

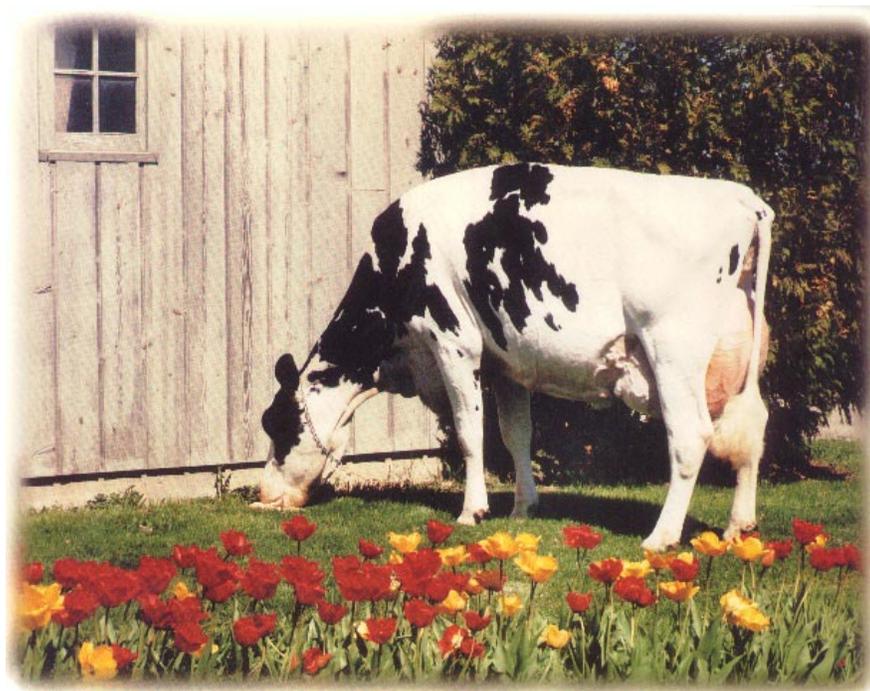
**NUTRITION AND
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How Do Nutrients Affect the Immune System?

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Abstract

Stress causes multiple interconnected endocrine, behavioral, and metabolic phenomena that result in single nutrient deficiencies, immunosuppression, and a variety of disease states in mammals. In fact, some nutrient deficiencies also activate stress responses and confound effects of the original deficiency on multiple organ systems. The bovine immune system, and thus cow health, is particularly susceptible to this complex stress-nutrition-stress cycle and dairy producers would be amiss to feed their cows diets that have not accounted for them. The tricky part, however, is realizing when and why these hidden nutrient deficiency states exist. While many overt nutrient deficiencies that alter immune system functions can be accounted for by poor feed quality, the more marginal deficiencies of stress-nutrition-stress cycles also impair immunity because of accompanying reductions in feed intake, changes in hormone axes, and oxidative tissue damage. Not surprisingly, it is during these complex cycles that most claims of immunoenhancing and healthful effects of single nutrients are reported. The main goal of our paper is to provide readers with several examples of hidden nutrient deficiencies imposed on cattle during stress-nutrition-stress cycles, using our own research to demonstrate how nutrition can enhance immunity and health in these times of production stress. However, we are still a long way from establishing immune system requirements for most nutrients during stress

because the complex physiology involved exceeds our current knowledge base. Therefore, ideas for future bovine nutritional immunology research are also offered.

Introduction

In mammals, including cattle, generalized malnutrition and select nutrient deficiencies weaken host immunological defenses and permit the establishment of infectious diseases (Galyean et al., 1999). Virtually all effector components of the immune system seem to be influenced by nutrient deficiencies. However, our lack of understanding of the physiology of nutrient deficiencies often precludes our ability to sustain animal health, especially during times of stress. Our main stumbling blocks are knowing when nutrient deficiency states exist, whether single or multiple deficiencies exist, whether these deficiencies are marginal or overt, and whether or not the problem is connected to ongoing physiological, metabolic, reproductive, behavioral, and (or) infection factors. These factors are perceived by animals as stresses and trigger complex sets of endocrine, oxidative, and gene expression events that impinge on nutrient balance and set the milieu in which the immune system must function. Indeed, nutrient deficiency itself can become a stress factor and amplify an already tenuous situation for the animal's health and well being. In cattle, we call this the stress-

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nutrition-stress cycle (Figure 1). During such cycles, supplies of energy and micronutrients that are normally adequate for maintenance or production may be inadequate for immunocompetence and health. Indeed, research is showing that increasing the supply of certain nutrients during these cycles enhances immune effector functions and improves the health status of production stressed cattle. To better understand how nutrition affects the bovine immune system and, therefore, why nutrient supplementation during stress-nutrition-stress cycles can be beneficial, a brief review of the key effectors of host immunological defense is relevant.

The Immune System is Complex But Has Three Main Effector Functions

The complexity of the immune system can be boiled down to three effectors, which come into play during acute infection and recovery from infectious diseases. These effectors are phagocytosis, antibodies, and cell-mediated cytotoxicity (Figures 2 and 3).

Phagocytosis

Phagocytosis is the job of neutrophils and macrophages of the innate immune system. These cells are continuously produced by the bone marrow and are always present in blood or tissues, ready for action. During acute infection, tissue macrophages send recruiting signals (cytokines) to blood neutrophils, which then rapidly migrate into the tissue to help the macrophages phagocytose and destroy the infecting microorganisms (Figure 2). This process is called inflammation, and phagocytosis is the first line of host defense against bacteria. Neutrophil migration is associated with leakage of blood fluids, proteins, and red cells into the tissue (Figure 2), which causes local redness, swelling, and pain. Phagocytosing neutrophils die rapidly from the same enzymatic and oxidative processes they use to kill bacteria, which forms the pus of infected

lesions. Therefore, pus is a normal and necessary outcome of a successful innate immune response against bacteria. During mastitis infections in dairy cows, acute elevations in milk somatic cells counts indicate that neutrophil migration has been successful (Figure 2). The milk flakes and clots that follow further indicate that migrated neutrophils are doing a good job of phagocytosing and killing bacteria and that speedy recovery of milk secretion may follow. However, neutrophils are “sloppy eaters”, dumping their killing reagents onto nearby healthy host tissue as they phagocytose bacteria. If bacteria have a chance to establish infection on the mammary epithelium, such as occurs during stress, prolonged phagocytosis by neutrophils can lead to permanent damage of the milk secretory tissue (Figure 2). Therefore, a critical component of mastitis management is maintaining the competency of the animal’s inflammatory response so it clears infection before causing significant tissue damage.

Tissue macrophages in inflammatory sites provide a different set of outcomes than those of neutrophils. Phagocytosis activates macrophages to produce potent pro-inflammatory cytokines, including interleukin-1 (**IL-1**), tumor necrosis factor-alpha (**TNF- α**), and interferon-gamma (**IFN- γ**) (Figure 3A). These cytokines work locally but also circulate in blood to affect target organs at sites away from the original infection. For example, IL-1 and TNF- α communicate with the brain and liver to induce the fever and anorexia typical of acute phase responses against bacteria and their toxins. A rapid but short-lived fever response helps the host recover from infection because elevated body temperature halts bacterial growth and promotes more efficient functioning of immune cells, especially the phagocytes. Short-term anorexia is also important to host survival because it restricts the availability of certain micronutrients (e.g., iron and glucose) used by bacteria for rapid growth. The IL-1 also communicates with helper T lymphocytes (**T_H cells**) of the acquired immune system, making them competent to facilitate antibody

effectors (see below) in case phagocytosis does not eliminate the bacteria. The $\text{INF-}\gamma$ primes neutrophils and macrophages for rapid destruction of bacteria they have phagocytosed (Figure 3A). Certain T_H cells also produce $\text{INF-}\gamma$ to help nearby neutrophils and macrophages and to activate cytotoxicity effectors for speedy recovery from virus infections (see below).

Antibodies

Antibodies, a second effector of immunological defense, are highly specific polypeptide molecules produced by activated B lymphocytes (**B cells**) of the acquired immune system (Figure 3B). The B cells originate and mature in bone marrow and then home to peripheral lymph nodes and the spleen where they await stimulation by noxious agents present in lymph and blood. Unlike the phagocytic cells that innately and indiscriminately attack foreign organisms, B cells work by specifically recognizing unique molecular arrays (antigens) on individual pathogens and their toxins. Antibody synthesis requires cytokines from macrophages (IL-1) and one type of T_H cell, called T_H2 (produces interleukin-4, or **IL-4**). Under the influence of these helper cytokines and antigens, B cells divide rapidly (causing the “swollen glands” typical of established infections) and differentiate into antibody secreting plasma cells (Figure 3B). The antibodies circulate in blood and lymph to the original site of infection where they bind tightly to corresponding antigens on extracellular pathogens and toxins. Antibody-coated pathogens are unable to colonize mucosal and epithelial surfaces and get swept away by the flow of cilia, mucous, saliva, sweat, urine, semen, or milk. Antibodies bound to pathogens and toxins also target these noxious agents for rapid clearance by neutrophil phagocytosis, a process called opsonization. Because antibodies so effectively block and neutralize pathogens and toxins on the outer surfaces of host cells, maintenance of this immune effector should be a priority for dairy producers. Indeed, generation of blocking and opsonizing antibodies is the main reason for vacci-

nating cows against coliform mastitis and other infectious diseases.

Cell-Mediated Cytotoxicity

Unlike extracellular bacteria and their toxins, intracellular bacteria and all viruses live and replicate inside host cells. Therefore, beyond giving assistance during initial penetration of host tissues by these types of pathogens, phagocytosis and antibodies are poor effectors against intracellular infections. A third effector, called cell-mediated cytotoxicity, is needed for this (Figure 3C). Cytotoxicity is the job of cytotoxic T lymphocytes (**Tc cells**) which, like B and T_H cells, are part of the acquired immune system. Both T_H and Tc cells originate from a precursor cell in bone marrow but differentiate and mature into their specific T cell subsets in the thymus. Limited numbers of immunocompetent T_H and Tc cells circulate in blood and lymph until being sequestered into draining lymph nodes of infected tissues. Then, appropriate T_H cells (called T_H1 cells) interact with Tc cells and with macrophages that have migrated to the node after phagocytosing the pathogen at its point of tissue entry (Figure 3C). Macrophages process phagocytosed bacteria and viruses into small pieces, called antigens, and present them in such ways to T_H1 and Tc cells that these cells can recognize and respond to them. Activation of Tc cells into cytotoxic effectors requires macrophage-derived IL-1 and cytokines (**IL-2 and INF- γ**) produced by antigen-activated T_H1 cells (Figure 3C). Effector Tc cells leave the lymph node and travel via blood to the original infection site, where they recognize their inducing antigens displayed on infected host cells (Figure 3C). This enables the Tc cells to bind to the infected cells and lyse them by lethal injection of a protein called perforin (Figure 3C). Effector Tc cells are capable of killing multiple neighboring cells infected with the same bacteria or virus. Finally, $\text{INF-}\gamma$ is produced by virus-infected cells, and this source of the cytokine protects healthy neighboring cells from infection by the virus. Therefore, Tc and $\text{INF-}\gamma$ are important



effectors against troublesome pathogens that cause chronic and often fatal diseases in dairy cows. Examples are *Mycobacterium paratuberculosis* (Johne's Disease) and Bovine Viral Diarrhea Virus (BVDV).

How Does Nutrition Influence Immune Effectors in Cattle?

It is becoming apparent that the availability of certain nutrients can have important consequences for immunity and health in cattle. One obvious factor in nutrient deficiency is feed quality, and this relates both to the nutrient content in soil and to factors such as feed type, age at harvest, processing, and storage. Less obvious, however, are the "hidden" deficiencies that arise during stress-nutrition-stress cycles and reek havoc on the immune system because of confounding endocrine and tissue oxidation factors (Figure 1). In the following sections, we use some of our own research data as examples of how nutrient replenishment can improve the status of immune effectors and animal health during stress-nutrition-stress cycles. However, despite data from our laboratories and from the work of other bovine nutrition researchers, we are still far from certain about the precise roles and recommendations for single nutrients in dairy cow health maintenance. Therefore, more effective approaches need to be employed in future studies so these issues can be resolved. Exciting developments for DNA technologies, designed so researchers can study the expression of thousands of genes at one time (Botwell, 1999; Debouck and Goodfellow, 1999; Khan et al., 1996), lend promise that nutritionists, immunologists, physiologists, and molecular biologists will soon work together to refine nutrient management for immunity and health maintenance of production-stressed cattle. Because a better understanding of complex gene expression profiles in production-stressed cows will be the key to successful nutrient management in the future, we comment briefly on DNA microarray technology in the

final section of the paper.

Stress-Induced Chromium Deficiency Can Be Alleviated By Chromium Supplementation

One of the best-studied endocrine axes in immune effector interference is the hypothalamus-pituitary-adrenal (**HPA**) axis (Figure 4). Stress induces HPA axis activation resulting in secretion of glucocorticoids, including cortisol, from the adrenal gland. Cortisol has multiple organ targets because it orchestrates an animal's "fight or flight" response. These organ targets include the brain (altered behavior and increased neural activity), heart and lungs (increased pulse and respiration rates), gut (decreased motility), fat (increased breakdown), liver (increased glucose production), and muscle (increased activity). Cortisol also acts to spare glucose for the brain and liver by antagonizing insulin's anabolic activities in peripheral tissues. Glucocorticoids transfer their hormonal messages to cells by binding with cytoplasmic glucocorticoid receptors (**GR**). Hormone-bound GR moves into the cell's nucleus where it interacts with DNA to alter the expression of key metabolic and functional genes (Figure 4). The bovine immune system is subject to both the insulin antagonizing and gene regulating actions of cortisol because neutrophils, macrophages, and lymphocytes express relatively abundant levels of GR in their cytoplasm (Preisler et al., 2000a,b). When blood cortisol is high, genes involved in inflammatory, antibody, and cytotoxicity responses are suppressed (Burton et al., 1995a; Burton and Kehrl, 1995, 1996; Nonnecke et al., 1997). Therefore, HPA axis activation can become a primary etiological factor in disease susceptibility of stressed cattle.

A relatively novel micronutrient, chromium (**Cr**), appears to be useful in buffering some negative activities of cortisol on immune effectors in cattle (reviewed by Burton, 1995; 1999). Chromium research actually had its start in the 1950's when human nutritionists began to document its beneficial roles in blood sugar and cholesterol regulation. The beneficial di-

etary form of Cr for humans is an organometallic compound called glucose tolerance factor (GTF) and is found in highest levels in brewer's yeast, organ meats, black pepper, and oatmeal. It is required for normal metabolism of carbohydrates, proteins, and lipids and is inactive without Cr at its core. The Cr in GTF appears to act by promoting the binding of insulin to its receptor and potentiating insulin's anabolic activities in cells. This is particularly important during stress because cortisol also causes profound losses of Cr in urine (reviewed by Burton, 1999). Therefore, HPA axis activation can further compromise immunity by inducing Cr deficiency (Figure 4).

The first studies demonstrating beneficial effects of Cr nutrition during putative Cr deficiency were performed in the 1990's using cattle (reviewed by Burton, 1995). Commercial feedlot calves that were subjected to weaning, commingling, long distance truck transportation, and marketing stresses had reduced levels of blood cortisol, increased blood antibodies, increased mitogen-stimulated T_H cell proliferation *in vitro*, and reduced rectal temperatures when they were fed supplemental Cr. Chromium supplementation also reduced morbidity from shipping fever (Figure 5A) and improved antibody responses to select antigens in a commercial shipping fever vaccine (Figure 5B). Potential beneficial properties of dietary Cr were then assessed in a second model of putative stress-induced Cr deficiency, namely, parturient dairy cows. Blood cortisol levels are elevated in these animals in association with the fetal stress response that terminates pregnancy and initiates milk secretion (Preisler et al., 2000a). Parturient dairy cows also suffer from insulin resistance, immunosuppression, and high incidences of mastitis and other infectious diseases, again suggestive that Cr deficiency is present. As we observed in the feedlot calves, dietary Cr supplementation had profound immune modulating effects in parturient dairy cows (reviewed by Burton, 1995, 1999). For example, Cr supplementa-

tion enhanced mitogen-stimulated T_H cell proliferation *in vitro* (Figure 5C), a property that was transferable in blood serum of the Cr-supplemented cows (Figure 5D). We suggested that some "Cr proliferation factor" occurs in blood of cows fed Cr, but showed that this was not cortisol, insulin, TNF- α , or other major metabolism altering hormones (Burton et al., 1995b). We then postulated that the factor must be Cr itself or a cytokine known to influence T_H cell proliferation (Figures 3B and C). Chromium was shown to have modest proliferation-enhancing effects for lymphocytes *in vitro*, especially in the presence of cortisol, insulin, and other metabolic hormones (reviewed by Borgs and Mallard, 1998). However, its effects on production of T_H -derived cytokines were much more curious and dramatic (Burton et al., 1996). The culture medium of proliferating T_H cells from Cr-supplemented cows had significantly lower IL-2, IFN- γ , and TNF- α than medium of cells from unsupplemented control cows (Figures 6A, B, and C). Because T_H1 cell proliferation would have been accompanied by increases rather than decreases in IL-2 and IFN- γ (Figures 3B and C), these results suggested that supplemental Cr acts preferentially on T_H2 cells. In support of this notion, Cr supplementation also improved antibody responses in the parturient cows (Figure 6D). Therefore, our combined data to date suggest that this simple nutritional management tool might profoundly impact antibody effector mechanisms in periparturient dairy cows and feedlot calves. This is exciting in light of the fact that antibodies are the key effectors that we elicit by vaccinating animals against coliform mastitis and shipping fever. It may be significant that supplemental Cr also improved insulin sensitivity and early lactation milk yields in primiparous cows (reviewed by Borgs and Mallard, 1998) and feed efficiencies and weight gains in feedlot calves (reviewed by Burton, 1995). However, Cr supplementation of the dairy cows severely reduced *in vitro* lymphocyte proliferation in response to the same test antigen that improved anti-



body responses *in vivo* (Figure 6E), suggesting that a caveat of improved antibody immunity may be reduced cellular immunity. This and other issues of Cr requirements will have to be resolved before Cr supplementation is publicly advocated (NRC, 1997). Regardless, Cr has been coined an “anti-stress” nutrient by researchers (Mowat, 1997) because of its demonstrated immune-, health-, and production-enhancing properties in husbandry stressed cattle.

Negative Energy Balance Might Compromise Immunity Via GH/IGF-I Axis Uncoupling

Another component of stress-nutrition-stress cycles that commonly gets blamed for the immunosuppression and mastitis susceptibility of periparturient dairy cows is negative energy balance (**NEB**). High producing cows, and especially those with concurrent mammary infections, have reduced feed intake, low blood insulin, and elevated cortisol, IL-1, and TNF- α , all of which signal the brain and liver to change feeding behavior, body temperature, and glucose metabolism. These factors confound NEB by reducing feed intake even further and contribute to multiple micronutrient deficiencies. In addition, NEB alters an important endocrine axis between growth hormone (**GH**) and insulin-like growth factor I (**IGF-I**) (Figure 7). Normally, pituitary secretion of GH is elevated after a meal to promote anabolic metabolism from the digested nutrients. It does this by signaling the liver to produce IGF-I, which acts to partition carbohydrates, proteins, and lipids into appropriate tissues. During NEB, the GH/IGF-I axis becomes uncoupled because liver GH receptors are down regulated (Figure 7). Therefore, blood IGF-I levels are low during NEB. High GH and low IGF-I and insulin cause adipose tissue to catabolize fat, leading to high blood levels of nonesterified fatty acids (**NEFA**). Though NEFA can be used by some tissues as an alternative energy source to glucose, positive correlations between blood NEFA concentrations and early lactation mastitis incidence (Dyk et al., 1995) led us to question the usefulness of this energy source for neu-

trophils, macrophages, and lymphocytes (Perkins, 1999). Furthermore, these immune cells normally express receptors for GH and IGF-I and respond to these anabolic hormones in multiple ways that promote immunocompetence (reviewed by Burton et al., 1994b). Therefore, we were curious to know if GH/IGF-I axis uncoupling per se impacts immunocompetence and health of cattle during NEB.

To address this question without confounding immunological or reproductive factors, we developed a model of NEB in healthy steers where animals were fed either at 60% of maintenance requirements for three weeks (NEB) or at 210% of requirements (positive energy balance; **PEB**) (Perkins et al., 2000a). Both diets met NRC requirements for vitamins and minerals, had similar protein-energy ratios, and were fed as complete mixes in two meals per day. Analysis of blood samples collected throughout the trial showed that GH/IGF-I axis uncoupling had peaked by week two, because blood GH and NEFA were higher (Figure 8A) and IGF-I was lower (Figure 8B) in NEB versus PEB steers. Peak GH/IGF-I axis uncoupling was associated with a 30% reduction in circulating lymphocytes that express the GH receptor (Figure 8C), and we attributed this to B cells because these lymphocytes amount to approximately 30% of total blood lymphocytes in cattle. In addition, macrophage IGF-I receptor expression was reduced during GH/IGF-I axis uncoupling (Perkins et al., 2000a). Neutrophils did not appear to be affected by NEB because neither hormone receptors nor key molecules used for migration into inflamed tissues (Figure 8D) were altered during GH/IGF-I axis uncoupling (Perkins et al., 2000b). We concluded from this study that NEB might cause problems with acute phase responsiveness, initiation of inflammation, and antibody effector functions if cattle were to become infected with pathogens during peak GH-IGF-I axis uncoupling. This proved to be the case because, in a second trial, lactating dairy cows subjected to NEB and challenged intramammarily with *E. coli* endotoxin (a cell wall component of coliform

bacteria that initiates inflammation; Figure 2) had blunted fever responses compared to identically challenged PEB cows (Figure 8E). The PEB cows also had significantly higher pulse and respiration rates than NEB cows (Perkins et al., 2000c). Antibody concentrations in blood and milk, serum TNF- α concentrations, milk somatic cell counts, and neutrophil responsiveness to pro-inflammatory mediators are currently being assessed in this NEB model. Once these data are analyzed, we should be able to conclude whether or not NEB and its associated GH-IGF-I axis uncoupling impinges on a key acute phase, inflammatory, and antibody responses required for defense against mastitis causing pathogens in dairy cows. If so, increased energy density of periparturient rations may be indicated. However, NEB is only one facet of periparturition, and it is clear that significant work remains to be done before the complexities of nutrient management for immunity and health during this stress-nutrition-stress cycle will be untangled.

Antioxidant Vitamins and Minerals Reduce Oxidative Tissue Damage During Inflammation

Normal metabolic processes in highly active tissues generate reactive oxygen metabolites (**ROM**), such as superoxide anion (O_2^-) and hydrogen peroxide (H_2O_2), that are involved in the chemistry of multiple enzyme systems in cells. However, excessive generation of ROM causes tissue damage, which is exasperated by conditions such as exposure to solar radiation, pesticides, infectious agents, and toxins (Miller and Brzezinska-Slebozinska, 1993). Superoxide and H_2O_2 are also natural products of oxidative metabolism in phagocytosing neutrophils and are used by these cells to generate highly reactive hydroxyl radicals ($\cdot OH$) that kill phagocytosed bacteria (Figure 9) (reviewed by Babior, 1984). They do this by attacking and oxidizing lipids, proteins, polysaccharides, DNA, and other macromolecules. Oxidized molecules abstract electrons from other molecules, setting up destructive chain reactions. These very same oxidative processes can rapidly kill neutrophils before they

have destroyed the pathogens they have phagocytosed. In this case, infection is not contained and leads to excessive and prolonged pus formation. If left uncontrolled, extensive damage can occur in otherwise healthy host tissues that come in contact with the phagocytosing neutrophils. This is called oxidative tissue stress and can become a significant etiological factor in the development of severe mastitis, udder edema, and retained placenta in dairy cows, especially in animals undergoing the stress-nutrition-stress cycle of periparturition (reviewed by Miller and Brzezinska-Slebozinska, 1993). Therefore, maintaining neutrophil bactericidal activity through extended longevity of the migrated cells is a critical component in limiting oxidative tissue stress during bacterial infections. Nutrition has an important role here (Machlin and Bendick, 1987).

Neutrophils and other metabolically active cells of well-nourished animals have several built-in antioxidant mechanisms to handle oxidative stress (Figure 9). First, reactive transition elements (e.g., Fe^{3+}) are normally sequestered into large complexes (e.g., transferrin) to keep them compartmentalized away from susceptible sites (e.g., plasma and nuclear membranes). However, stress can free bound transition elements, allowing them to participate in the generation of $\cdot OH$ (Figure 9). For this reason alone, minimizing exposure of cows to factors that activate the HPA axis is critical to maintaining their health and productivity. However, the stress-nutrition-stress cycle of periparturition is unavoidable in dairy production. Therefore, other antioxidant defense mechanisms must be optimized to reduce oxidative stress in important tissues, such as the mammary gland and reproductive tract. The first of these antioxidant systems is superoxide dismutase, which converts O_2^- into H_2O_2 (shown as **HOOH** in Figure 9). There are three main kinds of superoxide dismutase, one that requires zinc (**Zn**) for its activity and two others that require copper (**Cu**) or manganese (**Mn**) (Figure 9). In addition to other activities of these micronutrients in lymphocyte differentiation, proliferation, and gene expression



(Cerone et al., 1998; Keen and Gershwin, 1990; Sherman, 1992; Suttle and Jones, 1989), adequate dietary levels of Zn, Cu, and Mn may be important for handling oxidative stress in phagocytosing neutrophils and other metabolically active cells, especially during production stress (Nockels et al., 1993).

The H_2O_2 generated from superoxide dismutase activity is next converted into water (H_2O) by the joint activities of glutathione peroxidase and catalase (Figure 9). Glutathione peroxidase also detoxifies peroxy radicals that get bound to glutathione by the action of another antioxidant enzyme, glutathione S-transferase (Figure 9). Glutathione peroxidase requires selenium (**Se**) for its activity, which is directly dependent upon dietary intake of this micronutrient (reviewed by Hogan et al., 1993). Therefore, when feeds are deficient in Se or daily feed intakes are low, Se deficiency results. Selenium deficiency has well established negative effects on mastitis susceptibility, which have been linked to reduced longevity and bactericidal capacity of phagocytosing neutrophils (Erskine et al., 1990; Hogan et al., 1993; Miller et al., 1995). For example, our early work showed that blood Se levels and glutathione peroxidase activity were related and were lower in herds with high versus low milk somatic cell counts (Figure 10A). When cows were fed diets either sufficient or deficient in Se and challenged intramammarily with *E. coli*, Se-deficient cows had lower blood glutathione peroxidase activity, blunted levels of milk somatic cells during acute inflammation, and increased shedding of *E. coli* in milk compared with the Se sufficient animals (Figure 10B). In a later study, Se deficiency was shown to reduce killing of *E. coli* and *S. aureus* phagocytosed by milk neutrophils *in vitro* (Figure 10C). Therefore, adequate Se nutrition is critical for managing oxidative stress in infected mammary glands of dairy cows. As reviewed by Miller and Brzezinska-Slebodzinska (1993), Se supplementation is also an important factor in reproductive fitness, retained placenta, and metritis during the periparturient period

when blood Se levels are often low.

The critical detoxifying activity of glutathione peroxidase can be regenerated in cells as long as the enzyme has access to reducing equivalents (**H•**) in the form of **NADPH**. The NADPH is made available for glutathione peroxidase regeneration by the pentose monophosphate shunt, which is activated during ROM imbalance (Figure 9). The NADPH reducing equivalents are also used by the glutathione S-transferases, which act to break peroxidative chain reactions by conjugating oxidized lipids and other peroxy radicals to glutathione and feeding these conjugates back into the glutathione peroxidase system. However, excessive consumption of NADPH by these antioxidant systems diminishes the supply of reducing equivalents needed by other important physiological processes, putting cells in serious jeopardy. The ROM induction of the pentose monophosphate shunt also diverts valuable glucose away from other cellular pathways, which becomes of critical importance to animal health and productivity when glucose requirements are not met by dietary intake (e.g., the NEB of periparturition and stress). Fortunately, two other potent antioxidant micronutrients can help relieve the cell's need to consume NADPH during oxidative stress by supplying additional reducing equivalents and breaking peroxidation chain reactions. These micronutrients are lipid soluble vitamin E and water soluble vitamin C (Figure 9).

Vitamin E is a potent quencher of free radicals and contributes significantly to conservation of NADPH reducing equivalents by compensating for the glutathione S-transferase chain breakers (Figure 9) (Putnam and Comben, 1987). Because vitamin E is located close to ROM-generating oxidase enzymes in plasma membranes of cells, it is in a good position to quench free radicals before they leak into the cell. This is particularly important in neutrophils, which constantly internalize the plasma membrane during phago-

cytosis. In dairy cows, a relationship between vitamin E status and mastitis incidence is well known and, like Se, is due to the positive influences on neutrophil longevity and bactericidal activity during phagocytosis (reviewed by Hogan et al., 1992). Plasma vitamin E is lowest during periparturition when rates of intramammary infections are highest and neutrophil functions are depressed (Goff and Stabel, 1990). Vitamin E deficiency at this time has been blamed on reduced feed intakes (Hogan et al., 1992), reduced colostrum production (Goff and Stabel, 1990), and leaching from plasma membranes in response to elevated blood cortisol (reviewed by Hogan et al., 1993). Due to the severity of the deficiency, only injected vitamin E (as α -tocopherol) improves intracellular killing of opsonized bacteria by neutrophils at parturition (Hogan et al., 1992). Parenteral vitamin E also helps prevent reproductive disorders in periparturient cows (Erskine et al., 1997). However, dietary vitamin E can improve *S. aureus* and *E. coli* killing once colostrum production has ceased and feed intake increases (Hogan et al., 1990, 1992). Interestingly, though vitamin E and Se have similar effects on neutrophils, these are not additive and have led to the notion that one antioxidant pathway can spare the other (Hogan et al., 1993). Potential beneficial effects of vitamin E and Se supplementation on other immune effectors are not well studied, though one report showed that vitamin E incorporated into a coliform mastitis vaccine improved antibody responses, persistency of protection against mastitis, and abscess formation at the immunization site (Hogan et al., 1993). It was argued in that study that vitamin E protected macrophages at the injection site from oxidative stress, reducing inflammation and promoting better antigen presentation to B and T_H2 cells following migration of the macrophages into draining lymph nodes (Hogan et al., 1993). Even if true, rapidly dividing antigen-activated B and T cells would be expected to benefit from effective antioxidant nutrition, and this research needs to be done.

The final chain breaking antioxidant mechanism available in oxidation stressed cells involves vitamin C. Vitamin C is normally produced by the liver of adult cows and is active both in blood plasma and in the cytoplasm of cells. Its function is to scavenge free radicals and regenerate plasma membrane-bound vitamin E and cytosolic glutathione peroxidase. Neutrophils from healthy, unstressed cattle selectively acquire vitamin C from the blood and, therefore, have relatively high intracellular vitamin C concentrations. However, stress-induced activation of the HPA axis and resulting increases in blood cortisol lead to reduced hepatic output of vitamin C and losses of this micronutrient from blood and neutrophils. This confounds immunosuppression, oxidative tissue damage, and disease susceptibility in production stressed animals (reviewed by Roth and Kaeberle, 1985). Therefore, stress-nutrition-stress cycles may warrant parenteral vitamin C therapy (as ascorbic acid). We recently tested this possibility in dairy cows who were stressed by mammary infusion of *E. coli* endotoxin and then treated twice with bolus intravenous injections of ascorbic acid (Figure 11). Local and systemic indicators of inflammation and endotoxic shock were monitored intensively for several weeks (Chaiyotwittayakun et al., 2000). Vitamin C therapy caused acute increases in blood concentrations of ascorbic acid (Figure 11A), which were associated with rapid but transient increases in milk IgG₁ concentrations (Figure 11B). This early increase in mammary edema correlated with less severe milk loss and faster recovery of milk secretion than was observed for control cows not treated with vitamin C (Figure 11C). Milk somatic cell counts, pulse and respiration rates, fever response, and feed intake were not affected by vitamin C treatment (Chaiyotwittayakun et al., 2000). It is possible, therefore, that the increased milk IgG₁ (i.e., antibodies) during acute edema in the vitamin C treated cows promoted clearance of endotoxin by blocking and (or) opsonization without necessarily influencing macrophage function or neutrophil oxidative metabolism per se. That said, Roth and Kaeberle (1985) observed clear enhancing ef-



fects of parenteral vitamin C on neutrophil oxidative metabolism when cattle were additionally challenged with exogenous glucocorticoid hormone. Therefore, although further vitamin C studies are needed in cattle, these combined data suggest that parenteral vitamin C would be an effective treatment against oxidative tissue damage in mammary glands challenged to undergo active inflammatory responses during periods of husbandry stress.

Thoughts for Future Nutritional Immunology Research in Dairy Cattle

In this paper, we have presented what might be considered our most interesting data related to the impacts that single nutrients can have on immunity in cattle. Certainly, we must acknowledge that not all studies have corroborated our findings and that we have omitted many interesting micronutrients that others have shown to impinge on immunity in more or less striking ways. In writing this paper, we were also struck by the fact that information regarding nutritional impacts on cytotoxicity is scant. This is despite the fact that numerous serious diseases caused by intracellular organisms plague the dairy industry today. The reality is that we do not have a good handle on how to monitor cytotoxicity in cattle, let alone the potential effects that nutrient deficiencies might have on it. Upon reflection, the same can be said of inflammation and antibody mediated immunity and of the complex immunosuppression typical of stress-nutrition-stress cycles. Therefore, while our past efforts to generate knowledge about how nutrition influences the immune system were valiant indeed, it seems time to shift our research approach in favor of more holistic ways to study nutrition and immunity. In doing so, we are not rejecting our hypothesis that nutrition has fundamental influences on immunity and health; indeed data presented in this paper argues that we fully accept this hypothesis. Rather, we are preparing to broaden our perspectives on how we continue to test this hypothesis so our results become

meaningful to the dairy industry in more efficient and profitable ways.

Our group is now applying a new DNA technology, called DNA microarray, that allows us to perform large scale screening of gene expression patterns in immune tissues of nutrient deficient and supplemented animals exposed to relevant disease organisms and (or) stressors (Khan et al., 1996). Thus, DNA microarrays will allow us to scrutinize all genes involved in bovine immune functions to obtain integrated information on how, when, why, and to what extent nutrition impacts immunity and health in dairy cattle (Bowtell, 1999). Armed with this new knowledge, nutrient-specific diets and therapies, novel husbandry practices, and new ways of controlling susceptibility to diseases are envisioned that should have direct application in the dairy industry (DeBouck and Goodfellow, 1999). During development of the DNA microarray technology to study gene expression in the bovine immune system, we have discovered new ways to collaborate with colleagues in disciplines as diverse as nutrition and molecular genetics. In doing so, we have stepped into totally new dimensions in our own professional development. This should serve us well as we enter a new era of nutritional immunology research at Michigan State University.

Summary

Nutrition impacts immunity in dairy cows in many complex ways that depend upon the stress and health status of animals. Our past research in chromium, energy, and antioxidant vitamin and mineral nutrition demonstrates that nutrient supplementation and therapy can have profound influences on acute inflammatory and antibody responses during times of overt and hidden nutrient deficiencies. However, we are far from understanding all of the interconnected influences that stress and nutrition have on immunity

and health in cattle. To gain this understanding, it will require new ways to approach nutritional immunology research. Our group is applying gene expression profiling by DNA microarrays for this purpose, in the hopes that the knowledge generated will lead to timely applications of novel nutrient management practices that improve the health and productivity of high producing dairy cows.

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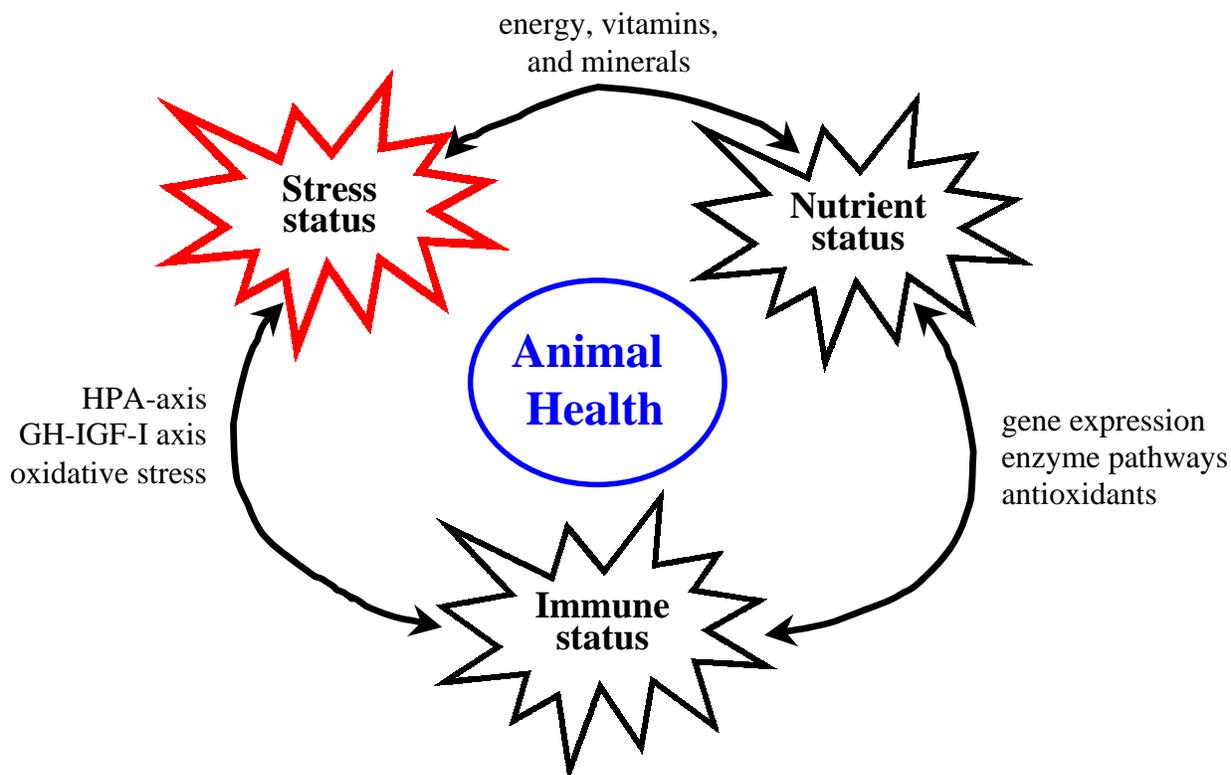


Figure 1. The stress-nutrition-stress cycle in periparturient dairy cows plays havoc on the immune system and leads to increased susceptibility to mastitis and other complex production diseases. Stress is a key factor that impacts the status of nutrient acquisition and retention, activity of endocrine-immune axes, the peroxidation-antioxidation balance, cellular gene expression, and health of periparturient cows. [HPA axis = hypothalamic-pituitary-adrenal axis; GH-IGF-I axis = growth hormone-insulin like growth factor-I axis].

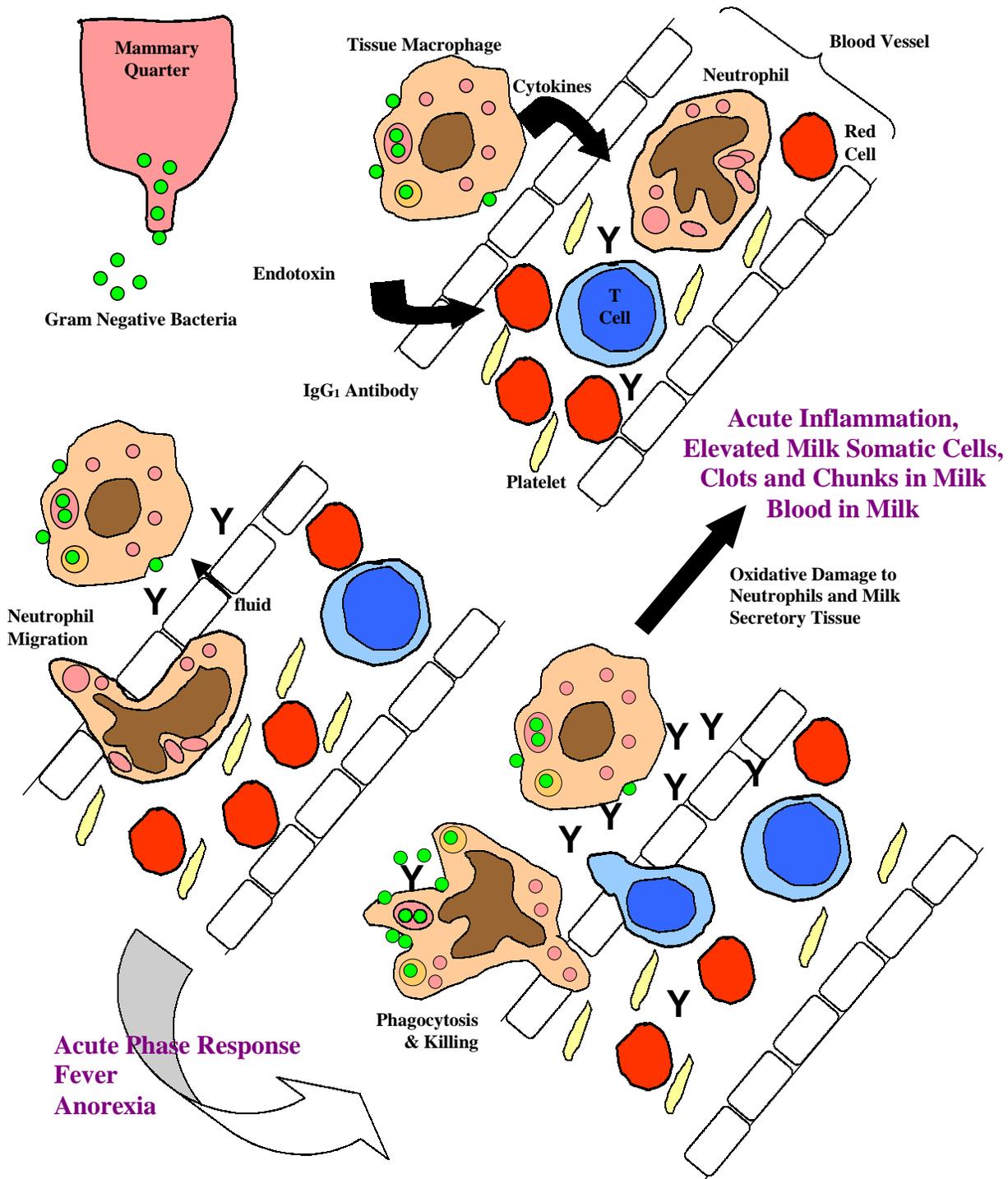


Figure 2. Acute inflammation, including edema [movement of blood fluid and antibody (**IgG₁**) into the mammary gland], neutrophil migration (increases milk somatic cell count), and formation of pus (milk clots and chunks) by phagocytosing neutrophils, is an appropriate innate immune response against coliform mastitis. If inflammation occurs rapidly enough, the infection will be cleared before significant damage occurs to the milk secretory tissue, promoting return of normal milk synthesis and secretion.

