various channels twice each week. Samples are collected to compare NIRS results of scissors-cut samples with GDD and PEAQ estimates of NDF. Michigan producers are encouraged to begin cutting alfalfa at 750 GDD for upright silos and 680 GDD for horizontal silos. Harvest should begin even earlier if it takes longer than one week to complete the harvest.

Cherney (1995) found that GDD prediction equations developed for different data sets in New York had considerably different intercepts (-6.0 to 13.5), but the slopes of the equations were relatively consistent (18 to 27 GDD per unit change in NDF). Because the slopes of the equations were similar but the intercepts varied, he proposed that alfalfa could be sampled several weeks ahead of harvest and analyzed to obtain a known NDF baseline value. The slope of the prediction equation (average of 21 GDD/unit NDF in New York) and the historic GDD for a given site could then be used to predict the date for 40% NDF, starting from the date of field sampling. This could potentially reduce the error in GDD predictions of the optimal harvest date. This method has been evaluated with fairly good success in New York (Cherney, 1995;

Cherney and Sulc, 1997) and needs to be evaluated in other environments. This technique is dependent on getting a good sample early in the spring, which is much more difficult than sampling taller alfalfa. It may be tempting to use PEAQ to estimate the early spring NDF baseline value, but the alfalfa must be at least 16 inches tall for greater reliability of the PEAQ estimate. One major disadvantage of building a prediction date for spring harvest on an estimated NDF foundation (such as using NIRS or PEAQ) is that the early estimate of NDF and GDD prediction could both err on the early or the late side, compounding the error to an unacceptable level. This combination method also requires historic GDD data for the site in question and adds labor, complexity, and the expense of laboratory analysis.

Practical Applications and Summary

Alfalfa forage quality estimates or predictions for harvest should be based on a defined forage quality goal. Alfalfa NDF of approximately 40% usually optimizes profitability in dairy rations containing 50% concentrate. Typical harvest and storage losses under good conditions can increase NDF content by 3 to 6 percentage units. We also know that NDF content increases about 4 or 5 percentage units in one week during the spring and early summer, but the change in fiber content is slower in mid to late summer. Based on this information and assuming good quality forage is desired, a reasonable goal is to begin mowing when the standing forage is approximately 35% NDF. Mowing should be completed by the time the standing forage is 40 to 41% NDF. The timing of harvest operations will depend on the desired quality, the amount of high quality forage needed, and the time required to cover all acres. Pre-harvest estimates of NDF content can be used to time harvests

and to guide the order of fields to harvest. These estimates might influence the storage location of the forage and may provide an early estimation of purchased feed needs. But it must be understood that pre-harvest estimates of NDF content do not replace the need to test the quality of stored forage before balancing rations and feeding.

Any method for estimating or predicting quality must be fast, simple and reasonably accurate. Based on research to-date, GDD data from the start of the season may not by themselves produce a consistent, reasonably accurate estimation or prediction of alfalfa NDF. Scissors-cut programs can provide general guidelines on the timing of first harvest but are too expensive to use routinely on individual fields. Research to date with PEAQ indicates that this method has the greatest potential to provide fast, simple, inexpensive, and reasonably accurate estimates of alfalfa NDF for individual farms and fields. In addition, it is reliable across all harvests during the growing season. When forward planning is needed or desired during the spring, a combination of methods may provide the best prediction of the optimal first harvest date; however, this involves more complexity than regularly monitoring NDF content with PEAQ as the spring progresses. An early prediction system involves the following: 1) collect a scissors-cut sample early in the growing season to determine NDF content, preferably via wet chemistry, 2) use the early season NDF content and historic GDD accumulation to predict the optimal harvest date, and 3) use the PEAQ method to estimate NDF content as the predicted optimal harvest date approaches.

It is not always possible to harvest alfalfa at the optimal time because of inclement weather. But methods of predicting or estimating alfalfa quality in the

field along with weather forecasts will help producers come closer to their desired forage quality goals. If performed correctly, these methods are certainly more reliable guides than visual appraisals or harvesting by calendar date, age, or maturity alone.

Acknowledgments

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Table 1. Estimation of alfalfa NDF using predictive equation of alfalfa quality (PEAQ) with a simplified staging scale.

Step 1: Choose a representative 2-square-foot area in the field.

Step 2: Determine the most mature stem in the 2-square-foot sampling area using the criteria shown in the table at right.

Step 3: Measure the length of the tallest stem in the 2-square-foot area. Measure it from the soil surface (next to plant crown) to the tip of the stem (NOT to the tip of the highest leaf blade). Straighten the stem for an accurate measure of its length. The tallest stem may not be the most mature stem.

Step 4: Based on the most mature stem and length of the tallest stem, use the chart at the right to determine estimated NDF content of the standing alfalfa forage.

Step 5: Repeat steps 1 to 4 in four or five representative areas across the field. Sample more times for fields larger than 30 acres.

NOTE: This procedure estimates alfalfa NDF content of the standing crop. It does not account for changes in quality due to wilting, harvesting, and storage. These factors may further raise NDF content by 3 to 6 units, assuming good wilting and harvesting conditions. This procedure is most accurate for good stands of pure alfalfa with healthy growth.

Length of Tallest Stem (from soil to stem tip)	Stage of Most Mature Stem		
	Late Vegetative no buds visible on stem	Bud Stage 1 or more nodes with buds visible	Flower Stage 1 or more nodes with 1 open flower
-- inches --	----- % NDF -----		
16	28.5	29.7	31.4
17	29.2	30.4	32.0
18	29.9	31.1	32.7
19	30.6	31.8	33.4
20	31.3	32.5	34.1
21	32.0	33.2	34.8
22	32.7	33.9	35.5
23	33.4	34.6	36.2
24	34.0	35.3	36.9
25	34.7	35.9	37.6
26	35.4	36.6	38.3
27	36.1	37.3	38.9
28	36.8	38.0	39.6
29	37.5	38.7	40.3
30	38.2	39.4	41.0
31	38.9	40.1	41.7
32	39.6	40.8	42.4
33	40.3	41.5	43.1
34	40.9	42.2	43.8
35	41.6	42.8	44.5
36	42.3	43.5	45.2
37	43.0	44.2	45.8
38	43.7	44.9	46.5
39	44.4	45.6	47.2
40	45.1	46.3	47.9

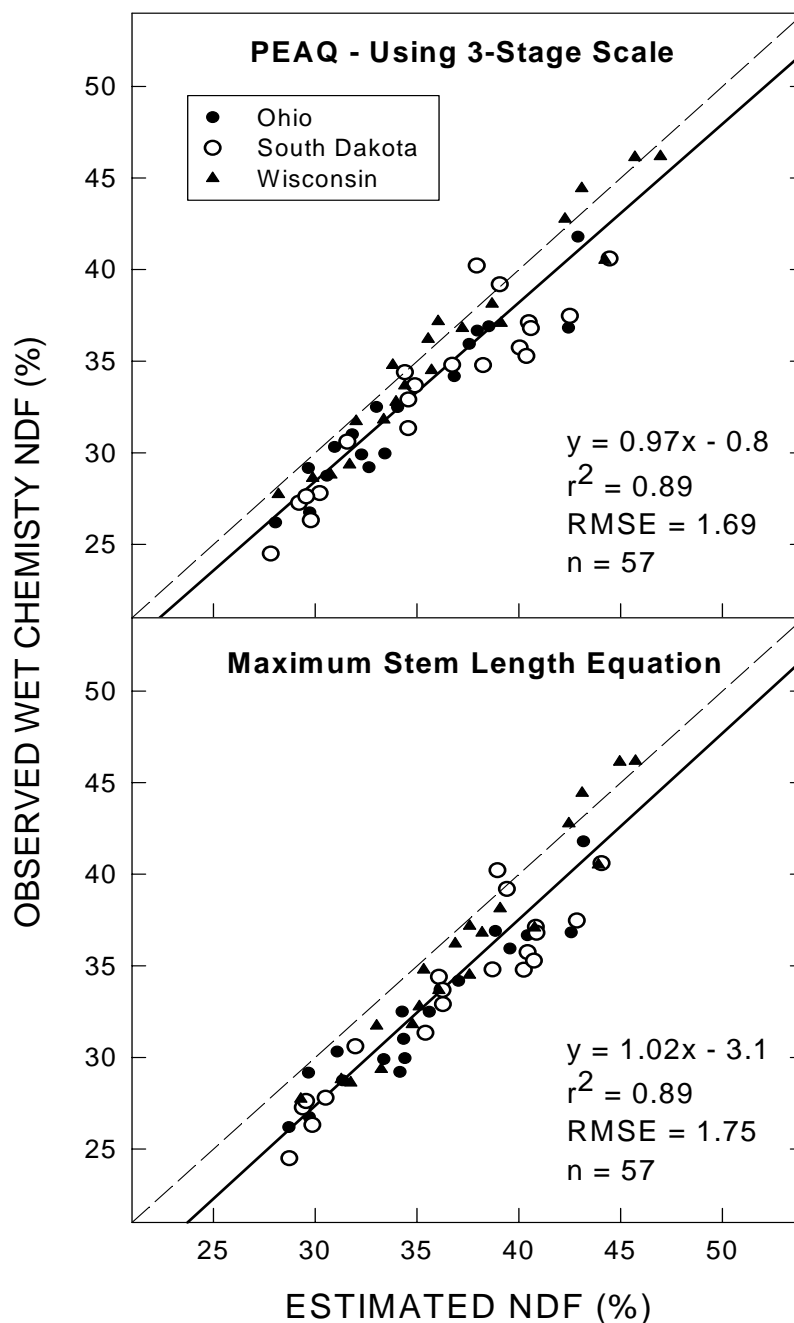


Figure 1. Estimated versus observed NDF of alfalfa. Estimates were calculated using predictive equations of alfalfa quality (PEAQ) with a 3-stage maturity scale (top panel) or using equations based solely on length of the tallest stem in the sample (bottom panel). Each point represents a composite sample from one field-sampling-date combination. The solid line is the observed regression and the dashed line represents a perfect 1:1 relationship (RMSE = root mean square error).

Brown Midrib Corn Silage

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Abstract

Commercially available corn hybrids with the brown midrib (**BMR**) gene were available a several years ago but diminished because of the low DM yields. The need to increase digestible DM intake to meet the nutrient requirements of high producing dairy cows and the willingness to plant corn specifically for silage has lead plant breeders to focus again on this BMR trait. Current BMR corn hybrids will result in lower yields of forage but will be generally similar in chemical composition to non-BMR corn silage, except that lignin will be lower in the BMR silage. The lower lignin will increase digestibility of the forage, thereby resulting in a forage with higher energy concentration. Lactating cows consuming BMR corn silage will likely have higher DM intake and milk yield than cows fed non-BMR corn silage. However, whether the BMR silage will be economical will depend on the yield reduction, amount of increase in DM intake, milk yield response, amount of BMR silage in the ration, and milk price. All of these risks must be evaluated being planting BMR corn, knowing also that the corn planted is for silage only. Also, farmers with limited land base will likely not have much interest in planting BMR corn.

Introduction

Corn silage has been one of the major ingredients in rations for dairy cattle for many years, and its use has been increasing in recent years. Factors contributing to this increase are energy yield per acre, relatively low cost compared to other forages, variability among different growing conditions, level of fiber and energy concentration, and good fermentation characteristics, leading to a stable feedstuff with minimal losses during storage if harvested properly. Considerable attention has been focused recently on improving the digestibility of the kernels and the stover. Use of processors to increase whole plant digestibility, but especially that of the kernels, has been increasing. Processing equipment holds promise but not without some important considerations (see paper by Dr. Kevin Shinnors elsewhere in these Proceedings). Seed corn companies also have been focusing some selection on hybrids with high, whole plant digestibility. Some improvements have been noted; however, repeatability from year to year is difficult because of varying growing and harvesting conditions and variation in animal factors.

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Incorporation of the BMR trait into forage genotypes has been an interest for many years. The BMR trait was first observed in corn in 1924 and since has been introduced into sorghum, sudangrass, and millet (Cherney and Cherney, 1991). The name "brown midrib" was attributed to this trait because of the reddish-brown coloration of the center midrib on the underside of the leaf. The interest in this trait occurs because of the reduction in lignin content of plant, thereby potentially increasing digestibility of the plant. However, the low yields per acre of the early BMR hybrids and the necessity to use it for silage (not grain) resulted in limited interest for widespread use. The need to increase digestible DM intake to meet the nutrient requirements of high producing dairy cows and the willingness to plant corn specifically for silage has lead plant breeders to focus again on this BMR trait.

This paper will focus on the research conducted with BMR corn silage, including the agronomic, animal performance, and economic implications. For your information, recent reviews on different corn hybrids have been written (Allen et al., 1997; Dado, 1997), and recent research with lactating dairy cows has revealed the value of the BMR trait in sorghum silage (Aydin et al., 1999; Grant et al., 1995).

Agronomic Principles

The concern with lower yield per acre of the BMR hybrids still exists. The yield for BMR silage was 10.4% (range = 2.8 to 16.9%) lower than for the controls among the studies reviewed (Table 1). The lower yield can be somewhat offset by the higher quality (more digestible) forage; however, the amount of yield reduction that can be economically justified depends on some other factors that will be discussed

later. The BMR hybrids must be harvested for silage because the plants will lodge if harvest is delayed for grain. Therefore, only enough of the BMR hybrid should be planted that will be definitely needed for silage. Given the lower yield and need to use it only for silage, the BMR results in more risks than with normal corn silage. The magnitude of these risks will vary from year to year and from farm to farm.

The DM yields for the BMR hybrids were ranked from lowest to highest (Figure 1). The ranking order for the control hybrids was very similar, indicating that factors germane to the study or farm affected the yield of each hybrid. It also indicates that quite respectable yields of BMR hybrids can be achieved; however, given the same conditions, the control hybrid would be expected to result in a higher yield. Although the extent of the yield increase varied, the occurrence of a yield increase was consistent among the studies. The economic implications of the lower yields with BMR are affected by other factors that will be discussed later, but in addition, the lower yields is a major concern for farmers with a limited land base.

Chemical Composition

Among the studies reviewed, the DM content of the silages was, on average, as desired (33 to 35% DM, Table 1). The BMR gene has little, if any, affect on the concentrations of CP, NDF, ADF, and ash in corn plants. However, lignin is reduced, thereby increasing NDF digestibility. Lignin is quite variable (coefficient of variation may range from 35 to 50%) because of the different methods of analysis and variability within a method. Use of the OSU equation for estimation of NE_L will result in high values for BMR corn silage; however modifications to the equation for

corn silage are being investigated (W. P. Weiss, OSU, personal communication).

Animal Performance

Feeding BMR corn silage has consistency resulted in higher DM intake, averaging 3.6 lb/cow/day among the studies summarized (Table 2). The range in DM increase was 0.9 to 7.3 lb/cow/day. These data represent the response to earlier and recent hybrids of BMR, forage ranging from 42 to 96% of dietary DM, and various milk yields. With higher fiber digestibility, we would expect rate of passage of particulate matter from the rumen to be faster, leading to higher DM intake. However, with such expectations, one would also expect the response in DM intake to be more at higher inclusion rates of the BMR silage in the diet. The BMR silage inclusion in diets ranged from 31 to 85%, with no consistent pattern in DM intake response (Figure 2). The use of BMR at lower rates may have some positive associative affects on utilization of other feeds, depending on how the rations are balanced, e.g. reduction of corn grain, when BMR corn silage is added to the ration.

Milk yield responses were more variable than DM intake responses, and cows fed BMR silage averaged 2.1 lb/day more milk than cows fed the control silage. There also was no consistent response in milk yield to level of BMR silage in the diet (Figure 2). Minor changes occurred, on average, for milk fat percentage, milk protein percentage, and rumen pH. The BMR silage appeared to increase ruminal acetate:propionate, consistent with the negative numerical response in milk fat percentage, and apparent total tract digestibility of fibrous fractions, consistent with in vitro and in situ NDF digestibilities (Table 1). Although difficult to access given

the design of several of the studies, body weight change was sometimes increased when BMR silage was fed (Block et al., 1981; Frenchick et al., 1976; Rook et al., 1977; Sommerfeldt et al., 1979).

Economics

The economics of using BMR corn silage will be affected by the production costs (especially additional cost of seed and any other variable costs), the level of inclusion of the silage in the ration, the animal's response (especially DM intake and milk yield), and the net price of milk (minus hauling and other assessments). Under the conditions assumed (10% yield reduction, 50% forage in the ration, 50% of the forage from corn silage, and net milk price not below \$12/cwt), economic advantages could be recognized (Table 3). However, risks associated with forage yield reduction being above average, insufficient milk yield response, and volatile milk prices must be evaluated. Planting only partially of the corn acreage as BMR corn may be advisable, and for larger farms that may be able to have more than one silage structure open at a time, feeding the BMR silage to the most probable responsive cows (highest producing groups) should be considered.

Summary

Planting BMR corn will result in lower yields of forage but will be generally similar in chemical composition to non-BMR corn silage, except that lignin will be lower in the BMR silage. The lower lignin should increase the digestibility of the forage, thereby resulting in a forage with higher energy concentration. Lactating cows consuming BMR corn silage will likely have higher DM intake and milk yield than cows fed non-BMR corn silage. However, whether the BMR silage will be economical

will depend on the yield reduction, amount of increase in DM intake, milk yield response, amount of BMR silage in the ration, and milk price. All of these risks must be evaluated before planting BMR corn, knowing also that the corn planted is for silage only. Also, farmers with limited land base will likely not benefit from use of BMR corn.

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Table 1. Agronomic principles and chemical composition of corn silages.¹

	BMR			N	Control		BMR versus Control
	n	Mean	STD		Mean	STD	
Yield, ton/acre ²	10	6.36	0.98	11	7.10	1.05	- 10.4%
Range		5.2, 8.3			5.4, 9.0		- 2.8, - 16.9%
Chemical Composition ³							
DM, %	22	33.1	...	23	34.6
CP, % of DM	21	9.34	1.71	22	8.74	1.64	+ 0.07 %
NDF, % of DM	13	47.2	6.7	14	47.9	7.3	- 0.01 %
ADF, % of DM	21	24.0	3.2	22	25.1	3.9	- 0.05 %
Lignin, % of DM	14	2.80	1.33	15	3.75	1.40	- 33.9 %
Ash, % of DM	7	4.63	0.53	7	4.51	0.61	+ 0.03 %
In vitro or in situ NDF digestibility, %	8	55.8	9.3	9	47.0	8.7	+ 18.7 %

¹BMR = brown midrib and STD = standard deviation; "Control" was not always an isogenomic hybrid.

²Data taken from Allen et al. (1997), Hutjens et al. (1998), Qiu et al. (1999), and Sniffen et al. (1999).

³Data taken from Allen et al. (1997), Block et al. (1981), Colenbrander et al. (1972), Frenchick et al. (1976), Hutjens et al. (1998), Hutjens et al. (1999), Keith et al. (1979), Oba and Allen (1999), Qiu et al. (1999), Rook et al. (1977), Sniffen et al. (1999), Sommerfeldt et al. (1979), and Stallings et al. (1982).

Table 2. Effect of corn silage hybrid on animal performance and digestibility.¹

Study	F:C	BMR	Control	BMR versus control
Frenchick et al., 1976	59:41	49	49	
DM intake, lb/day		46.0	44.0	+ 2.0
Milk yield, lb/day		49.5	47.7	+ 1.8
Milk fat, %		3.60	3.68	- 0.08
Rumen A:P		3.11	3.31	- 0.20

Rook et al., 1977	60:40	60	60	
DM intake, lb/day		44.5	41.0	+ 3.5
Milk yield, lb/day		68.9	72.4	- 3.5
Milk fat, %		4.52	4.23	+ 0.29
Milk protein, %		3.22	3.12	+ 0.10
DM digestibility, %		65.8	64.0	+ 1.8
NDF digestibility, %		61.8	58.9	+ 2.9
ADF digestibility, %		48.6	43.6	+ 5.0
	96:4	85	85	
DM intake, lb/day		45.5	38.8	+ 6.7
Milk yield, lb/day		51.5	49.7	+ 1.8
Milk fat, %		3.82	3.84	- 0.02
Milk protein, %		2.87	2.89	- 0.02
DM digestibility, %		59.7	61.4	- 1.7
NDF digestibility, %		45.5	53.0	- 7.5
ADF digestibility, %		40.3	44.4	- 4.1

Keith et al., 1979	75:25	75	75	
DM intake, lb/day		48.4	47.1	+1.3
Milk yield, lb/day		62.9	60.1	+2.8
Milk fat, %		3.58	3.66	- 0.08
Milk protein, %		3.41	3.41	0.0
	60:40	60	60	
DM intake, lb/day		48.4	47.5	+ 0.90
Milk yield, lb/day		62.5	59.0	+ 3.5
Milk fat, %		3.55	3.69	- 0.14
Milk protein, %		3.45	3.45	0.0

Sommerfeldt et al, 1979	69:31	57	55	
DM intake, lb/day		40.4	39.0	+ 1.4
Milk yield, lb/day		55	56.1	- 1.1
Milk fat, %		3.79	3.88	- 0.09
Milk protein, %		2.99	3.03	- 0.04
DM digestibility, %		62.9	59.5	+ 3.4
NDF digestibility, %		60.1	50.5	+ 9.6
Rumen pH		6.88	6.77	+ 0.11
Rumen A:P		2.92	2.84	+ 0.08

Table 2. continued.

Study	F:C	BMR	Control	BMR versus control
Block et al., 1981	65:35	65	65	
DM intake, lb/day		48.2	43.2	+ 5.0
Milk yield, lb/day		77.9	72.9	+ 5.0
Milk fat, %		2.87	3.15	- 0.28
Milk protein, %		2.96	2.89	+ 0.07

Stallings et al., 1982	48:52	49	47	
DM intake, lb/day		38.7	37.6	+ 1.1
Milk yield, lb/day		46.2	47.1	- 0.90
Milk fat, %		3.24	3.37	- 0.13

Oba and Allen, 1999	56:44	44.6	44.6	
DM intake, lb/day		56.3	51.7	+ 4.6
Milk yield, lb/day		91.7	85.6	+ 6.1
Milk fat, %		3.44	3.46	- 0.02
Milk protein, %		2.99	2.95	+ 0.04
DM digestibility, %		61.8	61	+ 0.08
NDF digestibility, %		33.1	30.9	+ 2.2
ADF digestibility, %		34.9	31.8	+ 3.1

Qiu et al., 1999	42:58	32	32	
DM intake, lb/day		57.6	55	+ 2.6
Milk yield, lb/day		78.1	74.8	+ 3.3
Milk fat, %		3.76	3.93	- 0.17
Milk protein, %		3.29	3.28	+ 0.01
Rumen pH		5.8	5.9	- 0.1
Rumen A:P		2.56	2.93	- 0.37
	52:48	39	39	
DM intake, lb/day		59.0	51.7	+ 7.3
Milk yield, lb/day		78.1	75.0	+ 3.1
Milk fat, %		3.89	3.79	+ 0.10
Milk protein, %		3.35	3.31	+ 0.04
Rumen pH		6.0	5.8	+ 0.2
Rumen A:P		2.79	3.12	- 0.33

Sniffen et al., 1999	48:52	31	31	
DM intake, lb/day		51.5	44.8	+ 6.7
Milk yield, lb/day		72.6	69.6	+ 3.0
Milk fat, %		4.13	4.24	- 0.11
Milk protein, %		3.20	3.24	- 0.04

Table 2. continued.

<u>Average Response</u>	<u>BMR versus Control</u>
DM intake, lb/day	+ 3.6
Milk yield, lb/day	+ 2.1
Milk fat, %	- 0.06
Milk protein, %	+ 0.02
Rumen pH	+ 0.07
Rumen A:P	- 0.21
DM digestibility, %	+ 0.90
NDF digestibility, %	+ 1.8
ADF digestibility, %	+ 1.3

¹Numerical numbers on the first row for each study reflect the forage: concentrate (F:C) ratio and the respective percentage of corn silage in the diet. BMR = brown midrib and A:P = acetate:propionate ratio. "Control" was not always an isogenomic hybrid.

Table 3. Economic comparisons of corn silage hybrids.

	BMR			Control		
Production costs (per acre)¹						
Seed	64			35		
Other variable	129			129		
Fixed costs	221			221		
Total	414			385		
	Yield reduction					
	5%	10%	15%			
Yield, t DM/acre	6.7	6.3	6.0		7	
Cost, \$/ton DM	62	66	69		55	
Cost, \$/ton @ 35% DM	22	23	24		19	
Feed costs²						
	---- % of forage --					
DM intake @ 52 lb/day	25	50	75	25	50	75
Amount of CS fed (F:C = 50:50)	6.5	13.0	19.5	6.5	13.0	19.5
Cost, \$/day	2.96	2.93	2.91	2.92	2.86	2.80
Cost, \$/lb DM	.057	.056	.056	.056	.055	.054
Animal response (per cow)						
DM intake, lb/day				3.6		
Feed cost, \$/day ³				0.20		
Milk yield, lb/day				2.1		
Milk net value, \$/cwt ⁴				12	14	16
Milk income, \$/day				0.25	0.29	0.34
Net response, \$/day				0.05	0.09	0.14

¹Production costs taken from Ohio Crop Enterprise Budgets (1999), assuming seed cost is 1.8 times higher for the brown midrib (BMR) hybrid.

²The DM intake and feed costs were estimated for a cow with the following characteristics: 1400 lb body weight, 150 days in milk, 85 lb/day of milk, 3.5% milk fat, and 3.2% milk protein. Feeds used in the ration were alfalfa silage (\$50/ton), corn silage (corresponding costs shown above, assuming 10% reduction in yield of corn silage), corn (\$2.25/bu), 48% soybean meal (\$240/ton), soybean hulls (\$80/ton), and mineral and vitamin supplements. F:C = forage:concentrate ratio and CS = corn silage.

³Assuming 50% forage in ration, 50% forage from corn silage, and therefore \$0.056/lb ration DM.

⁴Price of milk after removal of costs for hauling and other assessments.

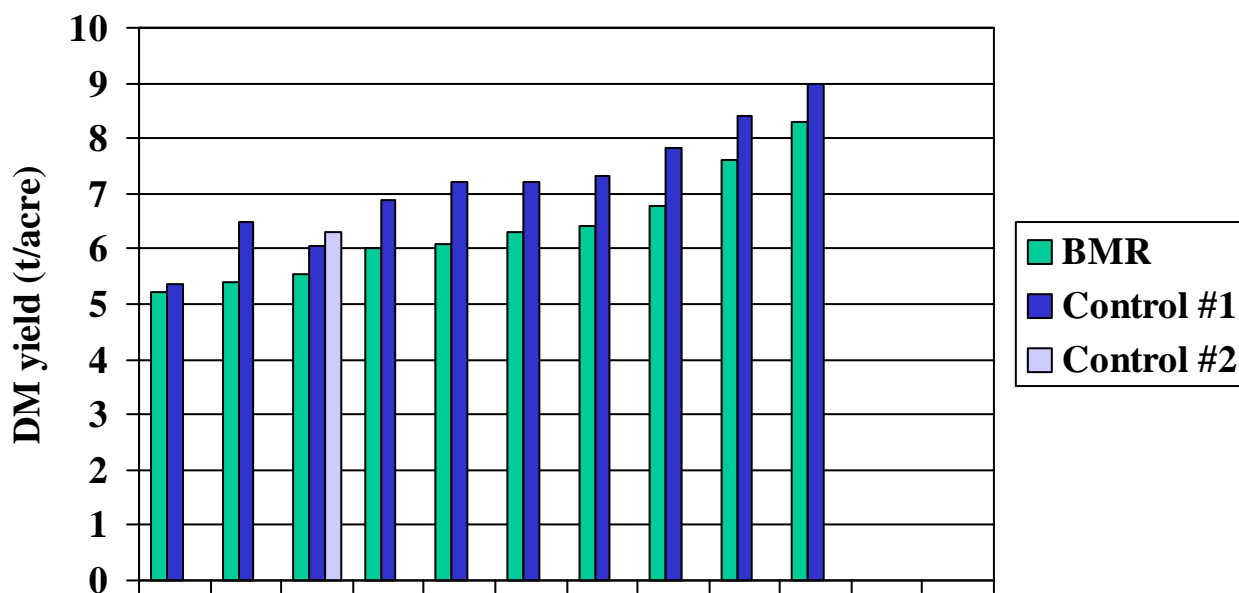


Figure 1. Dry matter yield of corn silages among the studies reviewed (see Table 1) and ranked from lowest to highest based on the yield of the brown midrib (BMR) hybrid.

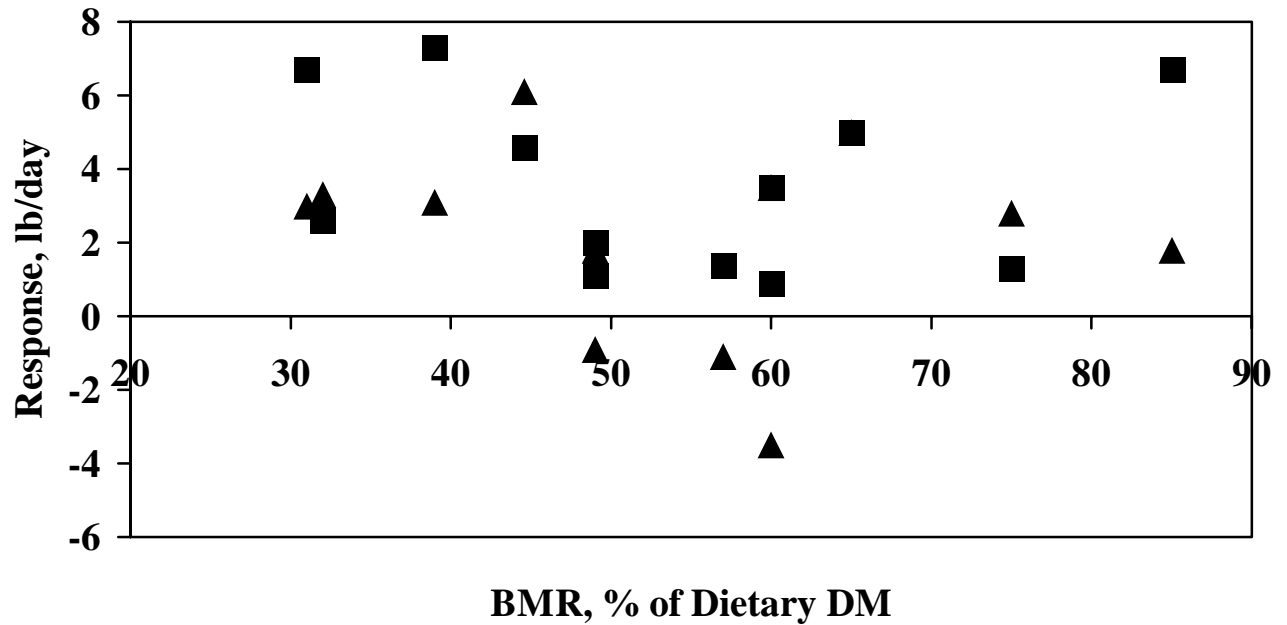


Figure 2. Change (pounds per day) in DM intake (■) and milk yield (▲) by cows fed brown midrib (BMR) corn silage versus corn silage without the BMR gene.

Evaluating Changes in Feeding Programs

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Abstract

Control is one of the five management functions. To have control, you must be able to monitor production processes. This implies that you must measure production outcome and assess change. In this paper, we focus primarily on evaluating changes in feeding programs, but our methods and discussion have much wider applications. Various short-cut methods have been proposed in the past to assess the magnitude of production change in a herd (e.g., 150-day corrected milk). Most are fundamentally flawed because nonlinear functions (lactation curves) are corrected using linear terms. Mixed model analysis is now available and should be implemented in all cases to ensure accurate estimates of production changes. Assessing the cause of such changes is an entirely different matter. Unless the change in the feeding program was implemented in a properly designed experiment, the assessment of cause and effect is at best subjective. However, subjective probabilities are perfectly acceptable in the context of decision making. A cost-of-being-wrong analysis can then be performed to identify the best decision.

Introduction

There are many instances where producers, their advisors, or agribusiness representatives want to assess the production response due to a change in the feeding program. For a producer, this evaluation is part of the controlling function of management. Therefore, evaluation of production should be done on a routine basis. For an advisor, this is a way to evaluate recommended changes. As for agribusiness representatives, this is often a way to justify their products and/or services. Unfortunately, we have witnessed many analyses that were wrong due to poor experimental layouts, erroneous statistics, or unsubstantiated cause and effect conclusions.

The evaluation of changes has three components. First, one must get an accurate estimate of the production response (milk production, milk components, dry matter intake, etc.). This is achieved by an appropriate experimental design and efficient estimation techniques. Secondly, one must try to determine the cause or causes of such change. Lastly, one has to determine the economic advisability of the nutritional change.

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Practical Experimental Designs

First, it must be realized that the farm is essentially running a small trial. The legal and scientific implications of such trials are clearly of a much lesser degree than those trials performed for regulatory purposes. Most would agree that the trail of documentation can be relaxed. However, this relaxation does not justify the use of improper designs or analyses that lead to incorrect conclusions.

There are a number of factors to consider when designing a farm trial. The most important and often abused ones are: randomization, confounding of effects, identification of experimental units, replication, and validation of measuring equipment.

Randomization. As discussed later on, a valid and robust design requires that some animals be placed in a control group, while others are placed in a treatment group. The allocation of animals to each group must be done at random with respect to physiological status, time, and location.

Confounding of Effects. When poorly planned, treatment effects are often confounded with time, location, or other management factors.

An example of confounding with physiological status would be the case where a feed additive is added to the first-lactation group with the high group serving as the control. The treatment effect is then confounded with parity.

An example of confounding with time occurs when a feed additive is included in the ration of a whole herd in a 'before and after' type of trial. The problem is that the treatment effect becomes completely

confounded with time. Imagine what happens when the control period is in April and May and the test period is in June and July. The changes in the environment associated with time are totally confounded with the treatment effect. In this instance, the estimate of the treatment response is biased considerably downward. Other times, the bias will be upward. In our example, one can have a pretty good guess of the direction of the bias but not of its magnitude. Generally, there are so many controllable and uncontrollable factors changing with time that any conclusion derived from such tests will be shaky at best. It may be acceptable for a producer who wants to evaluate a change in his own herd, but it is of questionable ethics when a feed company wants to "prove" something.

An example of confounding by management practices happened when a feed company nutritionist investigated the effect of a feed additive on milk production. The experimenter knew that the feed additive was generally very effective at improving milk production. He wanted to demonstrate the effect to one of his clients. Only one large pen of cows was available for the demonstration. Therefore, the experimenter chose a switchback design with an experimental period of one month. During the first month, cows were assigned the control diet. In the second month, they were switched to the treatment diet containing the feed additive. A month later, cows were switched back to the control. In the fourth month, cows were again assigned to the treatment diet. Milk production data were taken from monthly DHI test reports. An initial analysis showed that cows produced considerably less milk during the two periods in which they were fed the feed additive. It was later found that the farm was being tested on an a.m./p.m. schedule in which one month all cows were sampled at

the morning milking and the next month all were sampled in the afternoon milking. The treatment effect was totally confounded with management practices. The data were essentially useless.

Identification of the experimental unit. The proper identification of the experimental unit seems to cause many problems. Defined briefly, the experimental unit is the smallest unit to which a treatment can be applied randomly. In modern husbandry practices, it is customary to group animals in a pen. Depending on how the treatment is applied, the experimental unit can be the pen or the animal.

We once consulted (after the fact) for a company that ran an experiment using two pens of 50 calves each. Treatments were control and a feed additive fed in a TMR. The control treatment was randomly assigned to pen 1 and the feed additive treatment to pen 2. Calves were randomly assigned to pens. Initially, the investigator had analyzed the data as a completely randomized design, ignoring the pen effect. A schematic analysis of variance for this experiment, along with the expected mean squares (**EMS**), is shown in Table 1. Because there were no replication of pen within each treatment, the pen effect has no degree of freedom and is non-testable. However, the EMS of treatment and pen within treatment clearly shows that the latter is the proper error term for testing the treatment effect. Because the experiment was not designed properly, the pen effect could not be estimated. The only recourse left was to assume that pens did not have an effect on the results (i.e. the variance component of pen within treatment is null, $\sigma^2_{P:T} = 0$) and use calf within pen by treatment as the error term. In doing so, the experimenter would assume 1) no pen effect, and 2) that errors within pens were

independent. Both assumptions are generally not true. The analysis of properly designed experiments generally shows a significant and important pen effect (Snedecor and Cochran, 1980). With the improperly designed experiment, this effect is attributable to treatments. Consequently, it is likely that many experiments with pens that are not replicated have concluded erroneously to a significant treatment effect that, in fact, was solely attributable to a non-testable pen effect. Additionally, the assumption of independence of errors within pen is seldom true. Animals are generally weighted sequentially by pen. Animals within a pen are fed at the same time. The micro-environment is also more uniform within a pen than across pens. These factors and many others cause non-independence of errors. Mixed model analyses confirm that, generally, the independence of errors within a grouping factor cannot stand (Littell et al., 1996, 1998). Under these conditions, estimates of treatment effects (e.g. additive versus control) and their variances are biased upward or downward depending on the structure of the errors.

At this point, it should be clear that the derivation of the EMS is a critical step to insuring that solid tests are performed on a properly designed mini-experiment. Although several textbooks present rules for figuring EMS, those presented by Damon and Harvey (1987) appear to be clearest and should be consulted whenever there are doubts. We will not review those rules here. However, we must discuss the implication of fixed versus random effects in the derivation of EMS.

In Table 2, the EMS are shown for various models of the randomized complete block design. This table shows that the proper error term for treatments is the interaction of blocks by treatments if blocks

are considered random. However, if blocks are considered fixed, the residual (animals within blocks by treatments) is the proper error term for testing treatments. Therefore, the distinction between random and fixed effects is vital to determining the proper ratio of mean squares to be used in F tests. Traditionally, block effects have been considered fixed (e.g., Federer, 1955; Cochran and Cox, 1957). Convenience of computation to avoid the then non-solvable mixed models was the main justification for identifying blocks as a fixed effect. So, what should a random effect be? Historically, effects were considered random “when factor levels are not of intrinsic interest in themselves, but constitute a sample from a larger population of factor levels” (Neter and Wasserman, 1974). Others have worded it differently: “random effects are those in which the levels are considered as a random selection representing an infinite population” (Damon and Harvey, 1987). This concept that the levels must come from a *random* selection of an infinite *population* has created much confusion. At the limit, the numbers of pens or farms are finite numbers. Therefore, strictly speaking, pens or farms should not be a random effect. Also, some have argued that they are certainly not selected at random. The definition of a random effect has evolved especially since the tools to solve mixed models have become widely available. The critical question to answer is the following: Would a repetition of the experiment result in estimates of the same effects? If the answer is yes, then the effect should be considered fixed; otherwise, it is random. With this line of thinking, block effects should generally be classified as random. If commercial farms are used to conduct on-farm feeding trials, then the farm effects can be considered fixed or random depending on the inference range sought. If the interest is only in those specific farms

used for the trial, then farms can be considered a fixed factor. In such instances, inference is limited to the farms used in the trial. However, if the interest is on the treatment effects over the whole population of farms, then the farm effects should be considered random. In the latter case, you still have to answer the question as to whether the selected farms were representative of all farms, or just a subset of those. This ‘expert’ judgement has an obvious and large impact on the inference range.

Replication. The concept of replication is often abused either during the design or the analysis of on-farm feeding trials. Replications are best when independent of each other and should be done generally at the level of the experimental unit. Replications within the experimental unit do not increase degrees of freedom for the F test. In an experiment in which pens are the experimental units (i.e., pens are nested within treatments), the degrees of freedom for treatments and pen within treatment (the proper error term for treatments) are independent of the number of animals per pen. Only additional pens would alter the degrees of freedom. This does not mean, however, that the number of animals per pen has no effect on the analysis of variance. Adding animals to the pens (within managerial reason) reduces the variance of pens within treatments with the consequence of a higher F ratio for treatment effects. This is why experiments with large pens do not require the same number of replicates to exhibit the same power as an experiment with individual animals.

Validation of measuring equipment. Although precision should be considered in the selection of measuring equipment, accuracy (or lack of bias) should be the

prime determinant. Feed scales that are mounted on trucks or wagons are particularly vulnerable because of the harsh environment in which they are generally operated on commercial farms. No statistical technique can help recover from unknown, biased measurements.

Practical Application:

1. For commercial firms trying to assess the effect of a new nutrition technology, a multi-site design is generally a necessity because of an insufficient number of randomized pens at each site (farm). If at least two randomized pens are available at each site, the trial can be designed as a randomized block design with the farm acting as the blocking factor. Pens within farms are then the experimental units. If two randomized pens are not available at each site, the trial can be designed as a completely randomized design or a randomized block design, where farms are paired based on production characteristics. In this case, farms (or farms within blocks) are the experimental units. Clearly, a great number of participating farms must then be recruited to achieve satisfactory significance.
2. For individual farms trying to determine the effect of a change in the feeding program, it is best to use multiple pens as control and treatment pens, with the pens being the experimental unit. This is seldom possible. The next best scenario is to use two pens over three periods in a switchback design as shown in Table 3. In this instance, the pen effect should be considered random and the pen x treatment interaction serves as the error term

for the treatment effect. As a last resort, a single pen can be used (before and after design), but in such case, the treatment effect is completely confounded with the time effect. This is shaky at best and can often lead to wrong conclusions.

Estimation Techniques

Although pens are generally the experimental units when animals are fed in a group, it is generally advisable to correct individual cow data within pens to account for factors extraneous to the effect of interest. This is done to reduce the variance of error and to reduce possible bias caused by unbalanced designs (e.g., proportion of first lactation animals not equal in all pens).

In general, animal productivity is influenced by parity and stage of lactation. The effect of stage of lactation is best seen from lactation curves by parity group, which are typically skewed logistic curves (Wood, 1976). The DHIA also report 150-day corrected milk (**150 CM**). Although the 150 CM can assist farm managers in assessing whole herd productivity, it often results in erroneous conclusions. Remember that an average lactation curve is clearly nonlinear. Yet, 150 CM is an attempt to correct (standardize) data by using a *linear transformation* to what is basically a *nonlinear process*. At best, it is a little wrong. At worst, it is considerably biased. When using this statistic, data for cows less than 100 days in milk should be removed prior to analysis. Often, this defeats the purpose of running a mini-trial because the animals of most interest (early lactation) are removed from the analysis.

Fortunately, there are new statistical procedures that can correct observations for the unknown effects of age (parity), season

of freshening, season, and days in milk (Kachman and Everett, 1989; Keown et al., 1986; Stanton et al., 1992). Known as the test day model, this approach yields the most accurate and precise estimates of production responses in milk and milk components. The test day model belongs to the general class known as mixed models with correlated residual errors. These models are now readily solved using procedures such as PROC MIXED of SAS (SAS, 1996). For users who don't have direct access to such a package, we recommend that they find someone who does!

Example:

The following is an example of the SAS code that was used to assess the response to bST in a commercial herd:

```
Proc mixed;
CLASSES PARITY AGECLASS TESTDAT DIMCLASS ID;
Model milk = BST AGECLASS DIMCLASS(PARITY)
TESTDAT/S P ddfm = RES;
REPEATED/TYPE = AR(1) SUB = ID;
RUN;
```

where:

PARITY = Parity class (1,2)

AGECLASS = Age class in months
(20, 21, ...72)

DIMCLASS = Days in milk class in
two week intervals (1, 2, ...35)

TESTDAT = test day class (1, ...,
number of test days)

ID = Animal identification number

BST = 1 if animal received BST, 0
otherwise

The repeated statement accounts for the correlation of errors within cows. The result is an accurate estimate of the response to bST in the herd.

Assessing the Cause

The procedures outlined in the previous section can insure an accurate estimate of the change in milk production and milk components through time. That is, we can make an unbiased probability statement about the difference in milk production between time t_1 and t_2 . This probability statement will be correct from an animal standpoint. That is, we can say that, after two weeks, cows in pen 1 produced an estimated additional 2 lb/day, and we are 95% confident that a difference does exist (i.e. the response is greater than zero) after we have "equalized" the cows (i.e., simultaneous correction of records for all known cow factors affecting production). We cannot, however, equalize the environment. We cannot correct the measurements in week two for all environmental conditions different from those of the initial time. We know that ambient temperature affects production, and with a bit of work, production records could be corrected for ambient temperature. But there are a near infinite number of environmental factors that could possibly affect production, most of which we probably don't know about (phase of the moon?). The point is that a multitude of environmental factors add noise to our data. Therefore, we cannot make an inference statement about what caused the change in production unless we have replicated treatment and control experimental units through time. In our example, I can make an accurate statement about the change in milk production in pen 1, but I cannot make any statement, not even in a probabilistic way, about what caused the change.

Because there are so many factors (statistically we assume an infinite number of factors) that affect production, we must insure that all factors (uncontrollable),

except for the one of interest, affect all animals at random. This is not true for cows within the same pen, which is why pens are generally the experimental units.

By now, it should be clear that most farm data are not gathered in a way that allows for objective probability statements to be made about what caused changes in production. This results in an important dichotomy regarding statements of cause and effect. A producer can make an accurate assessment about change in production and can infer to the cause based on subjective probabilities, because such probabilities are valid for decision-making under uncertainty (DeGroot, 1970). However, an outsider (e.g., agribusiness) cannot make the same statement of cause and effect, even when based on the same data. The purpose is now shifting to that of an objective proof, which clearly cannot be based on subjective probabilities. This misunderstanding has resulted in many invalid statements in the industry.

Economic Advisability: Making a Decision

Let's say that we made a nutritional change (feed additive) and monitored production for a period of two weeks. After proper analyses, we conclude that milk production is up an average of 2 lb/cow/day. Statistically, we can make the statement "milk production is up" and have only a 5% probability of making an erroneous statement (Type I error). We have no clue what the type II error is (probability of concluding that milk production has not changed when in fact it has). Also, we now understand that with most farm data, we cannot make an objective statement about what caused the change, although we are "pretty sure that nothing else changed". As a producer, we have a decision to make: should we keep the feed additive in the

ration or not? This is a classic case of decision-making under uncertainty.

Havlicek and Seagraves (1962) suggested a useful methodology for decision making under uncertainty (i.e. when the probability of state cannot be established objectively). The method is called "the cost of being wrong" and considers the cost of making both types of wrong decisions. In our example, suppose that the additional milk is worth \$0.30/cow/day. The cost of feeding the additive is \$0.10/cow/day and, if it works, the additive induces an additional intake of dry matter valued at \$0.05/cow/day. The cost of being wrong table would look as reported in Table 4 with a subjective probability of success of 50% (i.e., the decision maker's estimate that there is a 50% chance that the production response of 2 lb/cow/day was due to the feed additive). In the example, the decision-maker would decide to use the additive. Other decision-makers, with different, lower subjective probabilities, would select not to use the additive. It becomes clear that a good decision-maker is one who can estimate effects accurately (magnitude of changes) and has a good perception of the real probability of what caused the changes.

Conclusions

Evaluating changes in feeding programs is not trivial. The assessment of the magnitude of the response in production is best handled using mixed model methodologies. Unless the change in the feeding program was carefully done using an appropriate statistical design, little can be said objectively about what caused the observed response. For decision-making purposes, subjective probabilities can be used to perform a cost of being wrong analysis.

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Table 1. Schematic analysis of variance table with expected mean squares for an example in which 100 calves were assigned at random to two pens and treatments were applied to the pens (fixed effects of treatments; random effects of pen).

Effect	df	Expected mean squares ¹
Treatment	1	$\sigma_w^2 + k_4 \sigma_{C:PT}^2 + k_5 \sigma_{P:T}^2 + k_6 \kappa_T$
Pen (treatment)	0	$\sigma_w^2 + k_2 \sigma_{C:PT}^2 + k_3 \sigma_{P:T}^2$
Calf (pen x treatment)	98	$\sigma_w^2 + k_1 \sigma_{C:PT}^2$

¹ σ^2 = variance components, k_i = coefficients, C = calf, P = pen, T = treatment, and κ_T = the fixed effect of treatments. The appropriate denominators for F tests are pen (treatment) to test the treatment effect, and calf (pen x treatment) for the pen (treatment) effect.

Table 2. Expectation of mean squares (EMS) with three models of randomized complete block designs.¹

Source	EMS of Models ²		
	Random Random	Fixed Random	Fixed Fixed
Treatments (T)	$\sigma_w^2 + k_4 \sigma_{TB}^2 + k_5 \sigma_T^2$	$\sigma_w^2 + k_3 \sigma_{TB}^2 + k_4 \kappa_T$	$\sigma_w^2 + k_3 \kappa_T$
Blocks (B)	$\sigma_w^2 + k_2 \sigma_{TB}^2 + k_3 \sigma_B^2$	$\sigma_w^2 + k_2 \sigma_B^2$	$\sigma_w^2 + k_2 \kappa_B$
T x B	$\sigma_w^2 + k_1 \sigma_{TB}^2$	$\sigma_w^2 + k_1 \sigma_{TB}^2$	$\sigma_w^2 + k_1 \kappa_{TB}$
Error (W)	σ_w^2	σ_w^2	σ_w^2

¹ σ^2 = variance components, k_i = coefficients, and k_j = fixed effects.

²First term describes treatment in model; second term describes block in model.

Table 3. Switchback design for single farm trial.

Period	Pen 1	Pen 2
1	A ¹	B
2	B	A
3	A	B

¹A and B refer to two generic treatments.

Table 4. Cost of being wrong analysis using an example with a 50% subjective probability of success.

Decision	True State		Expectation ²
	Works	Does Not Work	
Use additive	\$0.15 ¹	-\$0.10	\$0.025
Do not use additive	-\$0.15	\$0.00	-\$0.075

¹ Change in net returns = (2 lbs/cow per day @ \$0.15/lb) minus (\$0.10/cow/day for additive) minus (\$0.05/cow/day for additional feed).

²Expected change in net returns for a given decision, assuming a 50% probability of success.

Communicating With the Person Mixing the Feed

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Abstract

Communication is an important aspect of the on-farm nutritionist position. Communication between the nutritionist and a farm's feeder is essential and will impact the success of the nutritionist's rations and recommendations. Several Michigan State University Feeder Schools have been conducted to improve the technical skills of feeders. Feeders attending these schools indicated they do not communicate on a regular basis with the nutritionist. A farm's nutritional program can benefit by the nutritionist communicating with the feeder on feeding management and assisting in the development of standard operating procedures for the feeding program.

Introduction

As an on-farm nutritionist, how well do you communicate with the person who actually does the feeding? Have you ever evaluated how well you communicate? Or do you assume you're an effective communicator?

It has been said, "There are actually three rations for each group of cows": (1) the ration formulated by the nutritionist, (2) the ration mixed by the feeder, and (3) the ration consumed by the cows.

Nutritionists work hard to formulate precise rations using sophisticated computer

software, expecting the cows will consume and perform well on the rations. They expect the feeder to mix each batch with the correct ingredients and pounds; otherwise, their precisely formulated ration will not be fed to the cows. They hope the cows will consume the ration, but cows have the ability to sort a TMR and consume whatever they desire, thus the formulated ration may not be consumed. These are challenges nutritionists are confronted with on every farm. Unfortunately, they do not have the opportunity to directly communicate with the cows about the feeding program, but they do have the opportunity to communicate with the feeder.

During the past year, we, in the Dairy Extension Group at Michigan State University, conducted several "Feeder Schools". These are a two-day educational program designed for feeders, the people who actually mix and feed the cattle. Interestingly, when discussing the responsibilities of the feeder position and the need for them to communicate with their employer and other people (the nutritionist) who are involved with the feeding program, the feeders report that normally they are not involved in meetings or discussions concerning the feeding program. The majority reported that the nutritionist normally does not meet with them to obtain or give information relating to the feeding program. This appears to be a missed opportunity for the nutritionist to obtain

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valuable information. This also leaves the question, “How is the feeder obtaining essential feeding recommendations for rations that the nutritionist formulates to be successful?”

The feeder has an important position on the dairy farm. To a large extent how successful a nutritionist’s rations and recommendations will be depends on the feeder. The entire feeding operation is also complicated. The feeder makes a number of decisions every day that can impact a herd’s nutritional status.