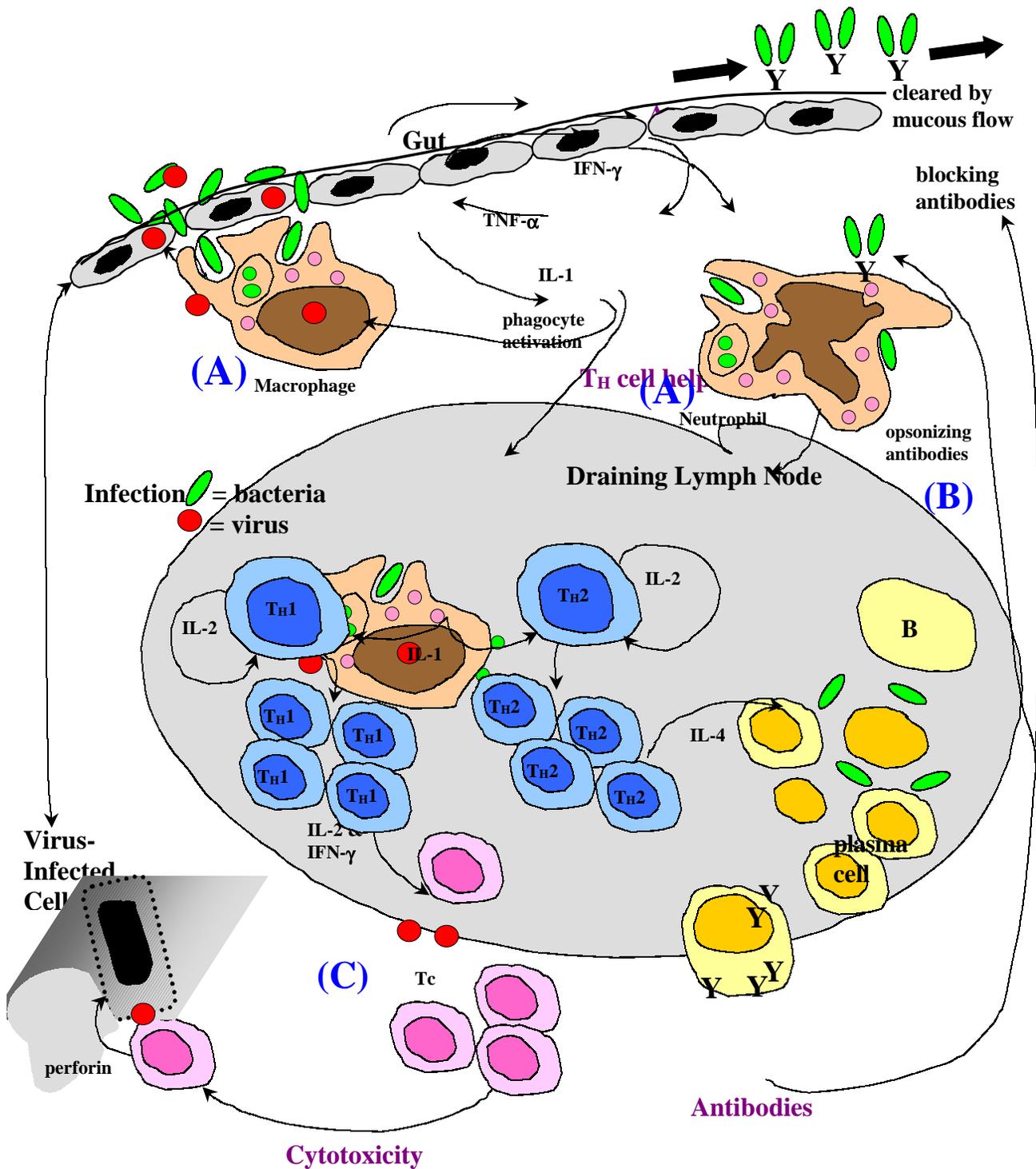


Figure 3. The immune response is highly complex but can be simplified into three effector functions: phagocytosis by neutrophils and macrophages (A), antibodies produced by antigen-activated B cells (B), and cytotoxicity mediated by antigen-activated Tc cells (C). Neutrophils and macrophages are part of the innate immune system that is always present and ready to act in response to infection. The B cells and T cells are part of the acquired immune system that requires antigen activation, amplification, and differentiation before it can respond to an infection. [IL = interleukin, IFN = interferon-gamma, and TNF = tumor necrosis factor]

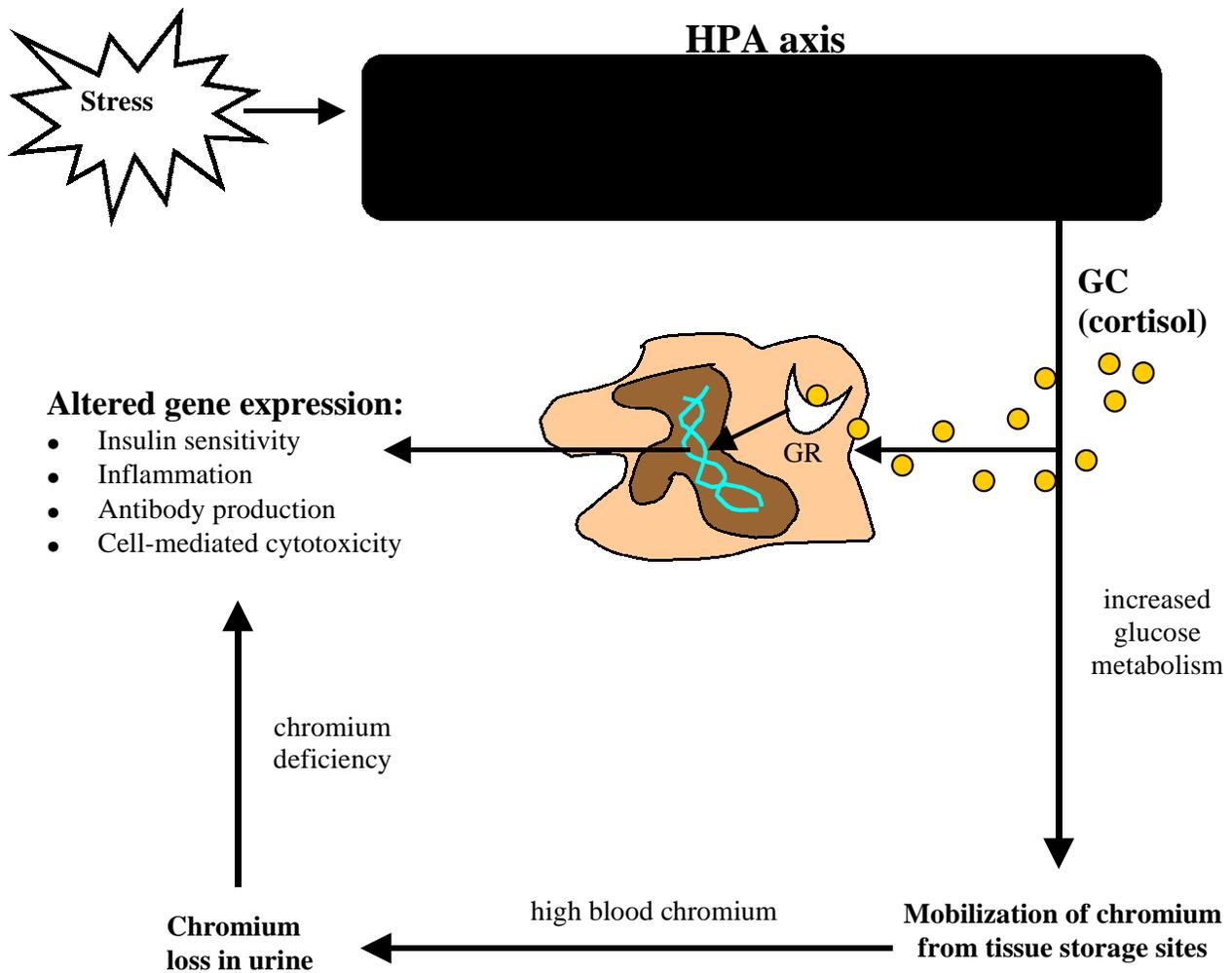


Figure 4. Stress activates the hypothalamic-pituitary-adrenal (HPA) axis, which causes insulin insensitivity, micronutrient deficiencies, and suppression of inflammatory, antibody, and cell-mediated cytotoxicity responses in cattle. The HPA axis activation starts when the brain's hypothalamus receives a stress signal and responds to it by secreting corticotropin releasing hormone (CRH) and arginine vasopressin (AVP). The CRH and AVP are detected by the brain's pituitary gland, which permits it to release adrenocorticotropic hormone (ACTH) into the blood circulation. The blood transports ACTH to the adrenal glands, where it rapidly stimulates secretion of stress steroids such as cortisol. Cortisol is a glucocorticoid (GC) hormone that binds to specific receptors (GR) in target immune cells, directly influencing the expression of key genes whose protein products affect insulin responsiveness, nutrient retention, leukocyte migration, antigen presentation, and cell proliferation and differentiation (see for e.g., Burton et al., 1995a; Burton and Kehrl, 1995, 1996; Nonnecke et al., 1997). Stressors that activate the HPA axis include a wide variety of environmental, psychological, and physical insults, nutritional deficiencies, and immune cytokines. [Adapted from: Preisler, 1999].

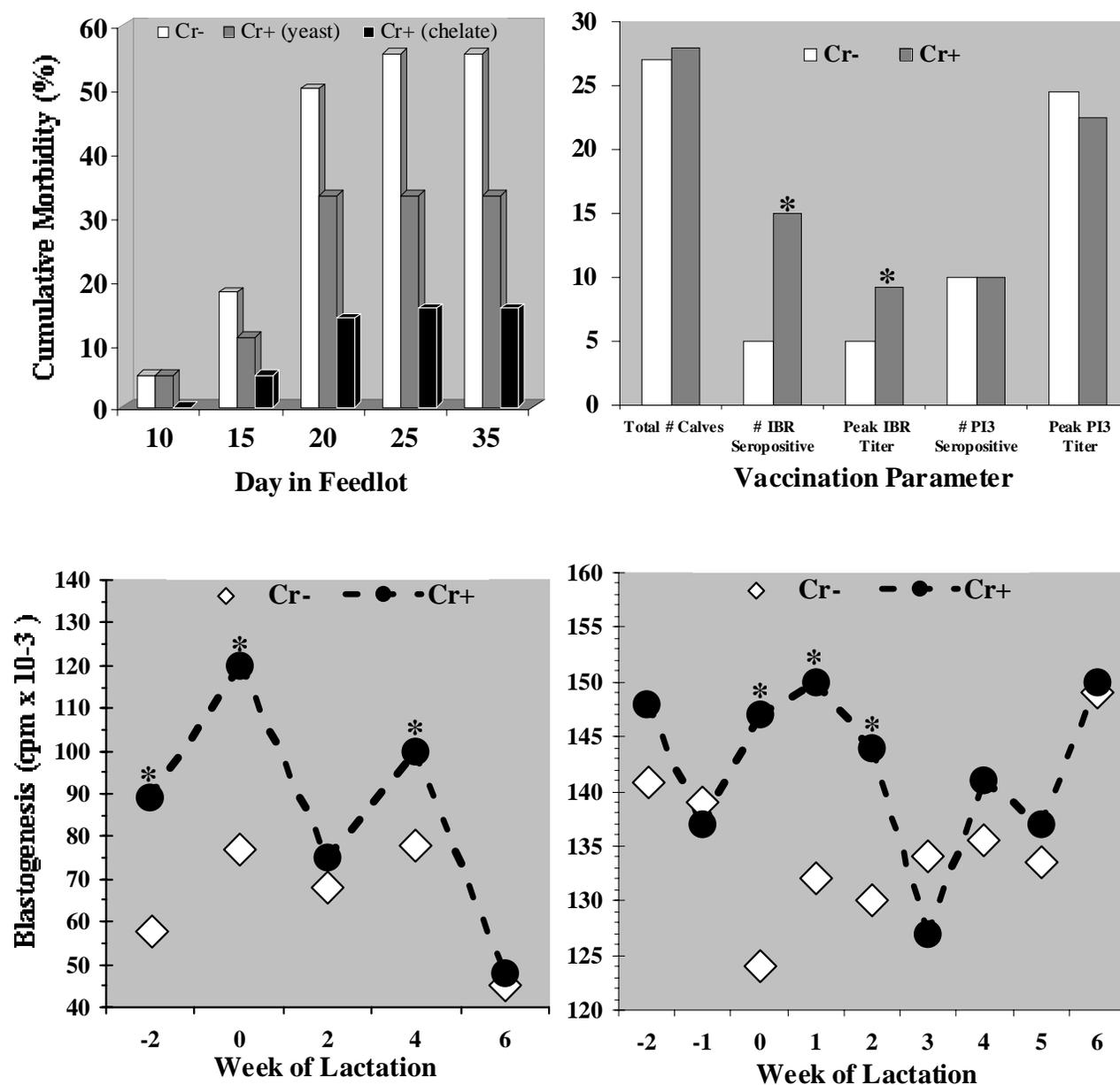


Figure 5. Dietary supplemental chromium (Cr) has been shown to enhance health (A) and antibody responses to a commercial shipping fever vaccine (B; y-axis units differ according to x-axis variables) in newly arrived feedlot calves previously subjected to weaning/transportation/marketing stress. In periparturient dairy cows, dietary supplemental Cr increased *in vitro* lymphocyte proliferation (blastogenesis, measured as counts per minute, or cpm x 10⁻³) in response to added mitogen (C). Mitogen-stimulated proliferation of heterologous lymphocytes was also increased when the culture medium supporting the cells was supplemented with 10% blood serum from Cr-supplemented periparturient dairy cows (D; y-axis unit same as for C). Therefore, Cr supplementation appears to have immunoenhancing and health-promoting effects in production stressed cattle. [IBR = Infectious Bovine Rhinotracheitis; PI3 = Parainfluenza 3 Virus; * $P < 0.05$].

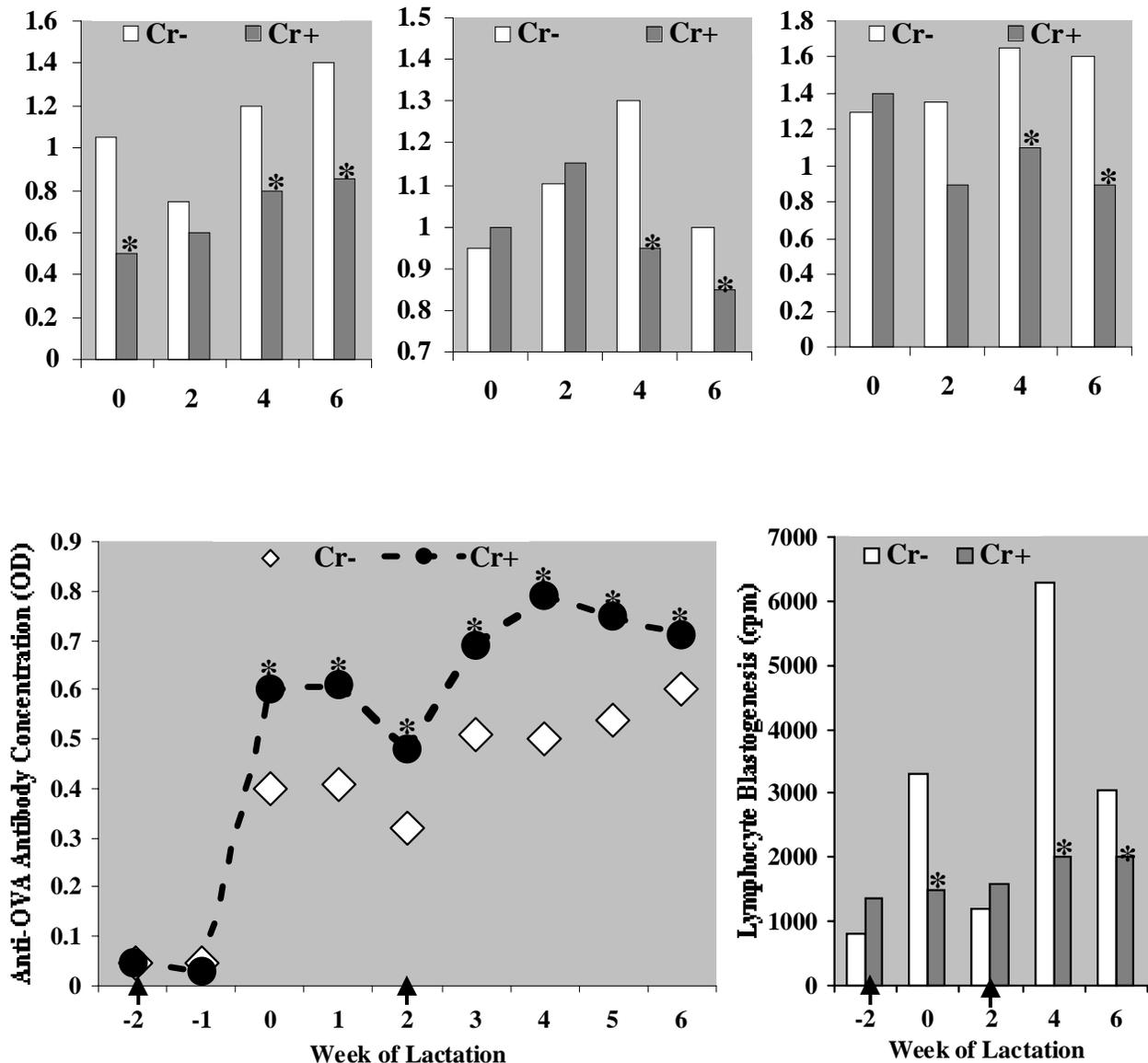


Figure 6. Dietary supplemental chromium (Cr) is immunomodulatory in periparturient dairy cows. Blood mononuclear cells (lymphocytes plus macrophages) from control (Cr-) and chromium-supplemented (Cr+) periparturient cows (weeks 0, 2, 4, and 6 relative to parturition) were stimulated with mitogen for 48 hours and the concentrations of various cytokines measured in culture supernatants. Data showed that concentrations of IL-2 (A), INF- γ (B), and TNF- α (C) were lower when supernatants were collected from rapidly dividing cells of Cr+ cows. Cows were also immunized twice (arrows) with ovalbumin (OVA; on weeks -2 and 2) to assess *in vivo* antibody responses and antigen-induced *in vitro* lymphocyte proliferative responses +/- dietary Cr supplementation. Results showed that primary and secondary antibody responses were higher in Cr+ than Cr- cows (D), while OVA-stimulated lymphocyte proliferative responses were lower in Cr+ than Cr- cows. Combined data suggest that supplemental dietary Cr promotes T_H2 (antibody) over T_H1 (cytotoxicity) responses in parturition stressed dairy cows. [Adapted from Burton et al., 1996 (A, B, and C) and from Burton et al., 1993 (D and E); OD = optical density; P < 0.05].

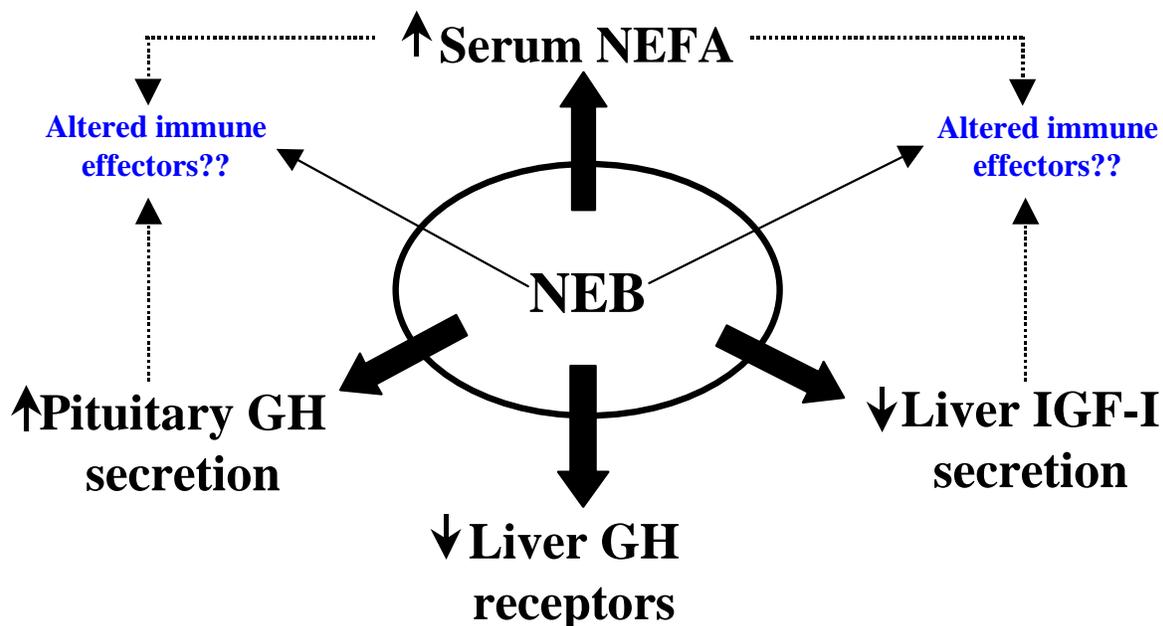


Figure 7. Negative energy balance (NEB) causes uncoupling of the growth hormone (GH)-insulin-like growth factor I (IGF-I) axis in cattle. During energy sufficiency, pituitary secretion of GH between meals activates liver GH receptors causing increased secretion of IGF-I. The IGF-I facilitates metabolism of carbohydrates, proteins, and lipids by peripheral tissues. During energy insufficiency (e.g., periparturition), liver GH receptors are down regulated, leading to reduced production of IGF-I even when pituitary secretion of GH is high. High GH and low IGF-I trigger mobilization of nonesterified fatty acids (NEFAs) from adipose tissue into blood. Blood NEFA can serve as an energy source for the mammary gland and other peripheral tissues when energy intake is low. Bovine leukocytes possess GH and IGF-I receptors and respond to both hormones *in vivo* and *in vitro* (reviewed by Burton et al., 1994a). Therefore, we were curious to know if GH-IGF-I axis uncoupling contributes to suppressed immune effector functions in NEB-stressed cattle. [Adapted from: Perkins, 1999].

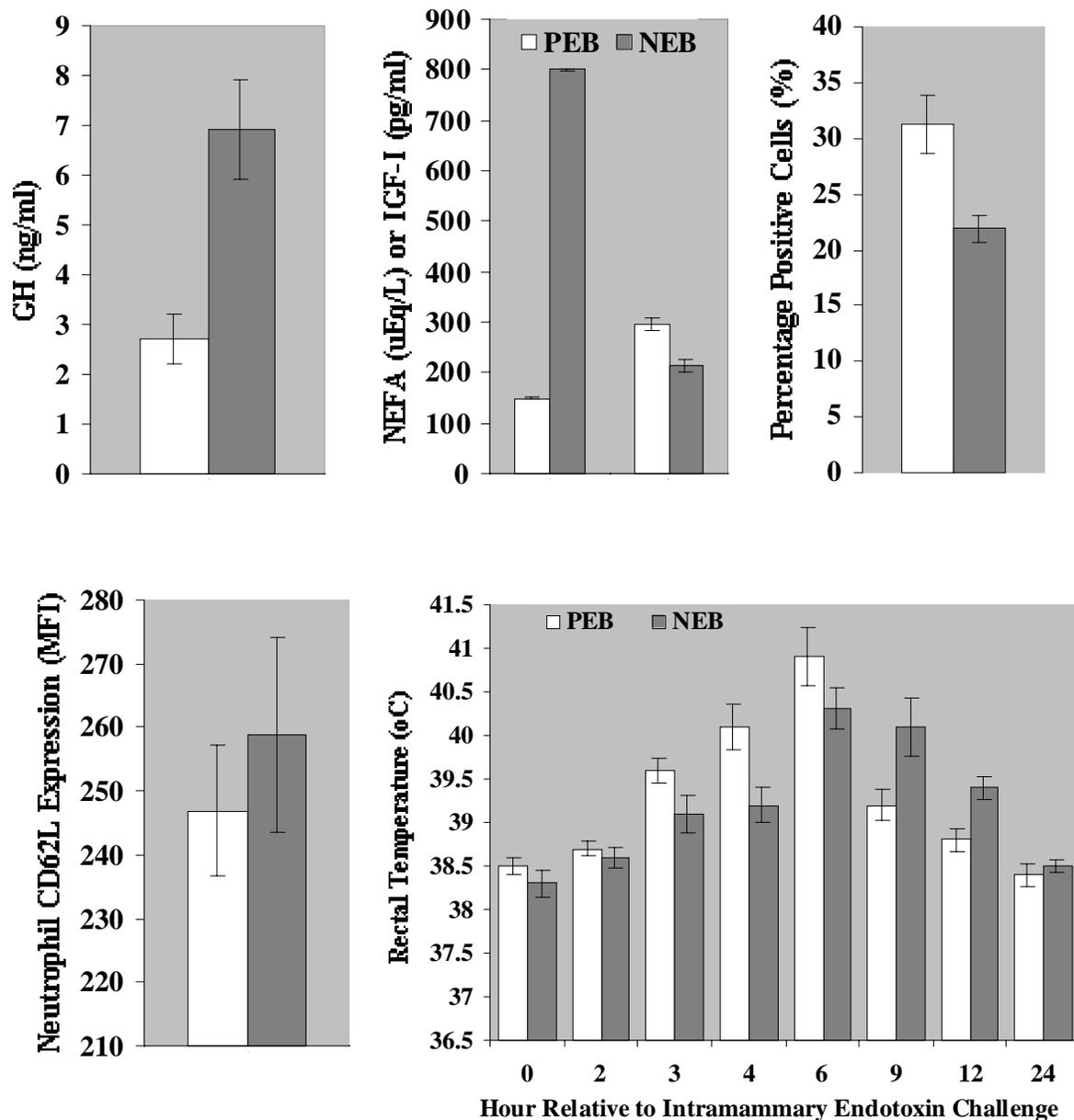


Figure 8. Negative energy balance (NEB) uncouples the growth hormone (GH)-insulin-like growth factor I (IGF-I) axis in cattle, causing high circulating levels of nonesterified fatty acids (NEFA). In the absence of other nutrient deficiencies or infections, high GH (A) and NEFA (B), and low IGF-I (B) during NEB were associated with a 30% reduction in percentage of circulating GH receptor-expressing lymphocytes (C), but did not have remarkable effects on total leukocyte counts (not shown) or expression of genes involved in neutrophil migration (D; measured as mean fluorescence intensity, MFI) or antigen presentation by macrophages (not shown). When lactating dairy cows were subjected to NEB and challenged intramammarily with endotoxin (lipopolysaccharide; LPS), fever took longer to peak, peaked at lower rectal temperatures, and took longer to normalize than for cows in positive energy balance (PEB) (E). Therefore, NEB might negatively impact acute immune effectors during active inflammation, perhaps in association with down-regulated lymphocyte GH receptors during GH-IGF-I axis uncoupling. [From Perkins, et al., 2000a,b,c].

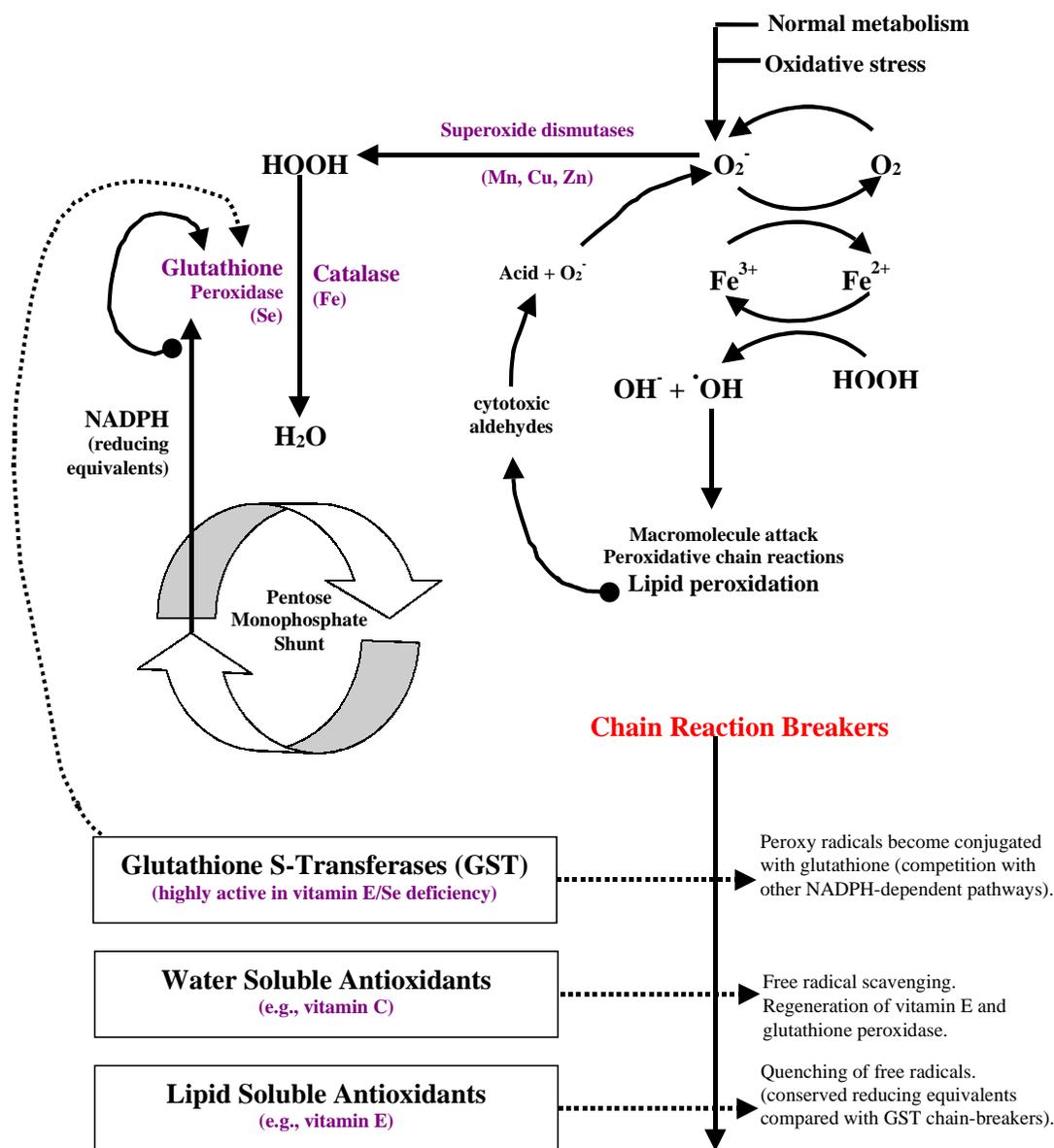


Figure 9. Antioxidant pathways used by cells in protection against free radical damage. Normal metabolism (e.g., respiratory burst in neutrophils following phagocytosis) and oxidative stress (e.g., solar radiation and infection) generate superoxide anions (O_2^-). In the presence of free transition elements (e.g., Fe^{3+}) and hydrogen peroxide (HOOH), O_2^- is converted to a highly reactive hydroxyl radical (OH^\cdot), which attacks cellular polysaccharides, proteins, DNA, and lipids and promotes further production of O_2^- . Two main antioxidant pathways exist to help cells cope with such oxidative stress. First, superoxide dismutases in combination with catalase and glutathione peroxidase convert O_2^- and HOOH into water (H_2O). Secondly, chain-breaking reactions occur through the activities of glutathione S-transferases, vitamin C, and vitamin E that scavenge and quench free radicals in cells under attack by OH^\cdot . Antioxidant vitamins (C and E) and minerals (Mn, Cu, Zn, Se, and Fe) are critical during periods when peroxidative processes exceed available antioxidant processes. [Adapted from Miller and Brzezinska-Slebodzinska, 1993].

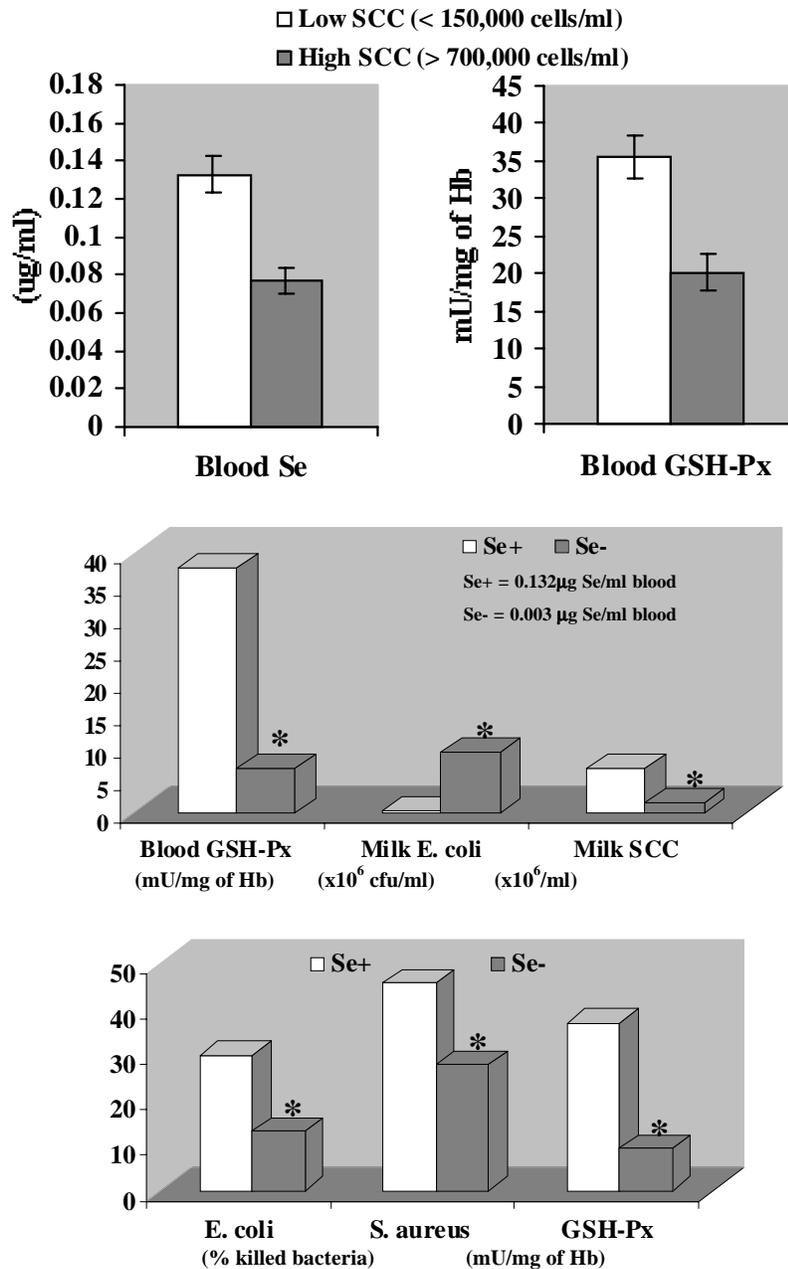


Figure 10. Selenium deficiency has well established negative effects on mastitis and killing functions of bovine neutrophils. For example, Erskine et al. (1987) observed that high herd milk somatic cell count (SCC) correlated with low blood selenium (Se) and glutathione peroxidase activity (GSH-Px) (A). Erskine et al. (1989) also showed that dietary Se deficiency (Se-) resulting in low blood Se and GSH-Px reduced migration of neutrophils (lower milk SCC responsiveness) and heightened bacterial shedding in milk during experimental *E. coli* mastitis infections (B). Lastly, milk neutrophils from Se- cows were shown to have lower *E. coli* and *S. aureus* killing ability than cells from selenium supplemented (Se+) cows, which correlated with low blood GSH-Px activity (Grasso et al., 1990) (C). [*P < 0.05].

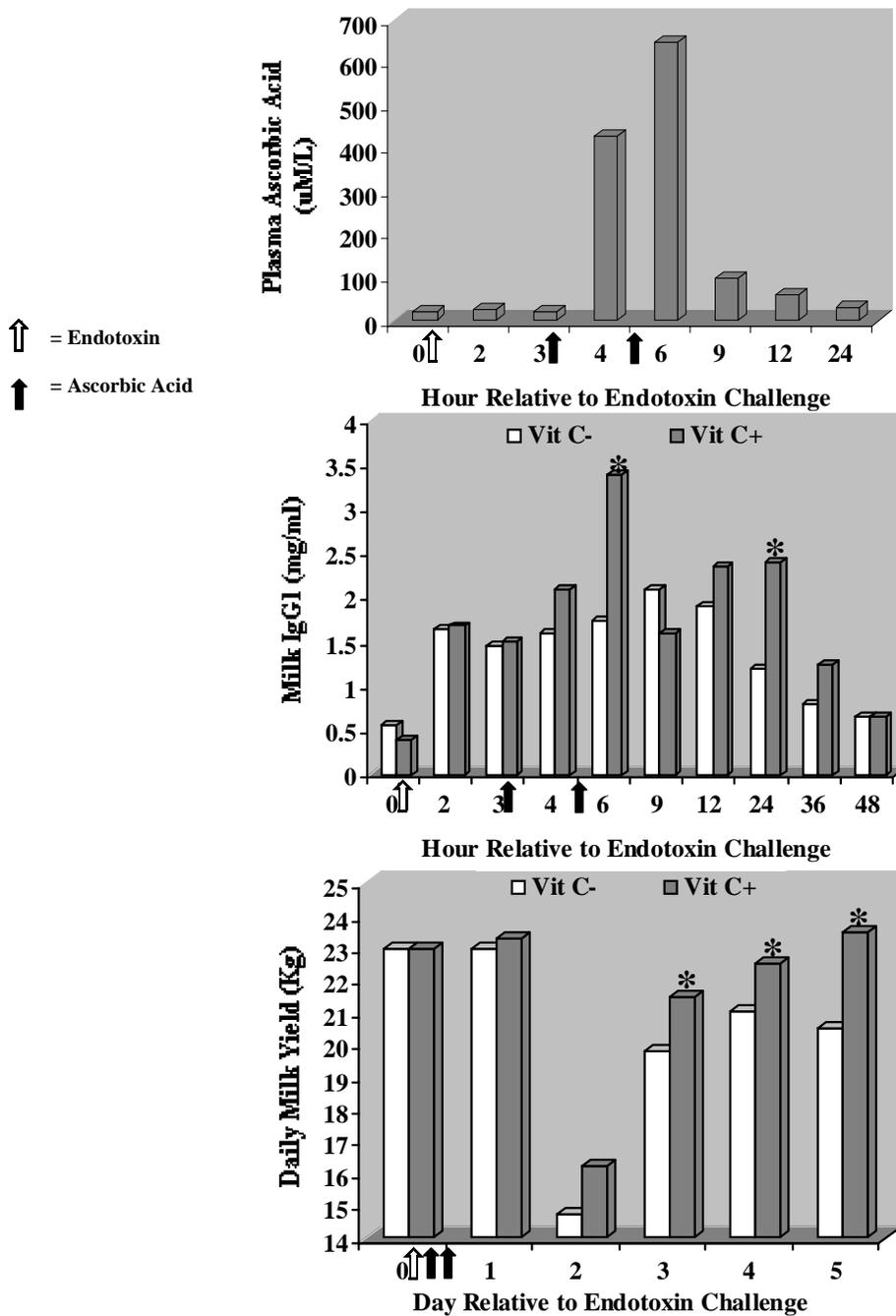


Figure 11. Intravenous administration of ascorbic acid into dairy cows (arrows) rapidly increases plasma ascorbic acid concentrations (A), which influences the rate and magnitude of acute inflammation during endotoxin-induced mastitis [measured as milk IgG₁ concentration; (B)]. Rapid and heightened mammary inflammation in ascorbic acid treated cows was associated with better recovery of milk yield following endotoxin-induced mastitis (C). Therefore, vitamin C therapy may be useful in treating acute coliform mastitis. [From Chaiyotwittayakun et al., 2000; *P < 0.05].



Is it Important to Adjust the Dietary Cation-Anion Difference for Lactating Dairy Cows?

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Abstract

Dietary cation-anion difference (**DCAD**) is defined as the summation of the dietary cations, sodium (**Na**) and potassium (**K**), minus the summation of the dietary anions, chloride (**Cl**) and sulfur (**S**), expressed as milliequivalents (**meq**) per unit of dietary dry matter (**DM**). As DCAD increases, so does blood buffering capacity, in terms of bicarbonate (HCO_3^-), as does blood pH. The high producing, lactating dairy cow, produces many metabolic acids from the liver, kidney, and mammary gland, which can theoretically impact productivity, health, and DM intake negatively if left unchecked. Recent data strongly suggest that by raising DCAD to 35 to 45 meq/100 g DM, feed intake and milk production will increase. Furthermore, when DCAD is raised using both Na and K, the effects are greater than the use of either one alone. Special consideration should be given to K, as there appears to be a positive relationship between this mineral and productivity, specifically in times of heat stress. When dietary K is increased, it is imperative to be certain that magnesium (**Mg**) is also adjusted, such that the dietary ratio of K-to-Mg is 4-to-1. This is to prevent interference of Mg absorption by K. It is obvious from the literature that DCAD and productivity are positively related. However, the ideal DCAD has yet to be defined in terms of days in milk or production level. While we are comfortable with the recommendation of a DCAD between 35 to 45 meq/100 g DM, further research is needed to better

define the relationships between the minerals used in the calculation of DCAD.

Introduction

The DCAD is an interaction among some of the macrominerals. Interacting effects among the macrominerals, Na, K, Cl, and S, have been observed in the prepartum cow, but little has been written on this subject for the postpartum cow. The objective of this paper will be to deliver the newest information on DCAD, with some additional focus on dietary K for the postpartum dairy cow. For a general review and broader examination of these and other related topics, please see some of the other recent papers from this conference and the review by Block (1994).

Acid-Base Status and DCAD

The DCAD affects the cow by altering its acid-base status. Only a brief review of acid-base status and DCAD will be presented here. Please see some of the other recent papers from this conference for more background on the subject.

The number of cation and anion charges absorbed into the blood ultimately determines the concentrations of both blood pH and the primary blood buffer, HCO_3^- . If more anions than cations enter the blood from the digestive tract, blood pH will decrease and blood HCO_3^- will increase. Mongin (1980) proposed that the sum of Na plus K minus Cl in

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milliequivalents [meq per 100 g dietary DM] could be used to predict net acid intake. This equation has commonly been referred to as the dietary cation-anion balance (Tucker et al., 1988) or dietary electrolyte balance (West et al., 1991). Sanchez and Beede (1991) coined the term “cation-anion difference” to represent, more precisely, the mathematical calculation used and to avoid the erroneous connotation that mineral cations truly are balanced with mineral anions in the diet.

Different DCAD Equations

The expression that has been used most often in non-ruminant nutrition is the cation-anion difference expressed using only the ions with single charges:

$$\text{meq (Na + K - Cl)/100 g dietary DM}$$

This expression is considered superior for non-ruminant nutritionists because it comes closest to representing feed ions that are completely dissociated and solubilized from their respective salts and absorbed into the body.

Because of the additional use of sulfate salts in pre-calving rations, the expression that has gained the most acceptance in ruminant nutrition, and is the most common expression used in ration software, is:

$$\text{meq [(Na + K) - (Cl + S)]/100 g dietary DM}$$

To help the reader understand some of the research described on DCAD, in studies where S was not reported, we will discuss the results relative to the Na + K – Cl expression and, in studies where S was reported, we will discuss the results relative to the Na + K – Cl – S expression. As a general rule of thumb, when S equals 0.2% of the dietary DM, S provides approximately –12 meq/100 g of calculated anionic charge. Part of the confusion with the effect

of S on acid-base status is related to its incomplete dissociation, and thus, reduced biological effect (Tucker et al., 1991).