Let’s look at some decisions a typical feeder will make at each feeding every day. Also, look at the number of areas or opportunities for which you as a nutritionist can provide guidance and assistance to help the feeder make the best possible decisions.

1. Determine what size (pounds) of batch will be mixed for each group. This will depend on:
 - a) Number of cows in each group. If the groups’ sizes change, how and when is the feeder informed as to the change?
 - b) Orts, the pounds of feed left in the bunks, will need to be weighed or estimated in order to decide the size of the new batch.
 - c) Decide what to do with the Orts, assuming there are Orts:
 - Leave the Orts in the bunk and place new feed over the top,
 - Push the Orts to the end of the bunk so the cows will clean it up, or
 - Remove the Orts and either discard, refeed to

the same group, or feed to another group of cattle.

2. After the pounds of Orts have been determined, the feeder then can determine what size batch to mix. This will require the feeder to make some calculations or to do some arithmetic. In the MSU Feeder Schools, we have found that most feeders are uncomfortable doing the arithmetic. They are often unsure if their answers are correct. They can use your help in this area.
3. Mix the new batch with the correct ingredients, pounds, inclusion sequence and mixing time. The feeder will need to evaluate the quality of the ingredients and decide if the ingredient should be added to the batch, fed to another group, or thrown away. Guidance from the their employer and the nutritionist on a frequent basis will probably be needed in this area.
4. How does the feeder handle DM fluctuations of high moisture ingredients? How often does the feeder run DM on ingredients? Are there scheduled days when the feeder is to run DM?
 - a) Many of the feeders in the MSU Feeders School had never run a DM.
 - b) Many of the farms did not have a moisture tester. If they did, most were located away from the feed mixing area.

- c) During the MSU Feeder School, when we had the feeders look and feel several different silages and TMR to determine the DM, none were very accurate at guessing. After doing that little exercise, they realized the importance of running DM.
5. Changing the pounds of an ingredient in a mix when the percentage of DM changes.
- The feeder will need to do some arithmetic to determine that. Again, in the MSU Feeder Schools when we went over this with examples, many of the feeders were uncomfortable doing the math and unsure if their answers were correct.
 - Do the batch mixing sheets that the feeder uses include a table or chart that gives changes in pounds of an ingredient for different DM percentages?
 - The feeder needs guidelines of when the employer or nutritionist wants to be informed about changes in ingredient DM.
6. What will the feeder do:
- If too many pounds of an ingredient are added to a batch? Do they stop and remove the extra?
 - If the feeder is just a few pounds short of an ingredient. Do they go and get more or just assume if the mix is a little off, it will still be close enough?
- These are tough questions. These questions will need to be discussed with the feeder and guidelines of standard operating procedures established. As a nutritionist, you have the opportunity to explain and teach the feeder, from a nutritional basis, the possible effects that even a small mixing error can have on the cows' production and health.
7. Is the feeder using the most current batch mixing instructions? The feeders in the MSU Feeder Schools related that they often do not receive "new" batch mix sheets. Do you as the nutritionist leave new batch sheets at the farm office, or do you take a copy to the feeder and discuss it with her/him?
8. Another decision the feeder may make is - - - "to feed so the cows just about clean up the bunk before they feed again". Here is an area where the nutritionist can be very helpful.
- Subscribing to this feeding philosophy basically says the cows will be limit fed. This is also a management strategy of trying to starve production out of the cows. This feeding philosophy will also undermine or limit the effectiveness of your carefully formulated rations.
 - This is the most common feeding strategy I find when doing nutritional consulting. This was also the most common feeding strategy used on the farms of the

feeders who attended the MSU Feeders Schools. Interestingly, these are farms with higher than average milk production.

- c) Is the decision to have the “cows just about clean up the bunks before feeding again” because there is no plan or system in place to deal with the orts?
- d) Dealing with orts and developing a plan is complicated and confusing on most farms. This is probably the biggest reason why so many farms feed - - - “So the cows just about clean up the bunk before feeding again”. Your assistance to the farm owner and the feeder in this area can pay big dividends for all.

Recording Feed Intakes

Another responsibility the feeder should have is recording feed intakes. The feeder will need assistance to accomplish this task. Communicating to the feeder, by the employer and nutritionist, the value of recording daily feed intake by groups is invaluable. Many feeders will think recording intakes is just a worthless task until they understand the value. For you, the nutritionist, knowing feed intake for each group on a per cow and DM basis is very useful. This is essential data when you are trying to evaluate a ration or solve a nutritional problem.

A majority of the feeders attending the MSU Feeder Schools have never been asked to record feed intake data. This is hard for me as a dairy nutritionist to understand. Why wouldn't a feeder record

feed intakes? I believe the underlining reason is the procedure is somewhat complicated. The farm's management and nutritionist have not sat down and attempted to develop a plan.

However, during the MSU Feeder Schools, when we taught the various methods of how to do and record DM intakes, many of the feeders were confused, even though we thought that we explained the methods well. The feeders were given a “homework assignment” to record intakes for at least one group of cows using a notebook that each feeder was given. The second class was held two weeks later. At each of the Feeder Schools, only one or two of the feeders had recorded any data. The reasons expressed for not having the data were: not fully understanding how to do it, not having the needed equipment (functioning scale on the mixer, no moisture tester, etc.), not enough time, or the employer showed no interest. By far, the main reason, in our opinion, was that the feeder was still confused on how to do feed intakes on their particular farm. They need more support and mentoring at the farm level until they feel confident.

Developing a plan for recording DM intakes requires the nutritionist to understand the every day feeding routines on a particular farm. A commitment by the farm's management is also needed as well as the cooperation of the feeder. Everyone involved in this will need to have a win-win feeling. The feeder will win if they feel they are doing a better job and maybe rewarded in some way for recording intakes. The farm will win if the recording of feed intakes results in higher cow productivity. The farm can also win by accurately knowing feed cost and by controlling feed wastage. The nutritionist can win by being able to more accurately evaluate the rations they have

formulated and by being able to predict possible metabolic and health problems associated with the feeding program.

On some farms, the feeder may be interested in improving his/her abilities and performance but are limited in doing this by the employer. To assist in this, you as the nutritionist may need to communicate to the herd's management the value of the feeder implementing new feeding management practices.

Communicating with the feeder is an important function that is becoming more essential as dairy farms become larger. Employees will have specialized position responsibilities, and as the science of nutrition becomes more complicated and precise, communication and trust are invaluable.

Perhaps, after reading this paper you will want to re-evaluate how you communicate with the feeder on all of the farms for which you work.

Summary

Communications are an important aspect of your position as an on-farm nutritionist. You communicate with the farm's management the value of your services and products. You also communicate your feeding recommendations.

Effects of Manufacturing on Chemical Composition of Plant By-Products

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Abstract

A significant amount of the total feed requirements for dairy cattle are supplied from the numerous by-products resulting from the manufacturing of plant materials. The amount has been estimated at 25% of the total concentrate needs, and in some dairy operations, the value may be higher. The type of manufacturing that is conducted on the original plant material, which is generally a cereal grain or oil seed, will have a major influence on the chemical composition of the by-product. Because of the diverse assortment of food and industrial products resulting from the primary reasons for manufacturing, it is difficult to rely on tabulated values from feeding tables for the by-products. Even though the Association of American Feed Control Officials provides a very complete description of by-product feeds based on the various waste streams involved, there are sufficient variations possible that name alone is not sufficient for most of the by-product feeds. Therefore, the nutritionist must either rely on tabulated nutritional values, which have been adjusted to account for the potential variation, or data bases must be established which are unique for specific processing plants. Even a by-product, such as whole cottonseed, will vary in protein and oil based on variety, season, and location. A seed value index, which is similar to a grain test weight, can be a very useful parameter to determine if the specific lot of cottonseed deviates from previous

lots. The best approaches for the nutritionist and dairy producer are to rely on by-product sources from which knowledge and experience have been obtained and to conduct frequent chemical tests on all other supplies where knowledge and experience are limited.

Introduction

A large volume of the total feed consumed by dairy cows originates as by-products from the manufacturing of plant materials into foods for human consumption or the manufacturing for other purposes. It is difficult to place a quantitative number on the actual magnitude of plant by-product use in dairy feeding, but a study of 1992 livestock feeding in California as reported by Grasser et al., (1995) suggested that the amount exceed 25% of total feed concentrate. They found that nine byproduct feeds consisting of almond hulls, dried beet pulp, wet brewers grains, wet citrus pulp, pressed citrus pulp, wet corn gluten feed, corn gluten meal, whole cottonseed, and rice bran contributed over 2.5 million tons of concentrate moved within California, which represented 27% of the total concentrate. Obviously, all areas of the country are not as heavy by-product feeders as California, but for the most part where the dairies are highly concentrated and have major cow representation, we find one or more by-products serving as major feed dry matter contributors.

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The chemical composition of by-product feed ingredients will be highly variable, depending primarily on the original plant material involved and the manufacturing processes involved. In fact, some of the older tabulated nutritional data become unacceptable because of the modern designs and efficiencies associated with newer facilities. This forces the dairy nutritionist to gain a full understanding about the manufacturing processes that are involved with the parent material and to have knowledge with respect to the plant origin. Today, for example, all sources of corn distillers grains are not the same because of the events associated with its production. There are significant differences for distillers grains originating from a beverage alcohol facility versus distillers grains from a fuel alcohol plant. The animal nutritionist must understand the potential differences that can result and be in position to make ration adjustments and recommendations accordingly. This situation is not unique for distillers grains as it relates to almost all the by-product feed ingredients. Some of the major factors for consideration will be discussed as we mention each class of by-product feeds.

Manufacturing of Corn Grain

Because of the magnitude of corn grain production in the U.S., by-products from corn are extensive in types and amounts. The major justification for the manufacturing of corn relates to the obtainment of starch for use in other food and industrial products or for conversion of the starch into sugars for use as sweeteners. Also, the abundant amount of starch serves as an excellent substrate for alcohol production through fermentation.

The by-products from manufacturing corn grain can be classified as follows: 1) products from wet corn milling, consisting of corn gluten feed, corn gluten meal, corn germ meal, and condensed fermented corn extractives, 2) products from corn distillery activity, consisting of corn distillers grains, corn distillers grains/solubles, and corn distillers solubles, and 3) products from dry corn milling, consisting mainly of corn hominy feed.

The chemical composition of almost all of the above feeds are highly variable, depending mainly on the manufacturing sight involved and the manner in which the various waste streams are combined within the plant. To gain a better understanding of the reasons for this variation, note the wet milling flow chart and potential production resulting from the processing of 100 lb of corn grain dry matter as illustrated in Figure 1. The most consistent by-product from corn milling will be the corn gluten meal (60% CP), because there is very little tolerance available for the production of this material. On the other hand, corn gluten feed, even though composed primarily of corn bran, will have variable amounts of the steepwater streams incorporated, depending on the type of by-product sales from the plant. Likewise even though the germ from corn is relative consistent in composition, oil is extracted prior to the obtainment of corn germ meal and the extent of this extraction varies depending on the methods utilized. For some operations the germ fraction may be diverted to corn gluten feed. Therefore, variability can be expected across the industry with respect to the feed by-products resulting from wet corn milling. The only action for the nutritionist is to test and compile results and demand information with respect to the origin of the feed material.

By-products from corn distillery activity consist mainly of corn distillers grains/solubles. The amount of solubles included with the spent corn distillers grains will vary between production sights and may vary within sights, depending on the market for corn distillers solubles.

There may be spent grains from other sources, such as rye and barley, but the by-product can be marketed as corn distillers simply because corn is the major grain source. Another component of distillers grains which represents a significant amount of the final product, are the residual yeast cells and metabolites associated with the fermentation process. This residual yeast component contributes significantly to the overall protein and fat of the by-product, but may not appreciably influence amino acid quality, as significant amounts of nitrogen are present as nucleic acids.

There is a general consensus throughout the dairy industry that color is a quality-determining factor for distillers grains. This results because a darker color is associated with grains, which have been over heated in the drying process, allowing protein to be present in an unavailable form. This may in fact be true, but it must be pointed out that color alone does not always indicate an excessively over heated grain. The amount of solubles incorporated back into the spent grains will influence color and the amount of solubles can increase the nutritional value of the spent grains. The protein quality of distillers grains can be evaluated only by chemical tests which evaluates the nitrogen associated with various fractions, such as that bound with the acid detergent fiber component and that which is insoluble in buffer solutions (Chase, 1991).

A major concern associated with distillers grains, especially for by-product originating from fuel alcohol plants, involves the grain quality initially used. Since the objective of distillery processing is removal and fermentation of the majority of the starch in the corn grain, any non-carbohydrate component of the spent grains will be increased in concentration for the residual material. Obviously, the increased concentrations of protein and fat are positive changes, but at the same time, mycotoxins or other potentially toxic materials will also increase.

Decisions with respect to the use of distillers grains from various sources must be based on past knowledge and experiences with respect to the by-product production and on the reputation of the parties involved in the supply channel. Unfortunately, there are documented serious nutritional wrecks associated with distillers grains which carried toxic amounts of various agents into the animal feeding program.

Corn hominy feed, a by-product from the dry milling of corn grain, is a feed ingredient which can generally be fed to replace a large amount of the cereal grains. By definition, hominy feed consists of the bran, germ, and some of the starch from the parent grain. But again, the actual chemical makeup of hominy feed is dependent on the efficiencies of the manufacturing plants involved, the original grain, and the food products that are being produced.

Within recent years, we have noted a general decline in the overall quality of corn hominy feed which seems to be primarily due to reduced fat content. This suggests that the processing plant is doing a more effective job of oil extraction of the corn germ, resulting in less fat entering into the hominy feed.

The type of corn utilized in dry milling, yellow versus white, has a dominant influence of the quality of resulting hominy feed. This seems to be almost totally due to the specific food products associated with white or yellow corn. As a result, the hominy feed from white corn is generally higher in fiber and lower in fat than hominy feed from yellow corn.

Since the production of hominy feed involves a primary manufacturing purpose for the production of a food grade product, we generally expect the grain quality of the starting material to be of standards above that for the feed industry. But at the dry milling sight, hominy feed will likely serve as the disposal route for all the cleaning fraction separated from the incoming corn grain prior to milling. This clean out fraction will include all the grain dust, foreign matter, cracked and small corn kernels, and any other components. The mycotoxin level of the incoming grain could be below limits established for food material, but as a result of concentration, levels of concern in hominy feed could be achieved.

Therefore, the nutritionist and feeder are confronted with some of the same problems as with other corn by-products. Frequent testing is necessary and hominy feed must be identified with respect to manufacturing sight as well as type of corn, yellow or white.

Manufacturing of Barley

The major by-product originating from barley manufacturing is the spent brewers grains originating from the brewery industry. This feed product is available to the feed industry as dried brewers grains and marketed to local dairies within reasonable distances to large breweries as wet brewers

grains. Within recent years, the majority of the spent grains from the beer industry have been marketed as wet brewers grains.

There will be significant differences from brewery to brewery with respect to the chemical composition of the spent grains, based on the type of beer being produced. For some brands of beer, the mash is composed almost totally of malted barley, whereas other brands of beer have a mash consisting of malted barley, ground corn, and rice (Stengel, 1991). Spent grains from brews consisting of barley, corn, and rice have much higher protein and energy than grains from malted barley only (Chandler, 1991).

In the brewery process, starch is removed from the grains through the action of enzymes and water hydrolysis. No fermentation action comes in contact with the spent grains, and the resulting product is composed only of residual grain nutrients without a yeast cell component as found in distillers grains.

Because of the variation existing among breweries, the composition of brewers grains must be established by brewery sight. Within breweries, it seems that variation between production runs is relative minor, with the exception of the wet product. This can vary considerably in dry matter, depending on the time grain is removed from the spent grain tank and delivered to the farm (Chandler, 1991).

Manufacturing of Wheat

Manufacturing of wheat for the primary purpose of flour production has a history of several thousand years. In fact, the emergence of the commercial feed industry in the US as we know it today developed from wheat milling operations to

provide profitable and efficient methods for disposal of the various by-products associated with wheat milling.

In typical milling operations, a flour yield of 72% is achieved with 28% of the incoming wheat available for by-product production, which accounts for 14% of a flourmill's gross revenues. The use of the remaining by-product fraction in livestock feeding, which constituted more than 7 million tons in 1995, may be viewed as simply a disposal route of waste materials, but it is interesting to note that the major removal of the more critical nutrients from wheat is accomplished in flour production and the by-products are in fact more nutritious (Blasi et. al., 1995).

Within the industry, we have a problem with respect to the by-product identification, which results in chemical and nutritional variations among the various feed types. Mill streams constituting the total waste from flour production can be described as ground screenings, coarse bran, fine bran, germ, and red dog. The AFCO (1998) provides an adopted naming and nutritional limits for products associated with wheat milling for flour production, but specific mills, based on potential sales of alternate products for human food and specialty feeds and guarantees on flour, will alter the mill streams associated with specific products and the resultant by-product must absorb the resultant variation. And today we find that most of the volume of by-products from flour production appears in the market as simply mill feed, mill run, or middlings. Table 1, as presented by Blasi et al. (1995), illustrates how variations can result.

The major factors influencing the chemical composition of the by-products include type of wheat milled, test weight of

milled wheat, guarantees for flour that is produced, and the manner in which the waste streams are handled in the production of the by-product. Because of the factors influencing chemical composition, it is necessary for the nutritionist to test on a frequent basis and to have knowledge with respect to the origin of the by-product. As an example, the chemical composition of middlings from a milling operation that produces flour basically for pasta will be significantly different from middlings associated with flour produced for general-purpose use.

Manufacturing of Soybeans

Soybeans have achieved the status as the major oilseed crop for not only the US, but for the world when considered in terms of supplying high protein meals for animal feeding. The manufacturing of soybeans originally was primarily for the extraction of the oil, leaving the resultant meal and the soybean hull as by-products for livestock feeding, but today, numerous human food and industrial products result from soybean manufacturing (Hoy, 1991). However, the resultant meal from soybean manufacturing is still a major world provider of supplemental protein for livestock feeding (Figure 2).

As shown in Figure 3, utilization in dairy cattle feeding is relatively minor when considered in terms of total utilization. The poultry and swine industries will be the driving factors with respect to determining the demand for soybean meals and also with respect to influencing any specific factors applied in the manufacturing of soybeans into high protein meals.

Soybean meals are marketed as the high protein product (48% CP) and 44% soybean meal. For crushing plants that have

a large volume of meal production for poultry and swine utilization, the high protein of 48% soybean meal may be the only meal production with a relative high volume of soybean hulls available as a by-product. But some plants have a market for significant amounts of 44% soybean meal, and this is achieved by diluting the protein from high protein meal with the introduction of ground soybean hulls.

There have been reported problems from the feeding of 44% soybean meal as certain crushing plants have at times utilized the seed cleanings as a dilution agent to bring high protein meal down to 44% CP. This procedure may be totally acceptable, but seed cleanings containing significant amounts of toxic weed seed, such as cycle pod, may not be acceptable for the dairy cow. In order to achieve dairy feeding programs with reduced risk, it seems advisable to concentrate on the use of the high protein 48% soybean meal and utilize the hulls as needed to balance the total program.

With respect to factors involved in manufacturing which influence the chemical content and nutritional value of soybean meal for dairy cattle, time and temperature involved with meal production will be of major significance. This will control the amount of protein denaturation accomplished, which will directly influence rumen degradation and post ruminal availability of critical amino acids such as lysine. Satter et al. (1991) described the relationship between heat input and soybean protein value for dairy cows and suggested the optimum heat input to be the point of maximum divergence between achievement of undegraded protein and intestinal unavailable protein. There are different combinations of time and temperature that

will achieve the same result, pointing out that total heat input is the common factor.

Most of the applications of heating for alteration of protein utilization have involved full fat soybeans and processing directly on the dairy operations. As pointed out by Satter et al. (1991), there is likely great variations in the nutritional value of this production because of the importance of correct temperature and time control. Commercial application of heating for special soybean processing to produce products specifically for high producing dairy cows are successful, with at least two products achieving marketing success.

Manufacturing of Cotton

Cotton grown for lint is a significant crop in the southern states, the southwest, and California. The removal of lint in the ginning process leaves the whole fuzzy seed as a by-product that can be fed directly to dairy cows or processed further. In earlier years, there was extensive seed processing for obtainment of cottonseed oil with the resultant by-products of cottonseed hulls and cottonseed meal available for animal feeding.

In the dairy industry because of increased herd size and total mixed ration feeding concepts, increased use of cottonseed as whole fuzzy seed has resulted. This utilization has approached 50% of the available supply.

Whole cottonseed are lower today in the content of protein and fat and higher in fiber than tabulated values generated from seed of earlier growing years (Calhoun et al. 1995). This does not seem to be due to any change in the manufacturing of cotton, but rather to a change in lint to seed ratio

caused for selection of cotton varieties with high lint yield.

Describing cottonseed in terms of a seed index, which is defined as the gram weight of 100 whole cottonseed (**WCS**), gives a good measure of the meat to hull relationship of the whole cottonseed:

$$\text{Meats (\% of WCS)} = 32.2 + (2.18 \times \text{seed index}) \\ R^2 = 0.76.$$

Whole cottonseed with a seed index of 8 relates to 50% meats and a seed index of 14 provides meats at 63%. The meats provide the protein and oils, the nutrient components which generally are expected from whole cottonseed. The seed index has declined in recent years with a current average value of 10.5 seeming appropriate.

But the seed index will vary with growing seasons, variety selection, and the amount of foreign matter present. Therefore, if the seed index deviates from standard values, it is important that each supply of incoming cottonseed be evaluated and subjected to chemical analysis.

There have been numerous attempts to improve the nutritional value of whole cottonseed by using various physical and chemical factors in processing. These include delinting, grinding, pelleting, extrusion, heating, and treating with agents to increase the density and improve handling. With the exception of handling, none of these efforts seem to be economically justified over that of feeding the intact whole fuzzy seed.

Handling of whole fuzzy seed certainly offers a major problem for the commercial feed industry, and the use of starch to coat the seed will result in a more dense and flowable product. Bernard and Martin (1998) have found very satisfactory

animal performance associated with the feeding of this form of processed cottonseed.

Even though heating and extrusion will alter the protein fractions of whole cottonseed, there are likely other plant and animal protein sources that can provide by-pass protein more economically. Grinding or pelleting certainly improves the handling by increasing the density of the product, but a very strong feature of whole cottonseed is that the intact seed coat encapsulates the protein and oil, which contributes to its great benefits in feeding the dairy cow.

Summary

Feed ingredients originating from the manufacturing of plant materials constitute a very significant portion of the dairy cow's diet. These by-products at many times provide unique and desirable nutrient ratios which allows the nutritionist to achieve a better balance of total nutrients for the high producing cow. Also many of the products have a very favorable price relationship compared to other feeding alternatives.

Because of the many diverse primary products, which are removed for food and industrial use, we find that the by-products will likely vary considerably from one manufacturing operation to another. It is also possible that variation will exist within a specific manufacturing sight if there are significant changes in primary product production. Thus, the dairy nutritionist must demand frequent testing and tabulate results according to production sight. The other alternative is to establish nutrient values within the formulation system which accounts for the likely lower values from a specific production sight, but this does not allow the total capture of the potential feeding value that is likely associated with a

specific by-product. By-product utilization will continue in the industry and the nutritionist must continue to gain knowledge concerning the manufacturing processes involved and the chemical composition of the residual by-product feed material.

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Table 1. Flour milling co-products.^{1,2}

Mill Stream Constituents	Co-Products					
	Wheat Bran	Wheat Red Dog	Wheat Shorts	Wheat Germ Meal	Wheat Middlings	Wheat Mill Run
Ground screenings					P	P
Coarse bran	O,P					O,P
Fine bran	P		O,P	P	O,P	O,P
Germ			O,P	O,P	O,P	O,P
Red dog		O,P	O,P		O,P	O,P

¹O = Official AFCO (1998) definition; P = Probable in many commercial milling operations.

²Blasi et al. (1995).

Figure 1. The corn wet milling process.

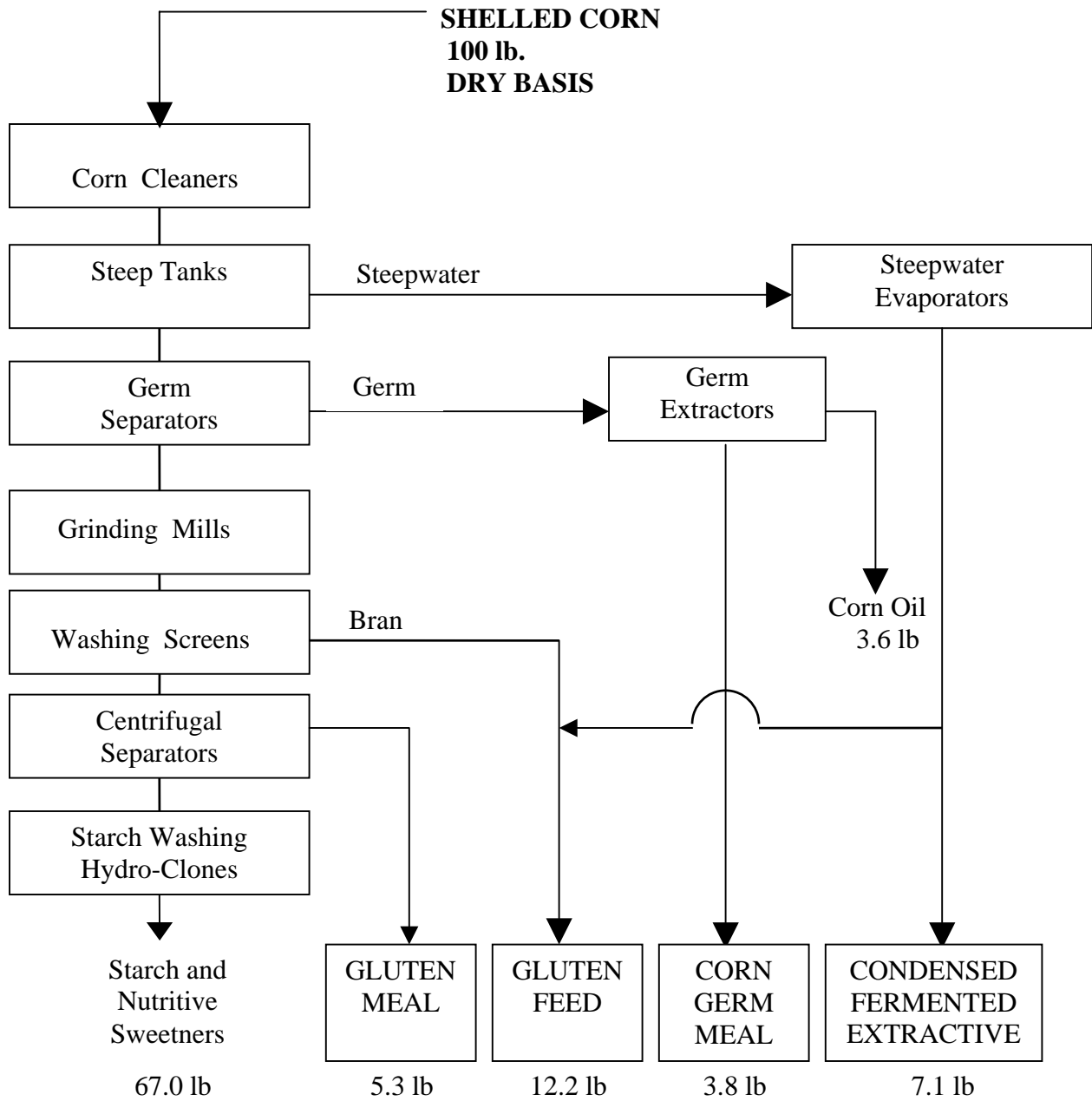


Figure 2. World protein meal consumption during 1996 (ASA, 1999).

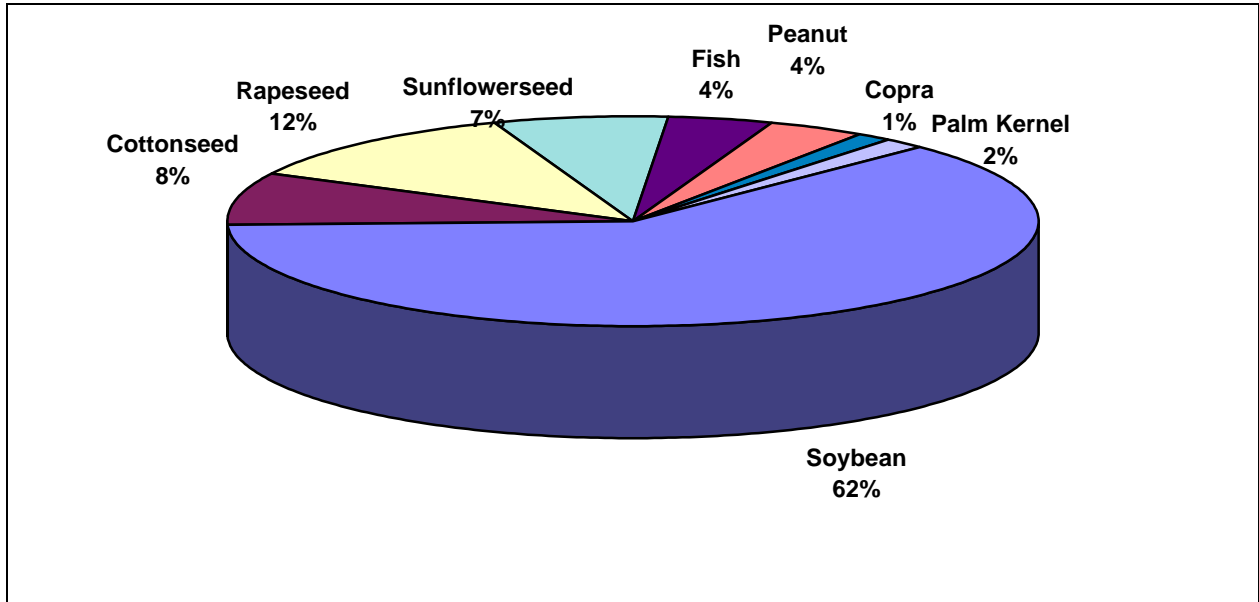
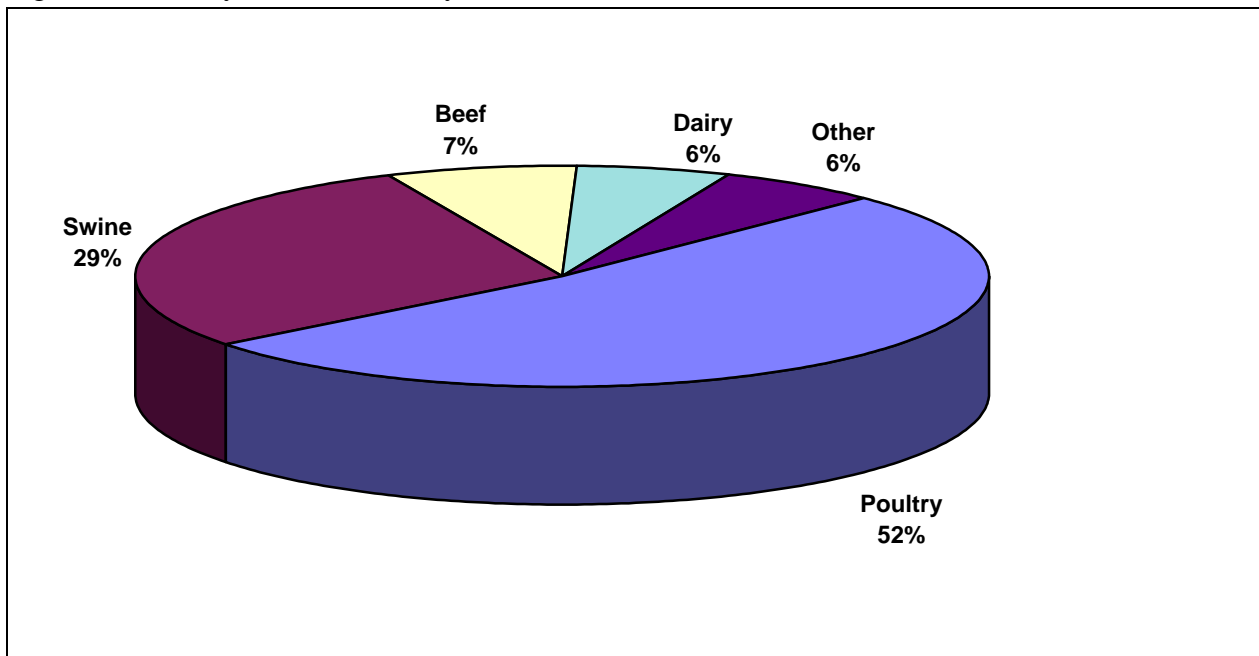


Figure 3. U.S. soybean meal use by livestock (ASA, 1999).



Composition and Quality of Porcine Meat and Bone Meal

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Abstract

Meat and bone meal (**MBM**) entries within ingredient composition tables reflect a mix of raw material sources and species. The 1997 FDA rule prohibits the feeding of mixed species (mx) MBM to ruminants; however, porcine (p)MBM is allowed. Characterization of pMBM is beginning to become available. The chemical composition of two data sets of 15 MBM were compared. The pMBM averaged higher protein and lower collagen and mineral contents than the mxMBM. A greater proportion of the mxMBM protein was composed of non-essential amino acids (**NEAA**).

Correlations from chemical analysis provided insights into raw material composition and potential feeding value. The ash content of MBM was negatively correlated to protein and essential amino acids (**EAA**) in both data sets. Protein was negatively correlated and ash was positively correlated with collagen in only mxMBM, suggesting pMBM contains other sources of collagen. Likewise, as collagen increased, EAA decreased and NEAA increased as a percentage of protein in mxMBM. In pMBM, only NEAA increased as a percentage of protein. This suggested that when bone content was high and the primary source of collagen, amino acid quality was reduced. Raw material other than bone

that contained collagen appeared to have a lesser impact on protein quality.

Ash content was unrelated to rumen undegradable protein (**RUP**) in pMBM. Ash content also was unrelated to protein digestibility. However, it was negatively correlated to efficiency of protein utilization. The MBM with lower protein and higher ash and collagen contents were indicative of a poorer array of amino acids and lower feeding value. Ruminant and non-ruminant growth performance and protein digestibility studies were cited. Results suggested that the protein quality of MBM was not a function of its digestibility, unless it had been processed at above normal rendering temperatures. The RUP value for pMBM was similar to that published by the National Research Council, (1989), for mxMBM (49%). Post-ruminal digestion of MBM protein, measured in-vivo, was high and equaled that of soybean meal.

The first limiting amino acid from MBM for cattle growth or lactation appeared to be methionine. The pMBM can be combined with other animal and marine proteins and/or rumen protected methionine to provide the metabolizable amino acids necessary to compliment microbial protein and improve protein utilization and cattle performance. Best responses were seen when the rumen undegradable protein from animal protein blends was not added at the

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expense of rumen degradable protein (RDP), unless RDP was excessive.

Nutrient variability was similar between pMBM and mxMBM. Identifying a few suppliers of pMBM having desirable specifications can reduce nutrient variability. National By-Products, Inc. (NBP; Des Moines, IA) reduces nutrient variation by blending to a targeted protein guarantee using segregated supplies with known protein levels. Such MBM supplies have coefficients of variation for protein that are low and similar to those for soybean meal.

Introduction

Rendering is an integral part of an efficient and sustainable agriculture. This is due to its place in the cycle of human food production. Like oilseed and grain processing, livestock and poultry processing create large quantities of by-products suitable for animal feeding. Approximately, 50% of beef cattle tissue, 44% of swine, and 25 to 30% of poultry tissues are not destined for retail trade. Thus, 133 million pounds of waste animal tissues are created daily, or 48.5 billion pounds per year. This annual amount would fill semi-trailers end to end over a four-lane highway stretched from New York City to Los Angeles. When one estimates the potential loss of by-product value, the cost of the landfill alternative, and the potential impact burying or incinerating would have on water or air quality, it becomes quite apparent how rendering influences the efficiency and sustainability of animal agriculture.

The primary objective of rendering is to remove moisture from the raw material through a cooking process. Different cooking equipment and conditions are used for each material in order to optimize flow

and yield, and improve the characteristics of the finished product for its intended use. Finished products include tallows, greases, MBM, meat meal, poultry by-product meal, blood meal, feather meal, and hides. In many areas of the US, MBM has been a valued resource for dairy rations, contributing economical RUP, fat, calcium, and phosphorus. For many nutritionists, the highly available phosphorus contribution has been most valuable. In 1997, the FDA ruled that ruminant proteins were no longer to be fed to ruminants. In order to comply, many producers, nutritionists, and feed manufacturers converted to pMBM in order to minimize disruption to their formulations. Characterizations of MBM contained within ingredient composition tables reflect a mix of raw material sources and species. Information on pMBM is sparse and just starting to become available. Fats and Proteins Research Foundation, Inc. (FPRF; Bloomington, IL) is funding university studies to further characterize the use of pMBM in ruminant diets. The purpose of this paper is to highlight some of that work and glean some information from emerging pMBM research. Comparisons will be made with mxMBM data and inferences made where possible. The strength of some conclusions will be based on the results of studies involving both poultry and ruminants.

Composition of MBM

Table 1 contains compositional information on 15 mxMBM (Lueking et al., 1996). Table 2 contains 15 pMBM (Orias, et al., 1999). Within both groups, the finished MBM were supplied by a representative cross-section of rendering companies from North America. The pMBM set averaged higher crude protein and lower collagen and mineral contents. Contents of EAA and NEAA were similar

between the two MBM. However, when expressed as a percentage of the protein, the NEAA content was 51% in the pMBM versus 58% in mxMBM. Since bone is the major contributor of ash and collagen, the higher ash and collagen and greater proportion of NEAA in mxMBM reflect a greater amount of bone and connective tissue. This suggests that lower ash MBM may be composed of superior blend of raw materials.

Nutrient Variability

Inconsistent nutrient content was a vital concern expressed by nutritionists in a recent survey taken by the FPRF. Indeed, there is moderate variation seen in the products listed in Tables 1 and 2. One should keep in mind that these are products supplied by different renderers, often with specific markets in mind. For example, one MBM producer may sell its MBM to layer operations that prefer a higher phosphorus, lower protein product. While another MBM producer may supply the pet food industry that prefers a higher protein, lower ash product. Limiting your source of MBM to a few suppliers, given clear specifications, can reduce expected variation. This seems to be confirmed by the results of a recent study conducted by NBP presented in Table 3 (Kirstein, 1997). These results are a comparison of the protein variability for over 2100 MBM samples produced at 12 Midwest rendering plants and three NBP blending plants. The protein coefficient of variation (CV) for the rendering plants ranged from 3.2% to 9.4%, indicating that it is possible to find MBM sources having less variation. The CV for protein in the mxMBM and pMBM in Tables 1 and 2 fell within this range, averaging 5.9% and 6.6%, respectively.

The CV for the NBP blending plants were considerably lower at 1.5 to 2.1%. The NBP uses a different approach to manage protein variation. Almost all MBM produced or purchased by NBP is taken to one of four blending sites. The protein level of all in-bound MBM is determined by on-site analysis prior to unloading. The MBM is then segregated into multiple storage areas based on actual protein content. Knowing the protein content of the material in each storage bay permits accurate blending for a targeted protein guarantee.

Table 4 shows the protein variability of three ingredients commonly used in broiler diets (Kirby et al., 1993). Data for corn, soybean meal, and MBM shipped to four broiler feed manufacturing sites in Georgia and Kentucky were collected. The protein variation of MBM in this study (CV = 3.8%) is on the low end of those reported above for MBM sourced from rendering plants. It is also interesting to note that the protein variation found in the soybean meal (CV = 1.7%) falls in the range of those found for the blended MBM produced at the NBP facilities (1.5 to 2.1%). This may be surprising to some, but it is reasonable to expect since soybean meal is also a blended product with a protein target. In contrast, the protein variation of corn (CV = 5.1%) was similar to that found for MBM sourced from rendering plants, and two to three times higher than that found in NBP blended MBM. This too should be anticipated since corn is not blended with a targeted protein in mind, although it is blended as it moves through marketing channels.

National By-Products has learned that by controlling protein variation, the amount of variation for other nutrients, such as phosphorus, can also be reduced. For example, a typical CV range for phosphorus in mxMBM is 12 to 16%. Testing and

segregating in-bound MBM on the basis of protein can reduce the variation in phosphorus content to 8 to 10%. These results validate this blending approach as a successful means to reducing nutrient variability in MBM.

Raw Material Influence on Composition and Feeding Value

Meat and bone meal is composed of bone, viscera, lean tissue, and fat. Insights into the raw material make-up and potential feeding value can be drawn from correlations found in the chemical composition data. Table 5 summarizes some of the relationships found with protein, ash, collagen, RUP, and amino acids in the mxMBM and pMBM sets. The most obvious relationship is between ash and protein. As ash rose, protein and EAA dropped. This was seen in both types of MBM. Collagen also rose with ash and dropped with protein in mxMBM. Since bone is a primary source of ash and collagen, it appears that high ash and collagen reflect a raw material composed of more bone. In the pMBM, neither ash nor protein was correlated with collagen. Since both protein and ash strongly reflect bone content, there must be other major contributors of collagen in pMBM, such as lung tissue (N.R. Merchen, University of Illinois, personal communication). This was further substantiated by the correlations of ash and protein to NEAA as a percentage of protein in mxMBM but not in pMBM. Higher bone content suggests a significant increase in the proportion of NEAA.

As collagen increased, EAA decreased and NEAA increased as a percentage of protein in mxMBM. In pMBM, only NEAA as a percentage of protein increased. This further suggests that when bone content was high and the primary

source of collagen, amino acid quality was reduced. When MBM contains significant amounts of collagen from other sources, as seen with pMBM, only NEAA was increased as a percentage of protein. Raw materials other than bone that contain collagen may have a lesser impact on protein quality.

Herold et al. (1996), found a positive correlation ($r = 0.51$, $P < 0.01$) between ash and the in-situ RUP in a set of 36 mxMBM. This set of MBM contained some poultry by-product meals, which contained low ash and low RUP values that would contribute to a more significant correlation. In the mxMBM set of Table 1, there were only four RUP data points, but they appeared to support the results observed by Herold et al. (1996). In the pMBM set, ash was not correlated with RUP. This was a more uniform set of samples, perhaps more indicative of results to be found within a well defined type of MBM.

Ash Effect on Feeding Value

Johnson and Parsons (1997) demonstrated with chick growth studies that a high ash MBM resulted in a lower protein efficiency ratio than a low ash MBM. They further showed that this was not due to dilution of amino acids or energy by higher levels of calcium and phosphorus. It was more likely due to a poorer array of amino acids contributed by the higher collagen, higher ash MBM.

Johnson et al., (1998), using cecectomized roosters, measured true amino acid digestibilities of nine animal proteins including MBM, lamb meals, and poultry by-product meals. They found no significant relationship between ash and digestible amino acids. They concluded that the negative effect of ash on protein quality

of MBM, as measured by protein efficiency ratio (**PER**), was primarily due to the reduced proportion of EAA, not reduced digestibilities of these amino acids.

In the previously mentioned report from Herold et al., (1996), total tract N digestibility was also determined by lamb feeding studies for the 36 mxMBM. The total tract N digestibility results ranged from 76% to 98%. There was no significant relationship of ash to total tract N digestibility ($r = -0.26$, $P = 0.13$). This suggests that the protein associated with bone is adequately digested in the ruminant small intestine. They further calculated the digestibility of the RUP ranged from 61 to 96%. Only 4 out of the 36 samples were below 70%, and the average RUP digestibility equaled that of the soybean meal controls (70%). They also noted that previous calf growth studies with MBM had shown a lower protein efficiency compared with blood meal. They suggested that the amino acid composition of MBM was inadequate to meet the needs of the growing calf and that methionine and tryptophan may be especially limiting since collagen contains negligible amounts of either.

These studies suggest that ash levels may have merit as an indicator of protein quality and feeding value. Ash values are not strongly related to the digestibility of the MBM protein fed to ruminants.

Ruminal Protein Degradability and Intestinal Protein Digestibility of MBM

Numerous methods exist for estimating the RUP for a feed ingredient, each with its own advantages and disadvantages. In reality, the RUP value is not one given number, but is dynamic depending upon such variables as DM intake and rumen turnover rate, to name a few.

Yet, many still inquire about what RUP value to assign pMBM. Table 6 lists RUP values for four different sets of MBM, arrived at using five different techniques. Both set # 1a and # 2 were evaluated using the in-situ technique. This comparison suggests that pMBM has a greater RUP value than mxMBM. However, the mxMBM set also included some poultry meals which have been shown to give RUP values in the mid 30% range (T.J. Klopfenstein, Univ. of Nebraska, personal communication). The average RUP for these two sets would probably not differ if the poultry samples were removed. The two sets appear to substantiate the 49% value listed for MBM in the NRC (1989).

The ammonia release method resulted in substantially greater RUP values compared to the in-situ technique. Herold et al. (1996) reported a strong correlation between the two methods ($r = 0.92$). The other two in-vitro techniques were performed on two different sets of MBM, (#3 and # 4), so direct comparisons can not be made but are simply noted and listed for reference.

Calsamiglia and Stern (1995) developed a three step in-vitro procedure designed to estimate the digestibility of the RUP fraction of a feed ingredient. They observed an average digestibility of the RUP fraction of mxMBM at $54.0\% \pm 6.2$. This was quite low compared with the reported values of 70 to 88% determined for blood meal, hydrolyzed feather meal, fish meal, soybean meal, lignin-sulfonate treated soybean meal, and corn gluten meal.

In order to further investigate the post-ruminal protein digestion of MBM, four of the mxMBM samples from Table 1 were chosen for in-vivo evaluation (Merchen and Drackley, 1997). Samples #

11, 12, 13, and 15 were selected based on their composition. The wide differences in their protein, ash, and collagen contents indicated there might be differences in ruminal degradation and post-ruminal digestion. Five Holstein steers (400 kg; 880 lb) cannulated in the rumen, proximal duodenum, and distal ileum were used in a 5 X 5 Latin square design. Isonitrogenous amounts of the four MBM were added (providing 4.2 percentage units of CP) to a basal diet containing no MBM (11.4% CP), resulting in diets with 15.6% CP. Dry matter intake was not effected by treatment (Table 7). Feeding MBM increased the flows of total nitrogen at the duodenum by an average of 22%, and disappearance across the small intestine increased an average of 41%. There were no differences among MBM sources for these two measurements. Most interesting to note was that the amount of N reaching the terminal ileum was similar among diets and within a narrow range of 88 to 96 g/d. Since all steers consumed identical amounts of basal N, this suggests that virtually none of the nitrogen from the MBM reached the terminal ileum. Conversely, almost the entire MBM N disappeared in the rumen and small intestine.

Flows of amino acids entering and exiting the small intestine found in Table 8 mirror the N flow results. When MBM was fed, flows of EAA, NEAA, and TAA entering the small intestine were increased 34, 44, and 39%, respectively. Flows of amino acids leaving the small intestine were not increased. Thus, nearly all the amino acids entering the small intestine from MBM disappeared there. The estimated amino acid digestibilities for MBM # 11, 12, 13, and 15 were 92, 90, 94, and 97%, respectively. This was calculated using the following equation:

$$\frac{[(\text{AA disappearing for the MBM diet}) - (\text{AA disappearing for basal diet}) \times 100]}{[(\text{duodenal AA flow for MBM diet}) - (\text{duodenal AA flow for basal diet})]}$$

Flows of individual amino acids appear to follow those seen with total EAA and NEAA (Table 9). One notable exception was seen when MBM # 11 was fed. This MBM had the highest levels of ash and collagen. The flow of glycine was increased 107% for MBM #11 compared with an average of 63% for the other MBM. Although not significant, MBM # 11 also contributed the lowest amount of EAA and the highest amount of NEAA. While MBM # 11 was equally effective in supplying total amino acids to the small intestine, the profile of these amino acids appeared to have been of a lower quality.

Temperature Effects

The processing temperatures of 14 of the 36 mxMBM were recorded by Herold et al. (1996). These represented seven different batches of material where the batches were divided and the same raw materials were processed at a low and high temperature. The average low and high temperatures were 249 and 286°F. They are not much different from the range of 235 to 280°F routinely used by the rendering industry. These temperatures did not influence total tract nitrogen digestibilities, RUP, or RUP digestibilities and no significant correlations were observed ($P < 0.05$).

Wang and Parsons (1998), using a chick growth study, showed that the PER of three MBM produced at above normal temperatures (300 to 305°F) were significantly less than three MBM produced at normal temperatures (230 to 264°F). The PER values for those produced at above normal temperatures ranged from 0.97 to

1.52. For those produced at normal temperatures, PER values ranged from 2.26 to 2.68. The PER values were also significantly correlated with amino acid digestibility. These studies suggest that measurements of MBM protein quality are not related to processing temperatures unless the MBM has been prepared at temperatures above those normally used by the rendering industry.

MBM Feeding Value For Growing Cattle

Klemesrud et al. (1997), showed that four MBM and six poultry by-product meals improved average daily gain of growing steers relative to urea, but the differences in protein efficiency were related to the amount of metabolizable methionine provided by each animal protein. In a follow-up study, Klemesrud et al. (1997), demonstrated that MBM contained adequate amounts of metabolizable lysine, but methionine was first limiting for growing steers. Addition of rumen protected methionine to MBM increased daily gain, feed efficiency, and efficiency of protein utilization.

Balancing the metabolizable amino acids from MBM can be achieved by the selection of other proteins having complimentary amino acid profiles, moderate to high resistance to rumen degradation, and high post-ruminal digestibility. Knaus et al. (1997) demonstrated the validity of this approach in two studies using 250 kg (550 lb) growing and 425 kg (935 lb) finishing steers. Using the Cornell Net Carbohydrate and Protein System model, they formulated a RUP supplement containing MBM, blood meal, feather meal, and fish meal to provide the amino acids needed to compliment the microbial amino acids produced on a corn-based diet. Improvements in N digestion, N absorption, N balance, and efficiency of N

utilization were recorded at both stages of cattle growth for the inclusion of the RUP supplement compared to the corn-based diet.

In a related study, Robinson et al. (1998) used the same approach of RUP supplementation of corn-based diets fed to 50 crossbred steers averaging 305 kg (671 lb). The RUP mixture of animal and marine proteins containing MBM was added at 0, 3, 6, and 9% of the ration DM. In the 6% RUP group, the daily gains were increased 30, 23, and 10% at 56, 84, and 112 days compared to the diet with no MBM. Carcass protein accretion rates were 14, 43, and 12% greater at the 3, 6, and 9% RUP levels, respectively, in comparison to the diet with no MBM. These studies demonstrate that other animal/marine protein sources can be combined with MBM to complement corn-soy diets and improve the protein utilization in growing cattle.

MBM Feeding Value for Lactating Dairy Cattle

Santos et al. (1998) published a 12-year literature review on the effects of RUP supplementation on dairy lactation performance. This review represented 127 comparisons from 88 lactation trials published from 1985 to 1997. Thirty-two of these comparisons involved soybean meal versus either individual animal proteins (AP), blends of AP, or combinations of AP with corn gluten meal. No net benefit to milk yield or milk protein concentration was observed for RUP supplementation. Negative responses were more frequent than positive responses for RUP supplementation. However, in only one of these studies did the researcher attempt to maintain RDP levels constant as RUP was increased, and even in this one study, consistent recommended levels of RDP intake were not achieved. Santos et al.

(1998) concluded that increasing RUP at the expense of RDP often results in insufficient RDP to meet microbial needs. Therefore, neither an increase flow of EAA to the duodenum nor an improvement in lactation performance would be expected in this situation. It was suggested that adequacy of RUP and RDP should be considered independently.

One animal protein study where RUP was added over and above adequate RDP was reported by Grummer et al. (1996). A corn, alfalfa haylage diet containing 8% roasted soybeans served as the control diet. It had a measured RDP of 11.3% (dietary DM basis) and RUP of 5.8%. Two treatment diets increased the RUP to 7.6% by adding either a blend of MBM and blood meal or more roasted soybeans. The RDP was maintained at 11.3% by the use of urea. All diets also contained equal levels of dietary fat. Dry matter intake was not influenced by treatments (Figure 1). Milk yield was increased by the addition of RUP, and in addition, 3.5% fat-corrected milk yield was greater for cows receiving MBM plus blood meal than for those receiving additional roasted soybeans. Milk protein yield was also increased by RUP, whereas milk fat yield was unaffected.