Research on DCAD for Lactating Dairy Cows

Studies Using the Three Element (Na + K – Cl) DCAD Equation

Research on the three-element DCAD expression has only been conducted with mid-lactation cows. A summary of the DM intake and milk yield responses is presented in Figure 1. Kentucky researchers (Tucker et al., 1988) were the first to conduct a study specifically designed to evaluate the effect of DCAD (Na + K – Cl) on acid-base status and lactational performance of dairy cattle. They compared diets formulated with -10, 0, +10, or +20 DCAD. A diet with a +20 DCAD improved DM intake by 11% and milk yield by 9% compared with a diet with DCAD of -10. Blood HCO_3^- increased linearly with increasing DCAD, which indicated an improvement in acid-base status with high DCAD compared with low DCAD. They concluded that responses to increasing DCAD were independent of specific Na, K, or Cl effects. Because lactation diets typically contain greater DCAD than +20, these results were initially more theoretical than practical. For example, the National Research Council (NRC, 1989) minimum Na, K, and Cl requirements indicate that DCAD should be greater than about +25 DCAD. The next question that had to be answered was whether or not responses would continue to increase with diets above +20 DCAD.

West et al. (1991) in Georgia answered part of this question when they evaluated diets with up to +40 meq/100 g of dietary DM. Their study used two 4 x 4 Latin squares blocked by environmental temperature (cool versus hot). Separate squares included four Holstein and four Jersey cows. Diets contained +2.5, +15, +27.5 or +40 DCAD. No effect of environment was noted, but increasing

DCAD from +2.5 to +27.5 increased DM intake, milk yield, and blood HCO_3^- . These findings suggested that performance was depressed with lower DCAD diets. At +27.5 DCAD, negative effects were overcome. Above +27.5 DCAD, no additional improvement was evident.

In another study by this group (West et al., 1992), diets with even higher DCAD (+10, +21.7, +33.4, and +45.1) were fed to a total of 16 lactating dairy cows during hot weather. Increasing DCAD increased DM intake linearly, independent of Na or K source. Yield of 3.5% fat-corrected milk (FCM) was not affected by DCAD or cation source. Milk fat concentration was greater with Na-compared with K-manipulated diets (3.92 versus 3.62%). Blood pH increased linearly; whereas, blood HCO_3^- increased curvilinearly. There was no effect due to cation source on acid-base status. Their results indicated that increasing DCAD improved DMI and acid-base status in a manner consistent with other studies.

Studies Using the Four Element DCAD [(Na + K) - (Cl + S)] Equation

A summary of studies that used the [(Na + K) - (Cl + S)] expression is presented in Table 1. A large study with 48 cows and 15 dietary treatments was conducted by Sanchez et al. (1994) to investigate lactational and acid-base responses to DCAD as [(Na + K) - (Cl + S)]. Treatments consisted of combinations of Na, K, and Cl, so that DCAD ranged from 0 to +50 meq [(Na + K) - (Cl + S)]/100 g DM. The basal diet was 54.5% concentrate, 5.5% cottonseed hulls, and 40% corn silage (DM basis). Dry matter intake and milk yield was highest when DCAD [(Na + K) - (Cl + S)] was between +17 to +38 and +25 to +40, respectively (Figure 2). There was one odd treatment (a low Cl, high K, and high Na treatment combination) that may have caused a Cl deficiency. Had that treatment not been included, the optimal DCAD would have shifted to

the right. As in the other studies, blood HCO_3^- also responded in a curvilinear fashion to increasing DCAD. Blood HCO_3^- was maximized with +38 meq DCAD [(Na + K) - (Cl + S)]. In support of the conclusions by Tucker et al. (1988) and West et al. (1991 and 1992), results of this study indicated that feeding diets with less than +20 DCAD depressed blood HCO_3^- and should not be fed. The optimal DCAD for mid lactation cows is between +27.5 and +40 meq [(Na + K) - (Cl + S)]/100 g DM.

Studies With the [(Na + K) - (Cl + S)] Equation Throughout Different Phases of Lactation

Three switchback experiments were conducted (Delaquis and Block, 1995) using 12 cows each in early, mid, and late lactation. Each experiment compared two DCAD levels calculated as [(Na + K) - (Cl + S)]/100 g DM. Increasing DCAD from +5.5 to +25.8 in early lactation and from +14.0 to +37.3 in mid lactation increased DM intake and milk production. These effects were not observed in late lactation (with either +20.0 or +37.5 DCAD). Concentration of blood HCO_3^- was decreased in early lactation and excretion of carbonate ions in urine was reduced by a lower DCAD at all stages of lactation. Responses in this study are consistent with the effect of DCAD on acid-base status observed in other studies; however, this study supports the concept that the DCAD response is most evident in early lactation.

Differences Between K and Na as the Source of Increased DCAD

In the study by West et al. (1992), the source of cation (Na or K) used to manipulate DCAD also was compared. In these mid-lactation cows, no difference between Na and K, was observed. Tucker and Hogue (1990) evaluated the influence of Na, K and Cl at constant DCAD. This study, therefore, compared effects of Na to K. Diets were formulated to provide +32 DCAD in either: a basal diet (ad-

equate in dietary Na, K, and Cl), a basal diet containing an additional 1.17% NaCl, or a basal diet containing an additional 1.56% KCl. Fifteen mid lactation cows were assigned to replicated 3 x 3 Latin squares. The KCl-fed cows consumed more DM and had lower milk fat percentage than NaCl-fed cows, but there were no differences in milk yield. Again, for these midlactation cows, it was concluded that dietary DCAD was a more important determinant of dietary impact on systemic acid-base status than actual dietary concentrations of Na, K, and Cl.

Perhaps the most complete study on the effects of Na, K, and DCAD on early lactation dairy cows conducted to date is a study by Elliot Block and associates from McGill University in Quebec (E. Block, personal communication, 1999). Block fed a control diet with no added Na or K (+18 DCAD) and two higher (+25 and +52) DCAD diets to early lactation (0 to 10 weeks in milk) Holstein cows. Within the higher DCAD diets, he manipulated the source of DCAD (by using either sodium bicarbonate or potassium carbonate alone or a combination of both) to determine the individual or combined effects of Na and K. The combination of Na and K resulted in the best response for DM intake and milk production, and the +52 DCAD diet resulted in the highest milk production response (Figure 3). The combinations of Na and K also resulted in the highest blood bicarbonate concentrations (Figure 3).

Two field trials were recently completed at Church & Dwight Co. In the first trial, dietary K was held constant at 1.3% of total dietary DM but DCAD was increased by reducing Cl in one diet (i.e., substitution of KCl by K_2CO_3). The DCAD comparison was +19 versus +25 meq/100 g DM. Sodium and K concentrations in both diets were equivalent at 0.4 and 1.3% of dietary DM, respectively, and Cl was 0.66 and 0.39% of dietary DM for the +19 and +25 meq DCAD diets, respectively. Fifty cows between calving and 200 days in milk (**DIM**) per treatment

were followed for four DHI tests. Statistical analysis of production data showed an increase ($P < 0.10$) in milk yield by 2.98 lb/day (86.49 versus 89.47 lb/day) for the cows fed the higher DCAD. Feed intake could not be evaluated. In a second field trial, 70 cows per treatment between calving and 200 DIM were fed diets with a low (+38 meq/100 g DM) or high (+43 meq/100 g DM) DCAD adjusted by the simple addition of K_2CO_3 to one of the diets. Sodium, K, and Cl concentrations in the diets were 0.48, 1.52 and 0.26% for the low DCAD diet and 0.43, 1.8, and 0.26% for the higher DCAD diet. Again, the cows fed the higher DCAD produced 2.4 lb/day more ($P < 0.05$) FCM (109.4 versus 111.8 lb/day) compared to cows fed the lower DCAD.

The above positive responses observed with combinations of Na and K point to the unique role that dietary K plays in early lactation. A similar role has been noted for cows in heat stress. Heat stressed cows lose K via sweat, and milk is high in K. Thus, the heat stressed dairy cow is often K deficient. Research conducted in Texas (West et al., 1986; West et al., 1987a,b), and in Idaho (Griffel et al., 1997) where potassium carbonate was the source of dietary K, indicates that there is a linear response to dietary K during summer at up to 2.1 % dietary K. Figure 4 shows the FCM responses to varying dietary K in both mid and early lactation.

Upper Limit of Dietary Potassium

In 1989, the National Research Council published 3% K as the maximum tolerable level (NRC, 1989). The Canadian researchers, Fisher et al. (1994), conducted more-recent research on the effect of high levels of dietary K. They fed diets with 1.6, 3.1, and 4.6% K (low, medium, and high) to lactating cows. Their study involved 15 early lactation Holstein cows housed in a free-stall barn and fed grass-haylage based diets. The reported DCAD values cows were very high at +36.6, +73.5, and +108.1 meq [(Na + K) - (Cl + S)]/

100 g dietary DM. In terms of palatability effects, the authors noted that ‘several cows preferred the 3.1% K diets to the others’. No significant differences were noted among diets for total DM intake (50.6, 52.4, and 49.1 lb/day for the low, medium, and high K diets, respectively). However, when expressed as a percentage of body weight (**BW**), cows fed the medium K diets had the highest intakes (3.54, 3.59, and 3.36 % of BW, respectively). Milk yields were reduced for cows fed the high K diet but similar for cows fed the low and medium K diets (69.5, 69.3, and 65.6 lb/day for the low, medium, and high K diets, respectively).

Dietary K and Nutrient Management Plans

Any program that increases the amount of K fed to the lactating cows must consider the overall effect of K on the dairy farms. This of course is due to the fact that feeding extra K to pre-calving dry cows can contribute to milk fever problems. Therefore, a nutrient management plan that considers both manure and purchased fertilizer K is needed to avoid growing forages with excessively high K. We are aware of two whole-farm potassium balance case histories that help illustrate the importance of nutrient management plans to control excess K in soils and harvested forages.

In the first case, The Cornell University Dairy Farm monitored N, P, and K balances over 25 years (Wang et al., 1999). Table 2 provides the details of the mass balance of K in 1979 and 1994. Feed imports of K increased greatly, but because fertilizer sources of K were drastically reduced and the amount of K captured in milk increased, the net balance of K on the farm was reduced by 30%. The second case history comes from the Washington State University Dairy at Puyallup (Joe Harrison, personal communication, 1999). At their dairy farm, they noticed grass-forage K concentrations increasing to levels as high as 6%. Therefore, they eliminated potassium in the

purchased fertilizer (they still had K coming in from manure). After a three-year period, grass-forage K concentrations returned to normal. Based on new soil samples, they re-introduced purchased K at a reduced level into the fertilization program.

Effect of Additional K on Magnesium Absorption

When adding additional dietary K, the absorption of dietary Mg will be reduced. Therefore, Mg needs to be increased due to the effect K has on reducing absorption of dietary Mg. When feeding high levels of dietary K, optimal levels of dietary Mg appear to be 0.35 to 0.38% of dietary DM. Another rule of thumb is to maintain a 4:1 ratio of dietary K to Mg (the ratio is calculated with minerals on a percentage of dietary DM basis).

Sources of Dietary Potassium

Potassium chloride is a common source of K when both K and Cl are needed but does not increase DCAD. Potassium carbonate is a source of K that increases DCAD. Potassium carbonate must be handled and mixed carefully in feed mills and on the farm; the manufacturer’s mixing directions should be closely followed. Potassium bicarbonate is also a good source of the cation; however, it is very expensive per unit of K. Other sources of K (without Cl) are limited in their use by the accompanying anion (i.e., potassium iodate).

Conclusions and Recommendations

- The optimal DCAD for mid lactation cows is between +27.5 and +40 meq [(Na + K) – (Cl + S)]/100 g DM.
- For early lactation dairy cows, the optimum DCAD may be as high as +50, but until more



field data on these higher levels become available, increasing DCAD to around +40 meq [(Na + K) – (Cl + S)]/100 g DM is the recommended strategy for early lactation cows.

- Dietary K for early lactation cows may need to be raised to as high 1.8% K to achieve maximum responses. Diets up to 3 % K appear safe but above 3% may be detrimental. Because excess dietary K can interfere with Mg absorption, extra Mg needs to be fed when feeding higher levels of K.
- Increasing DCAD with a combination of Na and K is better than using Na or K alone. Dietary K appears to have a unique role in early lactation independent of its effect on DCAD.
- Analyze feeds for macromineral content and use a nutrient management plan that accounts for the both manure and fertilizer sources of potassium added to the soil.

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Table 1. Summary of the effect of dietary cation-anion difference (DCAD) on milk, dry matter (DM) intake and blood bicarbonate (HCO_3^-) responses in studies using the $[(\text{Na} + \text{K}) - (\text{Cl} + \text{S})]$ DCAD expression.

Study	DCAD Meq $[(\text{Na} + \text{K}) - (\text{Cl} + \text{S})]$ / 100 g dietary DM	Parameter	Response
Sanchez et al., 1994	15 Treatments 0 to +50	Intake Milk Blood HCO_3^- Midlactation	+25 Max +31 Max +38 Max
Delaquis and Block, 1995	+5.5 to +25.8	Milk, Intake, Blood HCO_3^- Early Lactation	Positive
Delaquis and Block, 1995	+14 to +37.3	Milk, Intake Midlactation	Positive
Delaquis and Block, 1995	+20 to +37.3	Milk, Intake Late Lactation	Not Significant
Block, Unpublished 1999	+18 to +52	Milk, Intake, Blood HCO_3^- Early Lactation	Positive; Dependent on source of DCAD

Table 2. Mass balance of K on the Cornell University Dairy Farm between 1979 and 1999 (Wang et al., 1999).

	K (tons)	
	1979	1994
Imports		
Feed	9.4	22.0
Fertilizer	18.5	2.4
Total Imports	27.9	24.4
Exports		
Milk ¹	4.5	5.9
Animals	0.2	0.2
Feed Refused	3.3	4.4
Total Exports	8.0	10.5
Balance	19.8	13.9

¹Milk production increased from 14,964 to 22,559 lb/cow/year and cow numbers increased from 369 to 400 between 1979 and 1994.

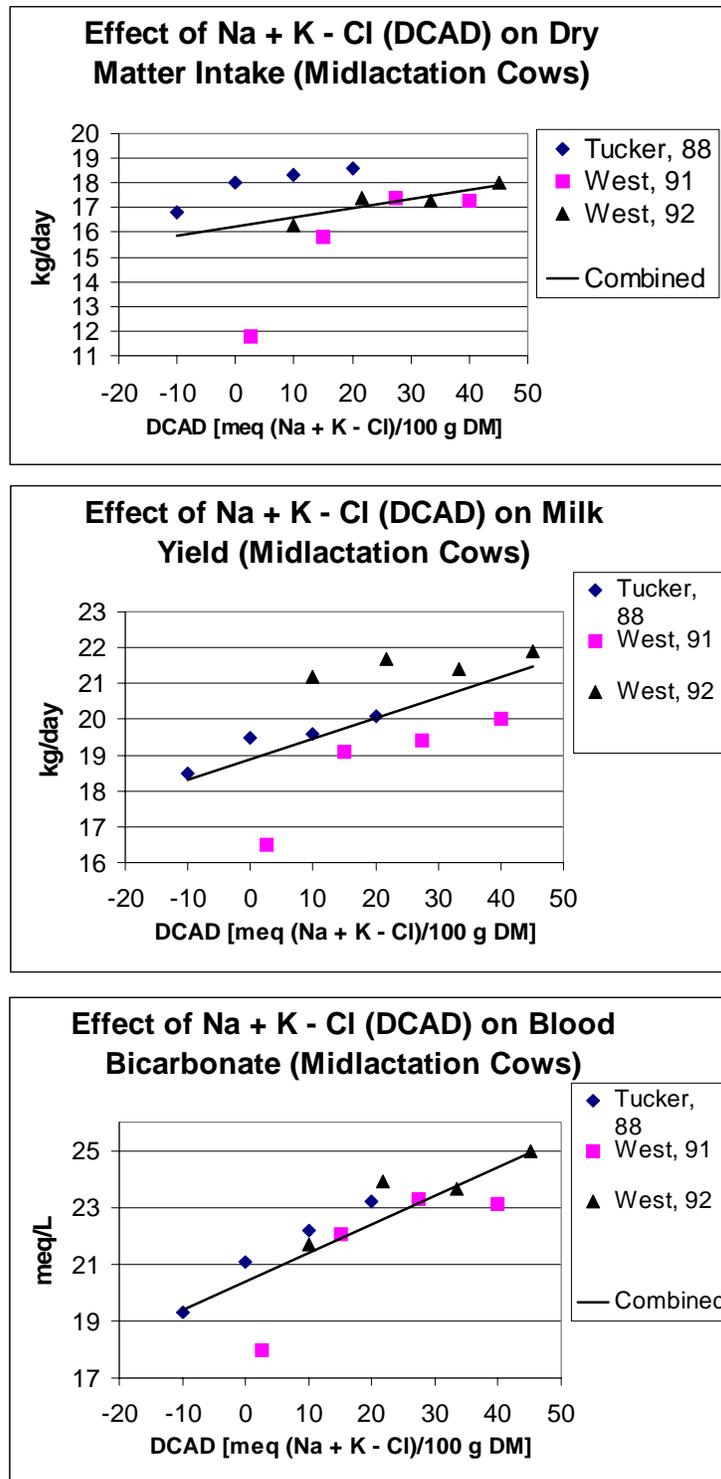


Figure 1. Summary of the effect of dietary cation-anion difference (DCAD) on dry matter intake and milk yield using the (Na + K - Cl) DCAD expression (data are from Tucker et al., 1988; West et al., 1991; and West et al., 1992).

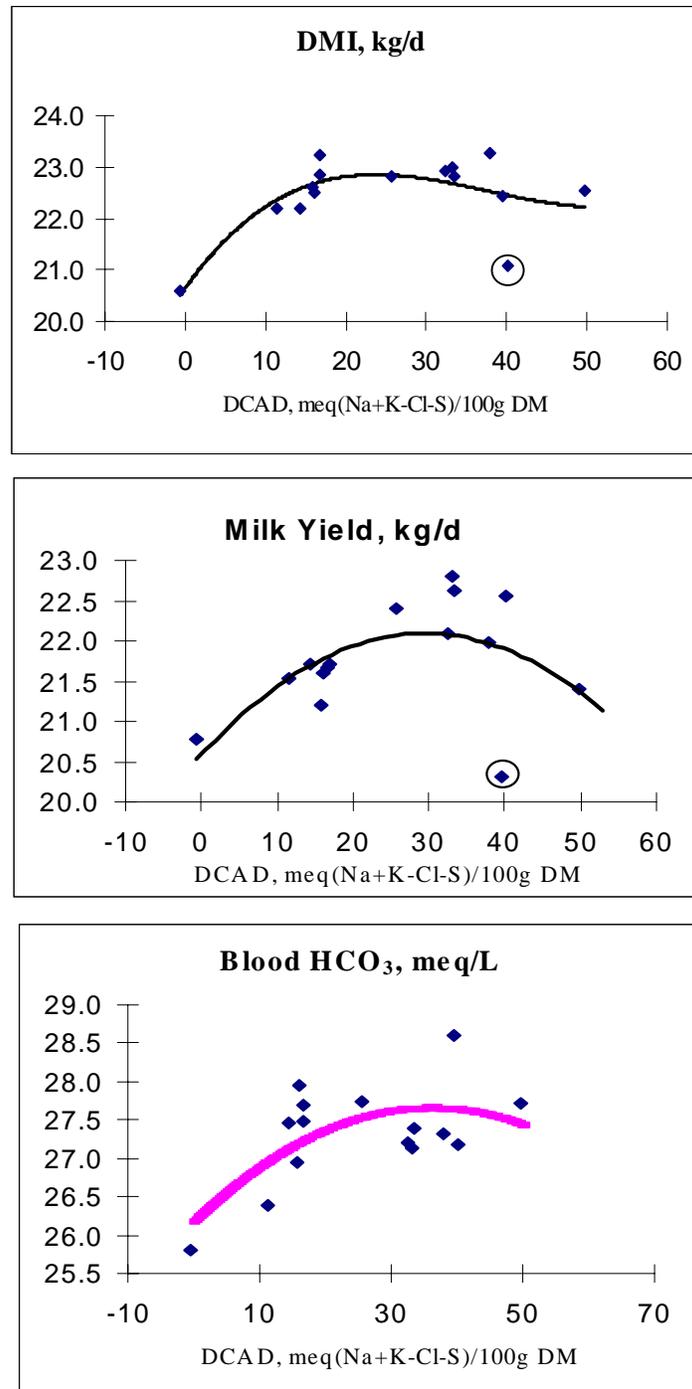


Figure 2. Dry matter intake (DMI), milk yield, and blood HCO₃⁻ response to dietary cation-anion difference (DCAD) $[(Na + K) - (Cl + S)]/100$ g DM] in mid lactation cows. Data are from Sanchez et al., 1994 (treatments circled are from a low Cl, high K, and high Na treatment combination that may have caused a Cl deficiency).

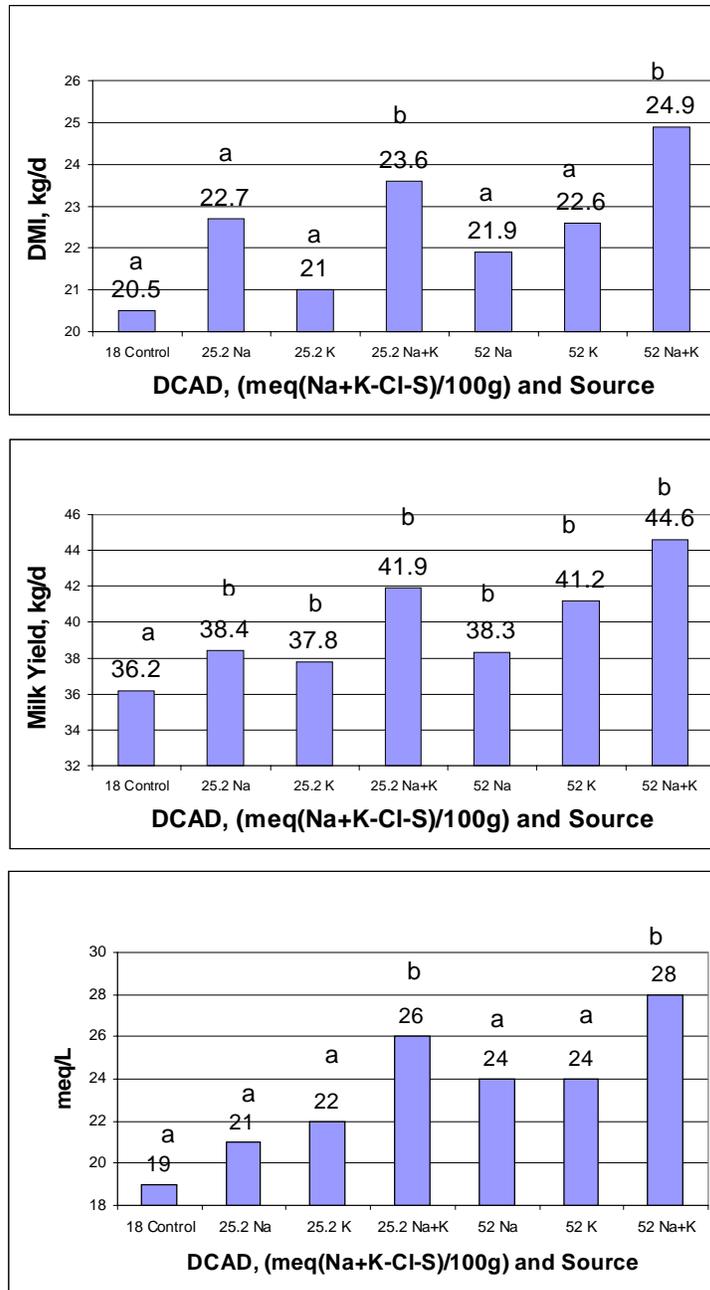


Figure 3. Dry matter intake (DMI), milk yield, and blood bicarbonate, respectively, responses to dietary cation-anion difference (DCAD) $[(Na + K) - (Cl + S)]/100$ g DM in early lactation cows. Data are from Elliot Block, McGill University (1999, unpublished data). Both DCAD concentration and source (either Na, K, or a combination of both) were evaluated in 10 early lactation cows (weeks 1 to 10 in milk) per treatment. Different superscripts indicate a statistical difference (a = $P < 0.05$; b = $P < 0.01$) between treatment and control.

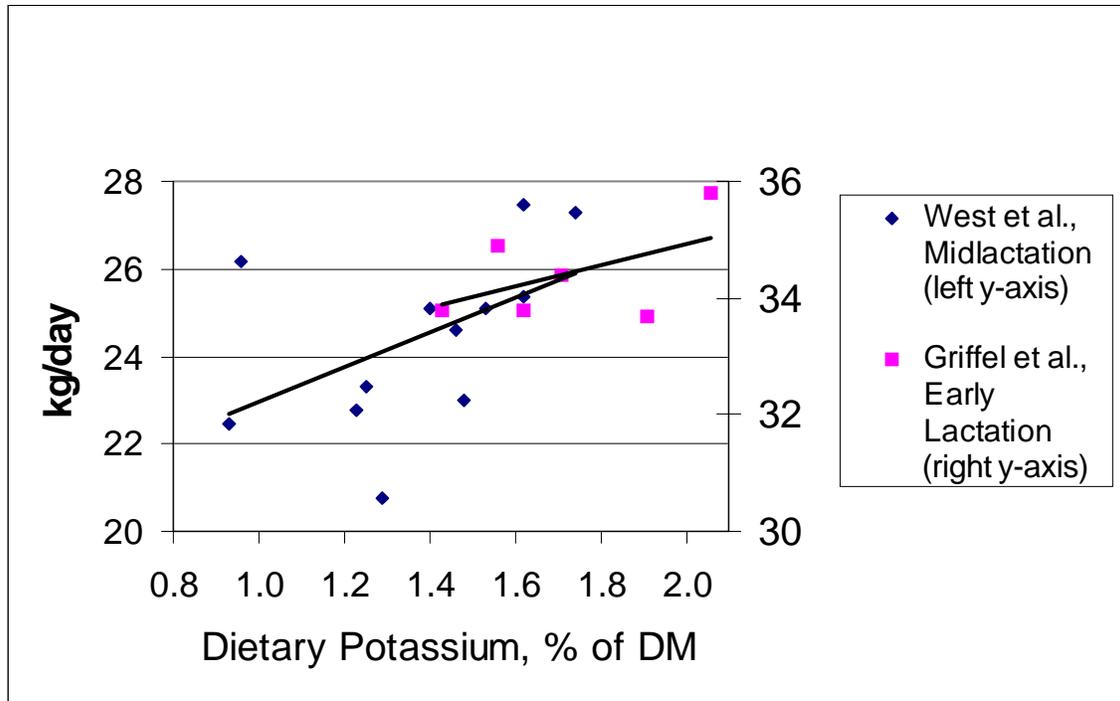


Figure 4. Fat-corrected milk response (3.5% FCM) to feeding various potassium concentrations (as potassium carbonate) to heat stressed midlactation dairy cows (left hand scale 20 to 28 kg/day of milk; data from West et al., 1986; West et al., 1987a,b) and early lactation cows during summer in Idaho (right hand scale 30 to 36 kg/day of milk; data from Griffel et al., 1997).



Effects of Nutrition on Hoof Health

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Abstract

The majority of lameness in dairy cattle is associated with the foot. Aside from digital dermatitis (“hairy heel warts”), most lameness of the foot is a result of the production of inferior hoof horn. In the past, low quality hoof horn has been most commonly attributed to a condition referred to as subclinical laminitis. The term “subclinical laminitis” is at best an umbrella term and does not always adequately describe all situations that may occur, and may at times even be misleading. For example, not all horn quality problems are related to inflammation of the laminae, as would be implied by the word “laminitis”. Recently the term “claw (or hoof) horn disruption” has been proposed to better describe what is occurring. Because numerous causative factors, acting independently or interacting with one another, may result in claw horn disruption, the condition is said to be multifactorial. Moreover, the lesions that are observed in the hoof horn may often look the same or similar regardless of the cause.

Introduction

Lesions of claw horn disruption include yellow discoloration of the sole, white line disease, heel erosion, hemorrhage of the sole, horizontal ridges of the wall, double sole, sole ulcer, and a relative increase in depth of the lateral claw of the rear limb. The prevalence of these lesions may be high in intensively managed dairy cattle. In a 13-herd

study of first lactation cows conducted in Ohio, 62% of cattle in their first 100 days of lactation had hemorrhages of the sole (Smilie et al., 1993; Table 1). Claw horn disruption is not limited to lactating cattle. Hemorrhages have been found in the soles of calves as young as 5 months of age (Bradley et al., 1989). Hemorrhages and ulcers are both indicators of events that have occurred in the vascular or dermal layer of the foot and are considered stages of the same disease process (Greenough, 1985). Management and other factors that predispose a herd to claw horn disruption need to be identified early and corrected because an initial episode of claw horn disruption (such as sole ulcer) tends to be repeated in subsequent lactations (Enevoldsen and Grohn, 1991).

Anatomy and Physiology

This paper will focus on metabolic risk factors thought to be associated with the production of inferior horn or hoof horn disruption. The entire hoof or hoof capsule is constructed of cornified epidermal tissue called horn. The capsule has both biological and mechanical functions (Budras et al., 1998). Biologically, it serves as a barrier to protect the underlying tissues, while mechanically, it transmits the weight of the cow from the skeleton to the ground. It is a mistake to think of the hoof as a simple, homogenous structure. Anatomically, the hoof is best considered a complex organ consisting of multiple horn components which function together as a cohesive unit (Leach et al, 1997).

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Further, hoof quality should not be measured only in terms of hardness. In the normal hoof, wall > sole > heel > white line in terms of hardness. Hoof horn in its various capsular locations should be both hard enough and soft enough to perform its various functions.

Lesions of hoof horn may be the result of a variety of insults that occur at the level of the keratin-producing cells. These cells, the keratinocytes, are located in the innermost and only living layers of epidermis and their response to insult is the formation of inferior hoof horn. The visible response is generally not specific to cause. For example, these lesions may result from vascular events that cause inflammation and prevent diffusion of nutrients and O₂ across the basement membrane to the epidermal cells. The response also may result from lack of a particular nutrient. Because there is usually a time lag between the time an insult to the keratin-producing epidermis occurs and when lesions are observed, correlating lesions to probable causation is dependent on understanding the anatomy and physiology of hoof horn formation.

Hoof horn consists of cornified, or dead, keratin-containing cells and membrane-coating material. Horn is arranged into tubular and inter-tubular horn. Cells in the basal layer of the epidermis produce filamentous keratin proteins and filament-associated proteins, the latter of which are characterized by their high content of the sulfur-containing amino acid, cysteine. Cysteine contributes the disulfide bonds necessary to crosslink the keratin protein complexes that are required for structural stability of horn. Membrane coating material is an intercellular cementing substance that is produced in the spinous layer of epidermis and consists of glycoproteins and complex lipids. The glycoproteins mechanically connect horn cells together, while the lipids contribute to the permeability barrier necessary to maintain proper horn

hydration (Budras et al., 1998).

Hoof horn of the wall is produced in the upper ½ of hoof at a rate of approximately 5 mm (0.2 inches) per month, dependent somewhat on season, claw, and the nutritional status of the animal (Prentice, 1973). The dorsal-anterior hoof wall of a normal mature Holstein cow is approximately 75 mm (3 inches) in length which means that normal horn generated in the coronary segment of the anterior wall requires approximately 12 to 15 months to reach the weight-bearing surface. Hoof horn formed in the sole and heel typically reaches the weight-bearing surface 2 to 3 months after it is produced.

The sole, wall, and white line are different anatomically and have different functions. The wall is rigid, but the sole is less rigid. The white line may be thought of as a hinged joint necessary to functionally connect the wall and sole. The white line consists of horn originating from three segments of the wall, namely horn leaflets, cap horn, and terminal horn. Horn leaflets provide structural rigidity to the white line and are produced proximally in the coronary region. The interdigitating cap and terminal horn originate from epidermis covering the distal dermal laminae of the wall and are relatively soft and pliable. Cap and terminal horn permit flexibility in the white line as the animal walks. Areas of the hoof capsule with high rates of horn production, eg. the heel bulb and abaxial white line near the junction of the wall, sole, and heel, are particularly prone to those problems of the keratin-producing cells that result in incomplete keratinization and production of low quality horn (Budras et al., 1996).

Risk Factors

Subclinical laminitis, or claw horn disruption, is generally considered to be of multifactorial causation with relative importance of a particular risk factor expected to vary among farms. Parturition, environment, feeding management

and nutrition, other management factors, socialization, foot and other diseases, individual animal traits, and genetics have all been implicated as risk factors in hoof horn disruption. The first parturition appears to be associated with particularly high risk. When investigating and attempting to prevent problems of hoof horn quality, it is important to distinguish those situations which are truly herd problems from those that may be merely problems with individual animals.

Nutritional and Feeding Management

Acidosis

Feeding diets not balanced correctly for carbohydrates (e.g., low in effective fiber, high in starch, and low forage:concentrate ratio), diets with small particle size, rapid changes to high concentrate feeding after parturition, “slug” feeding of concentrates, and the relative time of feeding forages and concentrates are associated with rumen acidosis and subsequent lesions of the hoof horn. These practices often chronically decrease rumen pH to less than 5.6. Low rumen pH leads to an increase in lactic acid producing bacteria and subsequently further decrease rumen pH. The result is death of rumen microorganisms with release of endotoxins and histamines. These substances can have a profound effect on the blood vessels in the dermal layer (corium) underlying the epidermis of the foot. For example, histamine is both a vasodilator and arterial constrictor (Nocek, 1997). The current theory is that a disruption of the microvasculature occurs in the corium with pooling of blood, hemorrhage, and failure to deliver O₂ and nutrients to the keratinocytes. In addition to the nutritional theory of hoof horn disruption, histamine release from tissue with essentially the same effect on the vascular layer can be caused by environmental stress, concussion, trauma associated with concrete floors, overcrowding, and infectious diseases (Stangassinger and Giesecke, 1978).

Although the general assumption that rumen acidosis is a major risk factor for the occurrence of the typical lesions associated with laminitis, few studies have been reported which determine its direct effect on laminitis. This is especially true in North America as most of the reports in the literature are from studies conducted in Europe. In 1988, Manson and Leaver in the UK demonstrated that cows fed 24 lb/day of concentrates (versus 15 lb) from 3 to 22 weeks of lactation had more lameness, with sole lesions being the major problem. However, the dilemma of managing modern dairy cattle for production was also evident in their study in that cows fed 24 lb of concentrates also produced 7 lb more milk that had 0.06 percentage units higher milk protein (Manson and Leaver, 1988a).

Virtually all agree that feeding cattle to maintain a stable rumen pH above about 6 is desirable and that acclimation of the rumen to feed changes is important. There is also agreement that acute episodes of rumen acidosis can result in hoof horn disruption. There is a lack of evidence regarding the relative importance of small alterations or cyclic alterations in rumen pH. Also not understood are the possible effects of numerous other interactions, including environment and hormonal changes associated with parturition, when combined with changes in rumen pH.

Transition Period

Observational as well as experimental evidence indicates that events that occur in the transition period around parturition are very important in maintaining healthy hoof horn. Possibly because of continued requirements for growth, socialization, and other factors, this appears to be particularly true for primiparous cows. Maintaining dry matter intake (**DM**) would appear to be important. The problem is likely more complex than merely the diet fed postpartum or the change in diet that occurs after calving. Livesey and Fleming (1984) reported on the nutritional ef-



fects of prepartum and early lactation diets on the occurrence of laminitis and sole ulcers. Precalving diet did not appear to have an effect on laminitis or ulcers. However, in the first 6 weeks after calving, cows fed a low fiber diet had an incidence of 68% laminitis and 64% sole ulcers compared to 8% laminitis and 8% sole ulcers in cows fed high fiber diets. During the last two weeks of gestation, DM intake may be decreased 10 to 30% as compared to earlier (Van Saun et al., 1993). The largest decrease begins about five days prepartum, with mean intake the last five days being about 20% less than mean intake during the rest of the dry period. This limited feed intake during the early postpartum period means glucose demand must be met by amino acid catabolism in addition to propionate conversion. Livesey et al. (1998) demonstrated that hoof wall growth rates increased in response to methionine supplementation after the first calving but not after the second calving. This led them to suggest that there may be a period of suboptimal supply of essential nutrients caused by low feed intake at a time of high demand, especially for heifers in late pregnancy and early lactation.

Protein

Microbial proteins are a very good source of the sulfur-containing amino acids, which may be of importance from a hoof health standpoint (Elliott, 1999). Evidence of the effect of feeding protein on the occurrence of hoof horn lesions either in terms of quantity or source of protein is not well-documented. One study (Bazeley and Pinsent, 1984) reported an increased occurrence of laminitis associated with feeding a high level of protein supplement that also contained an elevated level of free ammonia in silage. Manson and Leaver (1988b) reported that cows fed a diet with 19.8% crude protein (CP), as compared to those fed a diet with 16.1% CP, had higher locomotion scores (i.e., poorer locomotion), an increase in number and duration of cases of lameness, and an increase in outer claw length. Trimming hooves reduced locomotion scores and the number and dura-

tion of cases of lameness. Weaknesses of the study included small experimental groups (12 cows each) and that the neutral detergent fiber content of the low protein diet was much higher than that of the high protein diet. Again, both studies were reported from the U.K. In a Canadian study with feedlot cattle, while high energy rations increased the incidence of sole and toe lesions, increasing the level of protein in the diet from 11 to 19% CP had no effect on hemorrhage score (Greenough et al., 1990).

Biotin

Previously, it was thought that providing supplemental B-complex vitamins to ruminant animals was not necessary. Recently, however, especially in situations where dairy cattle are fed to maximize production, this concept has been questioned and there has been renewed interest in feeding supplemental biotin to cattle. Quantities of B vitamins normally supplied by the diet and by gastrointestinal microflora synthesis may not be adequate to optimize health and productivity (Girard, 1998). Biotin is involved as a coenzyme in the synthesis of long-chain fatty acids and glucose metabolism. It is also involved in keratin production. Last year, researchers in Germany determined that biotin is essential for keratin protein synthesis in hoof tissue and for the formation of the long-chain fatty acids present in the membrane cementing substance (Mülling et al., 1999).

Results of feeding trials have shown a variety of benefits to hoof health when biotin was fed. Studies conducted in various countries with cattle managed under a variety of conditions have found decreased incidence of sole ulcers and heel erosion (biotin, at 10 mg/day; Hagemester and Steinberg, 1996), improved healing process of sole ulcers (biotin, at 20 mg/day; Koller et al., 1998), decreased occurrence of vertical fissures in beef cattle (biotin, at 10 mg/day; Campbell et al., 1996), and decreased incidence in lameness in pastured dairy

cattle in tropical Australia (biotin, at 20 mg/day; Fitzgerald et al., 2000).

In January 1995, we began a biotin feeding trial utilizing recently calved, first-lactation cows in an 800-cow Holstein herd. Lactating cows in the herd were fed a total mixed ration and were confined to concrete and housed in freestalls. The biotin supplemented group (20 mg biotin/head/day; Rovimix-H100, Roche Vitamins, Parsippany, NJ) had significantly less separation of the white line than did the nonsupplemented group at 108 days after calving (Midla et al., 1998). White line originates from three segments of the hoof wall. The rigid horny laminae are formed proximally in the coronary segment. Soft cap horn and terminal horn are formed on the distal wall segment and would be expected to reach the weight-bearing surface within several months of formation. Finding significantly better white line health after feeding supplemental biotin for three months suggests that further investigation into possible relationships of biotin and the keratinizing process of the white line is warranted.

Taken together, the majority of the biotin feeding studies indicate that feeding biotin improves hoof health. Biotin, and probably any other nutrient, should not be viewed as a “magic bullet”. For example, in the second year of our study, horn lesions associated with rumen acidosis were equally present in both supplemented and control cattle. Biotin-feeding studies conducted under a variety of situations have shown improvements in horn health. In interpreting results from these studies, it should be remembered that the hoof capsule is neither homogenous in structure nor in function. Environment and other conditions that may be present in a particular study must be factored into interpreting results.

Copper and zinc are two micronutrients known to be involved in keratin synthesis. Few field studies for their effects on hoof health in cattle have been reported. In one, hooves of dairy cows

fed 200 mg/day of zinc methionine for an entire lactation were visually more sound than were hooves in control cows (Moore et al., 1988). Soundness was judged by hardness, cracks in hoof, prevalence of laminitis, and presence of interdigital dermatitis. In another experiment (Stern et al., 1998), beef calves fed organic zinc in a corn and grass silage based diet had greater improvements in macroscopic horn quality and tensile strength when compared to calves fed zinc oxide. A trend toward stronger hooves was also reported in feedlot heifers supplemented with 100 mg/head/day of zinc proteinate as compared to zinc sulfate (Reling et al., 1992).

Calcium is involved in the activation of biochemical pathways important in the differentiation of epidermal cells, including the induction of terminal differentiation (i.e., cornification) of keratinocytes. Mülling et al. (1999) suggested that the decrease in plasma calcium frequently observed near parturition may influence terminal differentiating epidermal cells and thus provide an explanation for “rings” in hoof horn that are observed with pregnancy in cows. This finding suggests that dietary interventions that maintain normal plasma calcium levels in the peripartum period might prevent damage in hoof horn structure that could influence hoof health throughout the life of the animal (Elliott, 1999).

Interaction of Management, Environment, and Nutrition

Cow Comfort and Environment

Decreasing the time that cows stand on concrete may reduce horn lesions associated with sub-clinical laminitis, even in situations where the diet may be contributory to rumen acidosis. Two, 130-cow herds in the UK were under the same ownership, fed identical rations, and had no apparent environmental or housing differences (Colam-Ainsworth et al., 1989). However, one herd routinely had a high incidence of lameness as a result of sole ulcers in first-



lactation cows, while the other had none. More careful observation revealed significantly greater standing time ($P < 0.001$) and less use of freestalls by cows in the herd with the lameness. Further investigation found that the problem herd used one bale of straw for bedding per 45 cows, whereas the other herd used one bale per 10 cows. When the amount of straw was increased in the problem herd, no new cases of lameness occurred. Ensuring a clean dry environment (Bergsten and Petterson, 1992) and permitting cows to stand on rubber mats (Bergsten and Herlin, 1996) reduced lesions of subclinical laminitis.

Summary

There are many questions that remain unanswered regarding maintenance of healthy hoof horn in dairy cattle. Much of the literature is available only in proceedings articles or other non-peer reviewed forms. Clearly, however, the evidence that is available indicates that lesions of hoof horn have multiple causes. Rumen acidosis is a major contributory factor but not the only one. Balancing the impact of the potential causative factors in a herd to lessen their negative influence on hoof horn quality remains our challenge.

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Table 1. Hoof horn lesions from a 13-herd Ohio study (Smilie et al., 1996).

Category of Lesion	Herds (n=13)	Cows (n=203)	Claws (n=812)
Discoloration of sole	89%	59%	36%
Hemorrhage of sole	100%	62%	38%
Separation of white line	100%	16%	9%
Erosion of heel	100%	27%	13%

Changes in Feeding Heifers to Meet Environmental Challenges

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Abstract

Economical feed conversion efficiency in pre-weaning dairy heifers requires energy intakes in excess of maintenance requirements. Extreme climatic conditions, resulting in effective temperatures outside the thermoneutral zone, result in increased metabolism to maintain thermoneutrality, depriving the calf of nutrients for growth. The Lower Critical Temperature (**LCT**) in the milk-fed calf is approximately 50°F. For each 25°F below the LCT, an extra 0.82 Mcal digestible energy (**DE**) is required. The energy deficit can be met by feeding 0.33 lb of milk replacer powder, 0.25 lb of tallow, or 0.5 lb of calf starter.