Finally, Beede et al. (1994) reported on a large dairy lactation field study, where an animal-marine protein blend (AMPB) was substituted for the original supplemental protein on the basis of an equal weight of crude protein. The average RDP levels dropped from 62.8% of CP in the control diets to 60.0% in the AMPB diets. The AMPB increased average RUP from 37.2% of CP in the control diets to 40.0% in supplemented diets. The experimental design allowed the risk that some of the AMPB diets might not have enough RDP, since they ranged from 55.0 to 65.5% of CP.

The AMPB consisted of MBM, blood meal, fish meal, feather meal, and ruminally protected methionine designed to provide a post-ruminal EAA supply that matched the amino acid profile of milk. Thirty-five herds consisting of 7,289 lactating cows in eight states participated. The average milk yield response to AMPB above control was 2.68 lbs/cow/day. Nineteen of the 35 herds had greater milk yield, 12 showed no difference, and four herds had less milk yield. Cows in early lactation (< 40 days in milk) showed a greater response, averaging 5.8 lb/cow/day over controls. For early lactation data, twenty-six of 35 herds had a greater milk yield, seven herds showed no difference, and in two herds milk yield was less with AMPB than control. The authors concluded that the positive responses were due to supplying greater amounts and/or higher quality EAA. This study was probably the largest ever performed to evaluate an AMPB. Research studies have demonstrated that improvements in lactation performance and cattle growth can be achieved using MBM blended with complimentary sources of metabolizable amino acids.

Summary

The pMBM may contain greater amounts of protein and lower amounts of ash and collagen and have a more desirable amino acid profile than mxMBM. The pMBM and mxMBM have similar variation in nutrient content. Blending pMBM to a targeted protein guarantee can reduce protein variation to similar levels found in soybean meal. Compositional information can provide insights into raw material makeup and the feeding value of finished MBM. High ash is not related to protein digestibility but is indicative of a poorer amino acid profile. Protein digestibility does not change over the normal range of

rendering temperatures. Post-ruminal protein digestion of MBM is quite high and may not be different from soybean meal. Metabolizable methionine appears to be the first limiting amino acid in MBM for cattle growth. Animal and marine proteins and/or rumen-protected methionine can be combined with pMBM to provide a balanced amino acid supply to compliment microbial protein. Best responses are seen when such blends are used to compliment adequate RDP. Improvements in lactation performance and cattle growth have been demonstrated with this approach. The pMBM remains a nutritionally sound and economically desirable source of nutrients for dairy diets. Chemical composition can provide indications of protein quality and feeding value.

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Table 1. Composition of mixed species meat and bone meal (MBM).^{1,2}

MBM	100% DM						% CP	% EAA (% of DM)									
	Crude Protein	Hydroxy-Proline	Collagen	Ash	Calcium	Phos	RUP	EAA	Thr	Val	Met	Ile	Leu	Phe	His	Lys	Arg
1	60.4	2.69	21.5	22.10	10.69	3.31		20.46	1.89	2.28	0.98	1.65	3.49	1.99	1.52	3.06	3.60
2	53.3	3.19	25.5	31.80	17.08	5.20		17.98	1.73	1.97	0.78	1.42	2.94	1.74	0.87	2.77	3.76
3	51.6	2.59	20.7	25.20	11.83	4.86		19.45	1.90	2.26	0.79	1.57	3.37	1.91	0.98	2.97	3.70
4	53.6	2.81	22.4	30.30	13.20	5.39		20.14	1.92	2.33	0.82	1.58	3.78	1.96	1.01	2.93	3.81
5	51.7	2.94	23.5	35.80	17.89	5.85		18.17	1.77	2.21	0.64	1.43	3.11	1.82	0.80	2.53	3.86
6	51.0	2.78	22.3	31.50	14.11	6.07		18.07	1.73	2.08	0.76	1.35	3.09	1.80	0.98	2.79	3.49
7	50.2	3.09	24.7	35.00	15.83	6.20		17.55	1.68	2.07	0.67	1.31	2.96	1.70	0.85	2.63	3.68
8	54.4	2.75	22.0	26.30	12.00	5.12		18.96	1.85	2.28	0.71	1.45	3.28	1.87	0.97	2.84	3.71
9	54.1	3.24	26.0	33.70	15.00	6.23		18.54	1.78	2.25	0.68	1.40	3.22	1.83	0.87	2.72	3.80
10	53.1	2.79	22.3	33.30	17.78	6.71		19.78	1.94	2.39	0.80	1.58	3.42	1.98	0.97	3.04	3.66
11	46.5	4.84	38.7	44.10	18.87	8.18	83.3	15.28	1.38	1.97	0.51	1.03	2.46	1.53	0.68	2.15	2.57
12	52.2	3.86	30.9	35.80	14.74	6.56	55.2	18.42	1.78	2.24	0.65	1.34	3.17	1.83	0.93	2.81	3.67
13	56.5	2.98	23.8	22.20	12.30	4.33	30.5	19.93	1.94	2.30	0.90	1.65	3.42	1.93	1.17	3.00	3.62
14	53.0	3.09	24.7	27.90	15.15	5.41		19.39	1.95	2.34	0.69	1.47	3.42	1.95	0.96	2.96	3.65
15	55.8	3.56	28.5	28.70	13.81	6.71	23.9	18.65	1.82	2.20	0.71	1.40	3.24	1.89	1.09	2.76	3.54
Ave	53.2	3.15	25.17	30.91	14.69	5.76	48.2	18.7	1.80	2.21	0.74	1.44	3.22	1.85	0.98	2.80	3.67
StDev	3.1	0.58	4.63	5.82	2.46	1.15	27.0	1.3	0.15	0.13	0.11	0.16	0.30	0.12	0.19	0.23	0.10
CV, %	5.87	18.38	18.41	18.84	16.78	19.93	55.96	6.89	8.10	5.89	15.40	11.00	9.41	6.65	19.49	8.39	2.82
Min	46.50	2.59	20.70	22.10	10.69	3.31	23.90	15.28	1.38	1.97	0.51	1.03	2.46	1.53	0.68	2.15	3.49
Max	60.40	4.84	38.70	44.10	18.87	8.18	83.30	20.46	1.95	2.39	0.98	1.65	3.78	1.99	1.52	3.06	3.86

¹Lueking et al., 1996.²RUP = rumen degradable protein, EAA = essential amino acids, NEAA = non-essential amino acids, StDev = standard deviation, and CV = coefficient of variation.

Table 1. Composition of mixed species meat and bone meal (MBM)(continued).^{1,2}

MBM	100% DM	% NEAA (% of DM)							
	Crude Protein	NEAA	Asp	Ser	Glu	Pro	Gly	Ala	Tyr
1	60.4	29.73	4.71	2.13	7.07	4.15	6.38	3.89	1.40
2	53.3	30.76	4.67	2.12	6.53	4.63	7.75	3.95	1.11
3	51.6	30.57	4.80	2.72	6.82	4.22	6.87	3.84	1.30
4	53.6	30.97	4.91	2.24	6.96	4.34	7.18	4.00	1.34
5	51.7	32.00	4.63	2.49	6.61	4.98	8.09	4.05	1.15
6	51.0	29.24	4.64	2.03	6.47	4.24	6.93	3.75	1.18
7	50.2	30.78	4.59	2.07	6.44	4.70	7.88	4.02	1.08
8	54.4	31.31	4.81	2.38	6.95	4.61	7.40	3.92	1.24
9	54.1	31.77	4.76	2.22	6.68	4.76	8.02	4.15	1.18
10	53.1	30.83	4.90	2.21	6.69	4.40	7.27	4.09	1.27
11	46.5	31.11	4.27	1.80	5.56	5.15	9.23	4.34	0.76
12	52.2	31.01	4.74	2.20	6.53	4.60	7.70	4.08	1.16
13	56.5	30.65	4.97	2.16	7.26	4.21	6.77	3.96	1.32
14	53.0	30.52	4.93	2.34	6.70	4.30	7.09	3.93	1.23
15	55.8	30.37	4.75	2.12	6.51	4.49	7.30	4.04	1.16
Ave	53.2	30.77	4.74	2.22	6.65	4.52	7.46	4.00	1.19
StDev	3.1	0.69	0.17	0.21	0.39	0.30	0.69	0.14	0.15
CV, %	5.87	2.25	3.67	9.58	5.80	6.54	9.29	3.49	12.54
Min	46.50	29.24	4.27	1.80	5.56	4.15	6.38	3.75	0.76
Max	60.40	32.00	4.97	2.72	7.26	5.15	9.23	4.34	1.40

¹Lueking et al., 1996.²RUP = rumen degradable protein, EAA = essential amino acids, NEAA = non-essential amino acids, StDev = standard deviation, and CV = coefficient of variation.

Table 2. Composition of porcine meat and bone meal (MBM).^{1,2}

MBM	100% DM							% CP	% EAA (% of DM)									
	Crude Protein	Hydroxy-Proline	Collagen	Fat	Ash	Calcium	Phos	RUP	EAA	Thr	Val	Met	Ile	Leu	Phe	His	Lys	Arg
1	55.3	2.5	20.2	14.2	27.1	8.4	4.8	48.8	18.92	1.80	2.15	0.86	1.44	3.34	1.83	1.20	2.82	3.46
2	61.3	3.4	27.0	11.1	24.0	8.3	4.8	49.1	19.30	1.80	2.10	0.84	1.37	3.26	1.83	1.15	2.95	4.00
3	49.6	3.2	25.7	11.0	34.0	13.4	6.0	54.4	15.45	1.47	1.71	0.66	1.09	2.66	1.51	0.86	2.24	3.25
4	56.8	2.9	23.3	12.8	30.0	10.6	6.0	48.5	18.30	1.68	2.02	0.75	1.20	3.17	1.79	1.22	2.80	3.67
5	59.8	3.1	25.0	9.7	27.8	10.1	5.5	46.2	19.20	1.77	2.14	0.77	1.36	3.31	1.87	1.15	2.84	3.99
6	60.1	3.1	24.8	11.4	26.5	9.0	5.5	49.4	19.48	1.86	2.15	0.81	1.43	3.45	1.84	1.14	2.79	4.01
7	62.5	2.8	22.3	10.2	25.7	9.1	5.5	47.7	18.82	1.77	2.08	0.76	1.33	3.27	1.80	1.13	2.72	3.96
8	60.0	3.4	27.0	13.8	22.4	8.4	5.1	45.8	19.40	1.84	2.10	0.86	1.42	3.30	1.83	1.14	3.05	3.86
9	61.2	3.2	26.0	12.1	23.5	8.9	5.3	53.5	18.92	1.77	2.05	0.83	1.37	3.18	1.76	1.14	2.91	3.91
10	55.8	1.7	13.6	16.6	21.6	6.6	4.6	51.1	17.49	1.71	1.98	0.78	1.37	3.13	1.70	0.97	2.49	3.36
11	63.6	2.5	20.0	11.6	21.5	7.3	5.3	54.2	22.05	2.29	2.49	0.83	1.63	3.98	2.03	1.19	3.20	4.41
13	61.5	3.8	30.4	11.4	26.8	9.5	6.7	41.4	19.58	1.84	2.12	0.83	1.39	3.30	1.85	1.16	3.07	4.02
14	62.1	2.6	21.2	10.7	21.8	7.8	5.9	49.9	19.62	2.01	2.14	0.76	1.40	3.41	1.79	1.07	2.87	4.17
18	64.2	2.9	23.5	10.1	21.9	7.2	5.8	47.5	21.73	2.08	2.40	0.91	1.58	3.76	2.05	1.29	3.37	4.29
Ave	59.6	2.9	23.6	11.9	25.3	8.9	5.5	49.1	19.16	1.84	2.12	0.80	1.38	3.32	1.82	1.13	2.87	3.88
StDev	3.9	0.5	4.1	1.9	3.7	1.7	0.6	3.5	1.59	0.19	0.18	0.06	0.13	0.30	0.13	0.11	0.28	0.34
CV, %	6.6	17.5	17.3	15.8	14.5	19.2	10.4	7.2	8.32	10.54	8.52	7.73	9.61	9.05	7.11	9.39	9.76	8.72
Min	49.6	1.7	13.6	9.7	21.5	6.6	4.6	41.4	15.45	1.47	1.71	0.66	1.09	2.66	1.51	0.86	2.24	3.25
Max	64.2	3.8	30.4	16.6	34.0	13.4	6.7	54.4	22.05	2.29	2.49	0.91	1.63	3.98	2.05	1.29	3.37	4.41

¹Orias et al., 1999.²RUP = rumen degradable protein, EAA = essential amino acids, NEAA = non-essential amino acids, StDev = standard deviation, and CV = coefficient of variation.

Table 2. Composition of porcine meat and bone meal (MBM)(continued).^{1, 2}

MBM	100% DM	% Non-Essential Amino Acids (% of DM)							
	Crude Protein	NEAA	Asp	Ser	Glu	Pro	Gly	Ala	Tyr
1	55.3	28.06	4.05	2.01	6.64	3.99	6.17	3.83	1.37
2	61.3	32.00	4.27	2.25	6.98	5.06	7.96	4.20	1.28
3	49.6	25.97	3.46	1.90	5.63	4.07	6.46	3.39	1.06
4	56.8	29.74	4.07	2.13	6.37	4.72	7.36	3.94	1.15
5	59.8	32.00	4.27	2.26	6.90	5.03	8.02	4.22	1.30
6	60.1	30.88	4.27	2.38	7.11	4.49	7.25	3.99	1.39
7	62.5	31.32	4.17	2.31	6.87	4.81	7.81	4.08	1.27
8	60.0	30.89	4.27	2.22	6.90	4.84	7.34	4.02	1.30
9	61.2	31.41	4.19	2.19	6.88	4.97	7.85	4.10	1.23
10	55.8	26.74	3.84	2.00	6.32	3.81	6.03	3.49	1.25
11	63.6	33.51	4.75	3.16	8.13	4.93	6.93	3.91	1.70
13	61.5	32.60	4.30	2.36	7.06	5.18	8.11	4.23	1.36
14	62.1	31.08	4.23	2.73	7.25	4.95	6.81	3.69	1.42
18	64.2	32.78	4.64	2.57	7.59	4.83	7.41	4.21	1.53
Ave	59.6	30.64	4.20	2.32	6.90	4.69	7.25	3.95	1.33
StDev	3.9	2.26	0.31	0.33	0.59	0.43	0.69	0.27	0.16
CV, %	6.6	7.37	7.37	14.09	8.51	9.24	9.47	6.79	11.82
Min	49.6	25.97	3.46	1.90	5.63	3.81	6.03	3.39	1.06
Max	64.2	33.51	4.75	3.16	8.13	5.18	8.11	4.23	1.70

¹Orias et al., 1999.

²RUP = rumen degradable protein, EAA = essential amino acids, NEAA = non-essential amino acids, StDev = standard deviation, and CV = coefficient of variation.

Table 3. Comparison of protein variability in Midwest meat and bone meal samples.¹

<i>Rendering Plants</i>	Number of Samples	Crude Protein, %	Standard Deviation	Coefficient of Variation, %
1	165	56.2	2.2	4.0
2	97	54.1	3.0	5.5
3	38	59.1	2.2	3.7
4	27	53.2	3.4	6.4
5	87	53.3	4.4	8.2
6	57	50.8	4.8	9.4
7	20	55.8	2.2	4.0
8	131	55.6	2.4	4.3
9	504	54.1	1.9	3.4
10	7	57.4	3.6	6.3
11	12	57.7	1.8	3.2
12	9	51.7	3.9	7.6
<i>NBP Blending</i>				
<i>Plants²</i>				
1	302	68.8	1.0	1.5
2	409	54.8	1.1	1.9
3	254	51.8	1.1	2.1

¹Kirstein, 1997²NBP = National By-Products, inc., Bloomington, IL.Table 4. Protein variability in common broiler feed ingredients.¹

<i>Ingredient</i>	Number of Samples	Crude Protein, %	Standard Deviation	Coefficient of Variation, %
Corn	415	7.8	0.4	5.1
Meat & Bone Meal	264	52.9	2.0	3.8
Soybean Meal	1986	48.4	0.8	1.7

¹Kirby et al., 1993

Table 5. Correlations for mixed species meat and bone meal (MBM) and porcine MBM samples found in Tables 1 & 2.¹

Ash Correlations							
MBM Type	% of DM					% of Protein	
	Protein	RUP	Collagen	EAA	NEAA	EAA	NEAA
Mixed species	-0.808***	4 data pts	0.716**	-0.829***	0.427	-0.276	0.855***
Porcine	-0.713**	0.006	0.340	-0.673**	-0.479	-0.220	0.454

Protein Correlations						
MBM Type	% of DM				% of Protein	
	EP	Collagen	EAA	NEAA	EAA	NEAA
Mixed species	4 data pts	-0.519*	0.792***	-0.263	-0.045	-0.948***
Porcine	-0.309	0.156	0.873***	0.928***	-0.167	0.068

Collagen Correlations					
MBM Type	% of DM			% of Protein	
	RUP	EAA	NEAA	EAA	NEAA
Mixed species	4 data pts	-0.776***	0.230	-0.587*	0.571*
Porcine	-0.443	0.032	0.407	-0.187	0.728**

¹RUP = rumen undegradable protein, EAA = essential amino acids, and NEAA = non-essential amino acids

* P < 0.05, ** P < 0.01, *** P < 0.001

Table 6. Comparison of rumen undegradable protein values (% of CP) for meat and bone Meal composed of various species and determined using different techniques.¹

Data Set:	#1a	#1b	#2	#3	#4
Raw Material Type:	Mixed w/PM	Mixed w/PM	All Pork	Mixed	Mixed
Researcher:	Herold et al. (1996)	Herold et al. (1996)	Orias et al. (1999)	Kirstein (1995)	Mantysaari and Sniffen (1989)
Technique:	In situ	NH ₃ Release	In Situ	Inhibitor In vitro	<i>S. griseus</i> protease
Number of Samples	36	36	15	13	15
Average	43.5	59.5	49.1	44.4	44.7
StDev	6.7	6.4	3.5	4.9	3.6
CV, %	15.4	10.8	7.2	11.0	8.1
Min	32.0	43.8	41.4	34.9	38.3
Max	56.1	74.1	54.4	50.3	35.2

¹PM = poultry by-product meal, StDev = standard deviation, and CV = coefficient of variation.

Table 7. Intake and digestion of N by steers fed mxMBM.¹

Item	Basal Diet	mxMBM Source ²				SEM ^a
		#11	#12	#13	#15	
DMI, lb/d	20.9	20.8	20.9	20.7	21.1	0.15
N intake, g/d	174 ^b	228 ^c	232 ^c	233 ^c	241 ^c	5.5
Duodenal N, g/d						
Total	217 ^b	280 ^c	271 ^c	252 ^c	253 ^c	12.3
Bacterial	160	177	182	177	180	8.4
Nonbacterial	57	102	89	75	73	9.7
Ileal N, g/d	96	91	94	95	88	4.9
Small intestine N disappearance, g/d	122 ^b	188 ^c	177 ^c	157 ^c	165 ^c	10.2

¹Merchen and Drackley, 1997.

²Refer to Table 1.

mxMBM = mixed species meat and bone meal; DMI = dry matter intake

^aStandard error of the mean for n = 5

^{bcd}Means in the same row without a common superscript differ (P < 0.05)

Table 8. Total (TAA), essential (EAA), and nonessential (NEAA) amino acids entering and disappearing from the small intestine (SI) of steers fed diets containing mixed species meat and bone meal (mxMBM).¹

Item	Basal Diet	MxMBM source ²				SEM ^a
		#11	#12	#13	#15	
Entering small intestine, g/d						
EAA	414 ^b	527 ^c	543 ^c	591 ^c	554 ^c	26.5
NEAA	523 ^b	772 ^c	737 ^c	769 ^c	730 ^c	35.4
TAA	937 ^b	1299 ^c	1280 ^c	1360 ^c	1284 ^c	61.6
Exiting small intestine, g/d						
EAA	162	164	175	172	163	5.9
NEAA	214	231	236	236	221	8.9
TAA	375	395	411	408	384	13.8
Disappearance from SI, g/d						
EAA	252 ^b	363 ^c	368 ^c	419 ^c	391 ^c	25.0
NEAA	310 ^b	541 ^c	501 ^c	533 ^c	509 ^c	34.4
TAA	562 ^b	904 ^c	869 ^c	953 ^c	900 ^c	59.1
%Disappearance from SI from that entering ^d						
EAA	60.9	68.9	67.8	70.9	70.6	
NEAA	59.3	70.1	68.0	69.3	69.7	
TAA	60.0	69.6	67.9	70.1	70.1	

¹Merchen and Drackley, 1997

²Refer to Table 1.

^aStandard error of the mean for n = 5.

^{b,c}Means in the same row without a common superscript differ (P < 0.05).

^dCalculated from mean values – not yet statistically analyzed.

Table 9. Flow of amino acids to the small intestine of steers fed diets containing mixed species meat and bone meal (mxMBM).¹

Item	Basal Diet	MxMBM source ²				SEM ^a
		#11	#12	#13	#15	
Essential AA, g/d						
Thr	52.7 ^b	65.7 ^c	69.2 ^c	75.8 ^c	69.4 ^c	3.30
Val	44.5 ^b	58.3 ^c	59.4 ^c	63.4 ^c	57.8 ^c	2.81
Met	21.8 ^b	26.9 ^c	28.0 ^c	31.4 ^c	28.5 ^c	1.71
Ile	36.9 ^b	43.7 ^{bc}	46.0 ^c	51.0 ^c	46.5 ^c	2.45
Leu	82.4 ^b	102.9 ^c	109.5 ^c	115.8 ^c	109.1 ^c	5.57
Phe	42.3 ^b	55.3 ^c	59.7 ^c	63.1 ^c	62.8 ^c	3.50
His	24.8 ^b	31.5 ^{cd}	27.8 ^{bc}	35.7 ^c	32.4 ^{cd}	1.87
Lys	63.9 ^b	76.5 ^c	79.8 ^c	88.0	82.1 ^c	3.66
Arg	44.5 ^b	65.6 ^c	64.0 ^c	67.1 ^c	64.8 ^c	2.90
Total EAA	414 ^b	527 ^c	543 ^c	591 ^c	554 ^c	26.50
Non-essential AA, g/d						
Asp	104.3 ^b	135.5 ^c	139.1 ^c	149.8 ^c	138.7 ^c	6.49
Ser	54.1 ^b	69.7 ^c	73.5 ^c	76.4 ^c	71.6 ^c	3.52
Glu	135.4 ^b	177.0 ^c	180.3 ^c	193.3 ^c	180.1 ^c	9.16
Pro	50.4 ^b	87.8 ^c	74.7 ^c	73.3 ^c	79.0 ^c	5.11
Gly	77.2 ^b	159.8 ^d	128.1 ^c	128.6 ^c	119.9 ^c	7.55
Ala	68.4 ^b	100.3 ^c	96.0 ^c	100.1 ^c	95.2 ^c	4.96
Tyr	33.4 ^b	41.4 ^c	44.9 ^c	47.5 ^c	45.7 ^c	2.39
Total NEAA	523 ^b	772 ^c	737 ^c	769 ^c	730 ^c	35.4
Total AA	937 ^b	1299 ^c	1280 ^c	1360 ^c	1284 ^c	61.6

¹Merchen and Drackley, 1997.²Refer to Table 1.^aStandard error of the mean for n = 5.^{bcd}Means in the same row without a common superscript differ (P < 0.05).

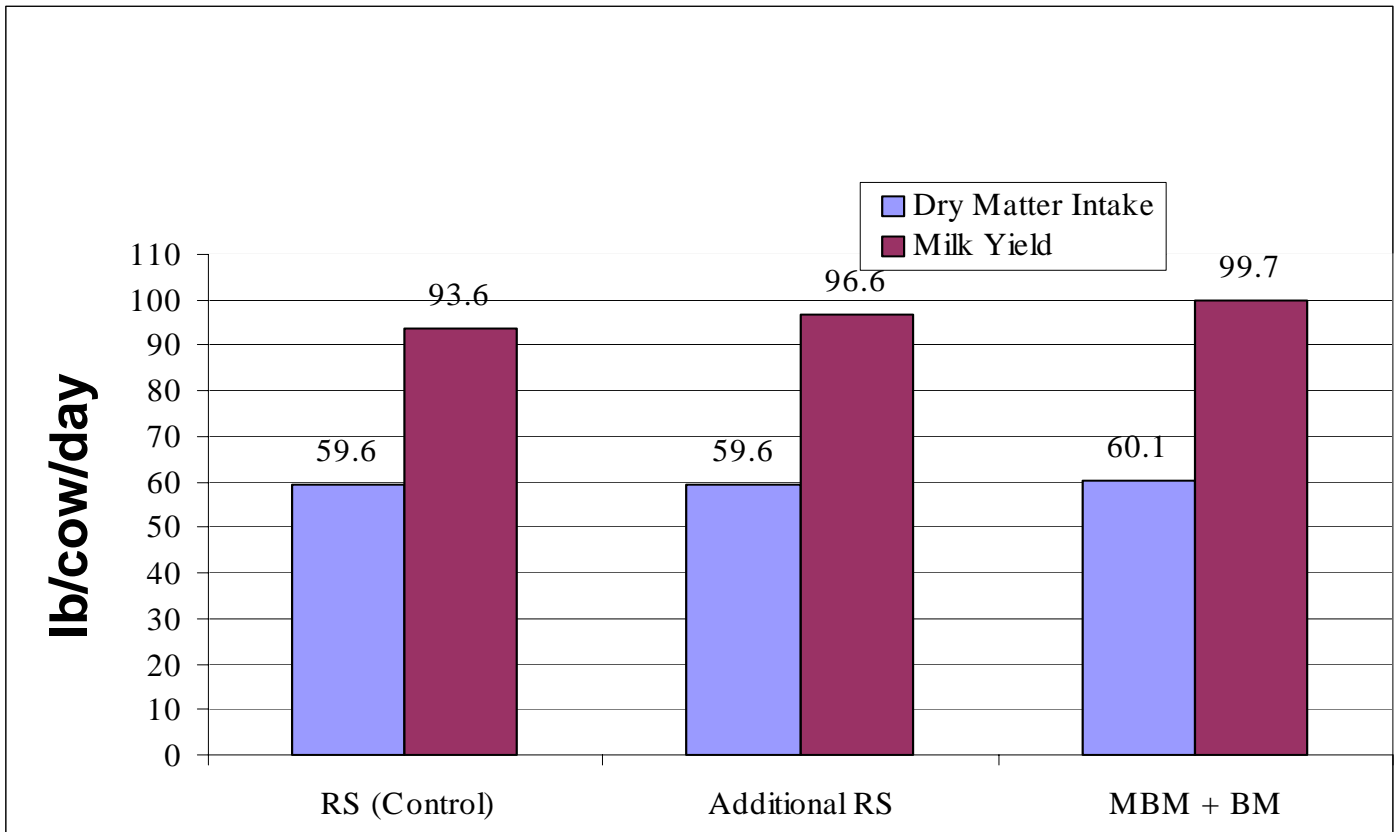


Figure 1. Dry matter intake and milk production of cows fed diets containing roasted soybeans (RS) or the control diet plus additional rumen undegradable protein from feeding more RS or meat and bone meal (MBM) plus blood meal (BM) (Grummer et al., 1996).

Digestibility of Dietary Fat Under Conditions of Today's Feeding Practices

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Abstract

Fatty acid digestibility is often a concern when additional fat is fed to dairy cows because of previously described limits to the amount of fat that ruminants can efficiently digest and absorb from the small intestines. Also, recent efforts to minimize ruminal fermentation problems through chemical hydrogenation of fats has had detrimental effects on fatty acid digestibility in some studies. A summary of 11 published studies examining fatty acid digestibility in lactating dairy cows revealed a very consistent intestinal digestibility of fatty acids across a wide range of fat sources and amounts. The few instances where fatty acid digestibility was unusually low occurred when dairy rations were supplemented with low iodine value (IV) hydrogenated tallow or various forms of soybeans. Intestinal digestibility of stearic acid was lower than other 18 carbon fatty acids having 1, 2, or 3 double bonds. However, flow of stearic acid to the duodenum is common for all sources of added fat and bears little relationship to the quantity of stearic acid in the fat supplement. Dramatic reductions in digestibility of the fat supplement must occur to prevent an increase in digestible energy (DE) intake when feeding fat. However, relatively small reductions in feed intake or feed digestibility by the added fat will prevent an increase in DE intake.

Although poor fatty acid digestibility can be a contributing factor accounting for the failure of some fat supplements to increase milk yield, it appears uncommon for this problem to be the major limitation to achieving a positive milk response from most typical sources and amounts of fat fed to dairy cattle.

Introduction

The purpose of this paper is to focus on the relative importance of fatty acid digestibility in determining the feeding value of fat supplements for dairy rations. It is understandable that fatty acid digestibility receives attention given that dairy cows and other ruminants are often regarded as having a limit to the amount of fat they can effectively absorb. Also, recent approaches to develop "rumen-inert" fats, primarily through chemical hydrogenation, have significantly lowered fatty acid digestibility in some studies. But based on the amounts and types of fat normally added to dairy rations, a pertinent question is under what conditions and how frequently is poor fatty acid digestibility a limitation to utilization of a fat supplement? To answer this question, data from published studies using lactating dairy cows were compiled and examined to determine the influence of various fat supplements on intestinal fatty acid digestibility. The data presented will show

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that for the great majority of fat sources used in dairy rations, the primary and most common limitation is how the added fat affects utilization of the basal diet rather than how the fat supplement itself is digested.

The Gross Energy Value of Fat Supplements

The gross energy (GE) value of fat supplements is determined almost exclusively by the type and amount of fatty acid present in the supplement. Most fat supplements are comprised of different proportions of 5 to 8 common fatty acids, all of which have similar energy values (approximately 9.4 kcal/g). Therefore, fatty acid content (g fatty acid/100 g fat supplement) is much more important than fatty acid composition (g fatty acid/100 g total fatty acids) in determining GE value of the supplement.

Fatty acid content of fat supplements can be diluted by nonfatty acid components that have lower or no energy value. Fat content has traditionally been determined as the ether-extractable component of the feed. When defined in this manner, there can be considerable variation in lipid composition among feed ingredients. Among the lowest is the ether extract in grains and forages. In addition to extracting fat, ether also extracts some carbohydrate, vitamins, and pigments. Therefore, fatty acids in corn grain is only 65% of the ether extract, and in alfalfa hay is only 40% of the ether extract (Palmquist and Jenkins, 1980). Because of the problems inherent with ether extract, many laboratories have moved to determining fatty acid content of feeds instead of ether extract.

With only a few exceptions, most fat supplements used in dairy rations contain a

high percentage (usually 90 to 100%) of fatty acids. The impurities extracted from animal or plant tissue, such as water and pigments, are removed during refining leaving the commercial plant (soybean oil, canola oil, corn oil, etc.) and animal (tallow, grease, etc.) fats with mainly triglycerides consisting of 90 to 93% fatty acids. The remaining 7 to 10% is referred to as unsaponifiables and is mainly glycerol. Glycerol is readily utilized as an energy source, but only contains the energy of carbohydrates. Caution is advised when obtaining fats from unknown vendors to be sure that considerable impurities do not still remain in the product that lower the fatty acid and energy content. Rather than guessing, it pays to have a sample of the fat analyzed for fatty acid content and profile.

Digestibility of Fatty Acids in Dairy Cows

Data on intestinal fatty acid digestibilities were compiled from 11 published studies (Table 1) that examined the effect of dietary fat supplements on duodenal fatty acid flow in lactating dairy cows. The data set included fatty acid flows for 14 control diets with no added fat and 35 diets with added fat that included 15 fat sources. Total fatty acid intake ranged from 162 to 1339 g/d.

Apparent digestibility of fatty acids in the intestines of the cows ranged from 32.1 to 91.4%, with most digestibilities in the range of 70 to 79% (Figure 1). Fatty acid digestibilities from 60 to 89% occurred for both the control and fat diets, indicating that addition of most of the fat supplements did not cause abnormal fat digestion. Based on the observations from this data set, intestinal fatty acid digestibilities in the 90's are rare and was only seen for a single control diet. There were seven instances where fatty acid digestibilities were below 60%, all

attributable to diets with added fat. The lowest apparent digestibility coefficient (32.1%) resulted when cows were fed partially-hydrogenated tallow. The other values (one in the 40's and five in the 50's) involved cows fed soybeans in various forms, or in a single instance, soybeans along with tallow.

True digestibility of fatty acids in the intestines was estimated from the slope relating fatty acids digested versus fatty acid flow to the duodenum (Figure 2A). The regression was linear, indicating that fatty acid digestibility was not depressed as duodenal fatty acid flow increased. The slope indicates $64 \pm 3.9\%$ true digestibility of fatty acids in the intestines of dairy cows. However, the data points with apparent digestibilities at $< 60\%$ (numbered 1, 2 and 3 in Figure 2A) deviated below this regression line. The point labeled 1 was for cows fed partially hydrogenated tallow, while points 2 and 3 were for cows fed soybeans in various forms. Eliminating the seven points labeled 1, 2, and 3 having digestibilities at $< 60\%$ increased true intestinal digestibility of fatty acids to $69 \pm 1.9\%$ (Figure 2B). The standard error of 1.9% was quite low considering that it reflects both within and between study experimental error. Therefore, fatty acid digestibility in the intestines of lactating cows is quite consistent over a wide range of fat sources and fatty acid intakes. While the data set does not include every source of fat utilized in dairy rations, it does include the most common sources including tallow, oilseeds, animal-vegetable blends, and calcium salts of fatty acids.

It was not surprising, based on results from previous studies, that feeding partially hydrogenated tallow (point 1 in Figure 2A) reduced fatty acid digestibility. Hydrogenation of yellow grease to reduce its

IV from 56 to 18 reduced apparent fatty acid digestibility in the total tract from 67.8 to 47.4% (Jenkins and Jenny, 1989). Fatty acid digestibilities pooled from 11 studies were normal (similar to control values) when IV exceeded 40, (Firkins and Eastridge, 1994), but below IV 40, fatty acid digestibility progressively dropped as IV declined. The partially hydrogenated tallow having the lowest intestinal fatty acid digestibility (32.1%) in this data set (point 1 in Figure 2A) had an IV of 17.8, supporting previous results that hydrogenation can compromise fat digestion.

Lower digestibility of hydrogenated fats may be related to their higher content of saturated fatty acids. Digestibilities for each of the 18 carbon fatty acids are shown in Table 2, with stearic acid having the lowest apparent intestinal digestibility. The presence of 1, 2, or 3 double bonds increased apparent fatty acid digestibility a similar amount. Grummer and Rabelo (1998) also reported similar improvements in apparent fatty acid digestibility from the presence of one or more double bonds. True digestibility of stearic acid was 53% and lowest among the 18 carbon fatty acids (Table 2). Introducing a single double bond improved true digestibility to 78.4%. There were no significant quadratic functions for either stearic or oleic acids, indicating that their digestibilities were constant over the entire range of duodenal flows. It should be pointed out that some studies did not distinguish between flows of cis or trans 18:1 to the duodenum, which might tend to lower 18:1 digestibilities because trans 18:1 may have a lower digestibility than cis 18:1.

The digestibilities of linoleic and linolenic acids were higher than either stearic acid or 18:1 when duodenal flows were low. However, their digestibilities declined with increasing duodenal flows. At

the highest flows of linoleic and linolenic acids to the duodenum, their true digestibilities were lower than 18:1 but still higher than stearic acid.

Because of the lower digestibility of stearic acid (and perhaps other saturated fatty acids), increasing the flow of duodenal stearic acid reduces intestinal digestibility of total fatty acids in dairy cows (Figure 3A). However, considerable variation indicates that stearic acid alone is not the only factor determining intestinal digestibility of fatty acids. Figure 3B shows that total quantity of fatty acids digested in the intestines eventually plateaus at higher duodenal flows of stearic acid. Fatty acids digested were appreciably lower and more variable when duodenal flow of stearic acid exceeded 400 g/day. As seen previously, fatty acids digested in the cows fed the partially hydrogenated tallow was lower than expected, even when taking the duodenal flow of stearic acid into account. The same was true when cows were fed high-linoleic sunflower oil.

Because of ruminal biohydrogenation, flow of stearic acid to the duodenum is not related to intake of stearic acid. In the study of Pantoja et al. (1996), cows fed animal-vegetable fat had several fold lower intakes of stearic acid compared to cows fed partially hydrogenated tallow, but duodenal flow of stearic acid was higher for cows fed the animal-vegetable fat. Therefore, hydrogenation of fat sources may reduce fatty acid digestibility not by creating unusually high flows of stearic acid to the duodenum, but perhaps by creating problems with emulsification and dispersion of the fatty acids within the aqueous milieu of the intestinal environment. Hydrogenated fats added to dairy rations as high melting powders may be solubilized in the small intestine with more difficulty than fats with

lower melting points. It is unclear how particle size of the hydrogenated fat affects intestinal emulsification and fatty acid digestibility.

Apparent fatty acid digestibilities in the total tract of nonlactating dairy cows were the same when hydrogenated tallow (IV < 15) was fed as prills or flakes (Elliott et al., 1994). The flakes in this study were approximately 1 to 2 mm thick and were prepared from the melted and resolidified prills. As pointed out by Grummer and Rabelo (1998), brittleness of flakes and their subsequent particle size reduction during mixing, mastication, and rumination all may influence the extent that flaking affects digestibility.

The Energy Value of Fat-Supplemented Diets

To judge fat supplements based only their GE value and fatty acid digestibilities would be to overlook several other potentially more serious limitations of fat feeding. For instance, fats that have the highest fatty acid content and increase ration energy density (kcal per lb of feed) the most, such as those containing 100% free fatty acids, may actually be the fat sources that are least effective in providing net energy for milk production. The extra energy available for production upon the addition of fat to the ration is not only a function of fatty acid digestibility but also is determined by the extent that the fat source inhibits feed intake or interferes with digestibility of the basal feed ingredients. As an illustration, a reasonable intake of DE for cows consuming 25 kg/day (55 lb/day; DM basis) of a typical lactation ration is 77.3 Mcal/day (Table 3). If 750 g (1.65 lb) of this ration is replaced with fat, intake of DE increases to 80.4 Mcal/day if the added fat causes no problems with DM intake (DMI) or

digestibility. However, adding the fat supplement might fail to increase DE consumed if the supplement was poorly digested, or it interfered with DMI or feed digestibility.

In a situation where the fat supplement reduced DMI without any negative effects on feed or fatty acid digestibility, intake would only need to decline from 25 to 24.1 kg (55 to 53.0 lb) to break-even on DE consumed (Table 3). Likewise, if the fat supplement reduced feed digestibility because of antimicrobial effects, but had no effect on DMI or fat digestibility, then energy digestibility of the basal feed would only need to decline from 67.5 to 64.6% to break-even on DE. Finally, if digestibility of the fat supplement was the only problem, it would have to decline from 82.3 to 34.9% to reach break-even on DE intake. Drastic reductions in digestibility of the fat supplement are needed to reach break-even since the negative response is compressed in only 3% of the feed DM. When the 3% fat supplement negatively affects the rest of the feed, either through reduced intake or feed digestibility, smaller changes are needed to reach break-even.

The fat supplement may cause all three limitations simultaneously, which requires only slight reductions in feed intake, fat digestibility, and digestibility of the basal ration to reach break-even on DE. Using the numbers in Table 3 as an example, DE break-even occurs if DE of the fat supplement is reduced 2% (from 7.30 to 7.15 Mcal/kg; 3.32 to 3.25 Mcal/lb), combined with 2% reductions in DE of the basal feed (reduced from 3.09 to 3.03 Mcal/kg; 1.40 to 1.38 Mcal/lb) and feed intake (reduced from 25 to 24.5 kg/day; 55 to 53.9 lb/day). Many of these reductions would be difficult to detect as statistically significant but are still economically

important since the high energy fat supplement fails to provide additional energy for production.

Table 4 shows a few examples of the effects of fat supplements on DMI and digestibility of energy and fatty acids. These studies were chosen because they were among the few that reported energy digestibility. There are several instances where fat was added to the ration without a statistical, or perhaps even numerical, increase in milk production. In the study of Jenkins and Jenny (1989), for instance, adding 5% yellow grease to the ration had no effect on milk production which dropped numerically from 70.4 to 69.3 lb/day. The reasons why the ration with higher energy density failed to increase milk was two-fold; a drop in DMI plus a drop in energy digestibility. The 5.3 lb/day decline in DMI was not significant but was still in excess of the 1.98 lb/day break-even point for DE shown in Table 3. Likewise, the 5 percentage unit drop in energy digestibility was in excess of the 3 percentage unit break-even point in Table 3.

Most of the examples in Table 4 point to a combination of limitations associated with feeding fat. Although reduced digestibility of fatty acids may account for some of the problem, the major limitations appear to be reduced DMI coupled with some depression in energy digestibility. This is not to say that fatty acid digestibility should be ignored, but for fat supplements usually added to dairy rations, it probably is the least of the negatives associated with fat feeding. In many cases, poor production responses to added fat can be traced to reductions in feed intake or energy digestibility which might not even appear as statistically significant. For example, milk production was not changed by tallow in the Weigel et al. (1997) study

because of declines in DMI and energy digestibility, both of which were not significant statistically. Fat digestibility appeared normal for all diets. Efforts to improve the digestibility of fatty acids should continue, but not without losing sight of the importance of maintaining DMI and feed digestibility while adding fat to dairy rations.

Summary

Based on a compilation of results from 11 published studies, the true intestinal digestibility of fatty acids was very consistent across a wide range of fat sources and amounts added to the diets of lactating dairy cows. Lower digestibilities for a few fat sources, such as partially-hydrogenated tallow and soybeans, indicate that deviation from normal does infrequently occur. Stearic acid has lower digestibility in the intestines than unsaturated fatty acids, with appreciable flow of this saturated fatty acid to the duodenum of dairy cows regardless of the quantity of stearic acid consumed. Fatty acid digestibility in the intestines was appreciably lower and more variable when duodenal flow of stearic acid exceeded 400 g/day.

Simple energy calculations illustrate that the failure of fat supplements to increase DE consumed can be caused by dramatic reductions in fatty acid digestibility, or much smaller reductions in feed intake or digestibility of the basal feed ingredients. The latter occur more often and probably are the major reasons why fat supplements fail to increase milk yield in most situations. For these reasons, improving production responses to added fat should continue to consider digestibility of the fat supplement, but focus most attention on the impact of the fat supplement on intake and utilization of the basal ration.

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Table 1. References, fat sources, and number of observations for a data set on intestinal fatty acid digestibilities compiled from studies using lactating dairy cows with duodenal cannulae.

Reference	Fat Sources ¹	n
Christensen et al. (1998)	WSB, T	4
Enjalbert et al. (1997)	CaP, CaR	3
Ferlay et al. (1993)	CaR, Rapeseed oil	3
Kalscheur et al. (1997)	HOSO, HLSO, PHVS	4
Klusmeyer and Clark (1991)	CaP	4
Murphy et al. (1987)	Crushed Rapeseed	3
Pantoja et al. (1996)	PHT, T, AVF	6
Pires et al. (1997)	WCS, GCS	5
Tice et al. (1994)	WSB, WRSB, CRSB, GRSB	5
Weisbjerg et al. (1992)	T	7
Wu et al. (1991)	CaP, AVF	5

¹Abbreviations: AVF = animal-vegetable fat, CaP = calcium salts of palm fatty acids, CaR = calcium salts of rapeseed fatty acids, CRSB = crushed and roasted soybeans, GCS = ground cottonseed, GRSB = ground and roasted soybeans, HLSO = high linoleic sunflower oil, HOSO = high oleic sunflower oil, PHT = partially hydrogenated tallow, PHVS = partially hydrogenated vegetable shortening, T = tallow, WCS = whole cottonseed, WSB = whole soybeans, and WRSB = whole roasted soybeans.

Table 2. Duodenal flows and apparent and true intestinal digestibilities of 18 carbon fatty acids and total fatty acids in lactating dairy cows (compiled from the references in Table 1).

Fatty acid	Apparent digestibility, % ¹		Duodenal flow, g/d ²		True digestibility, % ²		
	Mean	SD	Low	High	Low	High	R ²
18:0	69.5	13.7	4	744	53.0	53.0	0.77
18:1	77.7	9.4	4	290	78.4	78.4	0.94
18:2	76.6	9.3	9	212	95.0	70.3	0.97
18:3	75.6	9.4	2	27	108.0	68.0	0.96
Total	72.0	10.2	203	1783	64.0	64.0	0.87

¹Fatty acids digested from duodenum to feces as a percentage of duodenal flow; SD = standard deviation.

²The lowest and highest duodenal flows (single observation) within the data set were selected for each of the fatty acids. The corresponding true digestibilities were calculated from the slopes relating fatty acids digested in the intestines (duodenum to feces) versus duodenal flow. True digestibilities are shown for the low and high duodenal flows with similar values indicating no significant quadratic effect.

Table 3. The amount that 3% added fat must reduce DM intake, digestibility of the basal dietary ingredients, or fatty acid digestibility of the fat supplement to prevent any increase in digestible energy (DE) consumed.

	Control diet	Fat diet	Depression effects for DE break-even ¹		
			Intake	Basal digestibility	Fat digestibility
DM intake, lb/d					
Basal	55.00	53.35	51.44	53.35	53.35
Fat	0.00	1.65	1.58	1.65	1.65
Total	55.00	55.00	53.02	55.00	55.00
DE, % of GE					
Basal	67.5	67.5	67.5	64.6	67.5
Fat	82.3	82.3	82.3	82.3	34.9
DE, Mcal/d ²	77.3	80.4	77.3	77.3	77.3

¹The amount that each must be depressed by the fat supplement to yield no improvement in DE (Mcal/d) consumed.

²Assumes 1.40 and 3.32 Mcal DE/lb for the basal diet and fat supplement, respectively, prior to any depressions.

Table 4. Selected studies with lactating dairy cows showing the effects of fat supplements on DM intake (DMI), milk production, and digestibilities of fatty acids and energy.

Reference ¹	DMI, lb/day	Apparent digestibility, %		Milk, lb/day
		Fatty acids (EE)	GE	
Jenkins and Jenny (1989)				
Control	50.4	73.2	65.5	70.4
5% Yellow grease (YG)	45.1	67.8	60.5	69.3
3% Hydrogenated YG	49.5	53.6	58.9	70.2
5% Hydrogenated YG	51.7	47.4	56.6	73.9
SEM	1.01	2.29	1.22	1.32
P < (Control vs fat)	NS	0.01	0.01	NS
Andrew et al. (1991)				
16% CP control	45.1	77.5	67.4	70.0
+ 2.95% CaP	42.5	78.4	69.0	75.2
20% CP control	45.1	88.1	68.8	70.8
+ 2.95% CaP	43.1	90.0	69.8	75.5
SEM	0.88	2.0	0.8	1.32
P < (Control vs fat)	0.05	NS	NS	0.01
Schauff et al. (1992)				
Control	48.8	76.7	64.6	67.1
WSB	48.0	64.5	62.4	68.0
WSB + 2.5% T	47.7	61.5	62.4	67.1
WSB + 4.0% T	47.1	57.6	62.4	65.3
SEM	1.32	2.4	0.6	1.98
P < (Control vs fat)	0.05	0.01	0.05	NS
Weigel et al. (1997)				
Control	49.3	77.0	67.2	63.1
3.5% T (18% CP, SBM)	46.6	77.6	66.2	68.6
3.5% T (18% CP, BP)	47.7	78.1	65.3	69.7
SEM	1.32	3.2	0.9	1.98
P < (Control vs fat)	NS	NS	NS	NS

¹Refer to Table 1 for a description of fat abbreviations; EE = ether extract, SEM = standard error of mean, SBM = soybean meal, and BP = by-product protein supplement consisting of blood meal, meat and bone meal, and corn gluten meal.

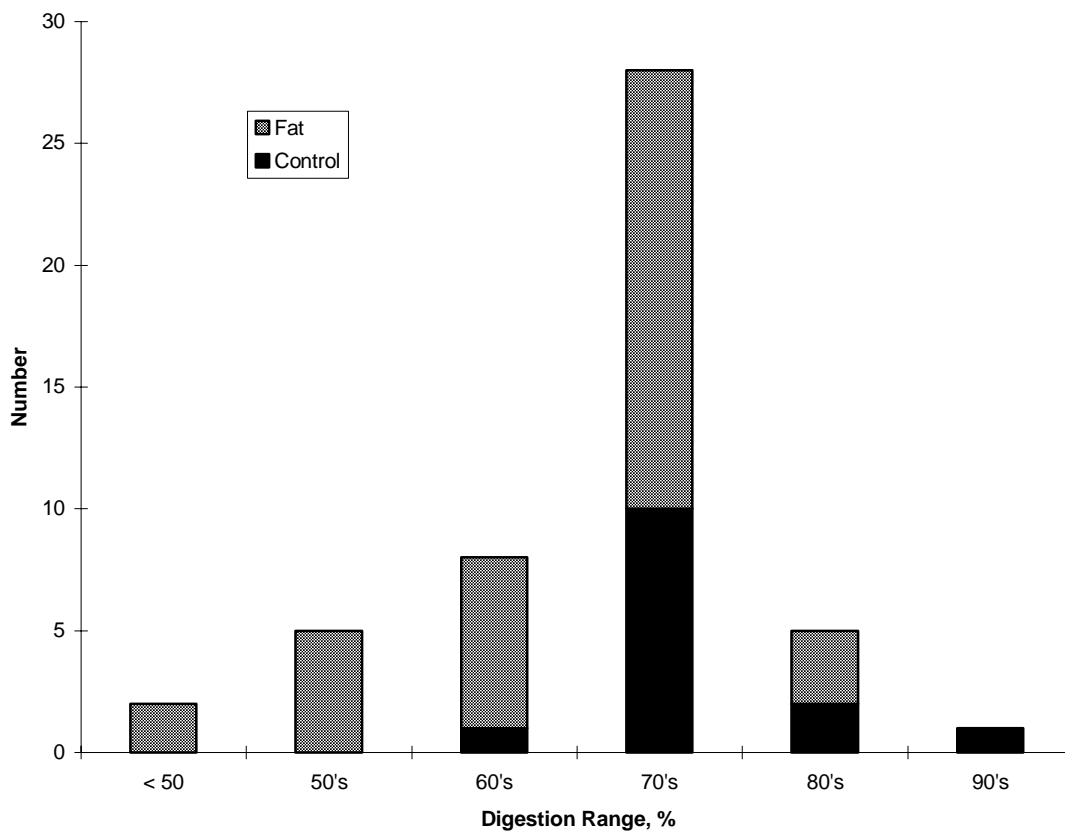


Figure 1. Frequency distribution of apparent intestinal digestibilities (duodenum to feces) of fatty acids in lactating dairy cows broken into 10 percentage unit increments. Data for the control diets ($n = 14$) or diets with added fat ($n = 35$) were taken from the 11 published studies described in Table 1.