Introduction

The milk-fed heifer is raised in a wide variety of environmental conditions and geographical regions. The efficiency of production depends upon cost effective modification of the environment and nutrition. Adaptation to extreme weather conditions begins in the uterus and is influenced by the birth process. Understanding of the physiology and nutrient requirements of young calves can improve management decisions.

Thermoneutral Zone

The thermoneutral zone is the environmental temperature range in which the amount of body heat produced is balanced by the heat lost from the body

from conduction, convection, radiant, and evaporative heat loss (Figure 1). In this zone, changes in environmental temperature are countered by shifts in heat loss, e.g. panting or heat gain, e.g. piloerection, and postural changes. The LCT in the calf is about 50°F. Below this temperature, metabolism and energy use increases linearly until summit metabolism (**SM**). Below this threshold, the animal decompensates rapidly without external assistance. The Upper Critical Temperature (**UCT**) for a young Holstein calf is approximately 78°F. Above this temperature, panting and sweating cannot compensate for external heat. Feed intake decreases, and above 100°F, heat prostration and death may result.

Critical temperatures have been determined by experimental, controlled studies in dry, still-air, laboratory conditions. These studies do not account for wind, mud, wet haircoats, or solar radiation. Variations in feeding level, haircoat, animal age, breed, health, and behavior all affect the thermoneutral zone (Table 1). Changes occur rapidly following birth. In one study, the LCT of Holstein calves decreased 2°F for every five days of age.

Laboratory data describing the thermoneutral zone are supported by behavioral studies in livestock species. Piglets and lambs were trained to trigger a radiant heat lamp. Heat lamp use began at or near the LCT and increased as temperature dropped. Heat lamp uses increased when animals were exposed to wind, had limited feed intake, had low body condi-

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tion, or were orally drenched with cold water. These studies confirm that thermoneutral zones are effectively changed under these conditions.

Cold Conditions

European cattle have evolved in cold climate and have been raised in a wide range of environmental extremes. The newborn calf is capable of adjusting to the dramatic temperature change from the uterine environment to ambient temperatures below freezing. The calf is more cold tolerant than other species because of a relatively dense haircoat and the precocious ability to ambulate quickly. The act of standing for the first time increases energy usage four-fold and warms the calf. However, like all neonates, the calf has a large surface area to body mass ratio, higher body water content, and is covered with amniotic fluids at birth. In cold conditions, shivering and fat metabolism must begin immediately to maintain body temperature.

The calf is also born with a generous supply of brown adipose tissue around the kidneys that represents 1.5% of body weight. This special type of fat releases energy as heat. In neutral temperature conditions, these reserves are depleted within the first few weeks of life. Under extreme cold conditions, brown fat deposits may be used in hours. A newborn calf is estimated to contain 380 to 600 g of fat and 180 g of glycogen that can be mobilized as energy sources. At the maximal metabolic rate, these reserves would be depleted within 18 hours. Colostrum intake becomes extremely important, not only as a source of passive immunity but also as a source of energy. In the newborn lamb, colostrum intake in the first day and a half provides four times more energy than the reserves of body lipid and glycogen. Colostrum has also been shown to elevate basal metabolism and SM. The change in metabolism caused by colostrum intake in calves improves short-term cold tolerance.

Maternal Factors

Maternal nutrition influences calf cold tolerance. The amount of brown fat available at birth is influenced by maternal nutrition at the end of gestation. Protein or energy deprived dams give birth to smaller, less mature calves, have longer births and more dystocia, and tend to have lower concentration and volume of colostrum. Calves experiencing difficult birth have lower metabolic rates, lower rectal temperatures, poor suckle reflex, reduced appetite, and lower colostrum absorption. A study of mortality rates from birth to weaning in beef calves born without dystocia shows an exponential increase in death loss as temperature at birth decreases. The curve is shifted higher as precipitation increases.

Weather

Environmental temperature is not the only factor that influences energy demands. Solar radiation, wind, and humidity all alter the effective temperature (Table 2). Wind chill tables have been developed for adult cattle with winter haircoats but not for milk-fed dairy calves. In general, a 25-mile per hour wind has the same effect as lowering the temperature 27°F. This would bring the ambient temperature for the lower end of neutral to 77°F for a newborn calf or 59°F for a month old calf. Wind chill represents the perceived or effective temperature as it is influenced by convection and should be used to determine energy requirements.

Haircoat has a large effect on insulation and heat loss prevention. In beef cattle with a short or wet haircoat, energy increases needed in cold weather are twice as high as those of cattle with a winter coat. Nutritionists for range cattle estimate that maintenance requirements increase 1% for each 1°F below the LCT of 20°F, and this increase is multiplied by a coat length factor.

Solar radiation effects the LCT. Animals with darker coat color have measurably greater solar heating than those that are predominantly white. Color of the hutch also has a measurable effect of the body temperature on the occupant when solar radiation is a factor.

Acclimatization and Adaptation

Short-term physiological adaptation involves increased metabolism through shivering, burning brown fat, standing up of the haircoat, and increased appetite. Acute cold stress increases the two to five fold plasma concentrations of norepinephrine. This hormone, in turn, stimulates brown adipose utilization. Acclimatization is the longer-term response to cold that includes growth in length and density of the haircoat and deposition of subcutaneous fat. Unfortunately, the newborn calf does not have time ex-utero to acclimate by growing a more insulating haircoat or accumulating fat. Therefore, more energy is used to stay warm and muscle mass and fat deposits decrease further. This can lead to a negative spiral downward in body mass and energy reserves. The young calf quickly uses up brown fat deposits. Unlike the one month old calf, the newborn cannot compensate by increasing feed intake. The newborn is usually fed a fixed amount, and immaturity and behavior limit consumption of liquid feed and solid feed intake.

The term behavioral acclimation refers to intentional or responsive changes in behavior that influence cold effects. These include huddling with other calves, assuming a hunched posture, lying versus standing, avoiding lying in mud, avoiding exposure to wind and rain, eating more, avoiding cold fluid intake, and seeking high radiation. In hot weather conditions, acclimation would include standing, seeking shade, increased fluid consumption, and wallowing in wet mud. It is important to understand that these behaviors can result in significant reductions in energy requirements. Good management and cold housing allow animals to select microenvironments.

Cold Effects

When an animal is subjected to extreme cold stress, substantial energy may be diverted from weight gain and growth to maintain core body temperature. Below the LCT, more energy intake is required. Season has a large effect on feed efficiency for this reason. Maintenance energy requirements for feedlot cattle in Colorado increase almost 33% from summer to winter.

The National Research Council (NRC, 1989) has defined guidelines for nutritional requirements for the neonatal calf, assuming a goal of 1.0 lb/day of gain for a 100-lb calf. This calf would require 1.75 Mcal of metabolized energy (**ME**) for maintenance and 1.26 Mcal ME for growth. A gallon of whole milk or milk replacer (mixed 1.0 lb to a gallon) will provide 2.0 Mcal ME. This is enough for 0.5 lb of growth under neutral environmental conditions. When environmental temperatures are below the LCT for calves, the NRC stated energy requirements are not adequate for maintenance and growth. Significantly lower rates of gain have been found in calves raised in cold housing when environmental temperatures are below the LCT.

Supplementing fat or increasing replacer concentration or volume can provide additional energy. Studies conducted under cold conditions in South Dakota (Schingoethe et al., 1986) found that increased replacer concentration or milk volume improved weight gains. Starter intake was unaffected by supplementation. In a second study (Jaster et al., 1992), performed under mild cold conditions, additional fat and increased concentration and volume of replacer powder were all found to improve gains through 28 days of age. Starter intake was reduced with 0.5 lb of additional fat or 1.33 gallon of milk replacer powder fed at 14% of body weight (**BW**) but not with 0.25 lb of extra fat or 1.33 gallon of milk replacer powder fed at 10% of BW. In a third study (Scibilia et al., 1987), three levels of fat supplementen-



tation to the milk replacer at 50 and 25 °F environmental temperature without starter available were compared (Table 3). Body weight gains were significantly improved by fat levels of 17.5 and 25% compared to 10% fat. The 10% fat dietary treatment resulted in weight loss at the lower but not the neutral temperature. Maintenance requirements increased 32% in calves housed at 25°F compared to those housed at 50°F.

As a general rule, supplementation of energy below the thermoneutral zone should always be cost effective. The cost of supplementation should be compared to the cost of reducing effective cold exposure through housing and environment modification. Additional fat supplementation is more cost effective than increasing replacer powder concentration or volume (Table 4). Below the LCT, protein and minerals are not required at higher levels than at neutral temperatures. Protein is an expensive heat source compared to fat or carbohydrate. A fat-protein balance is not a concern when additional energy is used for heat production rather than for growth. Increasing replacer concentration may be more convenient and will provide for excess growth during intermittent neutral weather conditions. The goal is to supplement energy up to the level required for maintenance, at which point, excess energy may limit starter consumption. Any change should be made gradually and remain consistent for the cold stress season. Supplementation should focus on calves under one month of age, before the time of adequate starter intake.

Under thermoneutral conditions, BW gains increased with increasing replacer, fat, and protein concentrations (Scibilia et al., 1987). Under these conditions and above the LCT, excess solids should promote excess gains. A balanced protein:fat ratio is important for growth. The cost effectiveness of supplementation must be compared to the cost of gain due to improved starter intake in older animals.

Increased energy demands with lower temperatures can be calculated (Table 5). These demands can be met from a variety of feed sources. Calf starter is not a viable source of increased nutritional energy for the first few weeks of life.

A national survey of dairy producers (Nahms, 1993) found that only one third increase energy availability to milk fed calves in winter. Three quarters of the producers fed 1.0 lb/day of milk dry matter per calf. Nineteen percent routinely fed less than two quarts of fluids per feeding. Many producers are feeding inadequate energy to meet metabolic demands without the added requirements caused by cold exposure.

Hot Conditions

Extreme heat, above the UCT, also results in increased energy needs and long term reduced feed efficiency. Energy is expended by panting and standing. Humidity increases heat stress effects because the transfer of moisture from the lungs and mucous membranes to the air is reduced. This exchange is required for evaporative cooling.

Water is the only increased nutrient need under short-term heat stress conditions (Table 6). Clean water should be provided *ad libitum*. Water availability increases starter intake (Table 7). Water feeding of milk-fed calves is essentially free, except for added labor, and is cost effective in all sizes of operations.

Conclusion

Extreme weather conditions require temporary modification and appropriate selection of housing and simple changes in the nutritional management of milk-fed calves. Provision of adequate dietary energy in cold conditions and adequate water in hot conditions reduces seasonal fluctuations in productivity and health.

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Table 1. Lower critical temperature (LCT) by cattle type and maturity.¹

Cattle type	LCT (°F)
Newborn calf	50
One-month old calf	32
Dry dairy cow	8
Finishing steer	-35
Peak lactation cow	-40

¹Adapted from Webster, 1973.

Table 2. Estimated critical temperature of a well-fed beef cow in different cold environments.¹

Solar Environment	Net Radiation (W m ⁻²)	Critical Temperature (°F)
Dry, calm, overcast	-10	8
Dry, calm, sunny	+63	-7
Dry, calm, night	-68	22
Dry, 10 mph wind, overcast	-10	27
Raining, 10 mph wind, overcast	-10	35

¹Adapted from Webster, 1973.

Table 3. Average daily gains of calves from 1 to 4 weeks of age.¹

Dietary fat in milk replacer	Environmental Temperature	
	25°F	50°F
10.0%	-0.09 lb/day	0.33 lb/day
17.5%	0.04 lb/day	0.48 lb/day
25.0%	0.20 lb/day	0.42 lb/day

¹Adapted from Scibilia et al., 1987.



Table 4. Marginal returns of supplementation under cold stress conditions.¹

	1 lb Replacer 10% BW ²	¼ lb Fat Added 10% BW	1.3 lb Replacer 10% BW	½ lb Fat Added 10% BW	1.3 lb Replacer 14% BW
Gain 7 to 28 days (lb)	15.2	15.8	17.4	17.4	16.9
Feed costs	\$16.76	\$20.18	\$20.47	\$21.68	\$27.65
Marginal cost/lb	-	\$ 5.18	\$ 1.69	\$ 2.24	\$ 6.24
Gain 7 to 42 days (lb)	27.5	31.9	31.2	28.6	25.5
Feed costs	\$24.74	\$28.69	\$29.01	\$29.31	\$35.59
Marginal cost/lb	-	\$ 0.90	\$ 1.14	\$ 4.15	-\$ 5.48

¹Adapted from Jaster et al., 1992.

²BW = body weight.

Table 5. Energy needs, dietary sources, and costs for milk-fed calves in cold ambient temperatures.

Temperature (°F)	Added DE (Mcal)	Replacer Powder (lb)	Replacer costs	Fat (lb)	Fat Costs	Starter (lb)	Starter Costs
50	-	-	-	-	-	-	-
25	0.82	0.33	\$0.33	0.25	\$0.05	0.51	\$0.09
0	1.65	0.67	\$0.67	0.50	\$0.10	1.02	\$0.18
-25	2.50	0.99	\$0.99	0.75	\$0.15	1.53	\$0.27

Table 6. Average water intake with change in environmental temperature.¹

Environmental Temperature (°F)	Water Intake (gallon/lb body weight/day)
35	0.05
50	0.05
60	0.06
70	0.06
80	0.08
90	0.12

¹Adapted from Johnson and Yeck, 1964.

Table 7. Water intake and dry matter consumption in calves.¹

Dry matter intake (lbs.)	Water intake (gallons)
1.0	0.75
2.0	1.5
5.0	4.0

¹Adapted from Kertz et al., 1984.

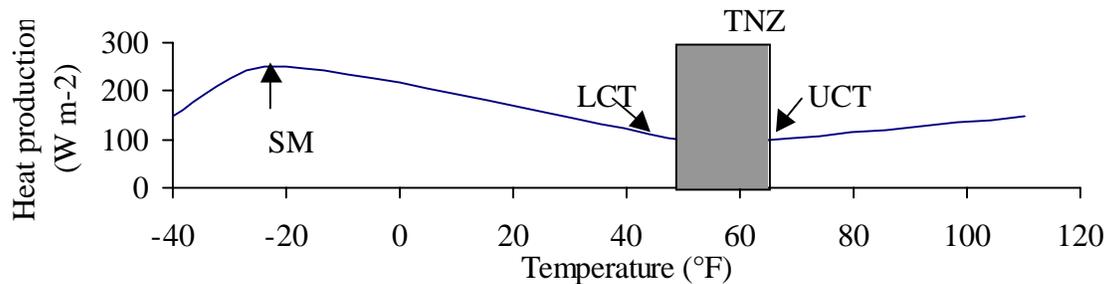


Figure 1. Temperature and metabolism curve for calves. Lower Critical Temperature (LCT) by cattle type and maturity (adapted from Webster, 1973). (SM = summit metabolism, LCT = lower critical temperature, TNZ = thermoneutral zone, and UCT = upper critical temperature)



Environmental Factors Affecting Feed Intake of Cows

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Abstract

Performance of dairy cattle may be enhanced or hindered by environmental factors affecting feed intake. Feed intake is the single most critical factor of dairy production. As production levels increase, intake becomes a greater barrier to performance of dairy cattle. Thus, the importance of designing and managing dairy facilities to enhance dry matter (DM) intake is increasing. Environmental factors include both physical and climatic aspects. Physical factors associated with confinement facilities may have a greater influence on cow performance than climatic factors. Since confinement facilities generally last 20 to 30 years or more, design choices have long-term effects on the dairy operation. Design of freestalls, feed barriers, housing pens, building, holding pens, and milking parlor combine to create the physical environment to which cattle are exposed. Physical facilities should provide adequate access to feed and water, while providing a comfortable environment for adequate protection from the elements of nature. In addition, consideration of management factors related to the interaction of cow and environment should be considered. Correct design and management of facilities can create an environment that enhances the intake and performance of dairy cattle.

Introduction

One of the keys to success in dairy production is to design and manage facilities to maximize the

DM intake of dairy cattle. Dry matter intake is impacted by environmental and management factors. Environmental concerns include the physical facilities and climate conditions to which the cattle are exposed. Management factors include feeding, grouping, and cow flow patterns that may be influenced by facility design. The goal of the system should be to provide adequate cow comfort which includes: 1) adequate access to feed and water, 2) a clean and dry bed which is comfortable and correctly sized and constructed, 3) acceptable air quality, and 4) adequate protection from the elements of nature.

Roseler et al. (1997) utilized data from many studies to develop an equation to explain DM intake. They concluded that milk yield explained 45% of the variability in observed DM intake of the cows studied (Figure 1). They also concluded that climate accounted for 10% and feed and management accounted for 22% of the variability in intake. Designing and managing facilities to increase milk production will most likely increase feed intake. In addition, one third of the variation in DM intake is explained by climate and feed factors that can be modified to enhance intake. Correctly designed facilities that are adequately managed will increase DM intake and milk production.

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Access to Feed and Water

4-row vs 6-row Barns

One of the critical decisions that producers make is the type of freestall barn that they build. The most common types are either 4- or 6-row barns, and many times the cost per cow or stall is used to determine which barn should be built. Data found in Table 1 represents the typical dimensions of the barns, and Table 2 demonstrates the effects of overcrowding on per cow space for feed and water. Grant (1998) suggested that feed bunk space of less than 8 in/cow reduced intake and bunk space of 8 to 20 inches cow resulted in mixed results. Even at a 100% stocking rate, the 6-row barn only offers 18 inches cow feed line space. When over crowding occurs, this is significantly reduced. Four-row barns, even when stocked at 140% of the stalls, still provide more than 18 inches cow of bunk space. In addition, when water is only provided at the crossovers, water space per cow is reduced by 40% in the 6-row barn as compared to 4-row barns. Much of the current debate over the effect of 4- and 6-row barns on intake is likely related to presence or absence of management factors which either reduce or increase the limitations of access to feed and water in 6-row barns.

Feed Barrier Design

The use of self-locking stanchions as a feed barrier is currently a debated subject in the dairy industry. Data reported in the literature are limited and conclusions differ. Shipka and Arave (1995) reported that cows restrained in self-locking stanchions for a 4-hour period had similar milk production and DM intake as those not restrained. Arave et al. (1996a) observed similar results in another study; however, a second study showed similar intake but 6.4 lb/cow/day decrease in milk production when cows were restrained daily for a 4-hour period (9 AM to 1 PM) during the summer. Increases in cortisol levels were also noted during the summer but not in the spring

(Arave et al. 1996b), indicating a greater amount of stress during the summer as compared to the spring. All of these studies compared restraining cows for four hours to no restraint, and all animals were housed in pens equipped with headlocks. The studies neither compared a neck rail barrier to self-locking stanchions nor addressed the effects of training on headlock acceptance. However, some have drawn the conclusion that self-locking stanchions reduce milk production and only the neck rail barrier should be used. The data indicate that cows should not be restrained for periods of four hours during the summer heat. The argument could be made that four hours of continuous restraint time is excessive and much shorter times (one hour or less) should be adequate for most procedures. These studies clearly indicate that mismanagement of the self-locking stanchions, not the stanchions, resulted in decreased milk production in one of three studies with no affect on intake in all studies. Another study (Batchelder, 2000) compared lock-ups to neck rails in a 4-row barn under normal and crowded (130% of stalls) conditions. Results of the short-term study showed a 3 to 5% decrease in DM intake when headlocks were used. No differences in milk production or body condition score were observed. It was also noted that overcrowding reduced the percentage of cows eating after milking as compared to no overcrowding. In this study, use of headlocks reduced feed intake but did not affect milk production.

The correct feed barrier slope is also important. Hansen and Pallesen (1998) reported that sloping the feed barrier 20° away from the cow increased feed availability because the cows could reach 14 cm (5.6 inches) further than when the barrier was not sloped. They also noted that when feed was placed within the cow's reach, much less pressure was exerted against the feed barrier, indicating greater cow comfort.

Correct design of the feeding area will allow the cow more comfortable access to feed. Figures 2

and 3 demonstrate the typical design for post and rail, as well as headlock-systems. It is important to lower the cow standing surface relative to the feed table and to provide the correct throat height. Incorrectly designed feeding areas may limit intake and thus reduce milk production.

Freestall Design and Surfaces

Freestall Design

Cows must have stalls that are correctly sized. As early as 1954, researchers demonstrated increases in milk production when larger cows were allowed access to increased stall sizes. Today, construction costs often encourage producers to reduce stall length and width. This may reduce cow comfort and production. Cows will use freestalls that are designed correctly and maintained. If cows refuse to utilize stalls, it is likely related to design or management of the freestall area. Table 3 provides data for correctly sizing the stall. In addition, the stall should be sloped front to back and a comfortable surface provided.

Freestall Surface Materials

Sand is the bedding of choice in many areas. It provides a comfortable cushion that forms to the body of the animal. In addition, its very low organic matter content reduces the risk of mastitis. In many cases, it is readily available and economical. In some areas it is not economical and some producers may choose not to deal with the issue of separating the sand from the manure. Since 25 to 50 lb of sand are needed per stall per day, it should be separated from manure solids to reduce the solid load on the manure management system. Producers choosing not to deal with sand bedding often choose from a variety of commercial freestall surface materials. Sonck et al. (1999) observed that when given a choice, cows prefer certain materials (Figure 4). Occupancy ranged from over 50 to under 20%. Researchers attributed the increase in occupancy rate to the compressibility of

the covering. Cows selected freestall covers that compressed to a greater degree over those with minimal compressibility. Cows need a stall surface that conforms to the contours of the cow. Sand and materials that compress will likely provide greater comfort as demonstrated by cow preference.

Supplemental Lighting

Lactating Cows

Supplemental lighting has been shown to increase milk production and feed intake in several studies. Peters (1981) reported a 6% increase in milk production and feed intake when cows were exposed to a 16L:8D photoperiod [hours light (L): hours dark (D)] as compared to natural photoperiods during the fall and winter months. Median light intensities were 462 lux and 555 lux for supplemental and natural photoperiods, respectively. Chastain et al. (1997) reported a 5% increase in feed intake when proper ventilation and lighting were provided, and Miller et al. (1999) reported a 3.5% increase without bovine somatotropin (**bST**) and 8.9% with bST when photoperiod was increased from 9.5 to 14 hours to 18 hours. Increasing the photoperiod 16-18 hours increased feed intake. Dahl et al. (1998) reported that 24 hours of supplemental lighting did not result in additional milk production over 16 hours of light. Studies utilized different light intensities in different areas of the housing area. More research is needed to determine the correct light intensity to increase intake. In modern freestall barns, the intensity varies greatly based on the location of the light within the pen. Thus additional research is needed to determine the intensity required for different locations within pens.

Another issue with lighting in freestall barns is milking frequency. Herds milked 3x can not provide 8 hours of continuous darkness. This is especially true in large freestall barns housing several milking groups. In these situations, the lights may remain on at all times to provide lighting for moving cattle to and

from the milking parlor. The continuous darkness requirement of lactating cows may be 6 hours (Dahl, 2000). Thus, setting milking schedules to accommodate 6 hours of continuous darkness is recommended. The use of low intensity red lights may be necessary in large barns to allow movement of animals without disruption of the dark period of other groups.

Dry Cows

Dry cows benefit from a different photoperiod than do lactating cows. Recent research, (Dahl, 2000) showed that dry cows exposed to short days (8L:16D) produced more ($P < .05$) milk in the next lactation than those exposed to long days (16L:8D). Petitclerc et al. (1998) reported a similar observation. Based on the results from these studies, dry cows should be exposed to short days and then exposed to long days post-calving.

Heat Stress

Effects of Heat Stress

Heat stress reduces intake, milk production, health, and reproduction of dairy cows. Spain et al. (1998) showed that lactating cows under heat stress decreased intake by 6 to 16% as compared to thermal neutral conditions. Wiersma and Armstrong (1988) also observed that cows cooled during the dry period produced more ($P < .05$) milk in the subsequent lactation than cows that were not cooled. The cow environment can be modified to reduce the effects of heat stress by providing for adequate ventilation and effective cow cooling measures.

Ventilation

Maintaining adequate air quality can be easily accomplished by taking advantage of natural ventilation techniques. Armstrong et al. (1999) reported that a 4/12 pitch roof with an open ridge resulted in

loss of an increase in cow respiration rate during the afternoon, as compared to reduced roof pitch or covering the ridge. They also observed that eave heights of 14 ft resulted in lower increases in cow respiration rates as compared to shorter eave heights. Designing freestall barns that allow for maximum natural airflow during the summer will reduce the effects of heat stress. Open sidewalls, open roof ridges, correct sidewall heights, and the absence of buildings or natural features that reduce airflow increase natural airflow. During the winter months, it is necessary to allow adequate ventilation to maintain air quality while providing adequate protection from cold stress.

Another ventilation consideration is the width of the barn. Six-row barns are typically wider than 4-row barns. This additional width reduces natural ventilation. Chastain (2000) indicated that summer ventilation rates were reduced 37% in 6-row barns as compared to 4-row barns. In hot and humid climates, barn choice may increase heat stress, resulting in lower feed intake and milk production.

Cow Cooling

During periods of heat stress, it is necessary to reduce cow stress by increasing airflow and installing sprinkler systems. The critical areas to cool are the milking parlor, holding pen, and housing area. First, these areas should provide adequate shade. Barns built with a north-south orientation allow morning and afternoon sun to enter the stalls and feeding areas and may not adequately protect the cows. Second, as temperatures increase, cows depend on evaporative cooling to maintain core temperature. The use of sprinkler and fan systems to effectively wet and dry the cows will increase heat loss.

The holding pen should be cooled with fans and sprinkler systems, and an exit lane sprinkler system may be beneficial in hot climates. Holding pen time should not exceed one hour. Fans should move

1,000 cubic feet per minute (**cfm**) per cow. Most 30 and 36 inch fans will move between 10,000 and 12,000 cfm per fan. If one fan is installed per 10 cows or 150 ft², adequate ventilation will be provided. If the holding pen is less than 24 ft wide with 8 to 10 ft sidewall openings, fans may be installed on 6 to 8 ft centers along the sidewalls. For holding pens wider than 24 ft, fans are mounted perpendicular to the cow flow. Fans are spaced 6 to 8 ft apart and in rows spaced either 20 to 30 ft apart (36 inch fans) or 30 to 40 ft apart (48 inch fan) (Harner et al, 1999). In addition to the fans, a sprinkling system should deliver 0.03 gallons of water per square feet of area. Cycle times are generally set at two minutes on and 12 minutes off.

Heat abatement measures for freestall housing should include sprinklers and fans in the feeding area to increase air movement. Sprinkling systems should deliver water similar to the holding pen system, except it should only wet the area occupied by the animal at the feed bunk. The hair coat of the cow should become wet and then be allowed to dry prior to the beginning of the next wetting cycle. Fans may be installed to provide additional airflow that will increase evaporation rate (Harner et al., 1999).

Cold Stress

Dairy cows can withstand a significant amount of cold stress as compared to other animals. Factors affecting the ability of the cow to withstand cold temperatures are housing, pen condition, age, stage of lactation, nutrition, thermal acclimation, hair coat, and behavior (Armstrong and Hillman, 1998). Feed intake increases when ambient temperature drops below the lower critical temperature of the animal. Protection from wind and moisture will reduce the lower critical temperature and minimize the effects of cold stress. When feed intake is no longer adequate to maintain both body temperature and milk production, milk production will likely decrease.

Summary

Environmental factors that affect feed intake can be divided into physical and climatic affects. On modern dairy farms, the physical factors may be more of a concern than the climate. Modern facilities provide the cow with protection from the natural elements. However, the same facilities that protect the cow from the natural environment may enhance or hinder DM intake. Facilities should provide adequate access to feed and water, comfortable resting area, and adequate protection from the natural elements. Critical areas of facility design related to feed intake include the access to feed and water, stall design and surface, supplemental lighting, ventilation, and cow cooling. The total system should function to enhance cow comfort and intake. It is important to remember that choices made during construction of a facility will affect the performance of animals for the life of the facility, which is generally 20 to 30 years. Producers, bankers, and consultants too often view the additional cost of cow comfort from the standpoint of initial investment rather than long-term benefit.

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Table 1. Average pen dimensions, stalls, cows, and allotted space per animal.¹

Barn Style	Pen Width	Pen Length (ft)	Stalls Per Pen (ft)	Cows Per Pen	Per Cow		
					Area (ft ²)	Feedline Space (linear inches)	Water Space (linear inches)
4-Row	39	240	100	100	94	29	2.4
6-Row	47	240	160	160	71	18	1.5
2-Row	39	240	100	100	94	29	2.4
3-Row	47	240	160	160	71	18	1.5

¹Adapted from Smith, et al., 2000.

Table 2. Effect of stocking rate on space per cow for area, feed, and water in 4- and 6-row barns.¹

Stocking Rate (%)	Area (ft ² /cow)		Feedline Space (linear inches/cow)		Water Space (linear inches/cow)	
	4-Row	6-Row	4-Row	6-Row	4-Row	6-Row
100	28.5	21.3	29	18	2.4	1.5
110	25.9	19.4	26	16	2.2	1.4
120	23.8	17.8	24	15	2.0	1.3
130	21.9	16.4	22	14	1.9	1.1
140	20.4	15.2	21	13	1.7	1.1

¹Adapted from Smith, et al., 2000.

Table 3. Freestall dimensions for cows of varying body weight.¹

Body Weight (lb)	Free Stall Width (inches)	Side Lunge (inches)	Forward Lunge ^a (inches)	Neck Rail Height Above Stall Bed (inches)	Neck Rail and Brisket Board Bed, Distance from Alley Side of Curb (inches)
800-1,200	42 to 44	78	90 to 96	37	62
1,200- 1,500	44 to 48	84	96 to 102	40	66
Over 1,500	48 to 52	90	102 to 108	42	71

^aAn additional 12 to 18 inches in stall length is required to allow the cow to thrust her head forward during the lunge process.

¹Adapted from Dairy Freestall Housing and Equipment, 1997.

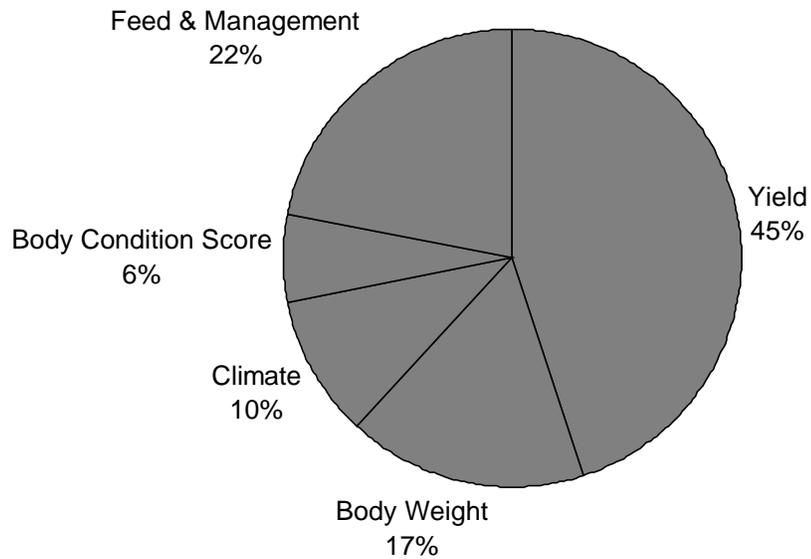


Figure 1. Description of factors that affect DM intake in lactating dairy cows and the amount of variability explained by each factor (adapted from Roseler, et al., 1997).

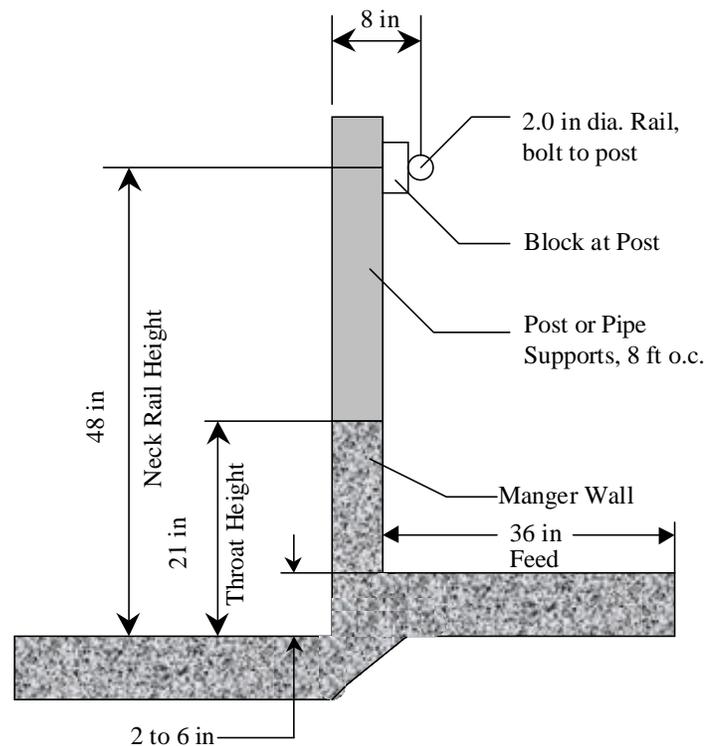


Figure 2. Post and rail feeding fence for cows (adapted from Graves, 1998).

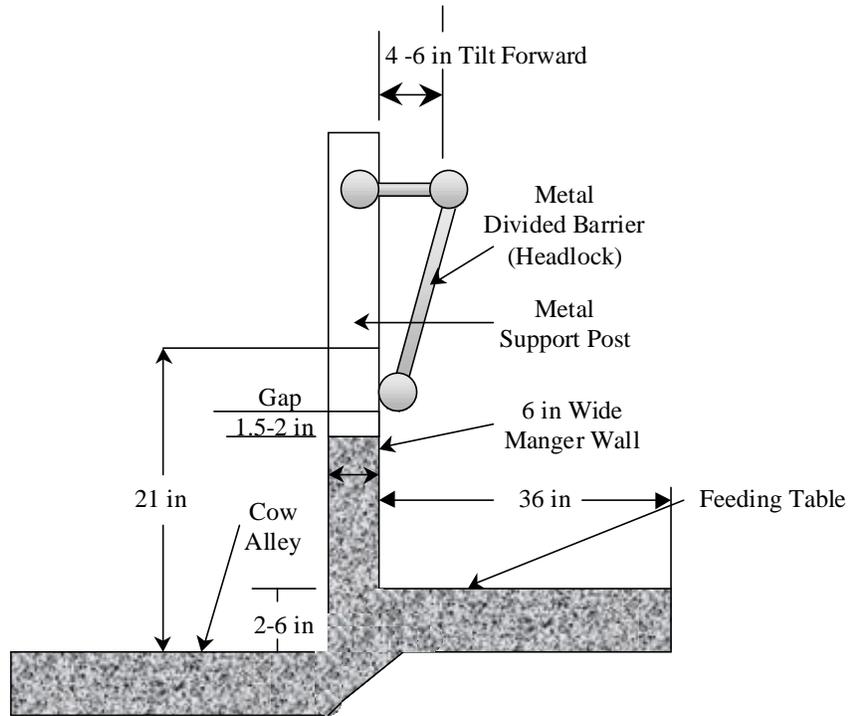


Figure 3. Divided feed barrier (headlock) (adapted from Graves, 1998).

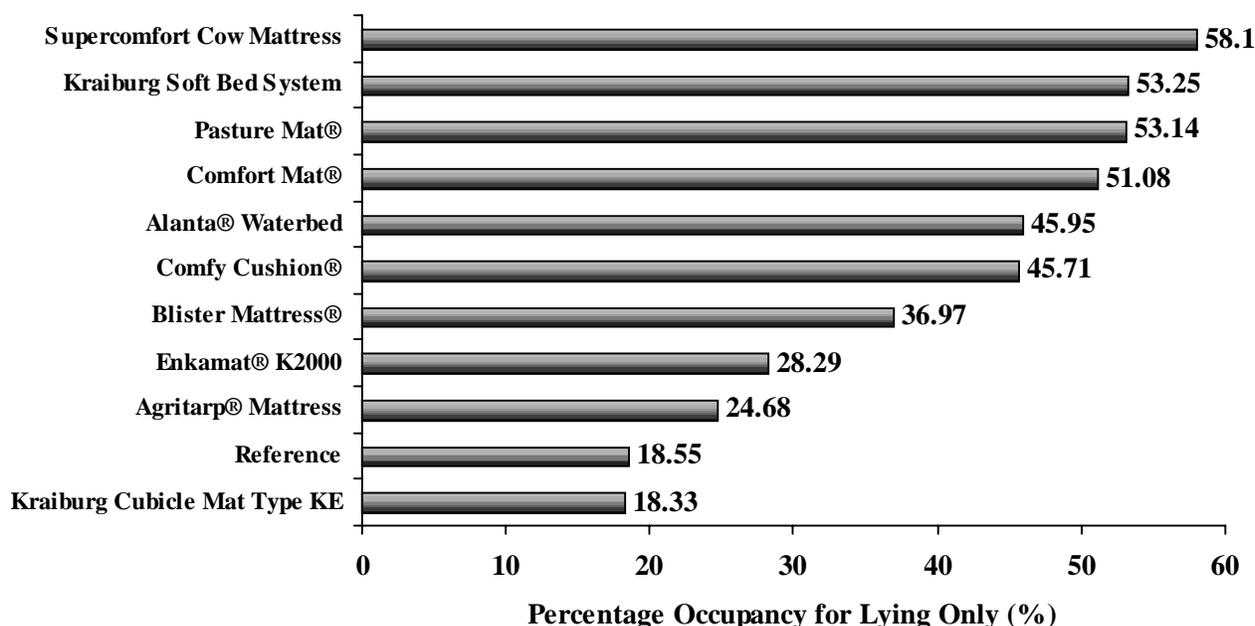


Figure 4. Classification of 11 freestall surface materials, based on the average percentage occupancy for lying only (%) (adapted from Sonch, et al., 1999).

Supercomfort Cow Mattress of R. De Cleene (Belgium) consists of a soft and elastic supporting layer of rubber tiles (30 mm thick) made from small rubber crumbs, combined with a top water-tight layer (6 mm thick) of polypropylene and a PVC back (weight: 3.8 kg/m²). The latter is the same top layer as the Blister Mattress.

Kraiburg Soft Bed System of Gummiwerk Kraiburg Elastik GmbH (Germany) is a mattress consisting of a rubber mat with a hammered finish (a thickness of 8 mm and a weight of 9.5 kg/m²) as nonporous top layer. The mat is combined with a 25 mm polyurethane foam underlay (weight: 3.5 kg/m²). An all-round insulation strip prevents dirt from penetrating the foam.

Pasture Mat® type CS of Pasture BV (The Netherlands) is made by filling rubber crumbs (4 to 7 mm in size) in 12 independent cells of a bag (57 mm thick and 26 kg/m² weight), made from polypropylene and nylon. The independent cells are covered with a non-woven polypropylene top sheet of 3.5 mm thick and 1.9 kg/m² weight.

Comfort Mat® of Alfa Laval Agri Belgium: is a soft rubber mat with a thickness of 20 mm and a weight of 4 kg/m².

Alanta® Waterbed of Dunlop-Enerka (The Netherlands): is an individual double-sided rubber mat (Styrene-butadiene rubber) filled with water. Thickness of the mat is 9 mm unfilled and 50 mm filled with 50 liters of water. The weight of the unfilled mat amounts to 10 kg/m².

Comfy Cushion® mattress of Mac Farm Systems (Belgium) is made by stuffing rubber crumbs in independent cells of a bag of 70 mm thick, made of polypropylene. The weight of this underlayer amounts to 28 kg/m². Two tubes spaced 16 cm apart are fastened onto a polypropylene sheet forming an element. Elements are linked to each other by placing them alternately facing up and facing down. The tubes are covered with a white woven polyester sheet with a thickness of 1 mm and a weight of 0.5 kg/m².

Blister Mattress® of Brouwers Stalinrichtingen BV (The Netherlands) is made from a combination of a soft supporting layer (20 mm thick) and a top water-tight layer (6 mm thick) of polypropylene and a PVC back (weight: 3.8 kg/m²).

Enkamat® K2000 of Vape BV (The Netherlands) is a compact mat consisting of 5 thin layers: a wear resistant top layer, an impermeable coating, a reinforcement textile, a second impermeable coating and a polyamide curling underlay.

Agritarp® Mattress of Agriprom Stalmatten BV (The Netherlands) is made by stuffing rubber crumbs in independent tubular cells of a bag of 60 mm thick, made of polypropylene. The weight of this underlayer amounts to 28 kg/m². The tubes are covered by a non-woven polypropylene top sheet of 1 mm thickness and a weight of 0.8 kg/m².

Reference: a concrete floor littered with sawdust.

Kraiburg Cubicle Mat Type KE of Gummiwerk Kraiburg Elastik GmbH (Germany) is a classic rubber mat with a hammered finish (18 mm thick and 20 kg/m² weight).





Using Production Records to Determine the Impact of Nutritional Changes in a Herd

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Monsanto Dairy Business

Abstract

This review discusses some of the useful techniques used to evaluate production records on dairy farms. The evaluation of trends and current test day performance is illustrated utilizing the computer software PCDart and Current Test Day Analysis Program (CTAP). The analytical approach in this review is to evaluate start-up milk, peak milk, summit milk, and persistency of lactation. The use of current test day versus previous test day information is also illustrated to assist the consultant in determining the change in performance from one test day to the next.

Introduction

Production records are an essential part of managing dairy farms. The PCDart and CTAP will be utilized in this review to illustrate the evaluation of dairy production records. The PCDart and CTAP are computer programs which integrate the daily production activities on the farm with regularly scheduled monitoring activities, such as milk production, milk components, and somatic cell counts as well as the more recently available milk urea nitrogen (MUN) test. These programs are the result of many years of development and the recent release of the windows version, PCDart 7.0, will generate and print reports on computers running the windows operating system. Version 6.2 is still necessary for data entry. The key to successful implementation of this software and other

dairy management software is to understand how the information is utilized.

The PCDart is an on-farm system which maintains data entered by farm personnel and generated by laboratory testing. The information available from this system is utilized to generate management and analytical reports. It is vital that the consultant be familiar with the software utilized by the producer so that they may assist in developing management reports necessary in the daily operation of the farm. Management reports are used to perform activities on the farm, such as drying off cows, breeding cows, grouping cows, giving injections, etc. As these activities are completed, the new information is entered into the computer to keep the system current. These reports are easily developed using a report generator to satisfy the specific needs of each farm and consultant. Other reports developed with PCDart can be used to analyze performance. The addition of a graphics program called PCDart Graphics makes analysis much more meaningful and easier to visualize. The CTAP is an analytical program used primarily by consultants for analyzing herd performance. It takes the data maintained by PCDart and other systems to generate reports and graphs which can be analyzed in an efficient, systematic, and consistent manner.

Production Evaluation

It is very important to develop a systematic approach to evaluating production. One such ap-

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proach is to evaluate trends, followed by evaluation of current performance for the entire herd, and followed by an evaluation for each lactation group; 1st lactation cows, 2nd lactation cows, and 3rd and greater lactation cows. The basic structure within this approach can be outlined as follows and involves looking at milk, fat, protein, and if available, MUN.

- First test day (start-up) performance
- Peak and summit milk performance
- Lactation persistency

The comparison of overall production trends to current production can provide valuable insight into the effectiveness of current management. Production trends can be easily visualized using the PCDart Graphics program. Figure 1 illustrates the rolling herd average milk, fat, and protein trends for 48 test days. The graph indicates an overall trend of increasing milk production. It also indicates a recent decrease in percentage of milk fat and protein. Figure 2 is a graph from the same herd, illustrating the adjusted 150-day milk and milk yield from lactating cows. Although the graph appears to go up and down quite a bit, the trend for average milk on test day and 150-day milk appears to be declining over the most recent eight months. To further evaluate this trend, average days in milk is evaluated. Figure 3 is a graph generated using the CTAP program of average days in milk for this herd. It illustrates that the average days in milk has increased over the interval associated with the decline in milk production. The overall conclusion from these graphs may suggest that average milk production is declining, and it started about five or six months previous to the current test.