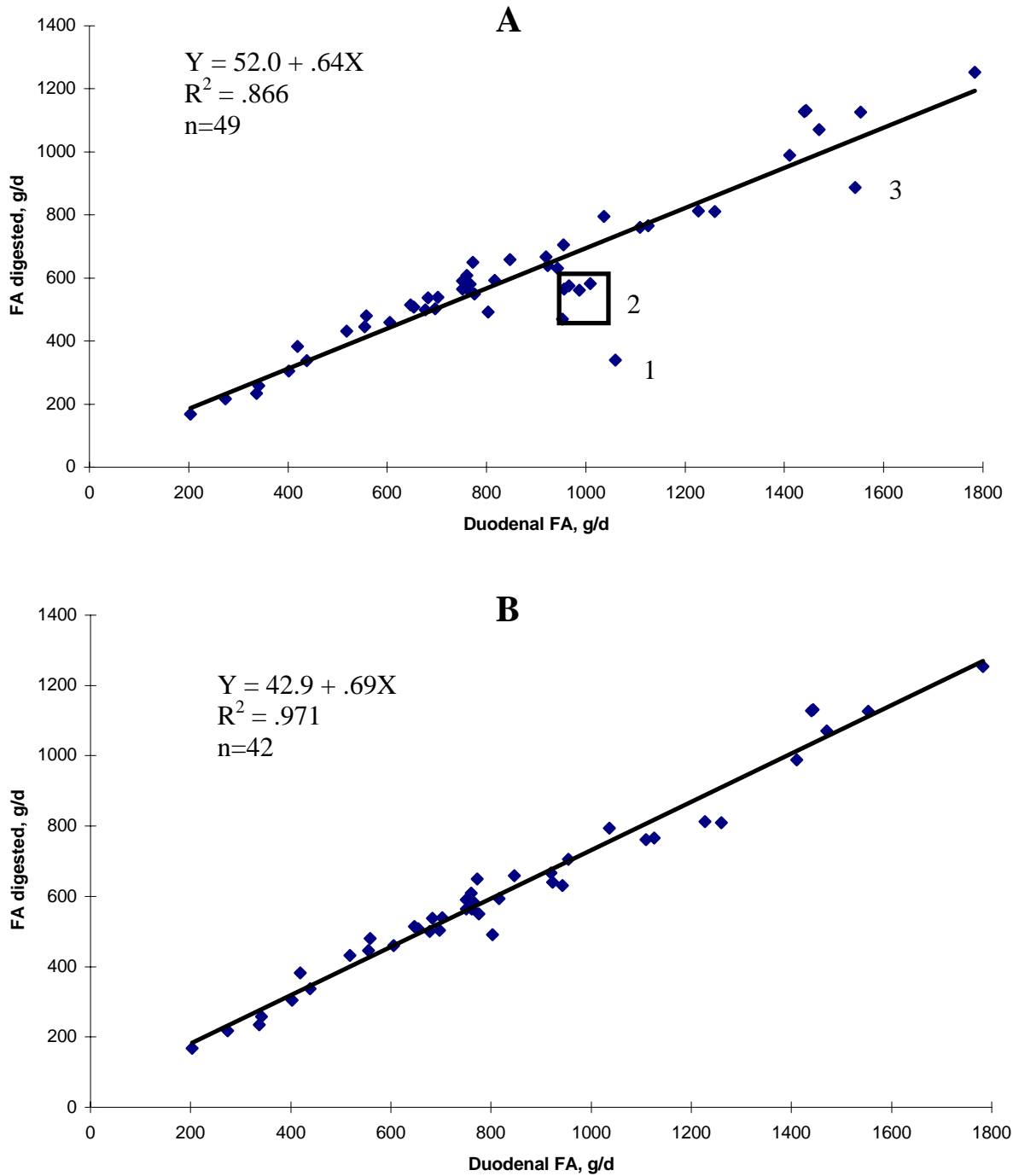


Figure 2. A) The relationship between fatty acids (FA) digested in the intestines versus fatty acids entering the duodenum in lactating dairy cows. Numbers refer to data points having intestinal digestibilities less than 60% where 1 is for cows fed partially-hydrogenated tallow, 2 is for cows (enclosed in a box) fed processed and unprocessed soybeans, and 3 is for cows fed whole raw soybeans plus tallow. B) Same as A except that points with intestinal digestibilities < 60% were deleted.

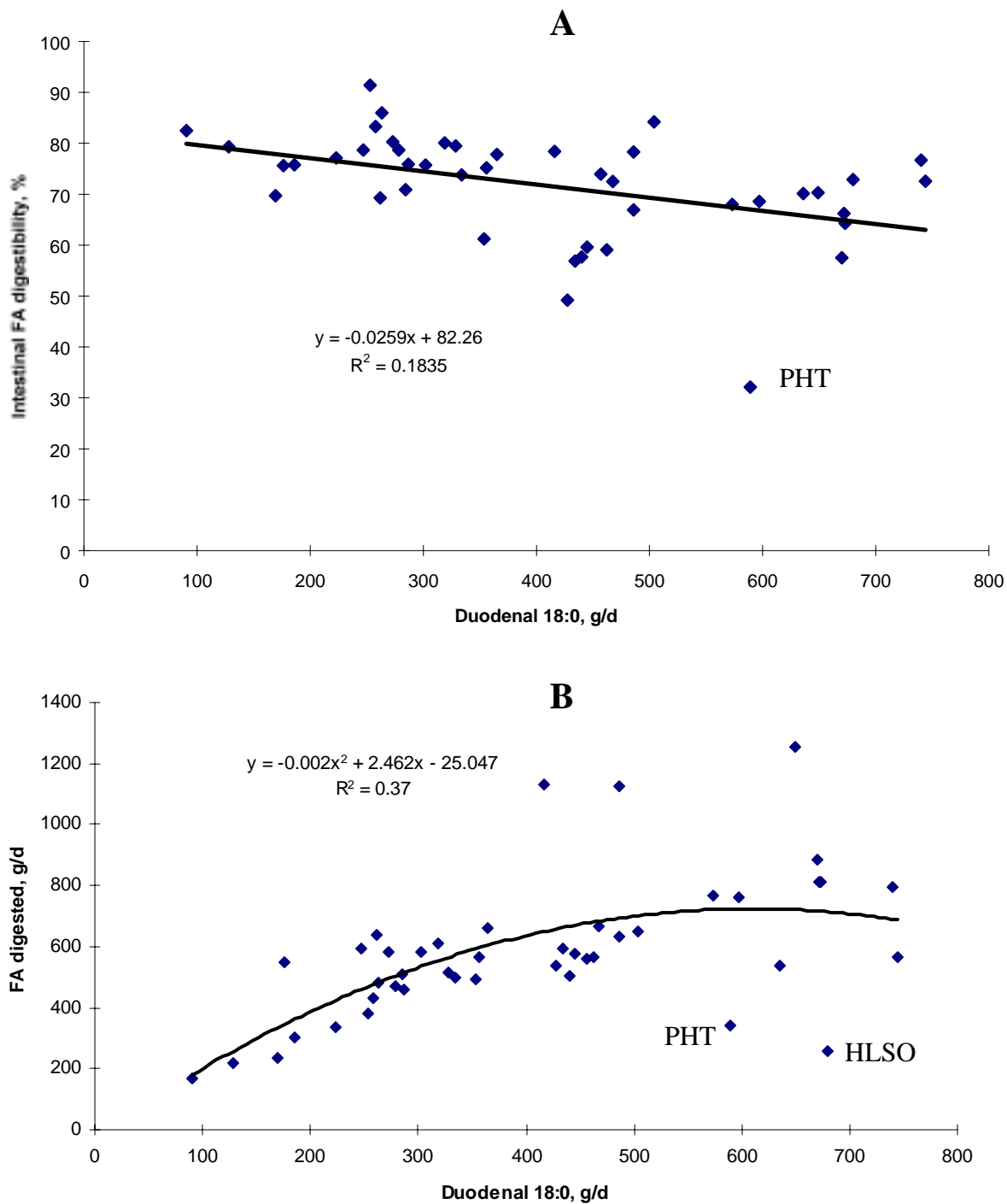


Figure 3. A). Relationship between grams of 18:0 reaching the duodenum and apparent digestibility of total fatty acids (FA) in the intestines (duodenum to feces). B). Relationship between grams per day of duodenal 18:0 and the grams per day of total fatty acids digested in the intestines (duodenum to feces). Cows fed partially hydrogenated tallow (PHT) and high-linoleic sunflower oil (HLSO) are labeled.

Current Research in Dairy Cattle Nutrition at Michigan State, The Ohio State, and Purdue Universities

Listed in this section are brief descriptions of the current dairy cattle nutrition research being conducted at the three universities which co-sponsor the Tri-State Dairy Nutrition Conference. The purpose of these descriptions is to allow people interested in dairy nutrition to be aware of the types of research that are currently being conducted and which will be published in the future. If there is an interest in learning more about a specific area of research, contact the researcher at their respective university.

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- **Spartan Dairy Ration Evaluator / Balancer – Version-3.**

Mike VandeHarr, Herb Bucholtz, Mike Allen, Dave Beede, Bob Kriegel, Roy Black

The dairy nutrition group is working on development a new Windows version of the Spartan Dairy Ration program. The program is scheduled for release shortly after the release of the National Research Council, Nutrient Requirements of Dairy Cattle in April, 2000.

Dr. Mike Allen, (517) 432-1386, msallen@msu.edu

- **Forage Utilization, Carbohydrate and Energy Intake – Maximizing Energy Intake in Early Lactation**

Graduate Students and staff: Richard Longuski, Dave Main, Masahito Oba, Jackie Ying

- A. Fiber Digestibility – Quantifying the importance of fiber digestion.
- B. Balancing production and removal of rumen fermentation acids.
 1. Adaptation of the rumen and rumen papillae.
 2. Effective fiber.
 3. Ruminant digestibility of carbohydrates – grains and fiber.
- C. Control of feed intake.
 1. Rumen fill.
 2. Fermentation acids
- D. Prediction of alfalfa NDF content
- E. Corn hybrid comparisons for silage

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- **Nutritional physiology of transition cows.**

Graduate students and staff: J. Davidson, D. Mashek, T. Pilbeam, S. Scheurer, R. Ashley, R. Kreft.

- A. Ca homeostasis
 1. Ca metabolism
 2. Comparison of different anion sources in prepartum diets.
 3. Optimal Ca concentration of prepartum diets with supplemental anions (HCl-treated feeds).
- B. Exercise physiology of pregnant dry cows.
 - A. Influence of programmed exercise on physical and physiological fitness in transition.
 - B. Effects of programmed exercise on energy metabolism of pregnant dry cows through transition.
- C. Energy (carbohydrate) nutrition of transition cows.
 1. Influence of dietary particle size distribution pre- and postpartum on animal health and performance.
 2. Effects of fermentability of the dietary fiber and other diet/nutrient characteristics on transitional health and performance.
 3. Influence of length of time (3 versus 6 wk) of feeding the close-up diet on peripartum health and performance.
 4. Effects of concentration of non-fiber carbohydrate in the close-up diet on peripartum health and performance.

- **Whole-farm nutrient management.**

- A. Influence/impact of dietary nutrients (e.g. phosphorus) utilization on whole-farm nutrient management.
- B. Development of phosphorus excretion models to predict on-farm excretion from cows for whole-farm budgets.

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- **Nutrition and Feeding Management for Michigan Dairy Herds**

Location of Research: MSU's Upper Peninsula Experiment Station, Chatham, MI

Research Staff: Paul Naasz, Alice Charlebois, Matt Thompson

- A. Effects of feeding management systems and grain supplementation on grazing dairy cattle.
 1. Effects of forage species on lactating cow performance grazing alfalfa or birdsfoot trefoil.
 2. Effect of grain feeding strategies on grazing lactating dairy cows.
- B. Practical feeding management methods that effect feed intake.
 1. Effect of the number of hours feed is available on feed intake and performance.
 2. Effect of diet dry matter on feed intake and performance.

Dr. Tom Herdt, Animal Health Diagnostic Laboratory, 517-355-8725 herdt@pilot.msu.edu

- A. Assessment of nutritional status in animals
 - 1. Vitamin and mineral status
 - 2. Energy status
- B. Transition cows and metabolic diseases
- C. Nutrition-fertility relationships

Dr. Mike VandeHaar, 517-355-8489, mikevh@pilot.msu.edu

Graduate students and staff: Jim Liesman, Kristin Perkins, Luis Silva, Brian Witlock, Maria Zavala

- A. Understanding the endocrine mechanisms by which energy and protein nutrition alter metabolism and mammary development in dairy cattle.

Mammary development: Previous work at MSU suggests that high protein along with high energy may accelerate mammary development of heifers, but this idea has never been directly tested. Research is being conducted to investigate the effects of protein nutrition on mammary development of dairy heifers grown at 2.4 lb/day before puberty. Insulin-like growth factor (**IGF**)-I may be the mechanism by which nutrition alters mammary development. Effects of IGF on mammary cells are complicated by the presence of several binding proteins. Thus, we are studying the role of IGF binding protein-2 on mammary cell proliferation in vitro. Eventually, this work will enable us to improve the growth and mammary development of dairy heifers and to manipulate mammary involution to control the lactation cycle.
- B. Role of nutrition on dry cow health.
- C. Dry cows: The relationship of prepartum lipid mobilization on farms to disease incidence, fertility, and milk production. They have found that cows mobilizing fat prepartum are much more likely to contract mastitis in the first 10 days after calving. Because neutrophils are the first line of defense against mastitis, work is underway to examine the effect of energy and protein nutrition on neutrophil function of cattle. Eventually this work will help us make more informed recommendations about feeding high-producing dairy cows in the periparturient period.

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Energy and Forages

- **Estimating available energy content of corn silage.**

Digestibility trials were conducted on various types of corn silage (different varieties, maturity ratings, and processing). Laboratory tests are being conducted in an attempt to develop an analytical method that can be used to estimate starch digestibility in vivo. One promising technique is the amount of starch found in the bottom pan after the particle size of silage is measured with the Penn State separator. Increased starch in the bottom pan was positively correlated with in vivo starch digestibility. These experiments are continuing. (*Weiss*)

- **Role of forage surface characteristics on absorption of fatty acids.**

An in vitro procedure to measure the amount of fatty acid adsorbed to feed particles was developed. Legume hay and silage adsorbed more fatty acid than did grasses or corn silage. Differences in fatty acid adsorption could account for improved rumen function and animal performance when fat is fed in high legume diets. (*Yang and Palmquist*)

- **Effect of yeast culture and level of forage NDF (FNDF) on transition cows.**

Sixty Holstein cows were assigned to two treatments at 21 days before calving and were group fed; thirty-six of the cows were fed the transition diet with yeast culture (YC) (Diamond V Mills, Cedar Rapids, IA), and 24 cows were fed the diet without YC. Cows fed YC prepartum were also fed YC postpartum (60 g/d). After parturition, cows were blocked and individually fed one of five treatments for 140 days: 1) 21% forage NDF (FNDF) without YC; 2) 21% FNDF with YC, 3) 17% FNDF without YC, 4) 17% FNDF with YC; and 5) 25% FNDF with YC for 30 days then switched to diet 4 for 110 days. A quadratic response to 25, 21, and 17% FNDF for cows fed YC during the first 30 DIM occurred with milk and milk protein yields and DM intake. Feeding 17 versus 21% FNDF resulted in higher DM intake as a percentage of BW and milk protein percentage from 31 to 140 DIM. During this time period, there tended to be an interaction between FNDF and YC supplementation on yields of 3.5% FCM and milk fat; YC supplementation increased these yields with 21% FNDF but not with 17% FNDF. Feeding 21% FNDF resulted in higher milk and milk protein yields and DM intake during the first 30 DIM,

but the benefits were not observed after 30 DIM. The 17% FNDF may be too low for the first 30 DIM, but may result in improved performance compared to 21% FNDF after 30 DIM. Yeast culture resulted in improved performance after 30 DIM for cows fed the higher level of FNDF. (*Wang and Eastridge*)

- **Effectiveness of cottonseeds in diets differing in forage NDF percentage and in source of starch.**

Work is underway to determine if the effectiveness of whole fuzzy cottonseeds increases with decreasing forage NDF concentration and, if so, if it increases linearly or quadratically or if it interacts with ruminal degradability of starch. Six diets include a control with 21% forage NDF from alfalfa haylage, three diets in which alfalfa haylage was replaced by three levels of whole cottonseed down to about 14% forage NDF (all diets have similar concentrations of fat), and two diets similar to the low and medium replacement of forage NDF with cottonseed NDF except that ground corn is replaced with steam-flaked corn. Chewing data, ruminal mat consistency, passage rates, site of nutrient digestion, and milk production are being measured in mid-lactation cows. (*Harvatine and Firkins*)

- **Brown mid-rib corn versus dent corn for silage.**

Eight intact multiparous cows and four cannulated primiparous cows were fed four diets in a 4 x 4 Latin square design: 1) 17% forage NDF (FNDF) with brown midrib (BMR) corn silage (CS), 2) 21% FNDF with BMR CS, 3) 17% FNDF with conventional CS (CCS), and 4) 21% FNDF with CCS. About 75% of the forage was from CS and 25% from alfalfa hay. For intact cows, DM intake was higher and milk protein yield tended to be higher for BMRCs than CCS. For the cannulated cows, rumen mat consistency, potential digestible NDF, and rate of disappearance of potential digestible NDF were similar among treatments. Total digestible NDF was higher for BMRCs than CCS. Cows fed BMRCs had higher ruminal propionate and lower butyrate than cows fed CCS. Cows fed 21% FNDF had higher acetate and lower propionate than cows fed 17% FNDF. There were no adverse effects of feeding BMRCs in the low FNDF diet. (*Qiu, Eastridge, and Sulc*)

Rumen Microbial Protein and Digestibility Markers

Separate requirements by ruminal microbes for peptides and ammonia. We used a continuous culture system to set passage rates and other variables to study ruminally degradable protein (RDP) and urea as protein sources for mixed ruminal microbes. Diets were balanced to provide RDP at 50 or 70% of total protein. To ensure adequate supplies of ammonia (separate from complete breakdown of RDP), urea was infused at the rate of 0.4 g/L of artificial saliva. The design was a 2 x 2 factorial arrangement of treatments in a 4 x 4 Latin square. Selected data are shown in Table 1.

Table 1. Effect of ruminally degraded protein (RDP) and urea on concentrations of metabolites and on digestibility of nutrients in continuous culture.

Item	Diets				SE	P values		
	Urea		No Urea			RDP	Urea	RDP x Urea
	50% RDP	70% RDP	50% RDP	70% RDP				
Total VFA, mM	97.5	100.1	78.5	78.6	10.1	0.49	0.01	0.83
Ammonia N, mg/dl	7.36	7.42	0.31	0.20	0.53	0.95	0.01	0.77
Organic matter (OM)	45.7	50.0	30.1	39.9	3.4	0.01	0.01	0.19
digestibility, %	52.7	52.5	47.5	53.2	1.7	0.03	0.03	0.02
NDF digestibility, %	46.0	46.8	38.7	41.1	3.1	0.21	0.01	0.65
ADF digestibility, %	56.8	69.3	38.4	51.9	7.8	0.01	0.01	0.91
Nitrogen digestibility, %								
Efficiency of bacterial protein Synthesis, g N/kg OM truly digested	44.1	48.8	38.3	40.1	3.7	0.08	0.02	0.50

Our results clearly show that providing urea to increase ammonia N concentrations increased volatile fatty acid (VFA) production by increasing digestibility of NDF, nitrogen (N), and organic matter (OM). Because NDF digestibility was affected most by lack of RDP and urea (interaction among treatments), while ADF digestibility was affected less, our results show that digestibility of hemicellulose (which is part of NDF but not ADF) was decreased more than digestibility of cellulose by lack of peptides. Digestibility of ADF was affected by urea but not RDP. Hemicellulose is degraded by cellulose-digesting bacteria that require ammonia and can't use peptides. However, it is also degraded by a bacterium, *Butyrivibrio fibrisolvens*, which also has a major role in protein and starch digestion. Therefore, our results show that models like the CPM Dairy that assume that ammonia N, but not peptides, is needed for fiber digestion oversimplify the actual situation because they are based on cellulose-digesting bacteria. Much more work is needed to characterize RDP needs of microbes that digest all fiber sources (not just cellulose) to improve prediction of RDP needs for dairy cows.

Interestingly, N digestion (feed protein but excluding urea) was reduced greatly when urea was not infused. The activity of protein degradation probably is proportional to bacterial cell concentration. Increasing growth factors (such as ammonia) increases bacterial growth (cell division), which increases the amount of proteolytic enzymes, enzymes that are mainly constitutive (constant expressing). Although this response in increased proteolysis often has been shown to be proportional to the supply of digestible carbohydrate, the effect of ammonia N supply on N digestion has rarely been shown. The efficiency of conversion of degraded N into microbial protein was decreased when RDP, but especially urea, was not adequate. (*Griswold and Firkins*)

Milk Composition

- **Effect of feeding whole roasted soybeans on spontaneous oxidized flavor (SOF) in milk.**

Milk fat composition and score for SOF were monitored in two groups of cows supplemented with no fat or with whole roasted soybeans (15% of dietary DM). Milk was sampled and scored at three-week intervals for three months. Feeding whole roasted soybeans increased milk unsaturated fatty acids and the development of SOF. Mean SOF (six-member trained panel) of pasteurized test milk was increased compared to control milk: at day 0, 0.2 versus 0.03; day 3, 2.0 versus 0.6; and day 8, 3.8 versus 1.9, on a scale of 0 to 1 = none, 1 to 2 = slight, 2 to 3 = moderate, 3 to 5 = strong, and > 5 = intense oxidized flavor. Feeding whole soybeans may contribute to SOF problems in the milk supply. (*Palmquist, Weiss, and Timmons*)

- **Effect of dietary *trans*-vaccenic acid on conjugated linoleic acid (CLA) in tissues and milk.**

Dietary *trans*-vaccenic acid (*trans*-11 18:1) fed to mice was desaturated and stored in tissues as CLA (*cis*-9, *trans*-11 18:2). Ten to 12% of dietary vaccenic acid was desaturated; this was equivalent to 50% of the amount stored. Vaccenic acid in milk fat potentially can double the amount of CLA available in the human diet. *Trans*-vaccenic acid should not be included in total trans fatty acid content of foods if labeling is mandated. (*Santora and Palmquist*)

- **Effect of rate of passage, pH, and level of linoleic acid on formation of CLA and *trans*-vaccenic acid in ruminal contents.**

Continuous fermenters were used to examine the effects of rate of passage (0.04 versus 0.08 /h), pH (5.8 versus 6.5), and dietary level of linoleic acid (1.0 versus 3.0%) on the effects of formation of CLA and *trans*-vaccenic acid via ruminal biohydrogenation. Laboratory analyses are underway. Results from this study will be used to design a trial with cannulated cows whereby the fatty acid profile in duodenal digesta and milk will be determined. Manipulation of the feeding program for lactating cows may result in increased CLA in milk, which may have positive human health implications since CLA has been identified as being anticarcinogenic. (*Qiu and Eastridge*)

Minerals and Vitamins

- **Effect of fat source and supplemental vitamin E on immunity in peripartum cows.**

At three weeks before calving, cows were assigned to one of four diets. Diets provided either 1000 or 3000 IU/day of supplemental vitamin E and either 3% tallow or 3% fish oil arranged factorially. Fish oil reduced DM intake significantly during the prepartum period (18.0 versus 21.8 lb/day) but did not affect colostrum yield. Milk production during the first 30 days of lactation was lower by cows fed fish oil prepartum, even though cows were fed a common diet after parturition. The fat content of colostrum was increased by feeding extra vitamin E. The combination of extra vitamin E and fish oil increased IgG concentration in colostrum, but treatments did not affect neutrophil function. Results from this study suggest fish oil does not greatly influence immunity in peripartum cows. (*Jones and Weiss*)

Effect of biotin on milk production. This experiment is being conducted to determine whether biotin influences milk production in early lactation cows. Starting two weeks before estimated calving and continuing until 100 days in milk, cows were fed diets that provided 0, 10, or 20 mg/day of supplemental biotin. Milk yield, milk composition, and DM intake are being measured and various indices of carbohydrate metabolism are being studied. The experiment will be completed in summer, 1999. (*Zimmerly and Weiss*)

- **Copper.**

Feeding diets that depleted liver copper stores of lactating cows increased unsaturation of blood plasma triglycerides; this was caused apparently by less complete ruminal biohydrogenation. Mammary desaturase activity compensated for unsaturation in plasma, causing smaller differences in milk fat unsaturation than observed in plasma. (*Morales and Palmquist*)

Dairy Farm Management

- **Management information systems.**

Economic design of control charts for monitoring longitudinal data: The objective is to develop nonparametric control methods optimized for the relative cost of Type I and Type II errors. The new methods should be more reliable and accurate at detecting changes in processes like milk production, milk composition, and body composition score. We have derived a general methodology to determine optimum sample size, sampling period, and location of boundaries for control charts used to monitor feed production processes. *Unbiased methods of estimation of gradient functions:* In the animal sciences, measurements are often taken for which the interest is in estimating their rates of change (e.g. weights of animal are taken periodically to estimate their average daily gain). We have proven that all current methods of estimation yield biased estimates. In this project, we want to estimate the magnitude of the bias and develop new methods that would yield unbiased estimates of the gradient. We have derived four alternative cubic splines methods. Two of them yield unbiased parameter estimates under most of the conditions studied for both growth and milk production data. However, the parameter estimates have generally larger variances than traditional (but biased) quadratic equations. So the choice is between unbiased or minimum variance estimates. (*St-Pierre*)

- **Optimization methods of agricultural systems.**

Development of methods for the maximization of mathematical preference models: Current ration balancing programs use linear programming (LP) models and algorithms to determine a least-cost ration. An LP model assumes perfect knowledge of ingredient costs, ingredient composition, and animal requirements. None of these are met in practice. As a result, applied nutritionists spend a large amount of time deriving a solution that meets their expert preferences. Such preferences can be quantified and models developed to directly optimize those preferences. We have developed two alternatives for the solution of what we call "Maximum Preference Programming Models". Both will be programmed and tested for their reliability and speed. (*St-Pierre and Posner*)

- **Financial strategies for U.S. dairy farms.**

Managing risk associated with milk income variance: The price paid for milk to farmers is expected to show much larger fluctuations through time than what has been customary, a direct consequence to prices being more market driven. New mechanisms, such as milk futures contracts, will emerge as means of price variance reduction. The price received for milk is only one component of the monthly

gross income from milk on a dairy farm, the other part being a function of the number of cows being milked, their daily milk production, and the number of days in the month. In this research, we want to evaluate the relative weight of milk price fluctuations versus herd monthly milk shipment fluctuations on monthly milk income variance. We have derived a method for predicting the future performance of a given herd (and its prediction variance) based on historical data, mixed model estimates, and transitional probabilities. The method is currently under evaluation. (*St-Pierre and Thraen*)

- **Methods of monitoring and improving nitrogen (N) utilization on dairy farms.**