Figure 4 is a graph of start-up milk over the previous 48 test days. It illustrates that start-up milk has been declining over the previous six to seven months but may be recovering recently. It is important to evaluate whether or not peaks have been following a similar trend. Figure 5 illustrates that average peak milk yields have been declining, although

2nd lactation cows are peaking above 3rd and greater lactation animals. The owner indicates that the 2nd lactation animals are the best group of animals currently in the herd. The use of a scatter plot can further evaluate the change in peak milk production of individual cows as illustrated in Figure 6. It appears that peaks have been declining only slightly over this interval. Some consultants prefer to evaluate summit milk due to the fact that peaks are the highest milk production for a cow at any stage of lactation. Summit milk is the average of the two highest milk weights of the first three tests during a cow's lactation. Figure 7 illustrates the summit milk production trends for this herd. This graph illustrates that summit milk yields have recently declined slightly. It also illustrates that 2nd lactation animals have the highest average summit milk values and are well above summit milk values for the same test period of the previous year.

Persistency of lactation is an important indicator of the management of cows throughout lactation. The use of CTAP allows the consultant to evaluate persistency each month and compare it to previous months for the same herd, another herd, or a set of herds which have been combined into a multiherd average. Figure 8 illustrates the current test day persistency values for the example herd. The current test day persistency for this herd is good. Figure 9 illustrates the comparison of this test day to the previous test day. The persistency appears to be good for both months but is slightly lower for the current test day.

The evaluation of milk fat and protein is done utilizing a similar approach. Figure 10 illustrates start-up or day 1 to 40 fat and protein trends. The July, 1999 start-up fat percentage appeared to be very low. Referring back to Figure 4 reveals that this interval was associated with the highest start-up milk production in nearly three years. An improvement in start-up fat percentage occurred subsequent to this test, and an improvement in body condition at calving has been observed in the herd over this same time

interval. Figure 11 illustrates the occurrence of a protein:fat inversion during 41 to 100 days in milk at the August, 1999 test. This situation started changing on September, 1999, and current start-up fat percentage appears to be high. This is associated with a loss of milk production as illustrated in Figure 12. The consultant and dairy producer must evaluate the changes and make adjustments which maximize yield of milk, fat, and protein to fit their market without compromising health. A consistent protein:fat inversion reflects an increased risk for rumen acidosis and the associated risks laminitis. This herd made adjustments and prevented the occurrence of a consistent protein:fat inversion in the 41 to 100 day interval.

A complete evaluation of production would proceed by repeating the analysis for each lactation group. Some consultants prefer to evaluate only lactation groups for larger herds and do not evaluate all cows to any great extent. When smaller herds are evaluated, the small number of cows associated with each lactation group is inadequate for accurate analy-

sis. A good general guideline is to perform a scatter plot of any values which have abnormal high or low average values. This may reveal that a small number of animals have biased the average.

Summary

An evaluation of production can provide the consultant with valuable insights into the management of dairy herds. The process is not difficult but requires accurate data and information provided by a modern dairy production records system. Hopefully, this discussion has illustrated the initial steps in utilizing a dairy production record system and the value that it offers.

References

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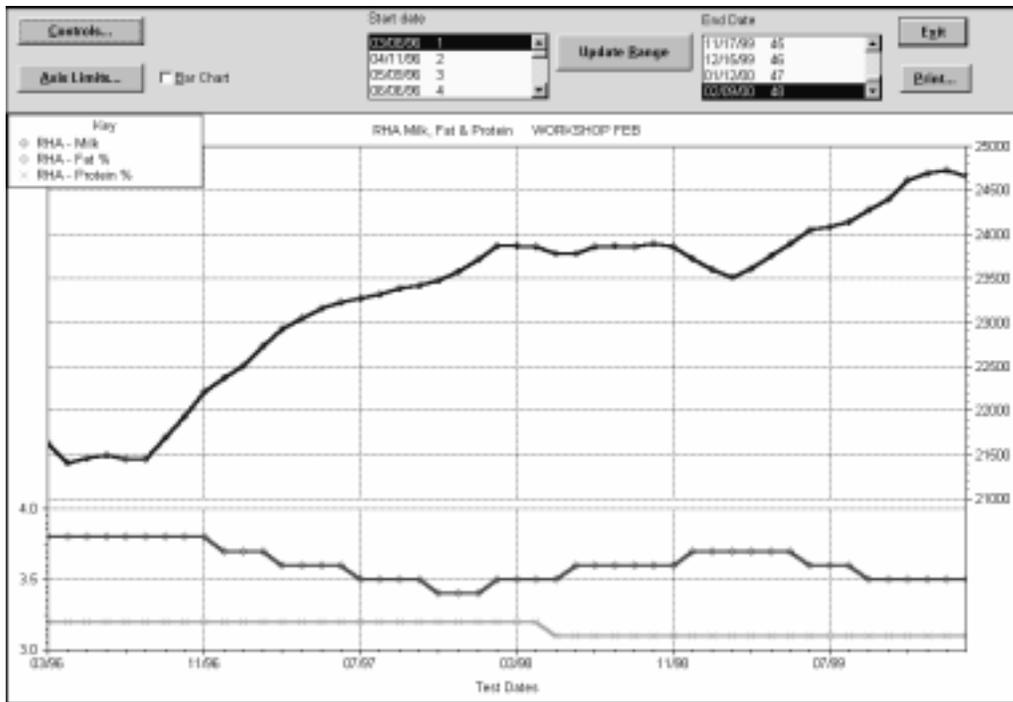


Figure 1. Rolling herd average for milk yield (lb/cow/lactation) and milk fat and protein percentages.

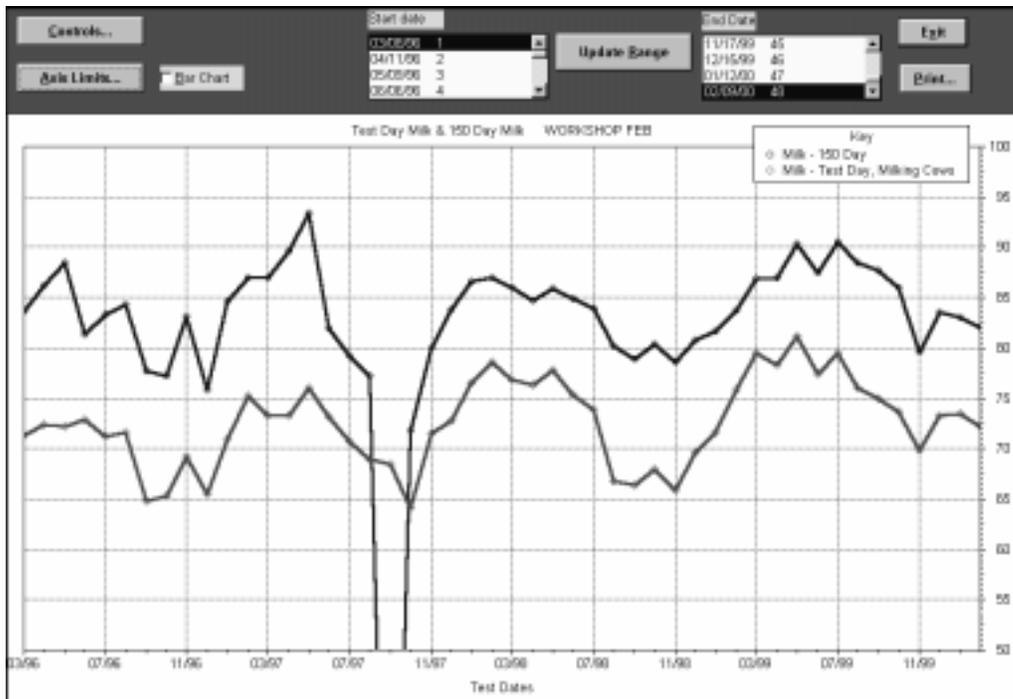


Figure 2. The 150-day milk yield (lb/cow/day) and the test day milk yield (lb/cow/day) for lactating cows.

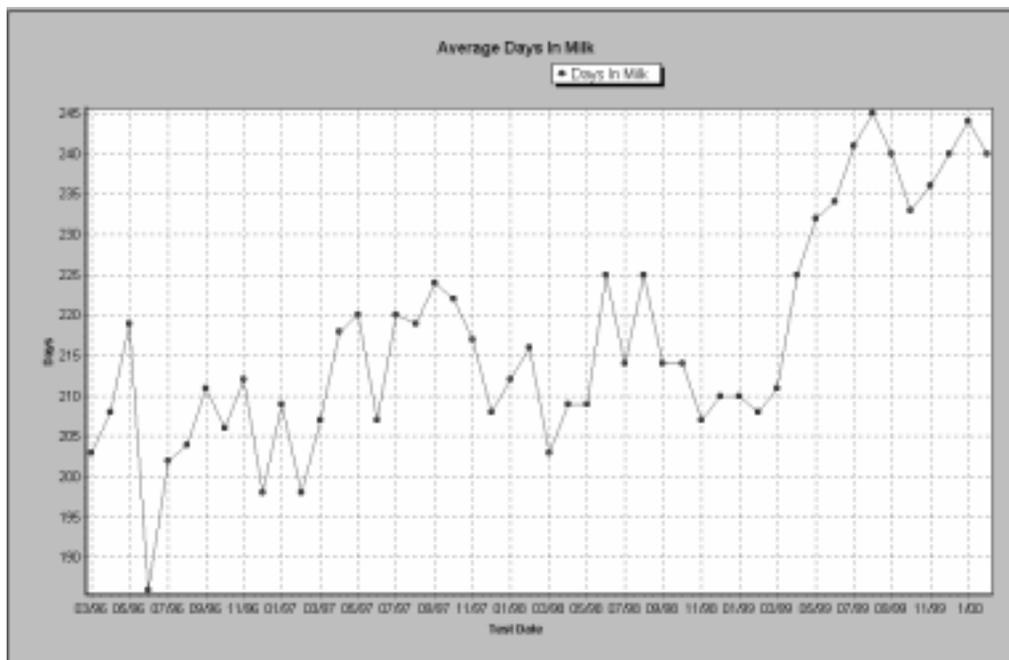


Figure 3. The CTAP graph of days in milk.

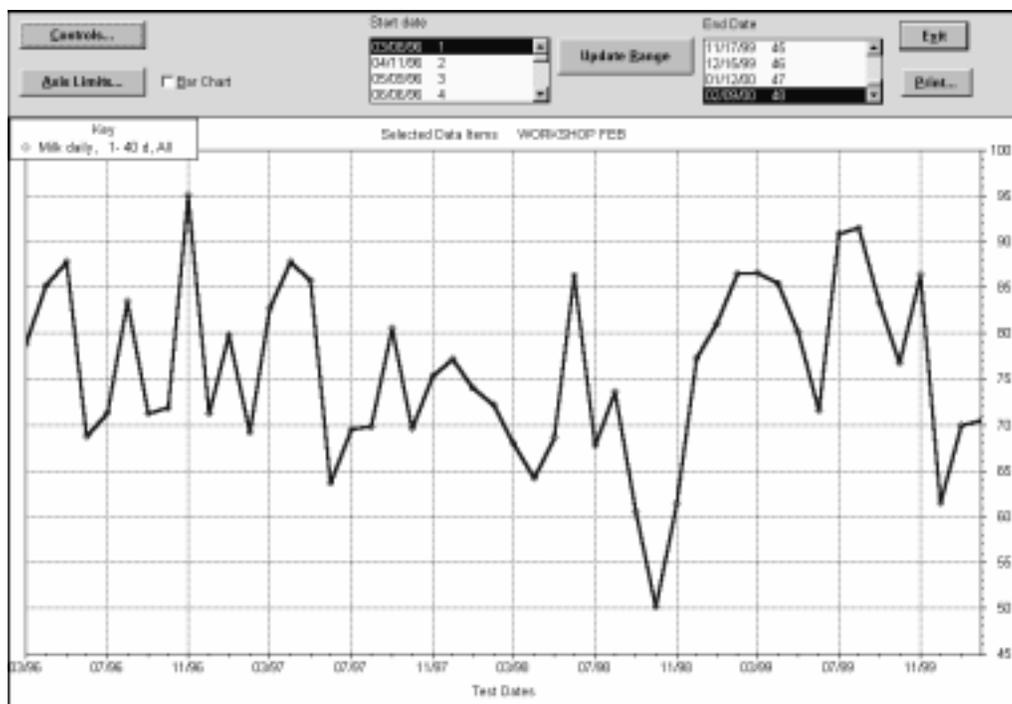


Figure 4. Graph of day 1 to 40 milk yield (lb/day) by test day.

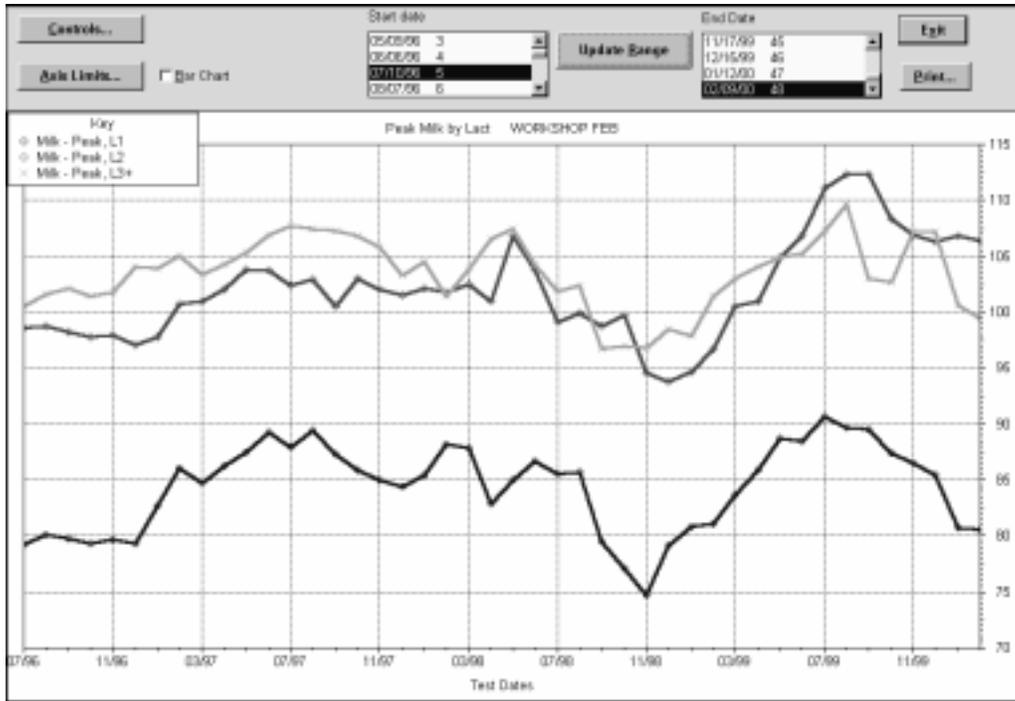


Figure 5. A PCDart Graphics plot of average peak milk yield (lb/day) by test day.

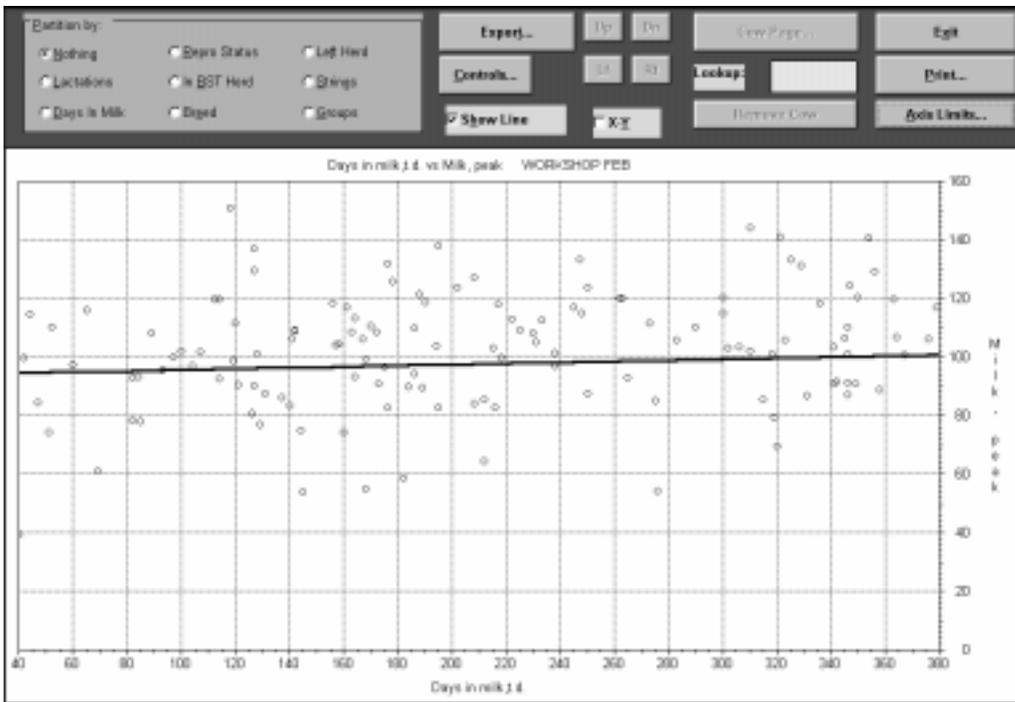


Figure 6. Scatter plot of peak milk yield (lb/day) versus days in milk over a 380-day interval.

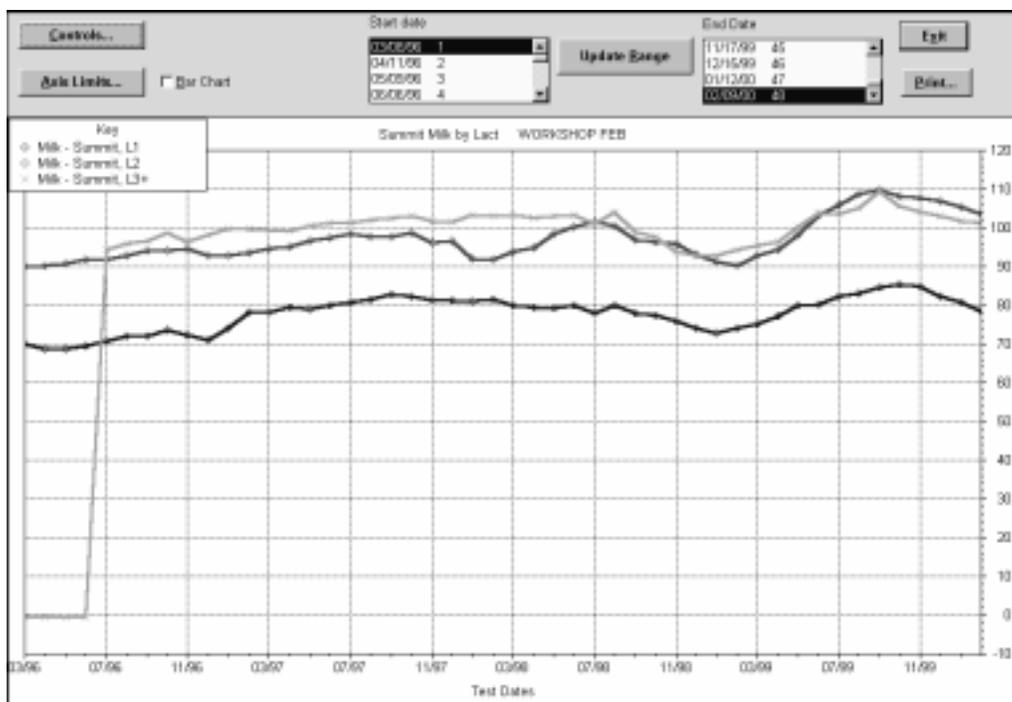


Figure 7. Summit milk production (lb/day) for a herd.

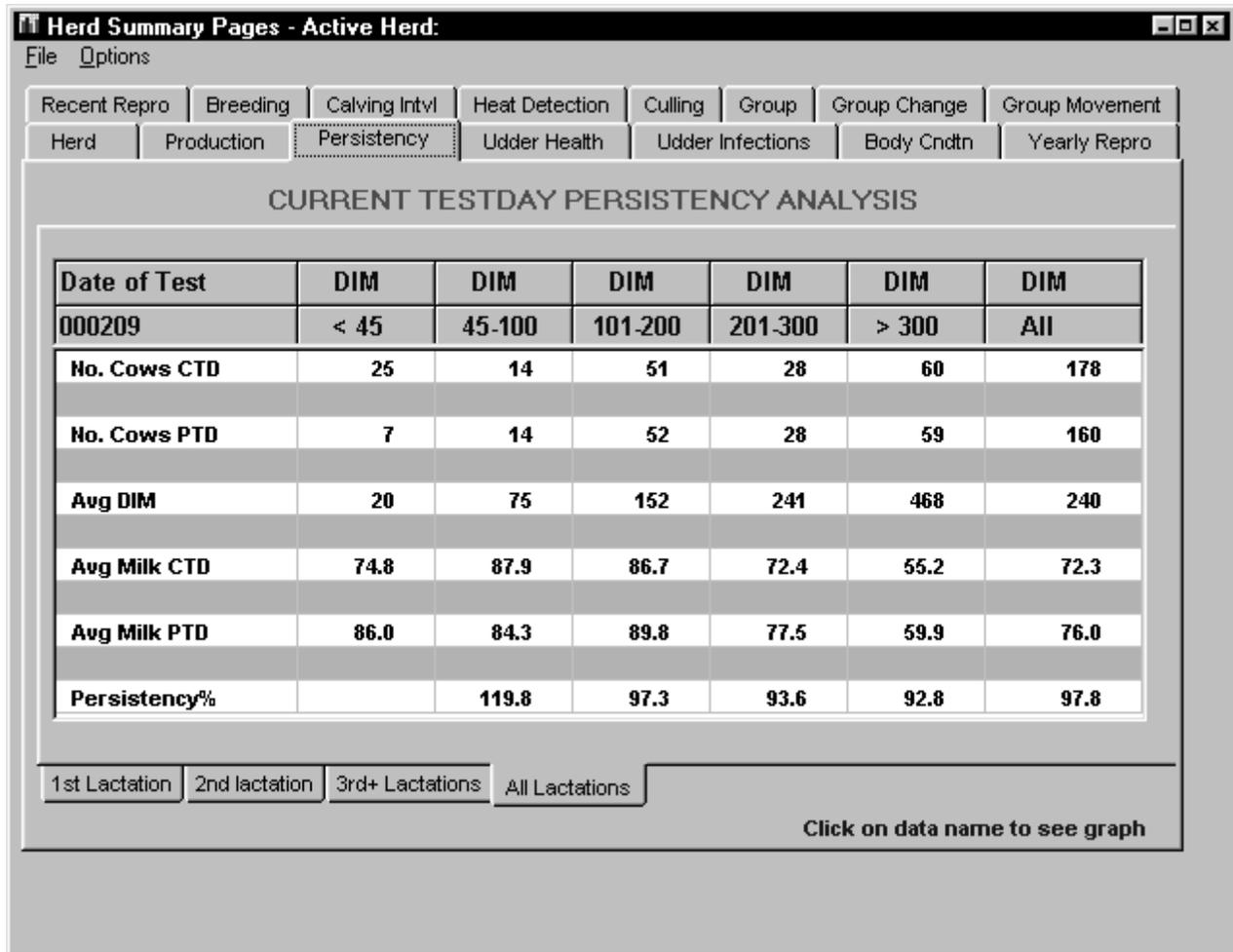


Figure 8. The CTAP persistency chart for milk production (DIM = days in milk, CTD = current test day, and PTD = previous test day).

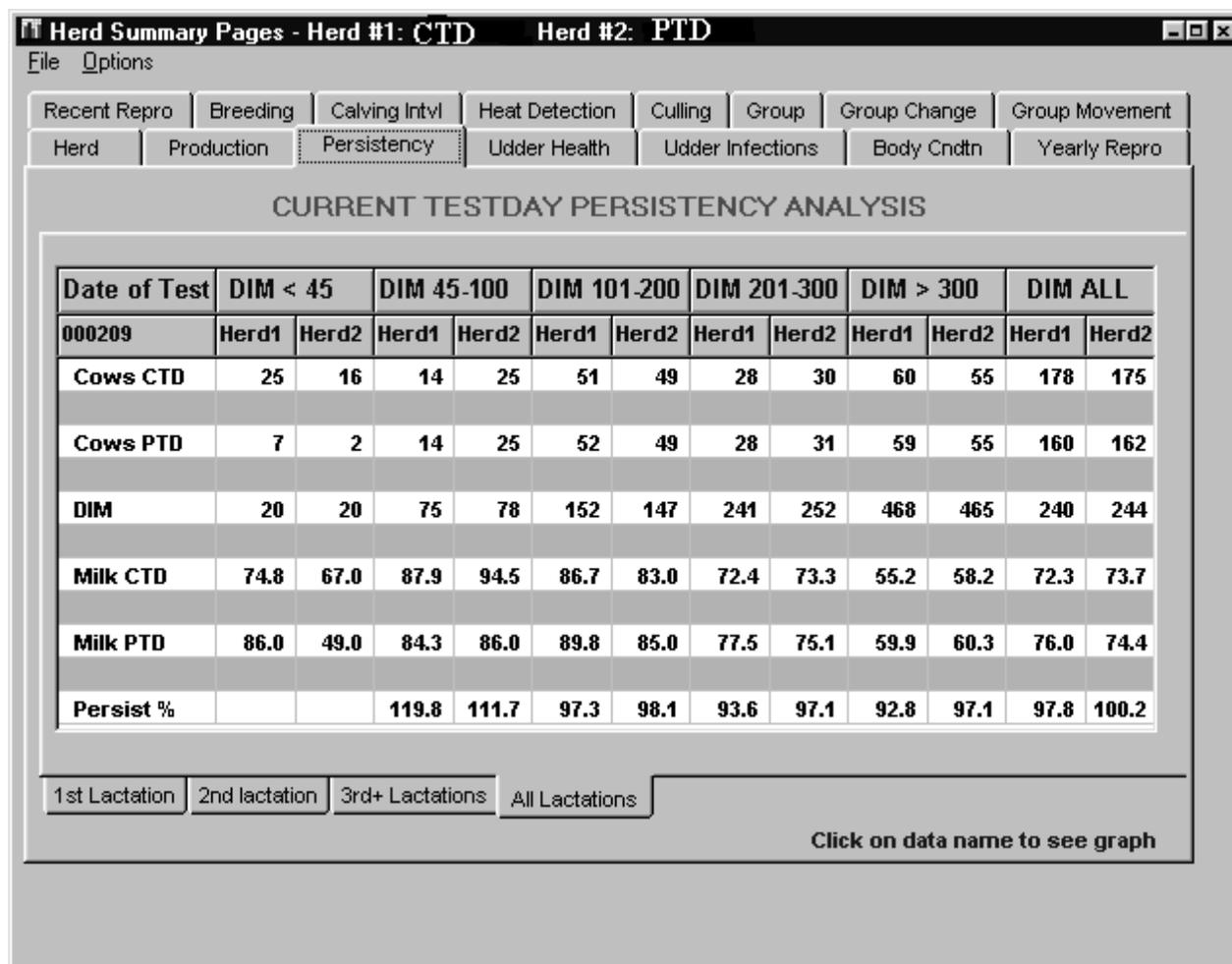


Figure 9. Persistency of milk production for two consecutive test days (DIM = days in milk, CTD = current test day, and PTD = previous test day).

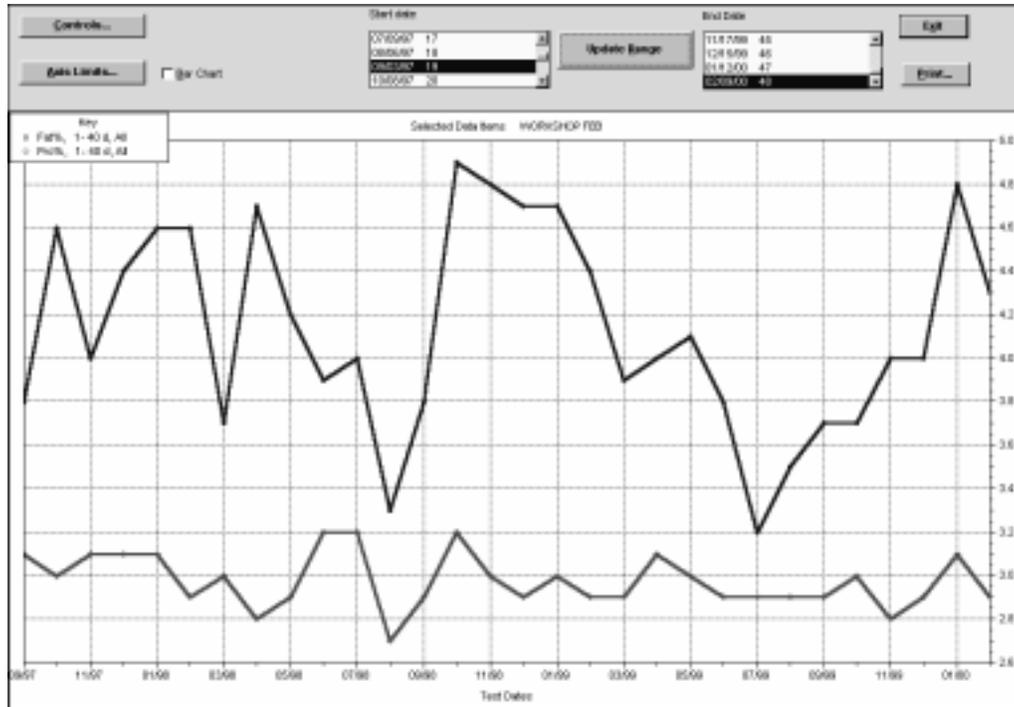


Figure 10. The PCDart Graphics average 1 to 40 day fat and protein percentages by test day.

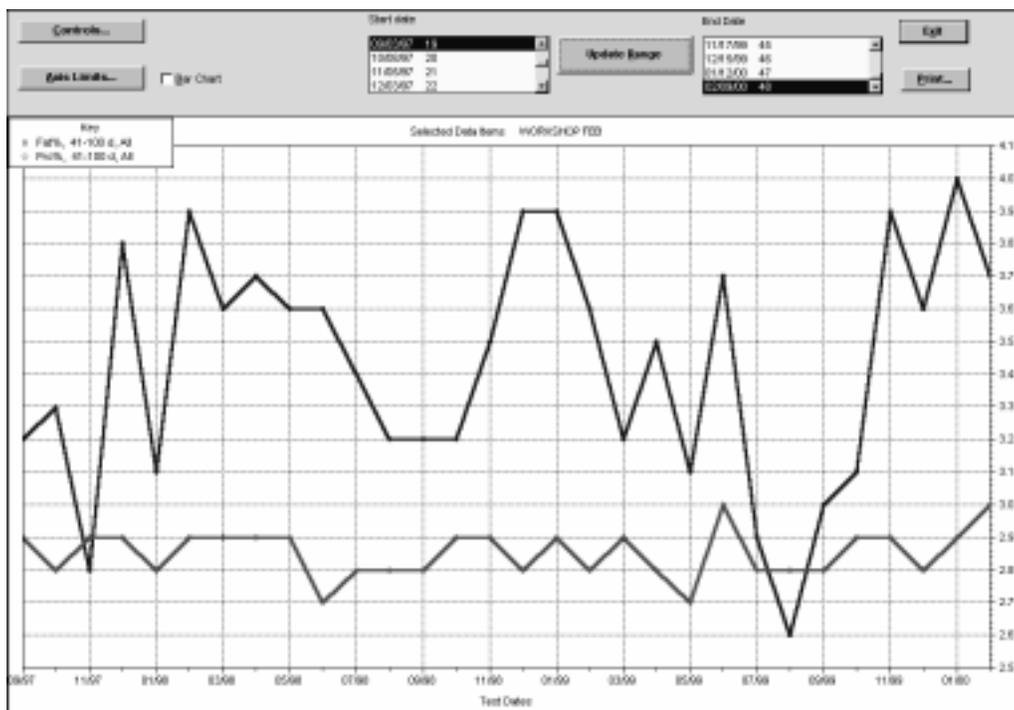


Figure 11. Average fat and protein percentages for cows during 41 to 100 days in milk by test day.

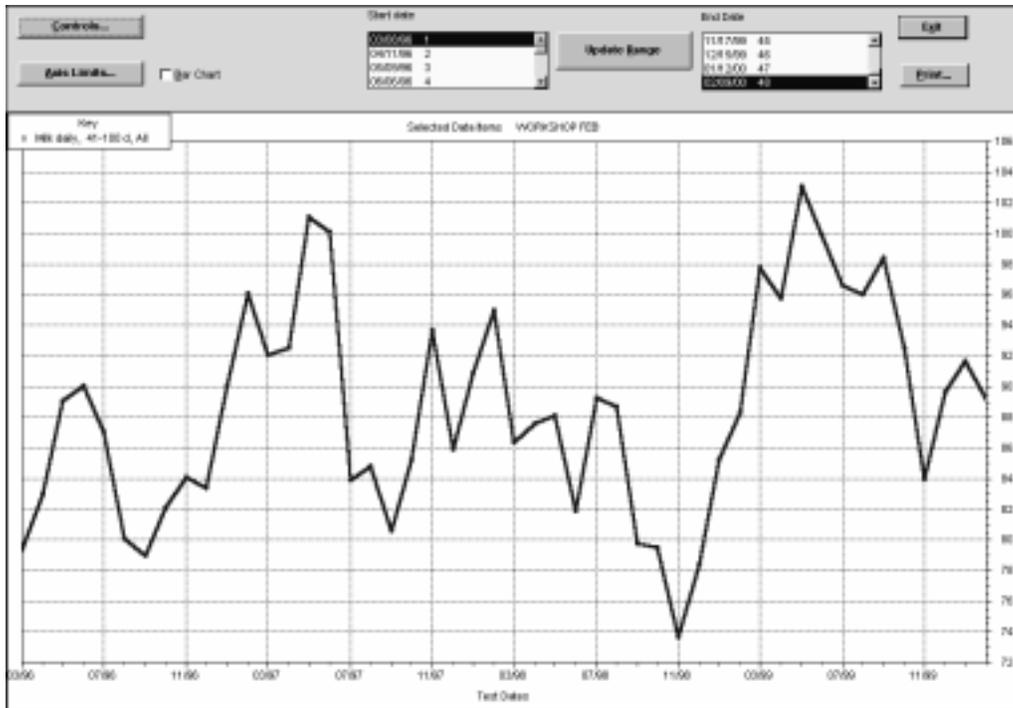


Figure 12. The PCDart Graphics average 41 to 100-day milk production (lb/day) by test day.



Enzymes and Direct Fed Microbials in Diets for Dairy Cows

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Abstract

Direct-fed microbials (DFM) contain live bacteria and yeast; others contain bacterial and fungal crude extracts or fermentation byproducts. Feed enzyme products for ruminants are refined extracts of bacterial and fungal origin that have an array of fibrolytic enzyme activities. Often, there is confusion over the differences between enzyme and DFM products because many DFM products are marketed, at least partly or implicitly, on their residual enzymatic content. However, in comparison to enzyme products, DFM products contain relatively little actual fibrolytic enzyme activity. Numerous DFM products are commercially available, while ruminant feed enzymes are just now entering the marketplace. Both DFM and feed enzyme products have been shown to enhance fiber digestion by ruminants, but the mechanism whereby they increase feed utilization differs. On the whole, responses in animal performance to DFM and feed enzyme products have been somewhat inconsistent. Production responses to DFM and enzymes can be attributed mainly to improvements in energy availability. Thus, animal responses will be greatest in situations in which fiber digestion is compromised and when energy is the first limiting nutrient. Furthermore, as with any new feed product, there is variability in the response when supplementation is viewed across all products. With increasing consumer concern about the use of growth promoters and antibiotics in ruminant production, and the magnitude of increased animal performance obtainable using feed

enzymes and DFM, there is no doubt that these products will play an important role in future ruminant production. A more complete understanding of the mode of action of these products will allow us to use enzymes and DFM to obtain the desired effects.

Introduction

Over the years, there has been a continual search for new additives that enhance feed utilization so that the nutrient demands of ever increasing milk production by dairy cows can be met. The relatively recent interest in the use of feed enzymes and DFM has developed as part of this initiative.

Both feed enzymes and DFM have been shown to improve fiber digestion in ruminants, but their modes of action differ. Often, there is confusion over the differences between enzymes and DFM, because many DFM products are marketed, at least partly or implicitly, upon their residual enzymatic content. However, in comparison to enzyme products, DFM products contain relatively little actual fibrolytic enzyme activity. This presentation will discuss the use of DFM and enzymes in dairy cow diets and the possible mechanisms by which these products may improve nutrient utilization.

Feed Enzymes

Enzymes are naturally occurring proteins that catalyze chemical reactions in biological systems.

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They are involved in the digestion of all complex feed molecules into their smaller base chemical constituents (i.e. glucose, amino acids, etc.). Without enzymes, feed would remain undigested by the bacteria and the host animal. Commercial feed enzyme products for ruminants contain an array of fibrolytic enzyme activities. There are numerous commercial products registered for use in ruminant diets; however, the major active ingredients in most of these products are DFM, microbial extracts, or vitamin/mineral preparations. Presently, there are relatively few true enzyme products commercially available in North America.

The use of exogenous enzymes in ruminant diets is not a new idea. In the 1960's, a number of studies were conducted to explore the potential of supplementing ruminant diets with enzyme preparations (as reviewed by Beauchemin and Rode, 1996). Several studies showed that the use of feed enzymes substantially improved feed digestibility and animal performance, although other studies reported no effects and even negative responses. Little effort was made to describe the enzymes used in these early studies and no effort was made to determine their mode of action. Furthermore, production of exogenous enzymes was expensive at the time, and it was not economically feasible to apply these preparations at the concentrations necessary to elicit a positive animal response. Recent reductions in fermentation costs, together with more active and better defined enzyme preparations, have prompted researchers to re-examine the role of exogenous enzymes in ruminant production.

Sources of Enzymes

Virtually all enzyme products marketed for livestock (primarily poultry) are derived from the bacterial species *Lactobacillus acidophilus*, *L. plantarum*, and *Streptococcus faecium* or fungal species *Aspergillus oryzae*, *Trichoderma reesei*, and *Saccharomyces cerevisiae* (Pendleton, 1998). It is

unlikely that this list of source organisms will expand substantially, given the restrictive stance taken by the European Union and the U.S. Food and Drug Administration to add new organisms.

Enzyme preparations for ruminants are evaluated primarily on the basis of their capacity to degrade plant cell walls. Typically, these enzymes fall into the general classification of cellulases or xylanases. Degradation of cellulose and hemicellulose alone requires a number of enzymes, all of which may loosely be termed cellulases or xylanases. Numerous specific enzyme activities contribute to cellulase and xylanase activities, thus two commercial products with the same enzyme level can substantially differ in their ability to digest fiber. Most commercial preparations are not single gene products, containing a single enzyme activity. Secondary enzyme activities, such as amylases, proteases, or pectinases, are also invariably present. Differences in the relative proportions and activities of these individual enzymes will have an impact on the efficacy of cell wall degradation by the marketed products.

Dairy Cow Production Responses

Recently, there has been a flurry of research activity to determine the effect of exogenous enzymes on milk production in dairy cows (Beauchemin et al., 1999, 2000; Chen et al., 1995; Kung et al., 2000; Lewis et al., 1995; Luchini et al., 1997; Nussio et al., 1997; Rode et al., 1999; Sanchez et al., 1996; Schingoethe et al., 1999; Stokes and Zheng, 1995; Yang et al., 1999, 2000). Production responses by dairy cattle to exogenous enzymes have been variable. While this variability may be viewed as an indication that feed enzyme technology is not suitable for improving feed utilization for ruminants, we believe that the variability can be attributed to factors such as enzyme type, level of supplementation, and particularly, method of enzyme application. Our group has conducted various feeding studies with a range of enzyme products using our knowledge of enzyme type,

level, and method of application to clearly demonstrate the potential of enzymes as feed additives for ruminants.

In one such study (Study 1), the xylanase/cellulase enzyme mixture, Pro-Mote N.E.T.TM (Biovance Technologies Inc., Omaha, NE; product currently marketed as PromoteTM by Agribrands International, St. Louis, MO), was applied to processed alfalfa hay cubes with the cubes comprising 45% of the total dietary DM (Yang et al., 1999). When the enzyme-enhanced cubes were fed to dairy cows with ruminal and duodenal cannulae, the digestibility was enhanced and milk production was increased (Table 1). Two levels of enzyme addition were used (low = 0.5 g/kg; medium = 1.0 g/kg dietary DM). The medium level was attained by adding the enzyme supplement to the cubes or to the cubes and concentrate. Milk yield was increased by about 2 lb/day (4%) for the low enzyme level and by 4 lb/day (8%) for the medium enzyme level, with no effects of enzyme on feed intake. When compared at the same level of enzyme, the response was similar whether the enzyme was added to the cubes or to both the cubes and concentrate. Increased milk yield due to enzymes did not change the fat or protein percentages of milk, but lactose percentage was increased.

We speculated that increasing energy availability of feed using enzymes would lead to a substantial increase in milk yield by cows in early lactation due to their negative energy balance. Thus, we conducted a lactation study (Study 2) with 20 cows in early lactation fed diets treated with the same enzyme mixture as used in Study 1 (Rode et al., 1999). The enzyme was applied to the concentrate during the first 12 weeks of lactation to provide 1.3 g/kg dietary DM. The diet was formulated to contain 24% corn silage, 15% chopped alfalfa hay, and 61% concentrate (DM basis). Digestibility of nutrients in the total tract was dramatically increased by enzyme treatment (Table 2). As a result, cows fed the enzyme-enhanced diets produced 7.9 lb/day more milk than

cows fed the control diet, yet feed intake was unchanged. However, there was a concomitant decrease in milk fat and lactose percentages, although yields were not affected by enzyme supplementation. The substantial reduction in milk fat content due to enzyme supplementation was not expected considering the significant increase in feed digestion.

In the next lactation study (Study 3), cows in early lactation were fed diets treated with a modified version of Pro-MoteTM (equivalent to 1.5 g/kg DM with respect to xylanase and 0.4 g/kg DM with respect to cellulase) (Yang et al., 2000). The enzyme was applied either to the concentrate or sprayed daily onto the TMR. The diet was similar to that used in Study 2, except that the diet was formulated to supply higher metabolizable protein levels. From weeks 3 to 15 of lactation, cows fed the diet with enzyme applied to the concentrate produced 4.6 lb/day more milk than cows fed the control diet, without a change in feed intake (Table 2). In contrast, there was no effect on milk production when the enzyme was applied to the TMR, although digestibility numerically increased. Similarly, Beauchemin et al. (1999) reported that applying enzymes to the TMR prior to feeding did not significantly increase milk production but increased feed digestibility in the total tract. In that study, the improvement in digestibility was mainly due to increased post-ruminal digestion. This study clearly illustrates that method of enzyme delivery is crucial in obtaining improvements in digestibility and milk production. Unlike in the previous lactation study (Study 2), enzyme supplementation did not affect milk composition, indicating that dietary effective fiber levels were adequate even after enzyme supplementation.

Method of Application

From Study 3 and other studies, it is clear that effects of exogenous enzymes are maximized when an aqueous enzyme solution is applied onto dry feed (either hay or concentrate). Feng et al. (1996) applied an enzyme solution directly to grass and



observed no effect when added to fresh or wilted hay, but when applied to dried grass, enzymes increased DM and fiber digestion. When we applied a low level of a fibrolytic enzyme preparation onto alfalfa silage prior to feeding, no effects on DM digestibility were observed (Beauchemin and Rode, unpublished data). However, when the enzyme was added to the silage after it had been dehydrated, DM digestibility increased by 2.9%.

Applying the enzyme to dry feed creates a stable enzyme-feed complex that increases enzyme effectiveness. This stable complex occurs quickly (within hours) and once stabilized onto dry feed, the enzymes are stable and effective for at least several months. Enzymes that are applied to silage or TMR immediately prior to feeding may be released into the ruminal fluid and passed quickly from the rumen before they can be effective in the rumen. This would provide a rationale for the larger intestinal effects when enzyme was applied daily to TMR (Beauchemin et al., 1999) compared to when the same enzyme was applied to forage or concentrate (Yang et al., 1999).

Learning From Animal Experiments

The positive effects of exogenous enzymes on milk production by dairy cattle have been demonstrated definitively, but the information required to improve the consistency and increase the magnitude of these responses needs refinement. Comparisons among experiments are exceedingly difficult because many enzyme products are poorly defined. Further, several studies have shown that over-application of enzyme can negate any potential increases in animal performance due to enzyme supplementation (Beauchemin et al., 1995; Kung et al., 2000; Sanchez et al., 1996). Thus, application of one enzyme preparation at a given concentration provides little information with regard to the potential effect on animal performance of a different application level, let alone a different product. It is obvious that many factors may influence enzyme efficacy in ruminants. Therefore,

an understanding of the modes of action by which enzymes improve nutrient utilization in ruminants is key to obtaining consistent positive responses to enzyme additives over a broad range of diets and animal types.

Mechanisms of Improving Feed Utilization

Based on the results from numerous animal feeding studies, it appears that the primary effect of enzymes is to enhance total tract fiber digestion, primarily by increasing fiber digestion in the rumen. In high producing ruminants, such as the dairy cow, fiber digestion is often compromised due to low ruminal pH and rapid transit time through the rumen. This is illustrated in a study in which dairy cows and sheep were fed a TMR, with and without supplemental enzymes. For dairy cows fed the control diet, total tract digestion was 63.9% for DM and 31.8% for ADF (Table 3). For sheep, total tract digestion was 77.1% for DM and 49.8% for ADF.

Supplementing the diet with an enzyme product improved digestion by dairy cows but not sheep. This study indicates that feed enzymes improve feed digestion only when the potential digestion of the diet is not attained because digestion is compromised. For dairy cows, the NRC (1989) assumes a 4% reduction in digestibility for each multiple increase in intake over maintenance intake. It is this Aloss@ in digestible energy that becomes potentially digested with the use of feed enzymes. Thus, existing enzyme technology is not likely to benefit cattle fed at maintenance; rather the greatest responses will be for cattle fed ad libitum diets that contain relatively high proportions of grain.

In light of the exceptionally high starch and fiber digesting capacity of the rumen, it is difficult to explain why treatment of grain or forage with enzymes prior to consumption would further improve its utilization. The precise mode of action of exogenous enzymes in ruminant diets has yet to be demonstrated. To date, there appears to be evidence that exogenous

enzymes alter feed utilization in ruminants through their effects on the feed prior to consumption and through their enhancement of digestion in the rumen and in the post-ruminal digestive tract. Preconsumptive effects of exogenous enzymes cause the release of soluble carbohydrates and the removal of structural barriers that limit microbial digestion of feed in the rumen. Within the rumen, exogenous enzymes act directly on the feed (hydrolytic effect) and indirectly by stimulating digestive activity through synergistic effects on ruminal microorganisms. Bacterial numbers in the rumen are also increased. Exogenous enzymes can remain active in the lower digestive tract, contributing to the post-ruminal digestion of fiber and can indirectly improve nutrient absorption in the lower tract by reducing viscosity of intestinal digesta. Ultimately, the goal of enzyme supplementation is to improve the efficiency of feed utilization in ruminants and reduce waste production. Undoubtedly, the mode of action of exogenous enzymes in ruminants is exceedingly complex and continues to be a major focus of our research program.

Direct-Fed Microbials

Direct-fed microbials, originally called probiotics, are defined by the U.S Food and Drug Administration as live, or viable, naturally occurring microorganisms. Numerous DFM products are commercially available for lactating dairy cows. Some contain live bacteria and yeast; others contain bacterial and fungal extracts or fermentation byproducts. Products containing live microorganisms must provide a cell count guarantee on the label. While fermentation products contain microbial cells, fermentation extracts contain enzymes that are extracted from a microbial fermentation (cells are not included in the product). All commercial products are from microorganisms that are generally recognized as safe (**GRAS**) by the U.S. Food and Drug Administration.

Bacterial DFM

The most common DFM of bacterial origin are from *Lactobacillus* sp. These organisms have their effect in the lower gut, with little effect in the rumen. Feeding *Lactobacillus*-based DFM is based on the premise that certain strains of *Lactobacillus* can associate with the mucous layer of the intestinal villi, thereby prohibiting pathogens from adhering there. Beneficial gut microorganisms not only compete with potential harmful organisms, but they also aid in feed digestion. There is also evidence that certain beneficial bacteria can out-compete other bacteria for nutrients in the gut, thereby dominating the colonization of the intestinal tract. Some *Lactobacillus*-based DFM also contain other bacterial species, such as *Bacillus* and *Bifidobacterium* which have been shown in vitro to reduce numbers of pathogenic organisms. Most of the research with bacterial DFM has been with preruminant calves to reduce diarrhea and intestinal pathogens. There are only a few studies in which *Lactobacillus*-based DFM fed to lactating cows have elicited a positive response (Kung, 1998). Furthermore, it is not known whether these microbes survive ruminal digestion.

Research with other bacterial species may eventually prove beneficial for lactating dairy cows. For example, research with *Megasphaera elsdenii* has shown it to have positive effects on reducing ruminal lactic acid concentrations, which could be beneficial in preventing lactic acidosis (Kung, 1998).

Fungal DFM

Most fungal-based DFM contain *Saccharomyces cerevisiae* (yeast) or are from *Aspergillus oryzae* (fungi). *Aspergillus* products contain cells and are used as a source of enzymes, whereas *Aspergillus* extracts contain only the enzymes, without cells. The mode of action of fungal products differs from yeast products. The effect of *Aspergillus* products appears to depend primarily on

their enzyme activity. However, the amount of enzyme added to the diet using crude fungal preparations, such as *A. oryzae*, is less than 10% of the enzyme activity added in the majority of the studies with exogenous enzymes (Newbold, 1995). Since enzyme activity of fungal DFM is relatively low, it would seem that the most effective approach to providing supplemental enzyme activity would be to use a true enzyme product. Consequently, it appears that the future of fungal-based DFM is somewhat limited.

In contrast, there is a growing body of evidence that supplementing diets with yeast-based DFM can increase milk production, as recently summarized by Quaife (1998). However, responses are often variable. Part of this variation may result from differences in the strain of *S. cerevisiae* used and the method of growing, storing, and harvesting the culture (Newbold, 1999). Production responses attributed to yeast are usually related to increased fiber digestion and/or increased flow of microbial protein from the rumen. The mechanism by which these improvements occur is not well defined. Various studies have shown an increase in the number of cellulolytic bacteria in the rumen as a result of feeding yeast, and a number of mechanisms by which yeast increases bacterial numbers in the rumen have been proposed. The most likely explanation is related to the high respiratory rate of yeast. While the rumen is considered to be anaerobic, it does contain 0.5 to 1.0% oxygen (McArthur and Multimore, 1962). There is evidence that yeast-based DFM remove oxygen from the rumen which inhibits bacterial growth and adhesion of cellulolytic bacteria to fiber (Table 4). There is also evidence that yeast cultures provide growth factors, such as organic acids, B-vitamins, and amino acids, that stimulate growth of rumen microbes (Callaway and Martin, 1997).

Conclusion

Interest in using feed enzymes and DFM in dairy cow diets has increased dramatically in recent

years. Numerous DFM products are commercially available, while ruminant feed enzymes are just now entering the marketplace. On the whole, responses in animal performance to DFM and feed enzymes have been inconsistent. Production responses to DFM and enzymes can be attributed mainly to improvements in fiber digestion and ultimately energy availability. Thus, animal responses will be greatest in situations in which fiber digestion is compromised and when energy is the first limiting nutrient. Furthermore, as with any new feed product, there is variability in the response when supplementation is viewed across all products. With enzyme products, a lot of the variation can be attributed to supplementation with insufficient enzyme activity (Aenzyme products@ containing little or no enzyme activity), or inappropriate method of application. There is sufficient evidence for certain products that animal responses are actually quite consistent and predictable.

With increasing consumer concern about the use of growth promoters and antibiotics in ruminant production and the magnitude of increased animal performance obtainable using feed enzymes and DFM, there is no doubt that these products will play an important role in future ruminant production. A more complete understanding of the mode of action of these products will allow us to use enzymes and DFM and obtain the desired effects. Additionally, an understanding of the interactions that occur among the ruminant host animal, the gastrointestinal microbial population, and new feed additives will give us the opportunity to produce new, safe, effective additives in the future.

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Table 1. Effects of supplementing a dairy cow diet with low or medium levels of a fiber degrading enzyme mixture applied to alfalfa hay cubes or a mixture of cubes and concentrate (Study 1; Yang et al., 1999).¹

Item	Enzyme				SE
	Control cubes	Low, cubes	Medium, cubes	Medium, cubes + concentrate	
DM intake, lb/day	44.9	45.5	45.5	45.8	1.5
Milk production, lb/day	52.1 ^b	54.1 ^{ab}	56.3 ^a	55.7 ^{ab}	1.3
Milk fat, %	3.79	3.70	3.78	3.76	0.11
Milk protein, %	3.36	3.41	3.48	3.49	0.04
Milk lactose, %	4.56 ^b	4.61 ^{ab}	4.60 ^{ab}	4.62 ^a	0.02
Ruminal OM digestibility ² , %	54.1	54.3	58.4	57.2	3.0
Total tract OM digestibility, %	64.4 ^b	65.9 ^{ab}	67.0 ^a	66.5 ^a	0.7
Ruminal NDF digestibility, %	30.7	34.9	36.9	35.6	4.8
Total tract NDF digestibility, %	38.8 ^b	41.2 ^{ab}	43.6	42.4 ^{ab}	1.3

^{a,b}Means in the same row with different superscripts differ ($P < 0.05$).

¹SE = standard error, DM = dry matter, OM = organic matter, and NDF = neutral detergent fiber.

²Organic matter truly fermented in the rumen.

Table 2. Effects of supplementing diets fed to cows in early lactation with an enzyme mixture.¹

Item	Study 2 ²		Study 3 ³		
	Control	Enzyme in concentrate	Control	Enzyme in TMR	Enzyme in concentrate
DM intake, lb/day	41.1	41.8	42.7	44.9	43.6
Milk production, lb/day	79.0	86.9 ^f	77.7 ^b	77.4 ^b	82.3 ^a
Milk composition, %					
Fat	3.87 ^a	3.37 ^b	3.34	3.14	3.19
Protein	3.24	3.03	3.18	3.13	3.13
Lactose	4.73 ^c	4.62 ^d	4.65	4.56	4.65
Milk component yield, lb/day					
Fat	2.97	2.90	2.73	2.68	2.82
Protein	2.49	2.62	2.51	2.53	2.60
Lactose	3.70	4.07	3.56	3.61	3.72
BW change, lb/day	-1.39	-1.32	0.33	0.31	0.09
DM digestibility, %	61.7 ^a	69.1 ^b	63.9 ^a	65.7 ^{ab}	66.6 ^b
NDF digestibility, %	42.5 ^a	51.0 ^b	42.6	45.9	44.3

^{a,b}Means within a study differ ($P < 0.05$).

^{c,d}Means within a study differ ($P < 0.10$).

^{e,f}Means within a study differ ($P = 0.11$).

¹TMR = total mixed ration, DM = dry matter, BW = body weight, and NDF = neutral detergent fiber.

²Taken from Rode et al.(1999).

³Taken from Yang et al. (2000).

Table 3. Effect of enzyme supplementation on total tract digestibility in dairy cows and sheep (Yang et al., 2000).¹

Item	Dairy Cows		Sheep	
	Control	Enzyme	Control	Enzyme
DM intake, lb/day	42.7	43.6	3.08	3.21
Digestibility, %				
Dry matter	63.9 ^a	66.6 ^b	77.1	76.8
Neutral detergent fiber	42.6	44.3	57.7	56.5
Acid detergent fiber	31.8	33.7	49.8	48.1

^{a,b} Means within a study differ ($P < 0.05$).

¹ Enzyme from Biovance Technologies, Omaha, NE.



Guidelines for Low Forage Diets

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Abstract

Variation in forage quality, limited supply of forage, high prices for forage, and attempts to maximize milk yield are factors for why low forage diets are often fed to lactating cows. Adequate effective fiber is critical for healthy, high producing dairy cows. Monitoring dry matter (**DM**) intake, milk fat percentage, ratio of milk fat to milk protein, percentage of cows ruminating, and incidence of metabolic disease can serve as simple indices of rumen function. Maintaining a stable rumen fermentation requires providing a minimum level of effective fiber and not exceeding a maximum level of nonfiber carbohydrates (**NFC**). Forage NDF (**FNDF**) is a good indicator of effective fiber, but particle size of forage, source of NFC, and fermentability of the NFC source must be considered when formulating diets based on minimum FNDF. Low forage diets generally should not be fed to dairy cows during the first 30 days in milk (**DIM**) because of the low DM intake at parturition and the risk of metabolic diseases. Intense feeding management is required when low forage diets are fed.

Introduction

The most critical function of the fermentation in the rumen is the digestion of fibrous components in plants, resulting in energy substrates and microbial protein for digestion and absorption by the host animal. Although the fermentation system is of major importance to the animal, this “digestion vat”, like any

other fermentation system, requires certain basic elements for its proper function. The balance between fibrous carbohydrates and NFC provided to the rumen greatly affect the microbial activity and the resulting fermentative products and pH. However, we must examine beyond the concentration of these carbohydrates in the diet when attempting to optimize fermentation and animal performance and health. Sources of the carbohydrates, particle size of the sources, and feeding management practices also must be monitored.

Feeding high levels of forage can result in low DM intake due to rumen fill and slow rate of passage; however, low levels of forage also can result in low DM intake because of an unstable rumen (most of the effective fiber in the diet is provided by forage). Traditional levels of fiber in diets for dairy cows was based on the general assumption that forage provided the fiber and cereal grain provided the NFC. However, with the vast availability of several alternative (by-product) feeds that have appreciable amounts of fiber (serves as source of partially effective fiber and diluter of starch) and additional research on balancing carbohydrates in diets for dairy cattle, lower than typical levels of forage are being fed on many farms.

Many reasons exist for decreasing level of forage in diets. Forages are typically lower in energy than concentrates; therefore, animal performance may increase by reducing forages until rumen health is compromised. Forage quality can be highly variable [e.g.,

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coefficient of variation (**CV**) for crude protein in legume haylage (18.3%) was higher than that for soybean meal (6.4%); CV = ~ 14% for NDF in legume and corn silages; Bucholtz, 1997] due to harvest and storage conditions. Because of poor growing conditions (i.e., limited rainfall), forage yields may be much lower than anticipated. In a given year, a limited supply of high quality forage may be available because of poor harvest conditions (e.g., excessive rainfall). On a continuous basis, a limited supply of high quality forage may be available because of limited land base. The lack of land base for forage production may be because of urban encroachment, high land values for agricultural purposes, or the explicit choice by the farmer to not be a crop producer. Sometimes nationally, but more commonly on a local basis, cost of forages increases sharply due to limited supply. At the same time, grain prices may be low or high. Expanding the range of amounts of forages that can be fed provides more elasticity in managing the feed costs associated with milk production. Therefore, variation in forage quality, limited supply of forage, high prices for forage, and attempts to maximize milk yield are factors that give credence to feeding low forage diets. This paper will focus on establishing some guidelines to follow when feeding low forage diets.

Animal Indicators of Unstable Ruminal Fermentation Available Under Field Conditions

Several factors can be monitored as indices of proper rumen function (or effective dietary fiber), some of which are certainly more applicable than others (Table 1). A quadratic relationship was observed between ruminal acetate:propionate and milk fat percentage (Erdman, 1988). Although the value (price) of milk fat has been quite variable in recent years, it has remained important as an indicator of rumen stability for the dairy farmer and nutritionist. Wisconsin researchers have used milk fat percentage in several studies (Clark and Armentano, 1993; Depies and Armentano, 1995; Swain and Armentano, 1994) as

a measure of effective fiber from nonforage fiber sources. However, high-producing Holstein cows consuming seemingly adequate fiber diets often produce milk with less than 3.5% fat. A well functioning rumen and the normal metabolism of the dairy cow dictate that milk fat be slightly higher than milk protein; therefore, the ratio of milk fat to protein is sometimes used in the field as an indicator of rumen stability; a ratio of less than or equal to 1:1 (milk fat to protein inversion) signals for the nutritionist to look at dietary or intake factors contributing to rumen instability.

Cows spend about eight to nine hours per day ruminating (Dado and Allen, 1993). Reducing particle size of alfalfa hay (Grant et al., 1990a) and alfalfa silage (Grant et al., 1990b; Mooney and Allen, 1997) will result in less time spent chewing per day. However, source of the NDF may have minimal effect on total time spent ruminating per day (Harmison et al., 1997; Weidner and Grant, 1994b). Observation of percentage of cows ruminating at a given visit to a farm can give some indication of balance of carbohydrates in the diet. Cows should be observed undisturbed, whether they are lying in a free stall or standing in an alley. About 40% of cows should be ruminating during a given observation.

Erratic and (or) low) DM intakes, low milk yield, and high incidences of metabolic problems occur when effective dietary fiber is inadequate. When feeding diets low in effective fiber, a TMR results in more stable intake than when forages and grains are fed separately. However, DM intake is more variable with a TMR that is low in forage NDF and (or) high in rumen degradable starch than with a TMR with higher FNDF and (or) lower rumen degradable starch (Harmison et al., 1997). Since the decreased intake with a TMR may be subtle, astute feeding management, including records of feed offered and refusals, are necessary. Increased incidences of ketosis, laminitis, and displaced abomasum are especially likely when feeding low effective fiber diets. Subclinical laminitis

is a problem in many dairy herds, and although some of the predisposing problems have been identified, delineation of a precise means of preventing subclinical laminitis in high-producing herds requires further research (Hoblet, 1993).

Using a procedure known as rumenocentesis, veterinarians can check rumen pH under field conditions while avoiding saliva contamination caused by stomach tube (Nordlund and Garrett, 1994). Ruminant pH may range from 5.5 to 7, with optimal being 6 to 6.5. However, average ruminal pH is not as reflective of ruminal conditions as time spent under pH 6.0 and weighted by the deviation from pH 6.0 (Allen and Beede, 1996). However, determining time spent under pH 6.0 would require many measurements at different time points, which is not practicable under field conditions. The following items should be considered when using the rumenocentesis procedure to detect subacute ruminal acidosis in dairy cattle (Allen and Beede, 1996): 1) collect samples from animals in different groups (i.e., 1 to 20 DIM and 45 to 150 DIM); 2) sample at least six cows per group; 3) ruminal pH can be classified as abnormally low (≤ 5.5), marginal (5.6 to 5.8), or normal (≥ 5.9); 4) collect samples two to four hours after concentrate feeding in component fed herds and four to seven hours after feeding a TMR; and 5) the same number of cows in the same groups should be sampled again in three to four weeks if corrective actions for low ruminal pH are taken.

Fecal pH has been shown to be positively correlated with dietary levels of ADF and NDF ($r = 0.70$ and 0.63 , respectively) and negatively correlated with dietary level of starch ($r = -0.63$) (Ireland-Perry and Stallings, 1993). Fecal pH decreased linearly as forage NDF was reduced from 21 to 16 to 11% of dietary DM, with NFC levels at 43% (21% forage NDF) and 35% (16 and 11% forage NDF) (Eastridge et al., 1995). Fecal pH may reflect the extent of carbohydrate fermentation in the rumen and starch passage from the rumen; however, using fecal pH as

an indicator of rumen stability is confounded by hindgut fermentation of ruminally escaped starch.

Dietary Factors for Balancing Carbohydrates

Carbohydrate indices for formulating diets are described in Table 2. A maximum amount of rapidly fermentable carbohydrates (i.e., NFC) and a minimum amount of slowly degradable carbohydrates (i.e., NDF) must be provided, and the ratio between these carbohydrate fractions is important. The historical index for adequate structural carbohydrates has been forage concentration (or forage:concentrate ratio); however, this provides neither consideration for quality of the forage (level of fiber) nor recognizes fiber from nonforage sources. Hence, minimum levels of fiber have been established. The National Research Council (NRC, 1989) suggests that at least 28 and 25% NDF and 21 and 19% ADF should be provided for dairy cows in early lactation and for high-producing cows, respectively. It further suggests that 75% of the dietary NDF should be from forages [$21\% \text{ FNDF} = 28\% \text{ NDF} * 0.75$]. Such recommendations take into consideration forage quality: as forage quality increases (NDF decreases), more of the forage must be fed to meet minimum fiber levels. As forage quality decreases (NDF increases), level of forage in diet should be decreased. High NDF diets reduce DM intake (1.0 lb of DM = about 2.0 lb of milk), thereby reducing milk production because of rumen fill (Beauchemin et al., 1994; Rayburn and Fox, 1993). Monitoring minimum FNDF also allows consideration of different fiber levels among plant species (e.g., legumes versus grasses).

Use of ADF instead of NDF as the index for minimum dietary fiber results in different minimum levels of forage. This occurs because of the different ratios of NDF to ADF among forage species, and, because ADF excludes hemicellulose, NDF should be used as the major index for monitoring minimum dietary levels of fibrous carbohydrates. However, ADF



is more reflective of effective fiber when a major portion of the total fiber in a ration is being contributed from nonforage sources. On the other hand, this limitation of total NDF can be overcome by monitoring levels of FNDF in rations. Simply expressing dietary NDF recommendations as percentages of body weight has merit for maximum fiber levels because of the relationship between rumen size and body weight; however, the meaningfulness of this approach waivers for assessment of minimum levels of fiber because milk yield, DM intake, and source of the NDF are ignored.

A maximum dietary level of 45% NFC has been suggested for dairy cows (Hoover and Miller, 1991). None of the fiber indices discussed above consider level of dietary NFC, and minimum level of dietary fiber could be met without holding NFC below maximum suggested levels. It has been suggested that 60 to 65% of dietary NDF from forages may be sufficient when alternative feeds, such as soyhulls, are used to limit dietary NFC (Firkins and Eastridge, 1992; Sarwar et al., 1992). Replacing high-starch grain with high-fiber grain in diets high in NFC may increase efficiency of nutrient utilization and animal performance because the high-fiber grain reduces negative associative effects (namely starch reducing fiber digestibility) in the rumen (Sarwar et al., 1992). Source of NFC and processing of grain affect rate of starch fermentation and can therefore influence animal performance (Mertens, 1992; Poore et al., 1993). Rate and extent of starch digestion in the rumen for dry grains can be ranked in the following order (high to low): oats, wheat, barley, corn, and sorghum (Mertens, 1992). Although not well identified, a minimum level of NFC is likely needed to maximize microbial growth (Hoover and Miller, 1991).

Maintaining a stable rumen fermentation by providing a minimum level of fiber and not exceeding maximum level of NFC must be complemented by the feeding system. A consistent flow of substrates to the rumen provides for an efficient and stable fer-

mentation. Yet, particle sizes for the forage, starch source, and TMR are very important for providing effective fiber (larger size), regulating rate of carbohydrate fermentation, stimulating saliva production (larger size), and for minimizing sorting by cows (smaller size). Forage for silage should be harvested at theoretical length of cut (TLC) at 0.25 to 0.38 inches, unless the forage is corn silage and a processor is used, in which case, TLC should be 0.75 inches (with roller spacing of 2 to 3 mm). Using the Penn State Particle Size Separator (Heinrichs, 1997), the TMR should have a distribution of 10, 45, and 45% in the top (> 0.75 inches), middle (0.31 to 0.75 inches), and pan (< 0.31 inches) with typical diets. The distribution of particles in a TMR consisting of nonforage fiber sources and low forage may be 5, 50, and 45%, respectively. Feeds in a TMR should be mixed only long enough, usually three to six minutes, to provide uniform distribution of all feeds because excessive mixing can cause reduction in particle size of forages (Kammel and Schuler, 1995). Increased ruminal digestibility of grain will occur as particle size is decreased, but excessively fine grain will have an increased rate of fermentation, and in conjunction with low to moderate levels of effective fiber, can lead to reduced rumen pH.

Relationship Between Animal and Dietary Factors

Using 29 studies (Aldrich et al., 1993; Allen and Grant, 2000; Batajoo and Shaver, 1994; Beauchemin et al., 1994; Beauchemin and Rode, 1997; Beauchemin et al., 1997; Clark and Armentano, 1993; Clark and Armentano, 1997; Coomer et al., 1993; Cunningham et al., 1993; Depies and Armentano, 1995; Elliott et al., 1995; Harminson et al., 1997; Kennelly et al., 1999; Mowrey et al., 1999; Pereira et al., 1999; Ruiz et al., 1995; Sarwar et al., 1992; Schingoethe et al., 1999; Slater et al., 2000; Swain and Armentano, 1994; Wagner et al., 1993; Weidner and Grant, 1994a; Weiss, 1995; West et al., 1997; West et al.,

1998; West et al., 1999; Younker et al., 1998; Zhu et al., 1997) from published literature whereby various forages were fed (alfalfa, bermuda grass, corn silage, barley silage, barley/triticale silage, elephant grass, orchard grass, and sorghum), relationships among animal response variables and dietary components were examined. Dry matter intake tended to decrease as FNDF increased; therefore, rumen fill appeared to be more evident at depressing DM intake than lack of effective fiber at lower levels of FNDF (Figure 1). Actually, DM intake may be higher at lower levels of FNDF if nonforage fiber sources are in the diet to provide some effective fiber and to dilute starch (Slater et al., 2000). In a review of the literature, Firkins (1997) found that DM intake does not appear to decrease much until forage NDF is decreased below 14 to 16% of dietary DM. Milk yield response was similar to that of DM intake in relation to FNDF (Figure 2), except possibly more variable. The milk fat to milk protein ratio was ≥ 1.0 when FNDF exceeded 16% of DM (Figure 3). Poore et al. (1993) suggested that at least a 1:1 ratio between FNDF and ruminally degradable starch is needed to promote efficient performance by dairy cows. The balance between FNDF and NFC was compared to the ratio of milk fat to milk protein (Figure 4). The milk fat to milk protein ratio was ≥ 1.0 when FNDF/NFC exceeded 0.4. The r-square was less for FNDF/NFC than for FNDF in accounting for variation in the milk fat to milk protein ratio, probably because of the variation in reported values for NFC and because of variable ruminal degradability of NFC. Some of the studies reported analytical starch or NSC, and in such cases, NFC was calculated using: $(NSC-15)/0.492$ (Firkins, 1998). Although considerable variation still occurs in the literature for methods of calculation of NFC and analytical methods for NSC, more consistency is evolving.

Unlike most all other nonforage fiber sources, the effectiveness of fiber from whole cottonseed (WCS) is similar to that of alfalfa (Clark and Armentano, 1993; Mertens, 1992). The comparison

was made with the NDF from WCS included as NDF from either concentrate or forage (Figure 5). The regression line from Figure 3 was plotted to examine how the NDF from WCS dispersed around the line. Assuming the NDF from WCS was FNDF resulted in the data points falling nearer to the line than assuming the NDF of WCS was from concentrate.

Conclusions

Generally speaking, diets should contain a minimum of 26 to 28% NDF using traditional diets consisting of little or no high-fiber concentrate feeds. Assuming that 75% of the NDF should be forage, 21% FNDF would be needed in the ration; however, recent research has revealed that lower FNDF can be fed. It is important to balance the amount of FNDF and starch in the diet, and the source of the starch must be considered. Based on several experiments, here are some guidelines for limiting forage in diets:

- Whole linted cottonseed is the best concentrate source to use as a forage extender. Limit WCS to 5 to 6 lb/day per cow because of its unsaturated fat content. Dietary FNDF may be as low as 9 to 11% of DM when WCS is in the diet if dietary starch is limited to 25 to 30%. High fiber concentrate feeds, such as soybean hulls, distillers grains, brewers grains, wheat middlings, corn gluten feed, etc., can be used to limit the starch content in the ration.
- If WCS is not in the ration, the FNDF content should be at least 16 to 18% of dietary DM when using the high-fiber concentrate feeds to limit starch to 25 to 30% of the diet.
- The above suggestions are made assuming that corn silage is not the sole forage in the ration. If corn silage is the sole forage, the lower limits on FNDF should be increased 3 to 5 percentage units, and adequate particle size of the forage becomes even more important. This is because



corn silage has fewer long particles than haylage and the corn grain is more rapidly degraded in the rumen than dry shelled corn.

- The above suggestions are being made assuming that dry corn is the principal concentrate providing starch to the ration. If more rapidly fermented starch sources are used (e.g., wheat, barley, high moisture corn, and steam-flaked corn), replace no more than 50% of the dry corn or increase the amount of fiber in the ration.
- It is not necessary to add hay to a dairy cow ration, but hay does provide a safety net when feeding low fiber diets because of its particle size – provides for more cud chewing and a more dense rumen mat.
- Always add a buffer to the ration at about 0.8% of DM when feeding low fiber diets.
- When using these guidelines, keep in mind that a balance needs to be maintained between fiber and starch in the ration. When feeding low fiber rations without WCS, a ratio of FNDF:NFC of 0.45 to 0.50 appears adequate.

Management of low forage feeding programs must be very intense; without such intensity in management, greater risk in metabolic disease and negative animal performance is assumed by the dairy farmer. Changes in forage quality or particle size can result in major problems with little notice. Watch for the following as indicators of inadequate fiber intake: highly variable feed intake and milk yield, several cows within a group with inverted milk fat and protein percentages, increased incidence of displaced abomasum, sore feet, and loose feces. Based on recent data comparing 17 to 21% FNDF, the low fiber levels described above should not be fed to dairy cows until beyond 30 DIM (Wang et al., 1999).

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Table 1. General guidelines for response variables of lactating cows as indicators of adequate rumen function.

Animal Indicators	General Guidelines	Troubleshooting
Milk fat percentage	Holstein: > 3.3% Jersey: > 3.8%	1. Check herd average. 2. If herd average appears good, investigate cow groups.
Milkfat/milk protein	> 1:1	If herd average appears good, investigate cow groups.
Ruminating (cud chewing)	> 40% of cows	Observe cows undisturbed while lying or standing.
DM intake	> 50 lb/cow/day	Watch for low or erratic intakes.
Milk yield	XXX	Not a good measure of rumen function because many factors affect milk yield.
Metabolic diseases		
Ketosis	< 2.0% primary < 5.0% secondary	Cause of secondary is usually due to low DM intake.
Displaced abomasum	< 5.0%	Cows at greatest risk during first 30 days in milk.
Laminitis	< 25% sole hemorrhages	60 to 90 day delay from time of insult.
Rumen pH	> 6.0	Sample at least 6 cows per group.
Fecal pH	> 6.2	Not a good indicator of rumen function.

Table 2. Dietary factors for balancing carbohydrates in diets for lactating dairy cows.

Dietary Component ^{1,2}	General Guideline	Comments
Forage, % of DM	40 to 60	Not a good indicator because forage quality, total NDF, NFC degradability, and particle sizes are unknown
NDF, % of DM	26 to 28 minimum	Source of NDF unknown
ADF, % of DM	19 to 21 minimum	Excludes hemicellulose, which varies among forage species
FNDF, % of DM	16 to 21 minimum	Good indicator of effective fiber
NFC, % of DM	35 to 42	Methods of calculations often differ
Starch, % of DM	25 to 35	Often unavailable
FNDF/NFC	0.45 to 0.50	Evaluative index for balance of carbohydrates to maintain rumen function

¹DM = dry matter, NDF = neutral detergent fiber, ADF = acid detergent fiber, FNDF = forage NDF, and NFC = nonfiber carbohydrates.

²Particle size of forage, grain, and TMR also must be evaluated.

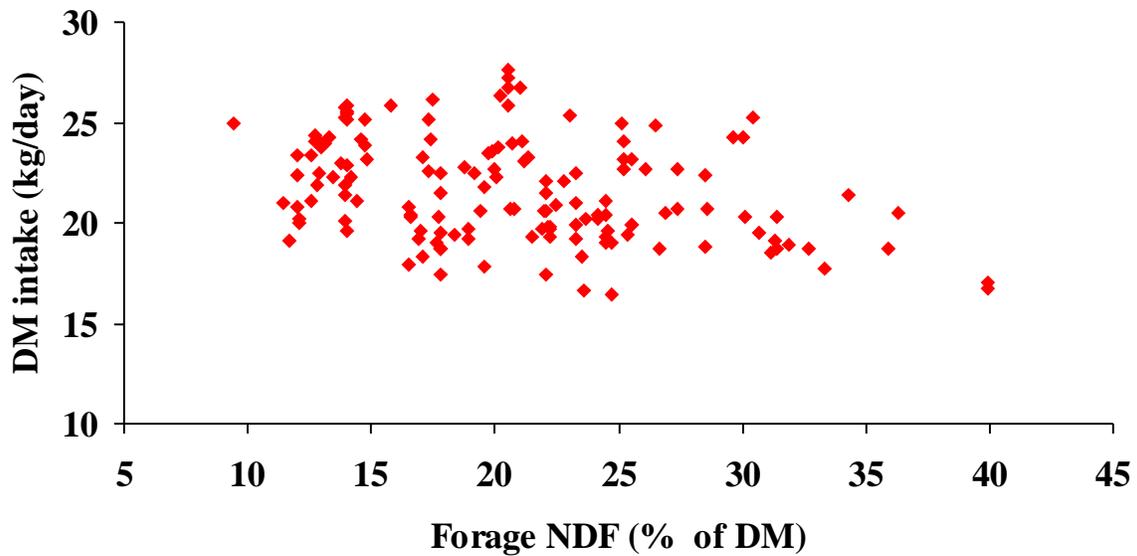


Figure 1. Relationship between forage NDF and DM intake by lactating cows (see text for references; 1.0 kg = 2.2 lb).

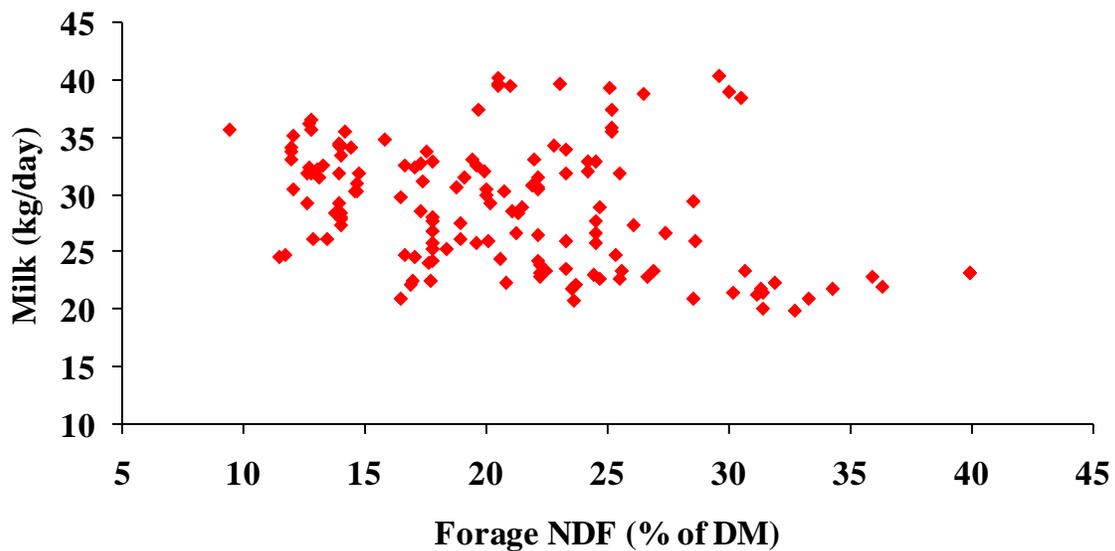


Figure 2. Relationship between forage NDF and milk yield (see text for references; 1.0 kg = 2.2 lb).

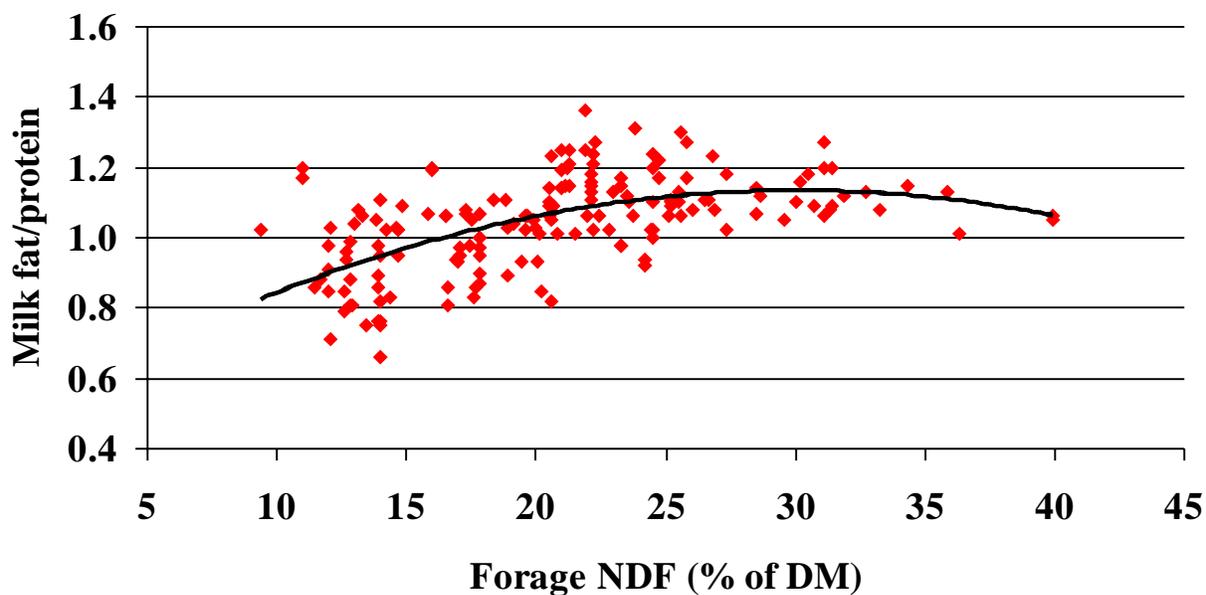


Figure 3. Relationship between forage NDF and ratio of milk fat to milk protein (see text for references; $Y = 0.484 + 0.0432x - 0.000716x^2$; $r^2 = 0.34$).

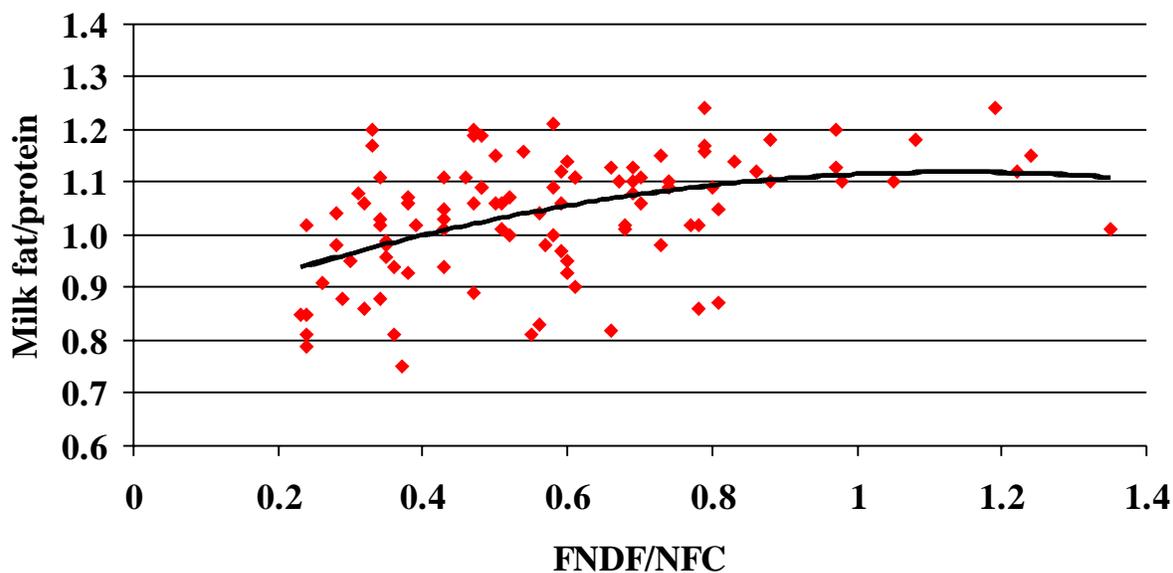


Figure 4. Relationship between forage NDF (FNDF, % of DM) divided by nonfiber carbohydrates (NFC, % of DM) and ratio of milk fat to milk protein (see text for references; $Y = 0.8338 + 0.5029x - 0.22099x^2$; $r^2 = 0.21$).

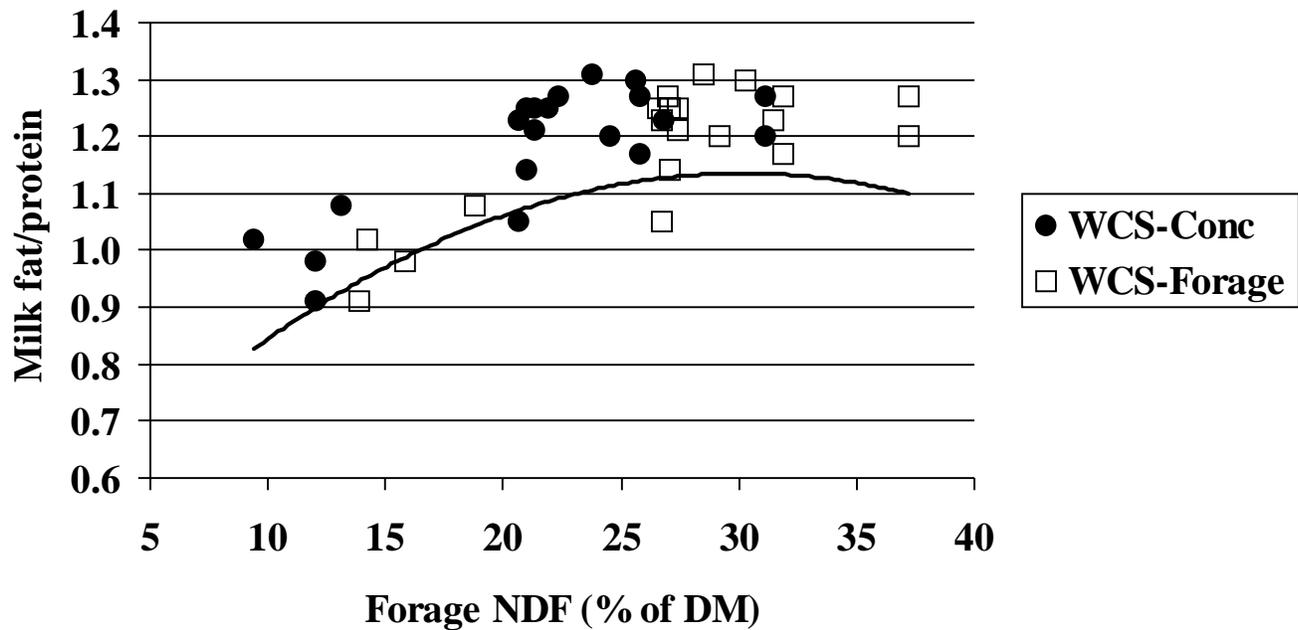


Figure 5. Comparison of assuming the NDF from whole cottonseed (WCS) as NDF from concentrate (conc) or forage and the response in ratio of milk fat to milk protein (data taken from Clark and Armentano, 1997; Slater et al., 2000; West et al., 1997; and West et al., 1998). The regression line from Figure 3 is shown.