Validation of a simple model linking blood urea nitrogen (BUN), milk urea nitrogen (MUN), and urinary nitrogen (UN): Kuhn at the University of Maryland proposed a simple model to predict N excretion in dairy cows. The model was developed exclusively with Holstein cows and needs to be validated with other breeds. Jersey cows would serve as good research models due to their high relative N (protein) output. Also, a critical relationship between MUN and urinary N excretion needs to be tested. Four diets differing widely in ruminally degradable protein and ruminally available carbohydrates were fed to four Holstein and four Jersey cows in a double Latin square design. The relationships between MUN, BUN, and total urinary N excretion are being quantified. (*St-Pierre and Kauffman*). *Improving nitrogen and phosphorus utilization in dairy rations:* Environmental concerns are making the issue of improving nitrogen utilization by livestock a more urgent one. We are evaluating: (1) how grouping strategies on dairy farms affect nutrient balance and optimum allocation of nutrient inputs, and (2) how uncertainty in levels of inputs, model structure, and parameter estimates influence the optimum allocation of inputs. (*St-Pierre*)

- **Ohio Dairy Ration Program.**

A new version (Version 5.2, 1998) of the Ohio Dairy Ration Program has been released. The program assists in developing feeding strategies for meeting nutritional requirements, minimizing feed costs, and monitoring the nitrogen and phosphorus balance on dairy farms. The feed library consists of 108 feeds, and the program can be used to evaluate diets and generate least-cost formulated rations for dairy cattle. Up to five lactating-cow, two dry-cow, and three heifer groups can be identified and worked with interchangeably. Feed costs per day can be summarized for any animal group, but income over feed costs and feed costs as a percentage of milk income are provided for lactating-cow groups and the entire herd. Duration of available forage is calculated when current inventories of forage are entered. Dry matter intake and nutrient requirements are based on body weight, weight gain (heifers, first- and second-lactation animals, and extra body condition), milk yield, milk fat, milk protein, days in milk (or proximity to calving for dry cows), and environmental temperature. The user can alter the recommendations for DM intake, CP, NE_L , minimum NDF, maximum forage NDF, Ca, P, and Mg. Lysine and methionine recommendations and amounts provided by a diet are expressed as a percentage of essential amino acids (EAA) flowing to the small intestine. Intakes and outputs (milk and manure) of nitrogen and phosphorus are calculated for each animal group and for the herd. (*Eastridge, Weiss, and Lemon*)

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• **Rumen Protected Choline and Dietary Protein for Transition Cows**

Researcher: Shawn Donkin

Potential milk production may be limited by choline status in transition dairy cattle if tissue requirements exceed postruminal supply and de novo synthesis. Protein supply during this period may indirectly impact choline status through amino use for choline synthesis. Effects of 0, 6, and 12 g/day of rumen protected choline (**RPC**) were tested with two dietary protein levels using 48 multiparous Holstein cows in a 3 x 2 factorial arrangement of treatments. This trial is part of Jennifer Hartwell's M.S. project. Dietary protein differed only by the addition of rumen undegradable protein (**RUP**) to the prepartum diet. Beginning 28 days prior to expected calving, cows were fed either 12% CP and 30% RUP (12CP:30RUP) or 14% CP and 40% RUP (14CP:40RUP) and the addition of RPC as CAPSHURE (Balchem Corp.). After calving and through 120 days of lactation, cows received a common diet and continued RPC as per their prepartum assignment. Prepartum intake of diets lacking RPC was decreased by the addition of RUP. Addition of 6 g/day RPC increased intake of the 14CP:40RUP but not the 12CP:30RUP diet. Milk production through 120 days of lactation was higher when cows were fed 12CP:30RUP compared with 14CP:40RUP during the prepartum period. The combination of 12CP:30RUP prepartum and 12 g/day RPC pre- and postpartum yielded the greatest amount of milk. Feeding 6 g/day RPC increased milk production when cows were fed 14CP:40RUP but decreased milk production when 12CP:30RUP was fed prepartum. Feeding 12 g/day RPC increased milk production in combination with the 12CP:30RUP prepartum diet but decreased production when fed with the 14CP:40RUP prepartum treatment. Postpartum intake was increased during the first 120 days of lactation when cows were fed a 12CP:30RUP diet during the prepartum period. Feeding 6 g/day RPC through lactation stimulated intake in cows fed 14CP:40RUP prepartum, whereas 12 g/day depressed intake regardless of the prepartum protein level. These data confirm and extend our previous observations of carryover effects of prepartum protein on postpartum performance and suggest an interaction between dietary protein and choline supply in the transition dairy cow.

- **Effects of Feeding Corn Silage From Bt-corn on Feed Intake, Milk Production and Dry Matter Digestibility in Lactating Dairy Cows**

Researchers: Shawn S. Donkin, Tim Johnson

The Bt corn hybrids offer a new weapon for corn growers against the yield reductions caused by European corn borer (ECB) infestation. However, as is the case with other specialty corn hybrids, the benefits of Bt corn on animal production have not been fully evaluated. The primary objective this ongoing research is to assess the effects of feeding corn silage prepared from Bt-corn on feed intake, milk production, and dry matter digestibility compared with silage from an isogenic corn variety grown under identical conditions and harvested at the same physiological maturity.

Twelve mid-lactation dairy cattle were selected from the Purdue Dairy Research and Education Center and blocked by previous milk production and randomly assigned to one of two treatment groups. Animals are fed diets containing forage as corn silage from either a Bt-corn hybrid or isogenic hybrid and grain from the same genetic sources. Diets are formulated according to NRC (1989) requirements for lactating dairy cattle and evaluated for amino acid adequacy using the Cornell-Penn-Miner model of ruminal carbohydrate and protein metabolism. Treatments are applied as a switchback design in three 21-day periods. The first 14 days of each period is used for adaptation to treatment and the last seven days used to determine effects of the treatments on feed intake, milk yield, and milk composition. Feed samples are collected weekly for DM, CP, ADF, NDF, and ash determination. Morning and evening milk samples collected daily during the last seven days of each period will be analyzed for fat and protein analysis.

In addition, samples of silage for Bt-corn and the isogenic line were freeze dried, ground through a 4 mm screen, and placed in the rumen in nylon bags in order to determine in situ dry matter digestibility in a series of time intervals over a 72-hour period. These determinations will provide information on whether the Bt gene product has any impact on digestion of corn in the rumen and the impact on the endproducts of rumen fermentation.

- **Pre-partum Milking of Heifers**

Researchers: Mike Schutz, Susan EicherPruitt

The peri-parturient period has many stressors for first-calf heifers. The overall objective of a project undertaken by Mike Schutz and Susan Eicher was to investigate the effects of parlor acclimation and pre-partum milking on behavior, production, and health parameters. Forty-eight first-calf heifers were blocked according to expected calving date. Two heifers per block were randomly assigned to control (CTL), parlor acclimation (ACC), or pre-milk treatments (PRE). The ACC heifers were taken through the parlor without milking and the pre-milk heifers were milked for three weeks prior to expected calving. Heparinized blood samples were taken from the tail-vein within 24 hours of parturition and on day 3, 5, 7, 10, and 14 following parturition. Plasma IFN- γ , IgG1, IgG2, haptoglobin, and α -₁ acid glycoprotein were measured. For all heifers, calving ease scores (1, easy to 5, severe), calf birth weights, and incidence of retained placenta were recorded. At first milking, udder edema was approximated by measuring the area between teats before and after milking and the change in area. Milk weights and SCC were

collected and measured for the first 14 days of lactation. Plasma IgG2 concentrations of the acclimated cows were less than those of the control cows at 24 h and day 5, 7, 10, and 14. The concentration of IgG2 of acclimated cows was lower than the milked cows at 24 hours ($P < 0.05$). Haptoglobin, an indicator of inflammation, increased for all treatments through day 3, but PRE cows began to decrease in haptoglobin concentrations by day 5. The PRE cows had lower plasma haptoglobin concentrations (126 $\mu\text{g/ml}$) than the control cows (426 $\mu\text{g/ml}$, $P < 0.05$) and tended to have lower concentrations than the ACC cows (237 $\mu\text{g/ml}$, $P < 0.10$) on day 10. By day 14, all haptoglobin treatment means were below 200 $\mu\text{g/ml}$, but haptoglobin of control cows was greater than that of pre-milked and acclimated cows. The other acute phase protein, α_1 acid glycoprotein, was not different among treatments, but the ACC group peaked on day 10 compared to day 1 peak of CTL and PRE cows. Plasma IFN- γ concentrations were not affected by treatment. These data suggest that pre-milking or parlor acclimation modulate some immune responses.

After accounting for sex of calf, no significant differences ($P > F < .05$) were observed for calving ease, calf birth weights, or incidence of retained placenta. Change in udder area was significantly larger for PRE than for ACC or CTL heifers. Compared to ACC and CTL, PRE heifers produced significantly more milk in the first and second weeks. Daily somatic cell score (SCS) was less for PRE heifers, but geometric mean of daily SCS was significantly different only for the second week. Prepartum milking of heifers appeared to have beneficial effects on production and health of heifers near parturition. Results will be reported at the 1999 American Dairy Science Association meetings in Memphis, TN.

- **Economic Values of Somatic Cell Scores**

Researchers: Mike Schutz

A joint project with Joan Fulton (Agricultural Economics) was undertaken to survey dairy cooperatives regarding their dairy pricing schedules. The first objective was to document changes in the structure of cooperatives in the dairy industry. The second objective was to develop a more precise formula to represent incentive payments to producers for milk with low somatic cell scores. There is great variation in how producers are rewarded for milk quality. However, it was found that a change of one unit in somatic cell score (doubling or halving of somatic cell counts) is worth approximately \$0.11/cwt at the Holstein breed average SCS. This result can be used to assist in determining appropriate selection weight to place on reduced SCS in a selection index or national breeding objective. Further, the result verifies the economic weighting for PTA SCS currently used in the Net Merit, Fluid Merit, and Cheese Merit indexes that are reported quarterly by USDA for evaluated bulls and cows.

- **Patterns of Somatic Cell Score**

Researcher: Mike Schutz

As part of her MS thesis work, Xin Li will look at methods to determine whether patterns of test day SCS can be used to distinguish between environmental and chronic episodes of mastitis, which may be under different levels of genetic control.

- **Antibiotic (Dry Cow Therapy) to Control Mastitis in Heifers**

Researcher: Mike Schutz

A cooperative research project will be initiated with the University of Nebraska (Dr. Jeff Keown) to study the efficacy of pre-partum antibiotic therapy for heifers in Midwest climates. Blocks of three heifers will be defined according to calving date, and heifers will be randomly assigned to three treatments within blocks. Treatments will be a control, a non-lactating cow (dry cow) antibiotic administered 60 days prior to calving, and a lactating cow therapy administered 2 to 3 weeks prior to expected calving date. Sires of heifers will be tracked to determine any possible genetic control on response to antibiotic treatment.

- **Tail Docking of Holstein Calves**

Researcher: Susan EicherPruitt

Research compared the effects of tail docking calves. Twenty calves were assigned to two groups with tails docked or remaining intact. In the docked group, tails were banded at three weeks of age and removed three weeks later. Calves were housed individually in hutches. Tail-docked calves showed increased agitation and lost heat sensitivity near the tail end at a maximum of 120 minutes after banding. Tail-docked calves had increased fly numbers on rear legs, but no differences in fly avoidance behavior were observed.

- **Measuring Impact of Nutrition and Transportation Stress on Immune Competence**

Researchers: Susan Eicher Pruitt, USDA-ARS and Tim Johnson

Profitability of dairy operations involved in raising replacement female youngstock and stand-alone, contract-raising enterprises is dependent on ensuring health of replacements and nutritional adequacy of diets fed growing replacements. Youngstock experiments will be performed at the Purdue Dairy, the ARS Animal Behavior Research Unit, or outlying stations. Immune status of animals will be monitored by determining plasma cytokines, acute phase proteins, and IgG concentrations. White cell counts, neutrophil to lymphocyte ratio and lymphocyte phenotypes are other measures that will be used to assess immune competency, (Eicher, et al., 1997). Body weight change and rate of gain and subsequent health status and cognition will also be monitored.

Contract raising of replacements has received national attention with the formation of the National Professional Heifer Raisers Association, which has held national conferences addressing management and nutritional factors effecting contract growers. Contract raising operations are dependent on co-mingling animals from different farms. This practice imposes additional demands on animal health protocols and efforts to promote biosecurity and to avoid transportation stress.

Feeding Practices of High-Producing Herds in Indiana, Ohio, and Michigan

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Introduction

The feeding programs of high producing dairy herds in the Northeast, Upper Midwest, and Western States have been previously presented (Bath, 1995; Chase, 1993; Keuning et al. 1999). Formulation of herd rations and management practices utilized on high-producing operations and records of individual cows producing greater than 70,000 lb of milk have received much attention in the popular press. The objectives of this presentation are not to suggest a single feeding formulation or feeding management protocol that will insure duplication of high producing herd records. Rather, the objectives are to recount specific unique and shared feeding practices utilized on some high-producing dairy farms (Table 1) in the Midwestern States of Indiana, Ohio, and Michigan. More detailed information (e.g. ingredient and chemical composition of rations, etc.) will be shared during the Conference than provided in this paper.

Indiana Farms and Dairy Rations

Darrell and Bonita Richard, Goshen Indiana own and manage a herd of 50 registered Holsteins, milked twice each day at 0515 and 1700 hours. The herd is housed

in free-stalls with central raised bunk and wall partitioned feeding system for TMR. Cows are milked in a flat barn parlor with 24-converted comfort stalls. Cows are not offered feed during milking and have access to a TMR for 22.5 to 23 hours/day. Cows are divided into three groups, one milking cow group, and a far-off and close-up dry groups. All lactating cows are fed one TMR mix (1x/day) with 8.3% of feed as orts that are fed to young stock.

Dry cows. Average length of dry period is 57 days; cows are dry treated at last milking with no cows being double dry treated. A TMR is available to dry cows 12 hours/day and separately fed hay is available 24 hours/day. In 10% or less of cows, feed and water are limited for 2 to 3 days to prepare for drying off by reducing milk flow. MuSe™ and vaccinations are also given at dry off. Hoof trimming of dry cows has been discontinued because Darrell thinks that trimming in late lactation is a better practice.

Close-up dry cows. Pre-fresh steam-up or transition cows are housed in freestalls in the same group as far-off dry cows. Three weeks before expected calving, close-up cows are put in gang locks 1x/day (0.5 hours) and receive additional grain supplement. During summer when the dry

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groups are on pasture, dry cows may be on pasture 6 hours/day and then around milking time are offered steam-up mix in ganglocks. MuSe™ is given IM to cows in steam-up group the week before calving.

Fresh cows. After calving, cows are kept in box stalls for 2 to 3 days, they are closely monitored, and may stay in the box stall for up to a week. A combination ration of milking herd TMR and pre-fresh steam-up TMR, available 24 hours/day, is fed to newly fresh cows in the box stalls. Cows may stay in box stalls for up to a week if they are “slow starters”, have sore feet, retained placenta, or other health problems. Ketosis is rarely seen, but if detected, it is treated by an IV of dextrose and drenching with propylene glycol.

Lactating cows. All first lactation and multiparous cows are fed a one group TMR that is available 22.5 to 23 hours/day. Bunk space measures 3 ft/cow (50 ft bunk, 2 sides and wall bunk 40 ft). Water is available from two freeze proof, no energy waterers.

Fred and Pat Beer are owners of a 275-cow herd in Milford, IN. They moved into a new six-row drive through free stall facility in 1994. Following the move, the old facilities are now being used to house the far-off dry and heifer groups. The herd increased 2,000 lb/cow of RHA milk the first year in the new barn and has continued to grow in size and increase production level in the subsequent years. Three quadrants of the drive through barn are stock at a density of 120%. Only the newly fresh group is stocked at a rate of less than 1 cow per freestall. Because the large lactating groups are stocked at 120% in a 6-row freestall barn, bunk space per cow is 16”. This works for the Beer’s but requires 23 hours of access to the TMR, a

generous feeding rate with feed delivered 3 x/day, and feed is pushed up 4 x/day.

Dry cows. Two dry cow groups are maintained. Cows are dried-off for a 60-day dry period. Far-off cows are housed in the farms old facilities. Twenty percent of cows are double dry treated with Quartermaster™ on the basis of previous history of mastitis problems or cows that fill back up and leak milk. Cows are vaccinated with J5, Scourguard™ and BovaShield™ at dry-off and again with the addition of MuSe™ as they move into the close-up group. At 14 to 18 days prior to expected calving, dry cows are moved to a portion of the northeast quadrant of the freestall barn where they are fed a dry-cow diet. Cows are feed 1 x/day, and feed is available 24 hours/day, with bunk space averaging 24”/head. Amount of orts is closely monitored but not routinely measured.

Fresh group. First lactation and multiparous cows are moved from a group calving pen to the hospital pen adjacent to parlor for 3 days or until clear of antibiotic residue. Animals are then moved to a fresh group pen. This group (45 cows) is fed once per day, DM intake is 47 to 50 lb/day, and feed offered is set to allow 3 to 5 lb/cow/day of as-fed weigh back (3 to 6% weigh-back, DM basis). Cows spend 30 to 40 days in fresh group and are moved out as pressure of new cows entering this group demands.

Large lactating cow ration group. All lactating cows are fed one TMR formulation after leaving the fresh group. Cows are separated into three strings for management not dietary reasons: 1) two-year old group, 2) early lactation (breeding) group, and 3) a breed cow or not-to-be-bred group. “Large group” TMR is mixed 3 x/day (3 batches), and 60% is delivered to the cows between 0530 and 0630 hours

following ort removal. The other 40% is mixed and feed in two batches at 1230 and 1630 hours following two push-up's (0930 and 1430 hours). A final push-up takes place during or following the third milking at 2130 hours. These lactating cow groups exhibit exceptional DM intake and milk yield (61 lb DMI / 98 lb milk) with 16" bunk space for all cows over 30 to 40 days in milk. It is the authors' opinion, that it is appropriate cow grouping, comfortable well ventilated facilities, excellent forages fed, frequent feed push-ups and a close working relationship of the herd owner with the nutritionist and feeders that allows this to work so well.

Michigan Farms and Dairy Rations

Steve Benthem operates a 138 dairy in McBaine, MI. Steve's herd is the only one of the six featured in this article which feed only hay and hay-crop silage. Dry cows are fed all dry forage. Lactating cows are fed hay crop silage from a combination of upright and bag storage structures. The Benthem herd has a very low rate of metabolic disease and a good breeding program. This and his efficient use of high moisture corn and commercial supplements, along with an excellent relationship with the cows, his employee, and the herd's nutritionist, help the Benthem herd to be one of the highest producing herds in Michigan.

Jim and John Hardy, Saranac, MI operate a 1,300-cow dairy. In general, their success may be attributed to a team of excellent professionals who take charge of specific aspects of the operation and are then held accountable for them. Each week there is a staff meeting with all middle-management people coming to the meeting with a written form of the status of their operation. The feeder comes to the meeting with tables and graphs of DM intake data.

The nutritionist and veterinarian also attend this meeting. Feeding management is excellent. After the orts are cleaned up and weighed, the feeder decides if the orts are to be refed (mixed as part of the next batch), fed to heifers, or disposed. The feeder makes sure that the correct poundage of each ingredient is in the mixer; he will actually remove excess ingredients if too much is added. Part of what makes this work is that the farm has purchased a mixer that directly down loads mixer scale weight logs to the farm computer. This accountability places a tighter quality control into the feeding program. Forage feed quality is good, but on the scale of this operation, they do have some feeds that need to be separated and fed to non-lactating cows. This is closely monitored and it is actually done.

Ohio Farms and Dairy Rations

Shannon Dairy Farm, owned by David Shannon, Mount Sterling, OH farms 2500 acres (1700 acres of cash crop – corn, soybeans, and wheat) and owns 262 cows that are milked 3x and housed in free stalls bedded with limestone sand (at 100% stall capacity). Feeds include silages stored in bunker silos. No processor was used on corn silage, and corn silage hybrids are selected based on yield and TDN. All dry corn fed is raised, then finely cracked using a roller mill at the farm.

Brewers grains are shipped every 6 days, and in summer, the exposed surface is sprayed with propionic acid to inhibit molds. The farm's feeding system consists of TMR fed 1x/day (2 x/day in summer). Water is provided free choice in three 6' tip tanks per group of cows.

New crop silage is handled by filling one bag and letting it ferment for at least two weeks. The herd is then switched to the

transition bag silage while the bunkers are being filled and allowed to ferment. Cows are then switched to silage in the bunker. The TMR mixtures are formulated to allow for 5 to 8% feed refusals. Orts are measured and dumped back in the TMR mixer and are fed to heifer groups.

Diets are formulated by a private nutrition consultant. The consultant has his own NIR machine that is used and wet chemistry analyses are done at the NY DHIA lab (now named DAIRY-ONE). Corn silage is analyzed about every two months and the herdsman measures DM of silages every other week with a Koster oven.

The BST is used with cows at + 60 DIM, < 3.4 BCS (there is no too low BCS as long as the cow is healthy. Approximately 70 to 80% of cows are on BST at any one time. Body condition scoring is done on every time a cow is palpated by the veterinarian.

Animal groups consist of: 1) dry cow groups of far off and close up – cows @ -21 days to parturition and springing heifers at -28 days prepartum and 2) four groups of lactating cows: 2 year-old group (85 lb/day milk), high group (105 lb/day), low group for 2 year olds (criteria: 2 years old, > 150 DIM, open, high BCS; 65 lb/day), and low group for aged cows (criteria: > 150 DIM, high BCS; 70 lb/day), with about 70 cows in each group. All fresh cows go into a hospital pen and stay for about one week and then are moved to the 2-yr. old or high groups. Fresh cows are fed the 2-yr. old group's ration. To minimize disruptions caused by moving, cows are primarily moved once a month when the DHI reports arrive.

When asked "What do you think are the 3 most important things about your feeding program that allow it's current success?", the herdsman answered:

- 1) Bunk management (e.g. cleaning daily and pushing up feed 5x/day),
- 2) High quality feeds, especially forages and byproducts (e.g. cottonseed and wet brewers grains), but quality of all feeds is very important, and
- 3) Raising as much of feed as possible to keep feed costs low.

Carl and Steve Ayers of Perrysville, OH operate Ayres Farms, Inc. as a partnership. Fourteen hundred acres are farmed (400 to 500 acres for cash crop – corn and soybeans). The cows are milked 3x and are housed in free stalls bedded with limestone sand (150% stall capacity). Feeds include corn silage stored in bunker and upright silos, and alfalfa haylage stored in bunker silos. Corn silage is harvested by a custom harvester and a processor is used. All forages (hay and silages) are raised on the farm. All hay except 1st cut orchardgrass and hay for dry cows is ammoniated. All corn is raised on the farm; high moisture ear corn (snappage) is harvested with a processor and dry corn is ground.

Soybean meal, soyhulls, cottonseed and Nutrimeal™ are purchased under contract. Special supplements include Ca gel or Ca dextrose given if a cow has twins or is sluggish.

The feeding system includes letting new crop silage ferment for two months before feeding; If have to use new feed sooner, then blend with old crop for one week prior to a complete switch to new silage. Cows are fed 1x/day, with feed being pushed up 5 to 6 x/day. Two 30" waterers are used per group. A trough is on one side of the exit lane from parlor with water from

a plate cooler (plan to place another trough on other exit lane).

Management of cows includes supplemental lighting with lights on 8 to 9 hours plus daylight. In the summer, cooling fans on a thermostat ($> 78^{\circ}\text{F}$; 3 fans/140 ft) and feed bunk misters also are on a thermostat ($> 80^{\circ}\text{F}$, 2.75 min on, 7 min off) are used to keep cows cool. Orts are not routinely measured to calculate DM intake. Intake is maximized by mixing feed for about four cows above number of cows in the group. Orts are fed to heifers and steers (fed from birth to feeder age).

Diets are formulated by a private nutrition consultant. The consultant has his own NIR machine that is used and wet chemistry analyses are done at the NY DHIA (DAIRY-ONE) lab. The herdsman measures DM 2x/week of silages with a Koster oven; ≥ 1 percentage unit change in DM, then the ration will be adjusted. Cows are body condition scored before being injected with BST. Cows are injected at + 63 DIM, and injections stop at 190 DIM; BCS > 2.8 and < 95 lb/day of milk for 1st lactation; BCS > 2.5 and < 125 lb/day of milk for $> 1^{\text{st}}$ lactation. Approximately 65% of cows are on BST at any one time.

Animal groups include: 1) dry cows: far-off and close up – cows @ -21 days to parturition and springing heifers at -10 days 2) lactating cows: -2 year-old group (82 lb/day milk), super high group (criteria: $< 1^{\text{st}}$ lactation, $> \text{fresh}$, > 100 lb/day, BCS, 111 lb/day), high group (criteria: mostly mature cows, but 33% of 1st lactation cows, BCS, milk yield, DIM; 96 lb/day), medium group (76 lb/day), low group (criteria: do not breed cows, culls, pregnant; 61 lb/day), and fresh group (51 lb/day). Cows are in the fresh group for about 14 days and heifers are in the group for about 7 to 12 days, then

switched to the medium group and then to heifer or super high groups

To minimize disruptions caused by moving, cows are moved after the morning feeding so cows will not fill up on the new ration. When asked “What do you think are the 3 most important things about your feeding program that allow it’s current success?” the herdsman responded with:

- 1) High quality forages,
- 2) Good communication between the nutritionist and feeder, and
- 3) Able to monitor cow response and monitor DM of forages.

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Table 1. Herd averages for six high-producing dairy farms in Indiana, Michigan, and Ohio.

State/Herd	Cows	Milk	Milk fat	Milk protein	SCC
		----- lb RHA/cow -----			cells/ml
Indiana					
Darrell and Bonita Richard (Darela Holsteins) Goshen, IN	56	2X 28,951	1,071	941	135,000
Fred and Pat Beer Millford, IN	275	3X 29,669	985	879	230,000
Michigan					
Steve Benthem (Benthem Homestead) McBain, MI	138	3X 31,000	1,178	961	130,000
Jim and John Hardy (Maple Row Dairy), Saranac, MI	1,300	3X 28,250	883	810	200,000
Ohio					
David Shannon (Shannon Dairy Farm) Mount Sterling, OH	262	3X 25,471	933	790	354,000
<i>Carl and Steve Ayers</i> (Ayers Farms, Inc.) Perryville, OH	437	3X 26,896	896	817	266,000