Particle Size of Forage When Feeding Processed Whole Plant Corn Silage

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Abstract

Particle size of corn silage affects fermentation in the silo, rumen pH and fermentation, and digestibility of certain nutrients when the silage is fed. Silage must be chopped fine enough to allow good packing in the silo, but silage must be coarse enough to stimulate rumination and chewing activity. Digestibility of starch from corn silage also tends to be reduced when the silage is chopped coarsely. At equal theoretical length of cut (TLC), processed corn silage will have a mean particle size 15 to 25% smaller than unprocessed corn silage. Processing can also influence the distribution of nutrients within particle size fractions. For unprocessed silage, distribution of neutral detergent fiber (NDF) and starch within particle size fractions tend to mimic distribution of dry matter (DM). For processed silage, starch is enriched in small particle size fractions, and NDF is enriched in large particle size fractions. To obtain a particle size equal to conventional corn silage (TLC = 3/8 inch), processed silage should have a TLC of 9/16 to 3/4 inch. Based on limited data, TLC can be increased with processed silage without adversely affecting starch digestibility, milk production, milk composition, and DM intake. The longer particle size obtained by increasing TLC may be beneficial to rumen health in certain situations.

Introduction

Corn silage is an important component of most diets fed to dairy cows in the Midwest, and to obtain good utilization by the cow, the silage must be made correctly. Chop length is a controllable variable in the production of corn silage. Silage chopped too finely can limit chewing activity of the cow and result in ruminal upsets, low milk fat percentage, and laminitis. Silage chopped too coarsely may ferment poorly in the silo (heat damage, mold, etc.) and have reduced digestibility (low energy content). The optimal chop length is a compromise between rumen health, silage preservation, and silage digestibility.

Kernel processing of corn silage is becoming more common in the U.S. Processing generally consists of two rollers within the silage harvester that crush and shear the material as it passes through. The often mentioned benefit of kernel processing is that it allows corn to be harvested at a more mature stage and/or at a longer TLC than a conventional forage harvester without depressing starch digestibility and available energy content of the silage. Processing increased or tended to increase starch digestibility when corn silage was harvested at ½ milk line in three studies (Bal et al., 1998; Bal et al., 2000; Weiss and Wyatt, 2000). In one of those experiments (Weiss and Wyatt, 2000), processing increased starch digestibility for only one of two hybrids of corn tested. Processing increased DM digestibility, an estimate of total digestible nutrients

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(TDN), or measured TDN for one variety of corn harvested at 1/2 milk line (Weiss and Wyatt, 2000) and when corn was harvested at 2/3 milk line (Johnson et al., 1998). No effect of processing on TDN or DM digestibility was reported in other studies when corn was harvested at less than 2/3 milk line (Bal et al., 2000; Johnson et al., 1998; Weiss and Wyatt, 2000). In the previously cited studies, milk production response to processing ranged from 0 to about 3 lbs/day.

Current recommendations for TLC of corn silage are based on data from conventional corn silage and may not be appropriate for processed corn silage. This paper will discuss available data on the effects of TLC of processed corn silage.

Effect of TLC on Characteristics of Corn Silage

Kernel processing reduces the particle size of corn silage so that at equal TLC, unprocessed corn silage will have a larger mean particle size than processed corn silage. Particle size is reduced as roll clearance decreases. Mean particle size of corn silage chopped at a TLC of 3/4 was reduced from about 0.55 inches when roll clearance was 3 mm to 0.47 inches at a roll clearance of 1 mm (Shinners, 1999). Mean particle size of conventional corn silage (3/8 TLC) is approximately equal to that of processed corn silage chopped at 3/4 TLC with a roll clearance of 1 mm. Mean particle size of processed (3 mm roll clearance) corn silage at 3/4 TLC is usually greater than that of conventional (3/8 TLC) corn silage (Bal et al., 2000; Shinners, 1999). Data on the effect of roll clearance on milk production and digestibility are not available but based on kernel damage, clearance should be set at 1 to 3 mm. Therefore, at recommended roll clearances, a TLC of 3/4 for processed corn silage yields equivalent mean particle size as conventional corn silage at 3/8 TLC. Although mean particle size may be equivalent, distribution of DM within different particle size fractions

are quite different between processed corn silage at 3/4 TLC and conventional (3/8 TLC) corn silage (Figure 1). The processed silage (3/4 TLC) had three times as much material retained on screens with ≥ 18 mm diameter holes and about twice as much material retained on screens with ≤ 5.6 mm diameter (Bal et al., 2000). Processed silage chopped at 9/16 TLC had a slightly smaller mean particle size than unprocessed silage at 3/8 TLC (8.9 vs. 9.2 mm, respectively), but the proportion of large particles (top screen) was slightly higher for processed silage (Figure 1).

Processing corn silage affects the distribution of NDF and starch within particle size fractions. Increasing TLC for unprocessed corn silage increases the number of undamaged kernels (Shinners, 1999) and can reduce digestibility of starch (Johnson et al., 1999). Those effects are much less with processed silage. Although processed silage (3/4 TLC) has significantly more DM in the top screen (using the Penn State Particle Size Separator) than unprocessed silage (3/8 TLC), much more starch is in the pan with processed silage (Figure 2). By processing the silage, particle size of the stover portion can be maintained while particle size of grain is greatly reduced.

Effect of TLC on Silage Fermentation

Bal et al. (2000) reported that silage fermentation as measured by pH and concentrations of lactic, acetic, and butyric acids were not different for processed silage chopped at 3/8, 9/16, or 3/4 TLC and unprocessed silage (3/8 TLC). Overall, statistical differences in fermentation measures between processed and unprocessed corn silage have been inconsistent among studies. All differences reported, however, have been small and are probably biologically insignificant. Processed corn silage chopped at 3/4 TLC will ferment properly if good silage making techniques are practiced (i.e., rapid filling, packed well, silo is sealed, and forage is allowed to ferment). Although data are not available, caution should be ex-

exercised when dry corn silage is chopped at a long TLC. Dry silage does not pack well, and a long TLC may exacerbate the poor packing. To prevent poor fermentation (i.e., heat-damage and mold) caused by poor packing, dry silage should probably be chopped at a TLC shorter than 3/4.

Effect of TLC on Cow Responses

Overall, milk production responses to processing of corn silage have been neutral to positive (Table 1), suggesting that other factors such as corn maturity, hybrid, and growing environment influence the response to processing. In the only study (Bal et al., 2000) examining effect of TLC on cow responses, processing did not affect DM intake but increased milk production; however, differing TLC (3/8 to 3/4) for processed silage had no effects. Cows fed processed corn silage have had lower (Johnson et al., 1998), equal (Bal et al., 1998; Bal et al., 2000), or higher (Bal et al., 2000; Weiss and Wyatt, 2000) milk fat percentage. Milk fat percentage is an indirect measure of rumen health and is reduced when ration particle size is inadequate. The differences in milk fat response among experiments were caused in part by type of diet fed and particle size differences among treatments. When corn silage was the sole forage in the diet, cows fed processed silage had higher milk fat percentage than cows fed unprocessed corn silage (Weiss and Wyatt, 2000). When diets contained alfalfa silage of adequate particle size in addition to corn silage, processing had little effect on milk fat percentage (Bal et al., 1998; 2000). The lower milk fat percentage for cows fed processed corn silage in one experiment (Johnson et al., 1998) was probably caused by dilution since milk fat yield was not affected. With processed silage, at least 3% of the TMR should be retained on the top screen of the Penn State Particle Separator to prevent milk fat depression when corn silage is not the sole forage. Long term lactation trials have not been conducted to determine whether that recommendation is adequate. Because of the high economic cost of feeding diets

with inadequate particle size, a conservative approach (i.e., a greater proportion of the TMR on the top screen) is advised. A safer recommendation is to have 6% of the TMR on the top screen. To obtain this, processed silage should have a TLC of at least 5/8 (Bal et al., 2000).

Digestibility of starch is usually higher when cows are fed processed corn silage than when fed unprocessed corn silage (Bal et al., 1998; Bal et al., 2000; Weiss and Wyatt, 2000). The average improvement is about 5% for the total dietary starch. Assuming corn silage processing did not affect digestibility of starch provided by the concentrate, then processing increases digestibility of starch provided by the silage by about 10%. Digestibility of other nutrients are usually not affected by processing, but numerical decreases in NDF digestibility when corn silage is processed have been reported (Johnson et al., 1999). Assuming an average starch concentration for corn silage of 30% of the DM (starch concentration of corn silage is variable), a 10% increase in starch digestibility, and no effect on digestibility of other nutrients, processing should increase the TDN of corn silage by about three percentage units. Based on all available data, processed corn silage at 3/4 TLC should have very high starch digestibility; a shorter TLC is not needed to improve starch digestibility when roll clearance is 1 mm (Bal et al., 2000). Digestibility data for wider clearances are not available, but kernel damage measurements suggest that a roll clearance less than 3 mm and a TLC of 3/4 should still result in good starch digestibility. Clearance greater than 3 mm results in substantially fewer damaged kernels (Shinners, 1999).

Recommendations

The TLC of processed corn silage can be much longer than unprocessed corn silage. A TLC of 3/4 when silage is processed with a roll clearance of 1 mm results in high starch digestibility, adequate par-



ticle size to maintain rumen function, and in some instances, will increase milk production. Decreasing TLC of processed corn silage had no effect on production or nutrient digestibility but decreases the mean particle size of the silage and the proportion of particles retained on the top screens of particle sieves. Because of the problems associated with diets that have inadequate particle size and because no benefits are observed by finer chopping of processed corn silage, a TLC of about 3/4 is recommended.

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Table 1. Effect of corn silage processing on production by dairy cows¹.

Treatment description	DMI	Milk	FCM	Reference ²
	----- lbs/day-----			
½ Milk line, 33% corn silage in dietary DM				1
Unprocessed (3/8 TLC)	55.7	98.6	84.0 ^a	
Processed (3/8 TLC + 1 mm RC)	57.0	102.3	88.4 ^b	
Processed (5/8 TLC + 1 mm RC)	57.0	99.9	85.8 ^b	
Processed (3/4 TLC + 1 mm RC)	56.8	101.4	87.6 ^b	
½ Milk line, 63% corn silage in dietary DM				2
Unprocessed (3/8 TLC)	38.9	59.0	48.6	
Processed (3/4 TLC + 1 mm RC)	41.4	61.2	50.6	
Unprocessed high oil (3/8 TLC)	42.2	62.9	52.4	
Processed high oil (3/4 TLC + 1 mm RC)	39.8	61.8	52.6	
½ Milk line, 34% corn silage in diet DM				3
Unprocessed (3/8 TLC)	58.5	97.2	...	
Processed (3/4 TLC, RC not given)	58.5	95.9	...	
Black layer, 43% corn silage in dietary DM				4
Unprocessed (TLC not given)	...	79.0 ^a	82.3	
Processed (TLC and RC not given)	...	81.0 ^b	81.8	

¹ DMI = dry matter intake; FCM = fat-corrected milk; TLC = theoretical length of cut (inches); DM = dry matter; and RC = roll clearance. Data not shown in table were not given in the original paper.

² Reference 1 (Bal et al., 2000); 2 (Weiss and Wyatt, 2000); 3 (Bal et al., 1998); and 4 (Johnson et al., 1996).

^{ab} Means within the same column for each experiment with different superscripts are significantly different (P < 0.05).



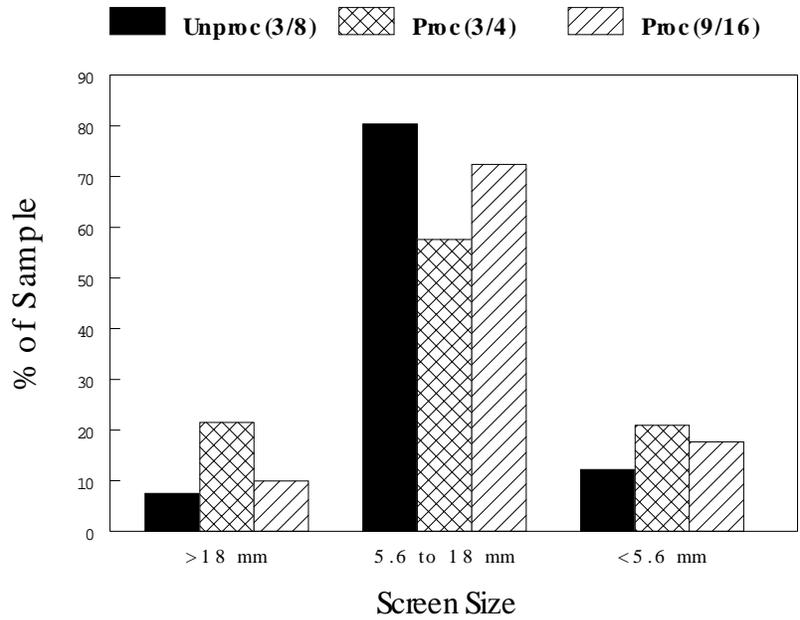


Figure 1. Particle size distribution of unprocessed (theoretical length of cut, TLC = 3/8) and processed (TLC = 9/16 and 3/4) corn silage. The silage was harvested at 1/2 milk line and the kernel processor had a roll clearance of 1 mm. Mean particle size of the three silages was essentially equal (9 mm) (adapted from Bal et al., 2000).

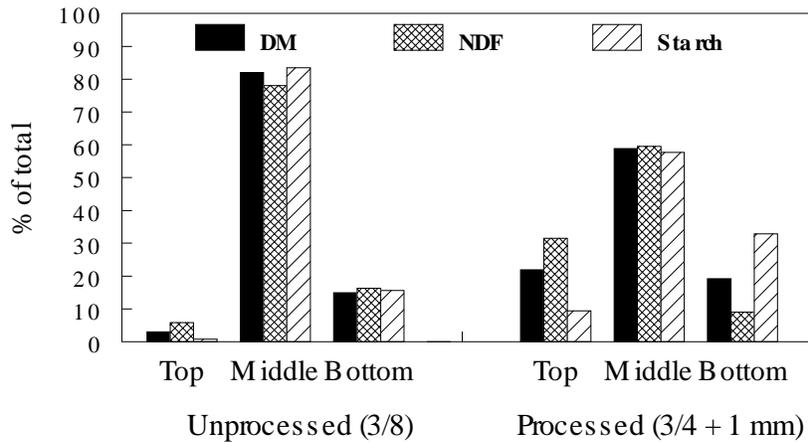


Figure 2. Distribution of dry matter (DM), neutral detergent fiber (NDF), and starch of corn silage among different particle size fractions based on the two screen Penn State Particle Separator. Both silages were harvested at 1/2 milk line and the kernel processor had a roll clearance of 1 mm (Weiss and Wyatt, 2000).

Fermentation Analysis: Use and Interpretation

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Abstract

The fermentation qualities of silages have been described by research laboratories for many years. This information has generally not been available for routine field use in the United States by nutritionists. Cumberland Valley Analytical Services, Inc. recently made available an analysis package that describes the fermentation characteristics of silages. Fermentation characteristics reported include dry matter (DM), pH, titratable acidity, ammonia, lactic acid, acetic acid, propionic acid, butyric acid and iso-butyric acid. This information may be valuable in certain situations as a comparative “report card” on silage management practices and as a troubleshooting tool. It provides limited information for ration balancing purposes. Data on over 3600 analyses are summarized by discrete DM ranges. Fermentation characteristics of silages are very significantly related to moisture level. The pH is shown to not be a sensitive index of fermentation quality. The relationship of high legume silage moisture to the presence of butyric acid and elevated ammonia levels is demonstrated. Soluble protein is shown to be a poor indicator of fermentation quality and is not related to ammonia content of haycrop silages.

Introduction

Characterization of feedstuff quality is of chief importance in allowing the nutritional advisor to assess the performance of farm management in harvesting

and storing of forage crops, as well as in understanding how feeds will function in a ration. Traditional forage evaluation centers on nutrients such as moisture, fiber, and protein. These indexes of forage quality do not allow us to adequately describe forage fermentation and its potential impact on animal performance. In recent years, more attention has been paid to the pH of a fermented feed as an indication of the quality of the fermentation. Few other evaluative tools have been available to the field person in attempting to describe forage fermentation.

Researchers evaluate forage fermentation by looking at not only pH, but the type and quantity of fermentation acids produced. Protein breakdown during fermentation is evaluated by ammonia, soluble protein, and true protein assays. Until recently these tools for evaluating forage fermentation had been limited to the research lab due to the cost and availability of commercial labs to run these assays.

Cumberland Valley Analytical Services (CVAS), Inc., of Hagerstown, Maryland introduced an analytical package several years ago with the goal of making available a set of tests at a reasonable cost that would allow for evaluation of forage fermentation. This “fermentation analysis” package (Figure 1) includes DM, pH, ammonia, titratable acidity, lactic acid, acetic acid, propionic acid, butyric acid, and iso-butyric acid. Additionally, ethanol may be requested in this analysis package as an indicator of yeast activity. Approximately 5000 samples have been

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run for this fermentation analysis package since its introduction. Data from approximately 3600 more recent analysis are summarized for the purposes of this review. Conclusions are specific to this data set and may not be representative of the population of forages as a whole. Samples are not submitted randomly – often the suspicion of a problem or a poor fermentation generates a request for a fermentation analysis.

Methods

The objective of the fermentation analysis is to offer information at a low cost with quick turnaround that justifies general field use. It was our intent to allow people working at the field level to be able to characterize the nature of the fermentation that a silage went through and to make general observations and recommendations based on that information. In order to keep the fermentation analysis package price low and be able to process a large number of samples, methods were chosen based on simplicity and cost. Analytically, the method of choice for determination of fermentation acids is high pressure liquid chromatography. This method is not practical in forage analysis due to cost and difficulty of high throughput of samples. Gas chromatography (GC) is also a preferred method, but running lactic acid can be problematic. We have chosen to use GC for determination of acetic acid, propionic acid, butyric acid, and iso-butyric acid. We currently use a Shimadzu gas chromatograph with two flame ionization detectors. Packed columns provided by Supelco are used.

Lactic acid is determined using a lactate-oxidase peroxide method on a YSI 5700 select biochemistry analyzer. This unit is specific for the L(+) isomer of lactic acid. Bacteria will produce either D(-), L(+), or a mixture of the two isomers of lactic acid. Which isomers are produced depends on the type of bacteria and pH. *Lactobacillus plantarum*, one of the most commonly isolated species of bacteria in silage, produces a slight excess of the D(-) iso-

mer (McDonald et al., 1991). Some bacteria, such as *Enterococcus faecium*, produce only the L(+) isomer (William Mahanna, Pioneer Hi-Bred International, Inc., Johnston, IA; personal communication). Our method assumes an approximately equal mixture of the two isomers; we evaluate for the L(+) and multiply the result by 2 for total lactic acid. In certain situations where predominating strains of bacteria produce a preponderance of one isomer, our methods may overestimate or underestimate the amount of lactic acid present.

Twenty-five grams of wet silage material are blended in 200 grams of distilled water for approximately two minutes. Material is filtered through a coarse, fast-flow filter paper and the filtrate is collected. This material is then partitioned to four different processes (Figure 2). A sample of the filtrate is run through a micro-filter and then 0.1 µl of sample is injected into the GC for determination of volatile fatty acids. A 0.25 µl sample is introduced to the biochemistry analyzer for determination of lactic acid. Ammonia is determined by running a 50 ml sample through the Foss Kjeltac 1030 distiller / titrator. pH and titratable acidity are determined concurrently on a 30 ml sample using a Mettler DL20 titrator.

Sample Handling for Fermentation Analysis

Sampling requirements for fermentation analysis would be the same as for other nutrient analyses. The preferred forage sample size is 250 grams or more. This allows for sufficient material for duplicate extractions with enough for DM determination as well as material for standard nutrient analyses. Optimally, a sample is placed into a plastic bag and air is squeezed out as much as possible prior to sealing the bag. The sample would be frozen and then sent overnight with an ice pack. In many farm evaluation situations the freezing and overnight mailing of samples may not be practical. Samples pulled from inside a stable silage mass may be sealed in a plastic bag with air removed and sent to the lab within two days with minimal change

in the fermentation analysis. We have evaluated sample stability by placing a sample in a sealed bag with air removed and storing it at room temperature in the lab. Sub-samples were removed and tested over a period of days with little variation in results. Samples that are drier or are potentially aerobically unstable will require better handling and quicker transit time to the lab in order to minimize changes. An aerobically unstable sample will experience dramatic changes in several days without proper handling.

Use of the Fermentation Report

There are those that argue that while the fermentation report is interesting, it is of little value, providing no information that can be used directly in the ration balancing process. While it is generally true that the fermentation data have little direct application, this challenge avoids the true value of the report. The fermentation report is meant to provide a comparative evaluation that allows the user to better characterize the silage and to lend insight into possible DM intake and performance problems. A silage at 30% DM that has 1.5 % butyric acid and 18% ammonia nitrogen as a percentage of total nitrogen will be utilized differently than a silage at the same DM level that has no butyric acid and 9% ammonia nitrogen. The degree or extent of an adverse fermentation can be better determined by the fermentation analysis than by visual and olfactory observation alone.

A second, and perhaps more important application of the fermentation report is as a “report card” on the management of the silage making process. The fermentation end-products are a summary of all conditions that effected the silage making process, including plant maturity, moisture, epiphytic bacteria activity, additive use, ambient temperature, packing, and face management. Significant breakdowns in the management of the silage making process will show up as silage with less desirable fermentation characteristics. The farm adviser can use the information gained from the fermentation analysis to docu-

ment on a third party basis the quality of the silage and to challenge a farmer to better silage making practices. Quality forage is the basis of profitable animal production.

The type and degree of fermentation will significantly effect the amount of DM recovery from the silage making process. Herbage that is ensiled properly exhibits a fermentation where pH drops rapidly and homofermentive bacteria predominate. Lactic acid should be a significant end-product of these fermentations. Silages that have high levels of acetic, propionic, butyric, or iso-butyric acids imply conditions where DM recovery from the silage making process may be poor.

Nutritional advisors with an Eastern U.S. feed concern recently adopted the fermentation analysis as a tool in advising farmers on silage making issues. The fermentation analysis revealed that moisture levels at ensiling were too high. Adverse fermentations were resulting. The fermentation analysis was used to document these problems and to be an evaluation tool as management practices were changed. In the following crop year, there was a concerted effort by producers to put up silage material at more appropriate moisture levels. With only small alterations in the moisture level at ensiling, quality of fermentation improved and increased animal productivity followed. Not only did the fermentation analysis point out the need for proper moisture at ensiling, but it challenged the nutritional advisor and producer both to focus on good silage management practices.

Nutritional Considerations

Fermentation Acids

Dry matter intake may be limited due to fermentation characteristics. It is well known that clostridial fermentations resulting in the creation of butyric acid and elevated levels of ammonia are characteristic of silages with poor animal acceptance. It



is suspected that the protein breakdown products, such as ammonia, amines, and amides, may be responsible for limiting intake. Butyric acid itself may not significantly limit intake but may be a marker for protein degradation products.

Less certain is the effect of high levels of lactic or acetic acids on animal intake. Research has proven that the addition of acids, such as lactic, acetic, and propionic acid to silages prior to feeding will reduce intake (Table 1). Intake of whole frozen (then thawed) corn plants is significantly higher than the same material fed as silage. The addition of acids to either fresh or frozen whole plant corn silage significantly reduced intakes (Erdman, 1993). Richard Erdman of the University of Maryland in a review of silage pH and intake studies developed a regression for adjusting DM intakes based on the pH of a silage: $\text{DM intake a(\% of bodyweight)} = -0.18 + 0.88\text{pH} - 0.077\text{pH}^2$. The degree to which intake is limited by particularly high levels of acids is, however, open to question.

Personal communications from individuals in the field suggest that there may be significant intake problems associated with some silages that have acetic acid levels above 5%. The mechanism is not understood. The acetic acid may not itself be a problem but may be a marker. It is recognized that those fermentations that produce excessive levels of acetic acid are more prolonged and are less conserving of silage DM. There are differences in the utilization of fermentation acids by the rumen. Acetic acid is not fermented in the rumen, whereas one form of lactic acid is fermented by rumen bacteria under normal conditions (Muck, 1993). Lactic acid may be a problem in silages where it exceeds 10% of DM, although that occurs only in rare fermentations in North America. Many feeding situations utilize silages with high acid content with no apparent problems. Feed bunk management, ration parameters, and associative effects of feedstuffs may determine whether high silage acid

levels may be a problem in any given feeding situation.

It must be noted that silages that are higher in lactic acid with minimal acetic and propionic acid, what we consider “better” fermentations, may actually be more aerobically unstable. Lactic acid is not a good antimycotic. A certain amount of acetic acid is desirable in order to minimize possible growth of yeast and mold organisms. Poor fermentations with elevated butyric acid levels are actually much more aerobically stable.

Yeast end-products, such as methyl- and ethyl- acetates which resemble the smell of fingernail polish remover, are compounds that may also be present and limit DM intake (Seglar). Ethanol is a primary yeast end-product that may be intake limiting. Yeasts are responsible for much of the secondary heating of silages exposed to air and associated DM losses.

Ammonia

While there is no current effort to look at ammonia or nonprotein nitrogen (NPN) as independent variables in most ration balancing programs, there may be justification to give more consideration to evaluating ammonia in forages. Ammonia would be part of the “A” protein fraction along with amino acids and peptides. These components are buffer soluble, as well as true protein such as albumins and globulins (Asplund, 1994). Ammonia is utilized differently than peptides and true proteins. It has value as a nitrogen source for bacterial growth, but beyond what is utilized by rumen bacteria, there is an energy and metabolic cost to the animal.

Traditionally nutritionists have looked at soluble protein as the most cost effective means of estimating a functional pool of ruminally degraded protein. Soluble protein has also been used to evaluate retention of protein quality in fermented silage.

Forage evaluation data compiled by CVAS would indicate that there is significant variation in the quality of protein in the soluble fraction. In Figure 4, one can observe a very strong relationship between moisture level of legume forage and the ammonia nitrogen as a percentage of total nitrogen. This would be expected as there are more clostridial and proteolytic organisms active at higher moisture levels. However, there is little correlation between soluble protein and moisture level, indicating that the soluble protein test is not sensitive to the quality of the protein in the soluble fraction (Figure 6). It would not be a good predictor of ammonia or proteolytic activity during the forage wilting and fermentation process. In Figure 5, individual ammonia and soluble protein data are plotted for over 1000 legume samples. No particular trend is apparent. The r^2 on the correlation between soluble protein and ammonia is less than 0.01% for the data. It appears from the data that there is little change in the percentage of protein that is soluble across DM levels and that the percentage of ammonia nitrogen in the soluble pool increases at higher moisture levels. It might be inferred that the proteolytic activity of bacteria is primarily on the soluble fraction of protein.

Ammonia levels do not vary significantly in corn silage (Figure 3). Due to the high concentration of water soluble carbohydrates in corn silage, pH tends to drop fast during fermentation and to a level that inhibits activity of most clostridial organisms. It is unusual to see more than trace levels of butyric or iso-butyric acid in corn silage (Table 2).

Estimating Non-fiber Carbohydrate (NFC) Components

There has been some use of the total volatile fatty acid level to infer the make-up of the NFC fraction of a fermented feed. Non-fiber carbohydrate includes primarily the starch, sugar, soluble fiber, and organic acid content of the plant. It is not valid to test for starch, sugar, and fermentation acids, and then by difference, arrive at a soluble fiber value. First, the

fermentation acids are determined on a wet forage sample. A traditional forage analysis determines nutrients on material that has been dried. The drying process will drive off 60% to 90% of the acetic acid. Eighty to almost 100% of the propionic, butyric, and iso-butyric acids are driven off by drying. The NFC of dried material will not be the same as wet. Secondly, the fermentation acids that are typically determined do not include the plant organic acids which are variable and may account for up to 10% of DM. Procedures are under development that will also allow commercial forage laboratories to report a soluble fiber value.

Use of the Fermentation Analysis as a Research Tool

The testing of fermentation acid levels, pH, and ammonia have been used by researchers for many years to describe the nature of fermentations. These data are the basis for determining the significance of management practices and forage treatments in effecting the probability of improved fermentation. Too often, however, nutritionists and field advisors attempt to make comparisons or determine differences in treatments based on uncontrolled experiments run with few or no replicates. Conclusions based on this approach are questionable and are potentially incorrect.

Review of Fermentation Analysis Data

Significance of Moisture to Fermentation Outcome

The significance of level of moisture in providing conditions opportune to various epiphytic organisms can not be overstated. Fermentation end-products are significantly related to moisture level because of the epiphytes supported at those moisture levels. Tables 2 and 3 list fermentation analyses for corn silage, legume silage, grass silage, and high moisture corn by DM ranges. Most evaluations vary significantly by DM of the plant material, with the ex-



ception of pH and ammonia in corn silage. In evaluating any given fermentation analysis, it is important to compare it to sample averages for similar DM levels. What would be an expected fermentation outcome at 38% DM in a legume silage would not be the same if the material were ensiled at 30% DM. It is important to note that forage fermentation is a dynamic process and the outcome is influenced by the interaction of many different factors. Fermentations may vary considerably from “average” values but still be reasonably efficient and provide for excellent stability.

The pH as an Index of Fermentation Quality

The pH has traditionally been used to evaluate the quality of a fermentation. It is a fast and inexpensive test to run and can easily be run at the farm. While pH in a broad sense can aid in differentiating between a good and poor fermentation, it is limited in the information that it can provide. In Figure 7, average pH and total fermentation acids are graphed by DM range in corn silage. Average pH levels by dry matter range do not vary by more than 0.14 pH units from < 26 to 38% DM. In that same range total acids range from 10.5 to 6.4% of DM. pH is somewhat more descriptive in legume forages but only varies by 0.47 pH units from 24 to 52% DM; while in that same range total fermentation acids varied from 11 to 4.5% of DM (Figure 8). The pH, as an evaluative tool, is also limited in that it can not tell us about the rate of change to arrive at a terminal pH (Mahanna, 1993). The faster the drop in pH, the more DM is conserved in the fermentation process.

The Difference Between pH, Total Acid Level, and Titratable Acidity

The relationship between pH and the amount of acids in a feed material is not as strong as one might expect. The pH measures the hydrogen ion concentration or the ratio of hydrogen to hydroxyl ions (H^+ to OH^-). A forage fermentation may have

a high ratio of hydrogen ions to hydroxyl ions but not have a large quantity of hydrogen ions (low pH, low acid level). In corn silage which has little buffering capacity, it does not take a lot of acid to reduce the pH to 4. Figure 7 shows the relationship of pH to total acid level in corn silage. There is little effect on pH from increasing fermentation acid levels. In legumes, the same relationship holds true (Figure 8) but not to the same degree.

Titrate acidity is an evaluation that has perhaps minimal value when pH and total acid levels are available. Titratable acidity for our use is defined as the milli-equivalents of base (0.1 M NaOH) necessary to titrate the pH of a silage sample to 6.5. It measures the total of all hydrogen ions neutralized in order to bring pH to 6.5 and would account for the strength of the acids present. Titratable acidity is correlated very closely to total acid levels in corn silage (Table 2; Figure 9) and high-moisture corn (Table 3). There is almost a one-to-one correspondence in those materials. In legumes (Table 10) this does not hold true due to proteins and other compounds that buffer the silage material.

Variation in Type and Amount of Fermentation Acids

Figure 11 shows the relationship between total acids, lactic acid, and acetic acid in corn silage by DM range. One can observe a very strong relationship between DM range and total acid content. Total acid content is greater than 10 at dry matter levels below 26% and drops to less than 5% at DM levels greater than 40%. Up to 36% DM, however, lactic acid remains relatively constant. The level of acetic acid increases steadily as DM decreases. These changes in acetic acid level are not due directly to DM differences, but the conditions that are created favor certain epiphytic organisms and their resulting end-products of fermentation. The level of propionic and butyric acids in corn silage is small in most situations (Table 2). Elevated levels would indicate a

fermentation problem.

In Figure 12, it is observed again that type and amount of fermentation acids are directly related to DM content in legumes. Levels of butyric acid and acetic acid increase significantly in silages with DM levels below 32%. The data on legumes was evaluated to determine if there was a particular DM level below which there was a significantly higher probability of fermentation problems. A fermentation problem or failure was defined as one where butyric acid was observed at greater than 0.25% of DM. Table 4 shows the percentage of legume samples that had butyric acid levels less than 0.25% by DM range. There appears to be a break point at about 32% DM. Below 32% DM, there was a probability of 55% or less that a fermentation success would be observed. Above 32% DM the probability of success jumped to 74% or more.

Conditions that determine whether clostridial activity occurs include the DM of the crop, buffering capacity, and water soluble carbohydrate (WSC) level (Muck, 1998). In order to observe a fermentation success at lower dry matter levels it is necessary to have higher levels of WSC. The WSC of legumes evaluated for fermentation analysis is not known, but we can generalize about WSC levels by looking at relative feed value (RFV). Legumes with higher RFV would probably have higher WSC levels at ensiling. In Table 4, the RFV of legumes were averaged by DM range for those samples where fermentation success was observed (< 0.25% butyric acid) and where fermentation failure (> 0.25% butyric acid) was observed. The average RFV of samples that experienced fermentation failure was on average 10 to 20 RFV units lower than where fermentation success was observed. Using ammonia level as a criteria of fermentation success or failure produced similar results. Legumes can be put up under wetter conditions successfully if the WSC level is high and other conditions necessary for good fermentation are met. It must be noted, however, that the less mature haycrop for-

age that may offer higher WSC also often has higher buffering capacity (Mahanna, 1993), which makes it more resistant to pH change and offers clostridia more opportunity to proliferate.

Conclusions

The following conclusions would be offered concerning the use of fermentation analysis and the interpretation of fermentation analysis data:

- 1) Fermentation analysis is a diagnostic tool that will allow the nutritionist to better characterize problem forages and their possible contribution to DM intake problems.
- 2) Fermentation analysis can be used as a management "report card" on the silage making process. It allows the advisor and producer to focus on potential weaknesses in management that may need to be corrected.
- 3) The fermentation analysis provides limited information that has direct application to the ration balancing process.
- 4) Evaluation of fermentation end-products is a common research tool, but the field person needs to be careful in using fermentation analysis to draw conclusions about treatments and practices.
- 5) The outcome of a forage fermentation is significantly related to DM level at ensiling due to the epiphytic organisms that are supported. Total acids, as well as types of acids present, are significantly correlated to DM level.
- 6) In evaluating any given fermentation analysis, it is important to compare the given sample analysis to averages for samples of similar DM levels and against ideal target levels.



- 7) The pH is not by itself a good evaluator of the fermentation process. Total acid level and the types of acids present are a much better means of characterizing a forage fermentation.
- 8) Soluble protein may not be a good predictor of fermentation extent or quality. There is no apparent correlation between ammonia and soluble protein in legumes. Ammonia level is a good predictor of proteolysis and fermentation quality.
- 9) Fermentation analysis data would suggest that for legumes, forage DM levels below 32% have a significantly higher risk of fermentation failure (elevated butyric acid and ammonia levels).

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Table 1. Silage quality factors that have been studied that affect forage intake (Erdman, 1993).

Factor	Treatment	Effect on Intake
Water	Increased silage concentration	Decrease
	Addition to feed	None
	Feeding dried silage	No improvement
Silage extracts and effluents	Addition to hay	Decrease
Lactic acid	Addition to silage	Large decrease
	Increased silage concentration	Slight increase
Sodium lactate	Addition to silage	Silage decrease
Acetic acid	Addition to silage	Decrease
	Increased silage concentration	Decrease
Sodium acetate	Addition to silage	None
Sodium propionate	Addition to silage	None
Butyric acid	Increased silage concentration	Decrease
Ammonia	Addition to silage	Decrease
	Added at ensiling	None
Soluble amines	Increased silage concentration	Decrease
pH	Partial neutralization of silage prior to feeding	Increase
	Added acid	Decrease
	Decreased silage pH	Decrease

Table 2. Average values for fermentation analysis by moisture level within feed class.

Corn Silage

DM Range (%)	Number	NH ₄ Nitrogen (% of DM)	NH ₄ Nitrogen (% Total Nitrogen)	pH	Titrateable Acidity (meq/g)	Lactic Acid (% of DM)	Acetic Acid (% of DM)	Propionic Acid (% of DM)	Butyric Acid (% of DM)	Total Acids (% of DM)	Lactic Acid (% Total Acids)
< 26	156	0.77	8.39	3.99	10.23	5.05	4.89	0.40	0.12	10.5	48.3
26-28	215	0.72	8.15	3.86	10.27	5.42	4.21	0.44	0.07	10.1	53.5
28-30	351	0.78	9.15	3.86	9.54	5.17	3.79	0.40	0.03	9.4	55.1
30-32	355	0.68	8.00	3.89	8.35	5.15	3.19	0.30	0.03	8.7	59.4
32-34	313	0.63	7.61	3.90	7.47	4.73	2.59	0.20	0.02	7.5	62.7
34-36	231	0.80	9.41	3.86	6.96	4.77	2.36	0.17	0.04	7.3	65.0
36-38	154	0.71	8.59	4.00	5.98	4.21	2.02	0.14	0.03	6.4	65.8
38-40	112	0.66	7.81	4.09	4.79	3.56	1.69	0.08	0.02	5.4	66.5
> 40	198	0.65	7.80	4.17	3.66	3.20	1.30	0.05	0.03	4.6	69.9

Legume Silage

DM Range (%)	Number	NH ₄ Nitrogen (% of DM)	NH ₄ Nitrogen (% Total Nitrogen)	pH	Titrateable Acidity (meq/g)	Lactic Acid (% of DM)	Acetic Acid (% of DM)	Propionic Acid (% of DM)	Butyric Acid (% of DM)	Total Acids (% of DM)	Lactic Acid (% Total Acids)
< 24	48	5.25	27.95	5.39	3.77	3.04	4.18	0.64	2.10	10.0	30.5
24-28	116	4.57	22.97	3.86	4.45	4.26	0.61	1.64	1.61	11.0	40.7
28-32	212	3.33	16.40	4.91	4.63	4.87	3.80	0.33	0.91	9.9	49.1
32-36	191	2.41	11.99	4.84	4.38	5.26	2.96	0.15	0.15	8.7	60.4
36-40	228	1.90	9.59	4.70	3.97	4.95	2.15	0.09	0.20	7.4	67.0
40-44	172	1.63	8.03	4.76	3.44	4.83	1.62	0.06	0.09	6.6	73.2
44-48	99	1.68	7.89	4.77	3.25	4.42	1.45	0.04	0.01	5.9	74.7
48-52	75	1.35	6.59	4.90	2.47	3.39	1.04	0.03	0.05	4.5	75.2
> 52	86	1.11	5.44	5.50	2.01	2.06	0.68	0.04	0.02	2.8	73.6

Table 3. Average values for fermentation analysis by moisture level within feed class.

Grass Silage

DM Range (%)	Number	NH ₄ Nitrogen (% of DM)	NH ₄ Nitrogen (% Total Nitrogen)	pH	Titrateable Acidity (meq/g)	Lactic Acid (% of DM)	Acetic Acid (% of DM)	Propionic Acid (% of DM)	Butyric Acid (% of DM)	Total Acids (% of DM)	Lactic Acid (% Total Acids)
<24	45	4.05	26.47	5.03	5.25	3.34	4.02	0.72	1.60	9.7	34.5
24-28	66	2.44	16.26	4.73	5.79	4.49	3.15	0.37	0.81	8.8	50.9
28-32	100	1.51	10.54	4.51	5.48	4.57	2.49	0.25	0.40	7.7	59.3
32-36	73	1.34	9.12	4.57	4.45	4.72	2.05	0.13	0.34	7.2	65.2
36-40	44	1.37	9.33	4.59	3.60	4.59	1.59	0.14	0.16	6.5	70.8
40-44	34	0.93	6.24	4.60	2.93	4.09	1.10	0.03	0.05	5.3	77.6
> 44	33	1.03	6.66	4.85	2.31	2.90	1.10	0.03	0.02	4.1	71.6

High Moisture Corn

DM Range (%)	Number	NH ₄ Nitrogen (% of DM)	NH ₄ Nitrogen (% Total Nitrogen)	pH	Titrateable Acidity (meq/g)	Lactic Acid (% of DM)	Acetic Acid (% of DM)	Propionic Acid (% of DM)	Butyric Acid (% of DM)	Total Acids (% of DM)	Lactic Acid (% Total Acids)
<64	11	0.53	6.02	3.66	3.26	2.35	0.97	0.05	0.01	3.4	69.1
64-68	28	0.53	5.72	4.04	1.51	1.24	0.48	0.02	0.01	1.8	68.9
68-72	66	0.48	5.20	4.38	1.12	0.96	0.33	0.04	0.02	1.4	68.5
72-76	83	0.30	3.23	4.26	1.03	0.84	0.24	0.01	0.00	1.1	76.4
76-80	23	0.20	2.15	5.07	0.42	0.43	0.22	0.01	0.00	0.7	61.4

Table 4. Probability of butyric acid < 0.25% by dry matter level in legume silage.

DM range (%)	% Samples < 0.25% butyric acid	Average RFV < 0.25% butyric acid ¹	Average RFV > 0.25% butyric acid ²
<24	39.5	96	112
24-28	44.3	125	103
28-32	54.9	125	109
32-36	74.4	130	113
36-40	82.9	133	120
40-44	90.7	131	120
44-48	98.5	135	99
48-52	97.1	132	110
> 52	98.9	127	124

¹The average relative feed value (RFV) of samples with butyric acid levels at less than 0.25% on a DM basis (fermentation success).

²The average relative feed value (RFV) of samples with butyric acid levels at greater than 0.25% on a DM basis (fermentation failure).

Cumberland Valley Analytical Services, Inc.
 Maugansville, MD 21767 301-790-1980

March 27, 2000

Sample No: 0169116

QUALITATIVE FORAGE ANALYSIS

Legume	Value	Unit	Average for DM Range 32 - 36%
Dry Matter	33.7	% DM	
pH	5.34		4.84
Titrateable Acidity	3.07	meq/g	4.38
Lactic Acid	1.90	% of DM	5.26
Acetic Acid	4.00	% of DM	2.96
Propionic Acid	0.57	% of DM	0.15
Iso-butyric Acid	0.12	% of DM	0.06
Butyric Acid	3.42	% of DM	0.34
Total Acids	10.01	% of DM	8.70
Lactic Acid, % of total acids	19.0		60.4
Ammonia N, Crude Protein Equivalent	4.8	% of DM	2.41
Ammonia N, % of total N	24.4		12.0

George Johnson
 Empire Dairy Nutrition
 1113 Lake Road
 Dryden, NY 13053

Sample : Haylage - Middle Trench
 Farm Name : Peta Holsteins
 Smpld/Rcvd : 03-08-2000 / 03-09-2000
 Complete : 03-10-2000

Figure 1. Example of fermentation analysis report.

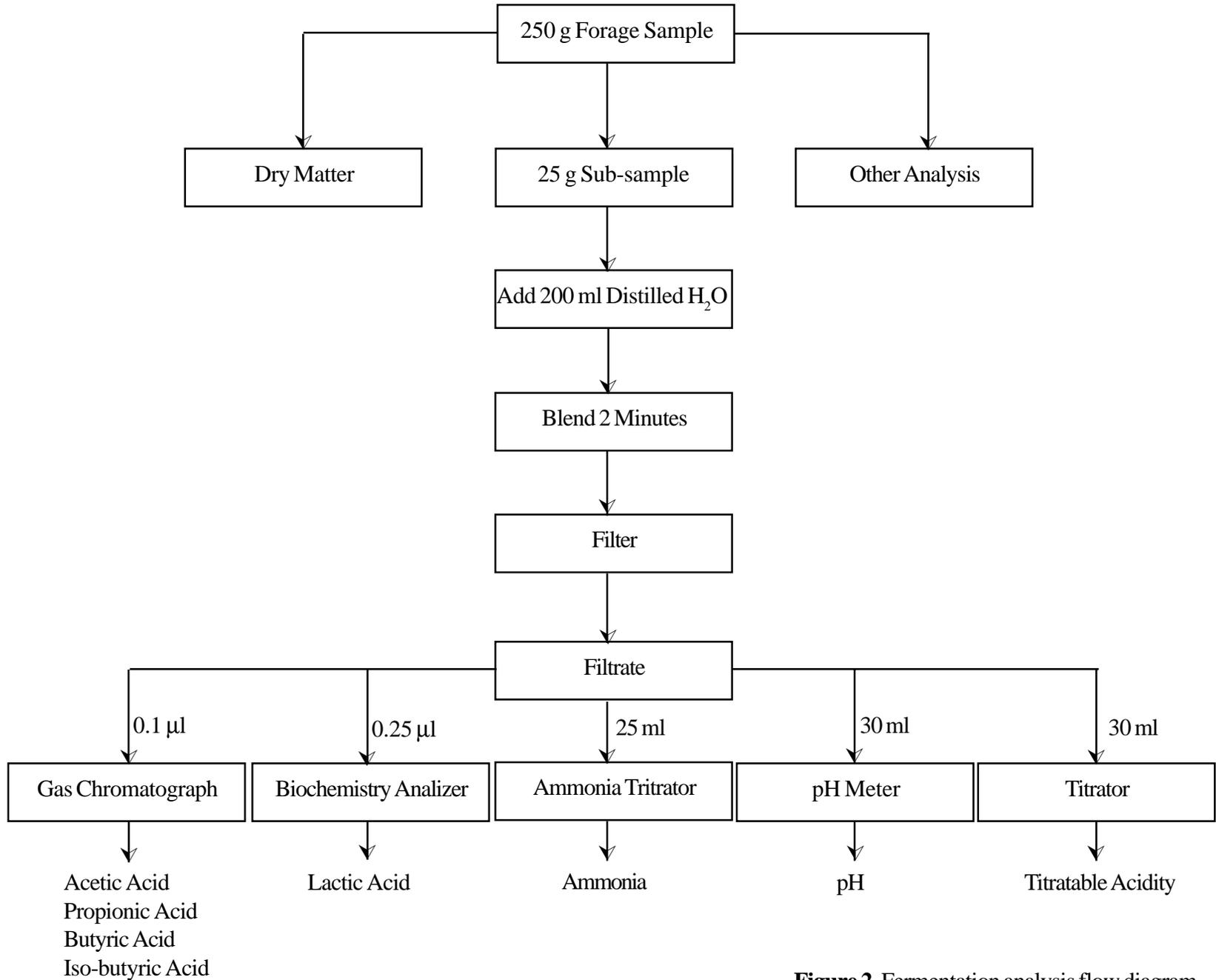


Figure 2. Fermentation analysis flow diagram

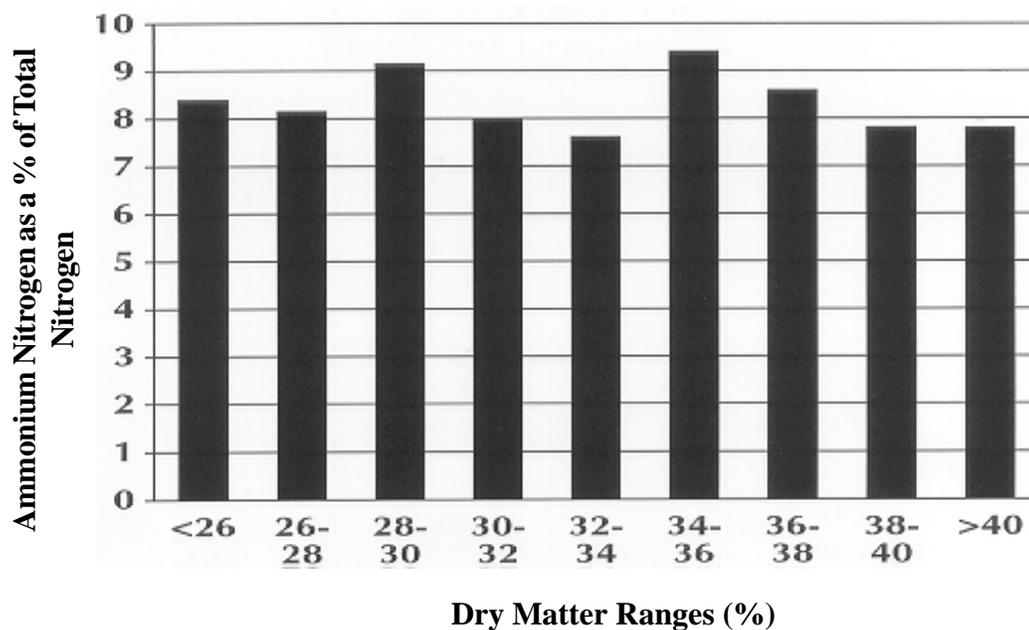


Figure 3. Ammonia nitrogen as a percentage of total nitrogen by dry matter level in corn silage.

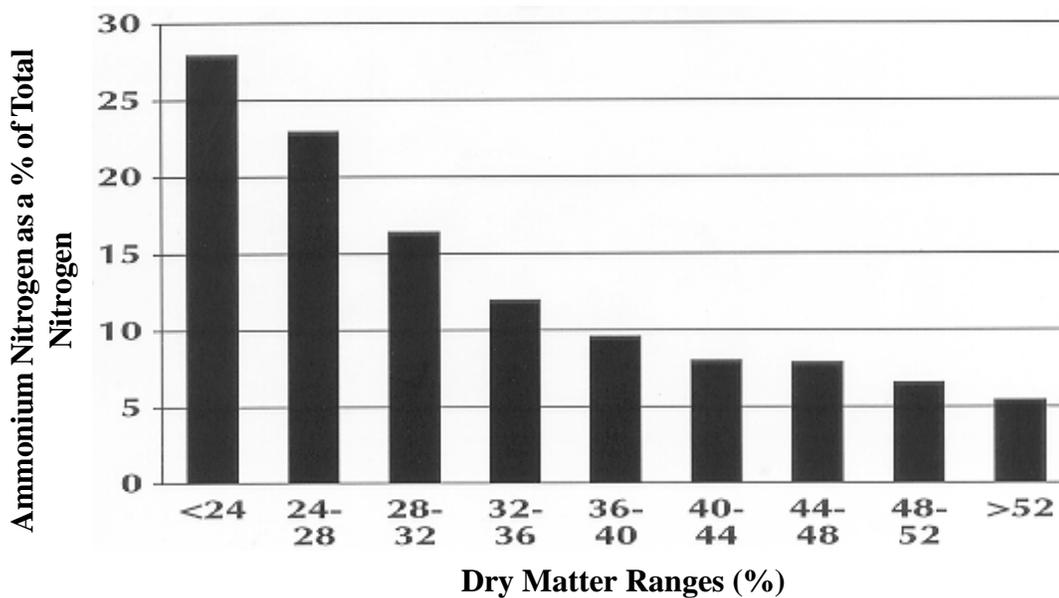


Figure 4. Ammonia nitrogen as a percentage of total nitrogen by dry matter level in legume silage.

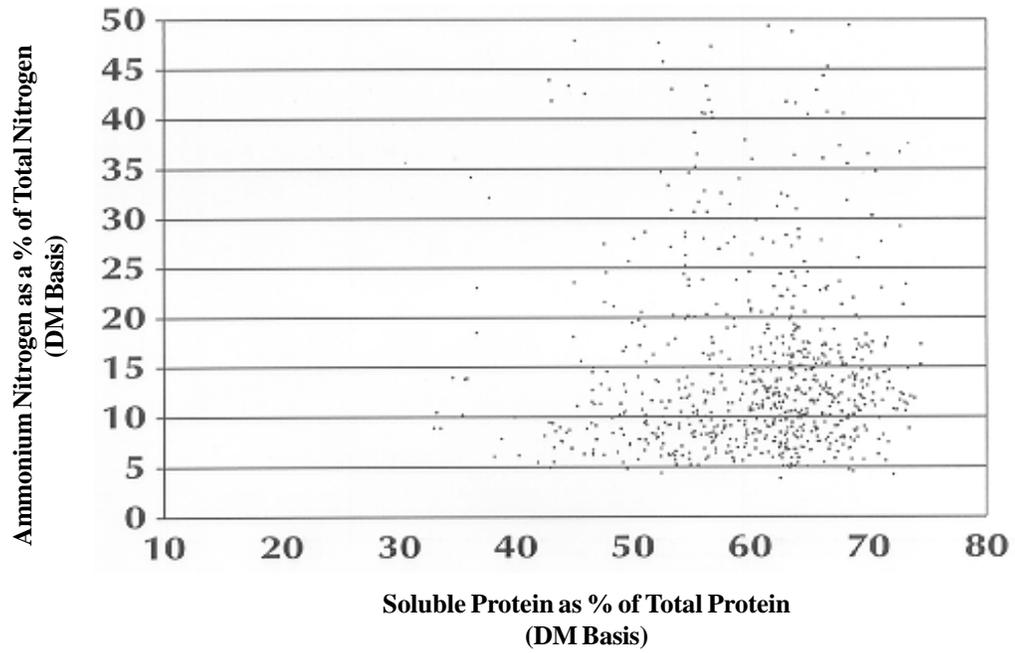


Figure 5. Ammonia nitrogen compared to soluble protein in legume silage samples < 40% dry matter.

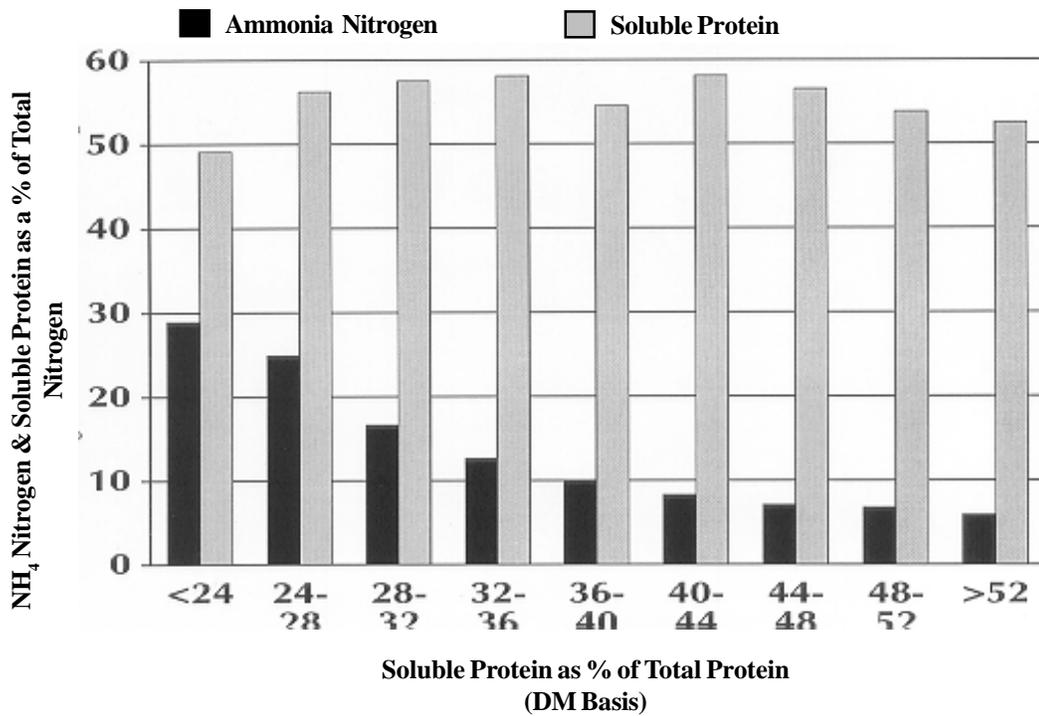


Figure 6. Ammonia nitrogen and soluble protein by dry matter level in legume silage.

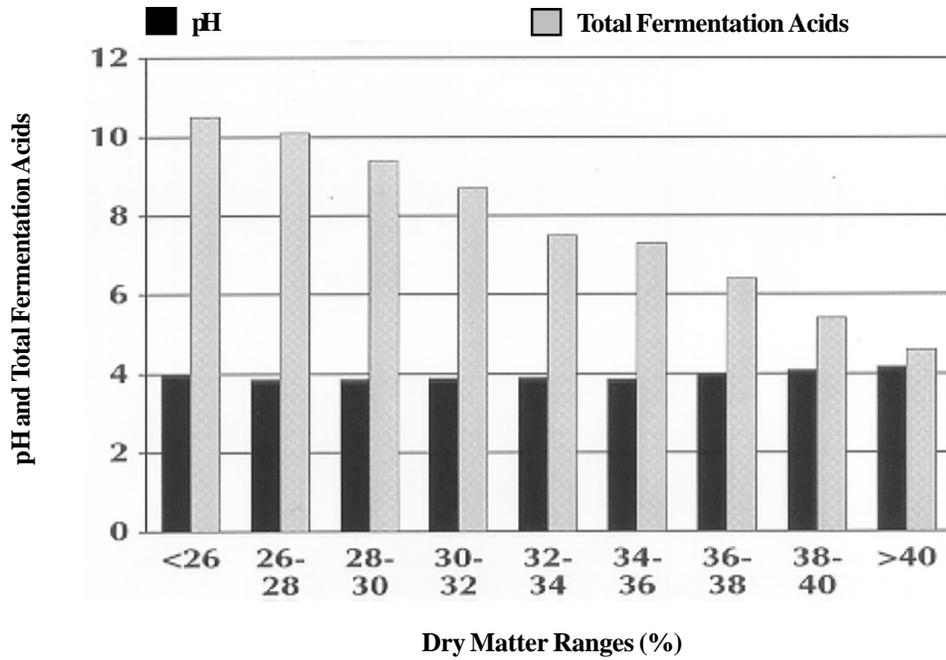


Figure 7. The pH and total fermentation acids (% of DM) by dry matter range in corn silage.

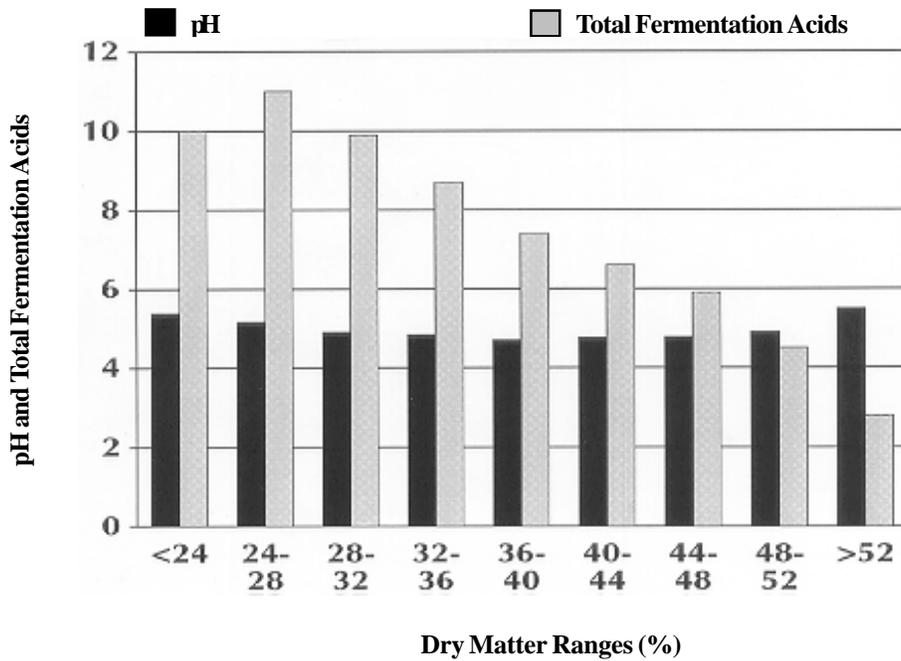


Figure 8. The pH and total fermentation acids (% of DM) by dry matter range in legume silage.

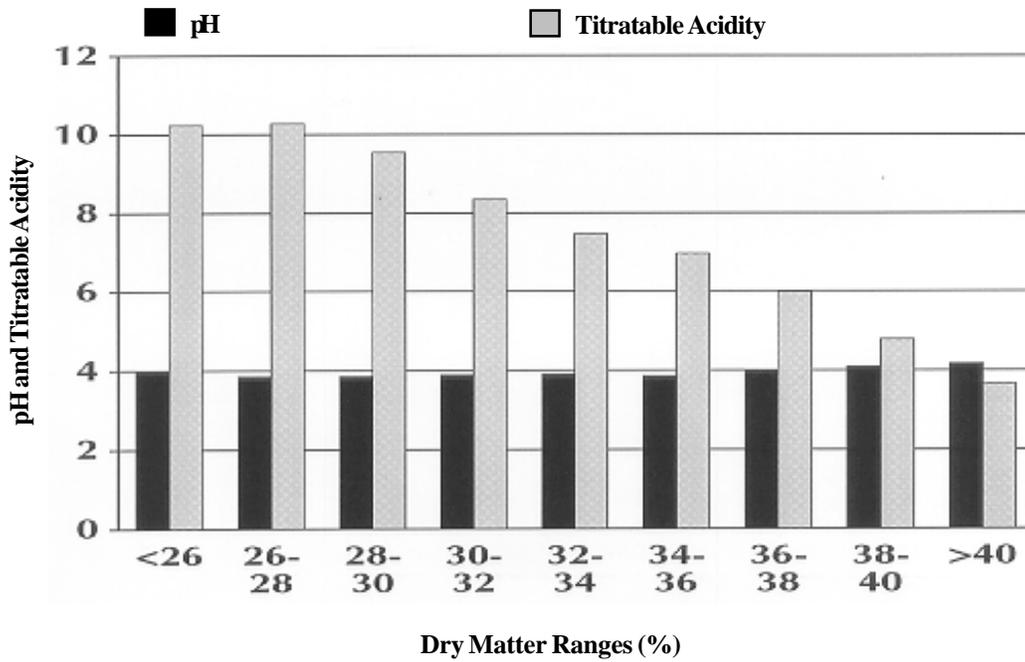


Figure 9. The pH and titratable acidity (meq/g) by dry matter range in corn silage.

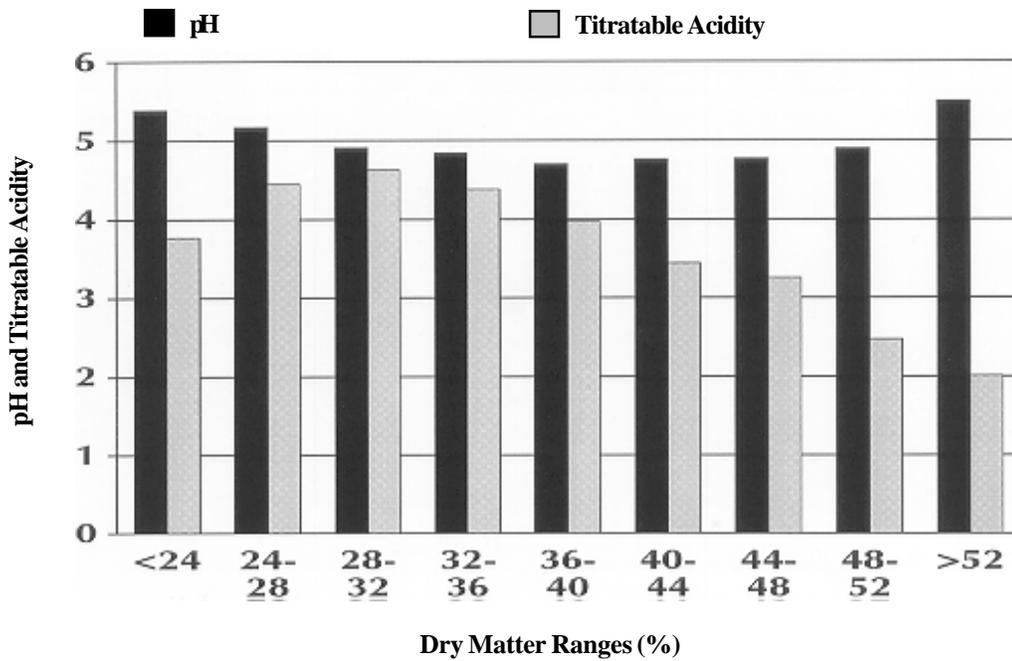


Figure 10. The pH and titratable acidity (meq/g) by dry matter range in legume silage.

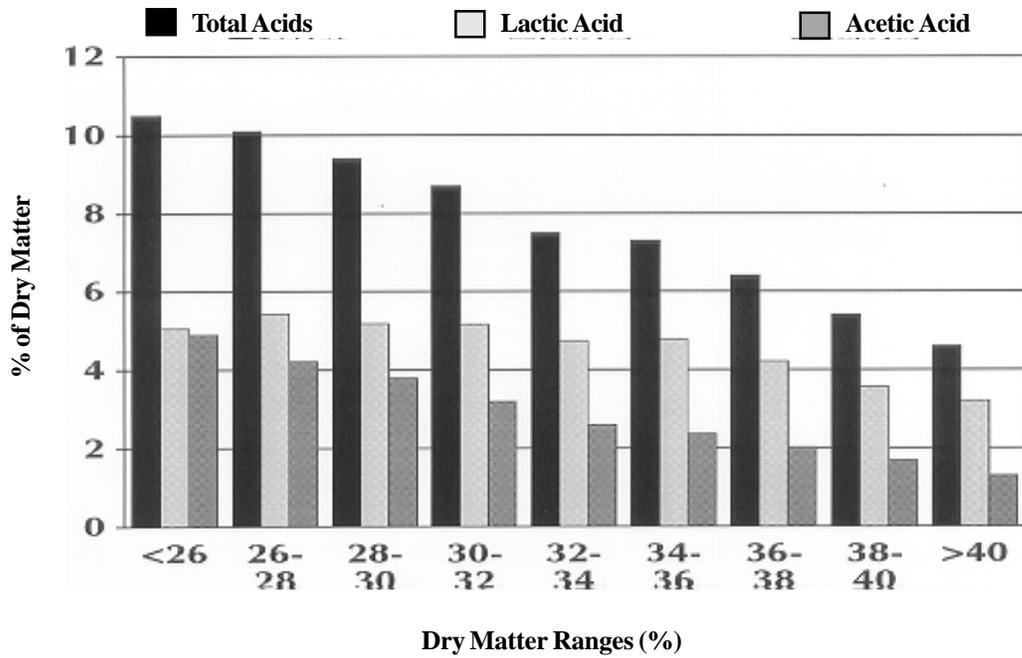


Figure 11. Fermentation acids by dry matter range in corn silage.

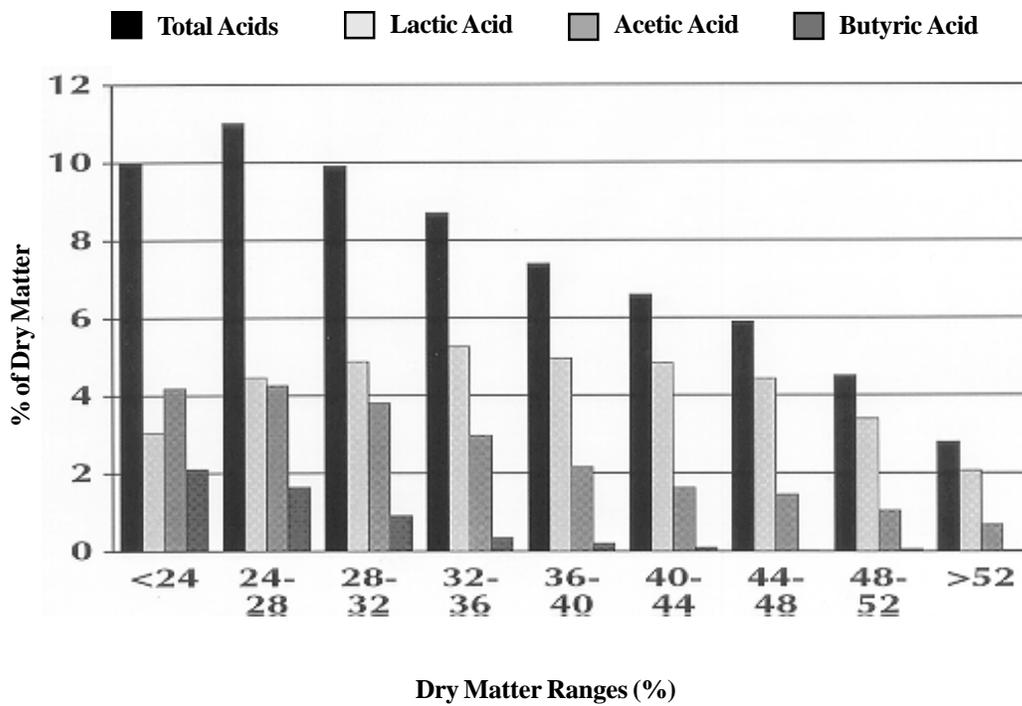


Figure 12. Fermentation acids by dry matter range in legume silage.

Estimating Value of Nutrients Based on Market Prices of Feedstuffs

Normand R. St-Pierre¹

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Abstract

In many instances, nutritionists, feed manufacturers, and dairy producers need an estimate of what a feed is worth on a nutritional basis to facilitate the formulation of balanced diets and the purchase of appropriate, price competitive feedstuffs. Up until now, all methods used shared common flaws. We derived a maximum likelihood method that uses composition and prices of all feedstuffs traded in a given market to estimate unit costs of nutrients and break-even prices of feedstuffs. The method was programmed as a Windows 95/98 application named *SESAME*.

Introduction

A variety of methods have been proposed to estimate unit costs of nutrients and, implicitly or explicitly, the break-even price of feedstuffs. All methods fall into one of two general categories: equation-based (**EBM**) and inequation-based methods (**IBM**). For EBM, a set of equations developed from the nutritional composition of referee feeds is solved using their market prices. The best known method among this group is the Petersen Method (**PM**) in which the energy and protein compositions of corn grain and soybean meal are equated to their respective prices, setting a set of two equations with two unknowns. The method dates back to 1932 (Petersen, 1932) and is presented and discussed at length by Morrison (1956). Although widely used, the method is funda-

mentally flawed in that it assumes efficient markets in commodity trading and implies economically incoherent behavioral patterns by buyers and sellers of commodities.

The second series of methods, **IBM**, are basically constrained optimization models solved using mathematical programming techniques (Beneke and Winterboer, 1973; St-Pierre and Harvey, 1986). Linear programming (**LP**) is the best known member of this group and became widely used in animal nutrition with the discovery of an efficient algorithm (Dantzig, 1960) and the advent of high-speed computers. Within an LP model, a cost function is minimized subject to a series of inequations forcing the solution to meet the nutritional requirements of the animal for which the diet is being optimized. Linear programs suffer from being case specific, and they deliver little information on the unit costs of nutrients. Nutrients with non-binding constraints have an implicit unit cost of zero. Shadow costs of binding nutrients provide information on unit costs that are valid only at the margin. Additionally, the information delivered has a very narrow inference range because it provides estimates that are sound only for one group of animals in a given herd. Consequently, LP is limited in providing estimates of aggregate unit costs of nutrients within a given market. To circumvent these problems, we developed a new procedure that provides estimates of aggregate unit costs of nutrients and break-even prices of feedstuffs based on the trading of all feed commodities in a given market (St-Pierre and Glamocik, 2000).

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The method is based on maximum likelihood estimation of nutrient costs. The objective of the paper is to describe briefly the computer software that we wrote to make our procedure available to the industry.

Assumptions

The method sets a series of m equations (m is the number of feedstuffs) with n unknowns (n is the number of nutrients). An error term S is added to each equation. Maximum likelihood estimates of unit costs of nutrients are those that minimize the sum of squares of S s. Maximum likelihood properties are obtained under the following assumptions:

1. Buyers and sellers of commodities act rationally, that is, a buyer would not keep buying an over-priced commodity and a seller would not keep selling commodities at discount prices.
2. The value of a feedstuff is equal to the sum of the values of its nutrients. Feedstuffs are used exclusively as sources of nutrients. Feedstuffs with valuable characteristics other than nutrient content (e.g., free-flow agents) are not evaluated properly by our method.
3. The errors S are independently and normally distributed. In our software, we insure that this assumption is met by eliminating any outlier feedstuffs.

SESAME™ Release 1.1

SESAME is a Windows 95/98 based program. Figure 1 shows the opening screen with the main menu items.

- **Feedstuffs** is used for viewing and editing the nutritional composition of feedstuffs.
- The **Solver** section is used to select feedstuffs, nutrients, and prices, and to get estimates of nu-

trients, costs and break-even prices of feedstuffs.

- In **Price lists**, the user can set different price series to reflect, for example, regional differences.
- **Backup** is used to produce a backup copy of the database, or to recover a previously saved copy.
- **DB Check** verifies the integrity of databases and makes necessary repairs when needed.
- **Configuration** provides access to the underlying structure of the nutrient definition table.
- **Help** opens a context sensitive help system.
- **About** prints a disclaimer and provides information on how to contact the authors.

Nutrient Composition: The Feedstuffs Menu

By default, *SESAME* contains three protected feedstuffs databases and two unprotected user libraries. Protected databases are: commercial feedstuffs, Cornell-Penn-Minor Dairy (CPM; 1998) library, and NRC (1989) library (Figure 2). Feedstuffs in those protected libraries can be used in setting up problems, but they cannot be edited. The user can customize the nutritional composition of a feedstuff by first copying it to a user library. The copied feed can be edited once it resides in a user library (Figure 3).

Nutrient Definition: The Configuration Menu

Over 140 nutrients are defined in *SESAME* to cover applications in a multitude of species (Figure 4). Nutrients can be defined as direct entries (e.g. crude protein), or as calculated nutrients [e.g. nonfiber carbohydrates (NFC)]. Calculated nutrients are defined using equations inserted in the **Formula** section of the program.

Market Prices of Feedstuffs: The Price List Menu

Various price lists can be set to reflect different prices across space (markets) or time (Figure 5). Feedstuffs can be added to a price list using a convenient drag-and-drop feature. There are no limits to the number of price lists.

Setting up a Problem and Finding Break-Even Prices: The Solver Menu

The core engine resides within the **Solver** section of the program (Figure 6). To create a problem, the user must indicate what feedstuffs, nutrients, and prices are part of a problem. The calibration set (Figure 6) contains all feedstuffs traded in a given market. Feedstuffs are added or deleted from this set through a simple drag-and-drop function. Alternatively, the user can identify in the appraisal set those feedstuffs for which they have no current price but for which estimated break-even prices are desired.

The chemical composition tab allows the selection of nutrients whose values are to be estimated. Active prices of feedstuffs are selected using the price list button.

An Example

We used February, 2000 Ohio prices and standard nutritional composition of 22 feedstuffs to estimate their break-even prices when used with high producing dairy cows (Table 1). Thus, we selected the following nutrients for our evaluation: rumen undegradable protein (**RUP**), effective NDF (**eNDF**), non-effective NDF (**neNDF**), rumen degradable protein (**RDP**), rumen undegradable methionine (**U-Methionine**), rumen undegradable lysine (**U-Lys**), and net energy for lactation (**NE_L**). Nutritional composition values were those reported in Table 1. Prices used were those reported by Feedstuffs magazine for the week of February 14, 2000 for the Buffalo, NY market with an additional \$20/ton added

to cover handling, margins, and transportation charges. In a few instances, Chicago, IL prices had to be used for which a \$30/ton gross margin was added.

Results as reported by *SESAME* are shown in Figure 7. The numbers in the column labeled “Estimate” in the Estimate of Nutrient Unit Costs table are the calculated values per unit (per pound for all nutrients except **NE_L** which is per Mcal) of nutrient. Thus, a pound of RUP has an estimated worth of \$0.031. This estimate would appear low except that it represents the value of one pound of RUP which is free of both methionine and lysine because the value of those nutrients are already factored in the evaluation. In fact, markets are valuing U-Methionine at \$10.36/lb and U-Lysine at \$1.27/lb. Effective NDF is valued at close to \$0.04/lb, whereas neNDF is valued at - \$0.036, indicating that the markets are currently discounting feedstuffs for their neNDF content. Likewise, markets are giving little value to RDP (\$0.015/lb) but are valuing **NE_L** (\$0.065/Mcal).

The break-even prices of feedstuffs (Predicted value) are reported in the two tables labeled “Calibration Set” and “Appraisal Set”. Additionally, the Calibration set contains the lower and upper 75% confidence limits of break-even prices. Using these results, for example, a user would determine that under present Ohio conditions, brewers dried grains are relatively over-priced, whereas wheat middlings are relatively under-priced. Results are also shown graphically in Figure 8. In this figure, feedstuffs appearing above the middle horizontal line are relatively well-priced whereas those appearing under the line are relatively over-priced.

During the solution process, *SESAME* concluded that dehydrated beet pulp is currently so over-priced that it appears to be an outlier. Automatically, *SESAME* moved this feedstuffs from the Calibration set to the Appraisal set (Figure 7). Out of curiosity, we added the NRC (1989) alfalfa hay, sun-cured, early vegetative to the appraisal set. *SESAME* cal-

culated its breakeven price at \$128/ton, a reasonable figure given the current market conditions.

Conclusion

Our maximum likelihood method uses the prices of all feedstuffs traded in a given market to estimate the implicit costs of nutrients. Because it is a statistically-based method, it provides measures of dispersion of estimated nutrient costs and break-even prices. Also, because it does not use referee feeds (e.g., corn and soybean meal), each feedstuffs used in the estimation can potentially have a break-even price above or below its market price. The method has been programmed into a Windows application available from the author or from Church and Dwight Company who is acting as a distributor.

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Table 1. Nutrient composition and market prices of 22 feedstuffs, Ohio, February 14, 2000. Composition values are on an as-fed basis.^{1,2}

	RUP (%)	eNDF (%)	neNDF (%)	RDP (%)	U-Methionine (%)	U-Lysine (%)	NE _L (Mcal/lb)	Price (\$/ton)
Bakery waste, dehydrated	2.412	0.002	16.558	7.432	0.043	0.076	0.860	92.00
Beet pulp, dehydrated	5.064	16.216	32.924	3.763	0.033	0.152	0.739	155.00
Corn grain, ground	4.869	0.000	7.920	3.931	0.055	0.080	0.783	110.00
Hominy feed	5.435	4.455	45.045	4.915	0.060	0.174	0.821	110.00
Molasses, sugarcane	0.000	0.000	0.000	4.350	0.000	0.000	0.559	86.00
Soybean hulls	4.625	1.219	59.751	6.386	0.022	0.210	0.729	82.00
Tallow	0.000	0.000	0.000	0.000	0.000	0.000	2.650	350.00
Wheat middlings	3.742	0.659	32.271	12.634	0.038	0.141	0.733	66.00
Blood meal	66.387	0.000	0.828	14.573	0.710	6.201	0.625	430.00
Brewers grains, dehydrated	15.395	7.618	34.702	7.973	0.194	0.331	0.625	141.00
Canola meal, solv-extd	11.878	5.693	19.059	25.068	0.166	0.792	0.648	149.00
Corn gluten feed	5.760	14.580	25.920	17.280	0.097	0.086	0.781	96.00
Corn gluten meal, 60% CP	35.683	4.536	8.064	24.797	0.746	0.442	0.841	306.00
Cottonseed meal, 41% CP	17.843	8.518	15.142	23.653	0.112	0.687	0.719	175.00
Cottonseed, whole	6.441	40.480	0.000	14.719	0.041	0.248	0.931	174.00
Distillers dried grains	12.650	1.619	38.861	10.350	0.152	0.261	0.850	115.00
Feather meal	56.036	0.429	1.437	24.015	0.275	1.440	0.675	225.00
Fish meal, menhaden	36.818	0.184	1.656	24.546	1.046	2.625	0.696	415.00
Meat and bone meal	24.653	0.000	3.720	25.660	0.330	1.247	0.683	195.00
Poultry byproduct meal	34.122	0.000	5.640	27.918	0.457	1.727	0.753	230.00
Soybean meal, solv, 44% CP	15.544	3.050	10.211	28.867	0.157	0.833	0.782	186.00
Soybean meal, solv, 48% CP	17.357	1.656	5.544	32.234	0.144	1.055	0.821	196.00

¹SESAME: Chemical composition of Ohio - 2/2000 - High (Dr. N.R. St-Pierre, The Ohio State University, Columbus).

²RUP = Rumen undegradable protein, eNDF = effective NDF, neNDF = non-effective NDF, RDP = rumen degradable protein, U-Methionine = rumen undegradable methionine, U-Lysine = rumen undegradable lysine, and NE_L = net energy for lactation.

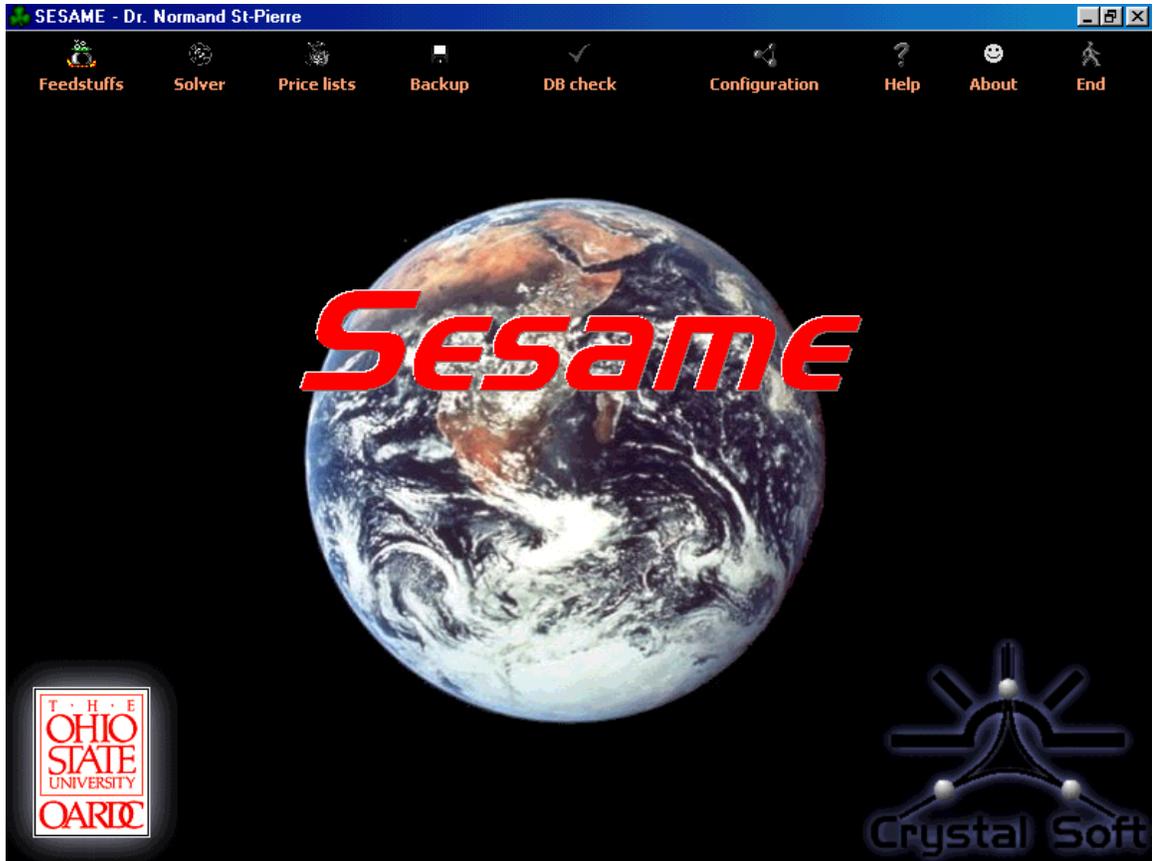


Figure 1. Opening screen showing the main menu options.

Item	Group	Name	DM %	CP %	Price	Unit	Quantity
2	1	Alfalfa Hay-a, sun, early veg	DM	90.00	23.90	T	
4	1	Alfalfa Hay-b, sun, late veg	DM	90.00	20.90	T	
6	1	Alfalfa Hay-c, early bloom	DM	90.00	20.90	T	
8	1	Alfalfa Hay-d, sun, mid bloom	DM	90.00	17.90	0.01 T	
10	1	Alfalfa Hay-e, sun, full bloom	DM	90.00	15.90	T	
12	1	Almond hulls	DM	90.00	2.10	0.01 T	
14	1	Apple pomace, dehydr	DM	89.00	4.90	T	
16	1	Bromegrass Hay	DM	83.00	12.90	T	
18	1	Brome Hay-a, late veg	DM	86.00	14.90	T	
20	1	Brome Hay-b, late bloom	DM	89.00	10.90	T	
22	1	Citrus pulp, dehydr	DM	91.00	6.70	T	
24	1	Clover Hay, Ladino	DM	90.00	22.90	T	
26	1	Clover Hay, Red	DM	89.00	16.90	T	
28	1	Cotton hulls	DM	91.00	4.10	T	
30	1	Fescue Hay, late veg	DM	91.00	10.90	T	
32	1	fl of Hay, head-emerged	DM	90.00	14.90	T	
34	1	Orchardgrass Hay, late bloom	DM	91.00	8.40	T	
36	1	Peanut Hulls	DM	91.00	7.90	60.00 T	
38	1	Timothy Hay-a, late veg	DM	89.00	17.90	T	
40	1	Timothy Hay-b, early bloom	DM	90.00	15.90	T	
42	1	Timothy Hay-c, mid bloom	DM	89.00	9.10	T	
44	1	Timothy Hay-d, full bloom	DM	89.00	8.10	T	
46	1	Timothy Hay-e, late bloom	DM	88.00	7.90	T	
48	1	Timothy Hay-f, milk stage	DM	92.00	7.90	T	
50	3	Alfalfa Silage-a, early veg	DM	35.00	23.90	T	
52	3	Alfalfa Silage-b, late veg	DM	35.00	20.90	T	
54	3	Alfalfa Silage-c, early bloom	DM	35.00	20.90	T	

Figure 2. Feedstuffs section showing the three protected libraries [Commerical Feedstuffs, Cornell-Penn-Minor (CPM) Dairy (1998) Library, and NRC (1989)] and the unprotected (User) library. Menu items appear at the top.

Name	Value	Unit	Use/Formula
300 RLP (% of CP)	35.00000	%	
301 RLP	18.28500	%	R
302 Protein Solubility (% of CP)	29.00000	%	
303 SolP (Soluble protein)	11.02000	%	R
304 NPM (Nonprotein-nitrogen)		%	
305 NDF (% of DM)	23.00000	%	
306 aNDF	1.84000	%	R
307 ureN	8.10000	%	R
308 FDP	26.97500	%	R
309 C:BT		%	

Figure 3. Chemical composition section showing the grouping of nutrients. Values in the right-hand side window are the defaults for soybean meal, solvent extracted, 48% CP.

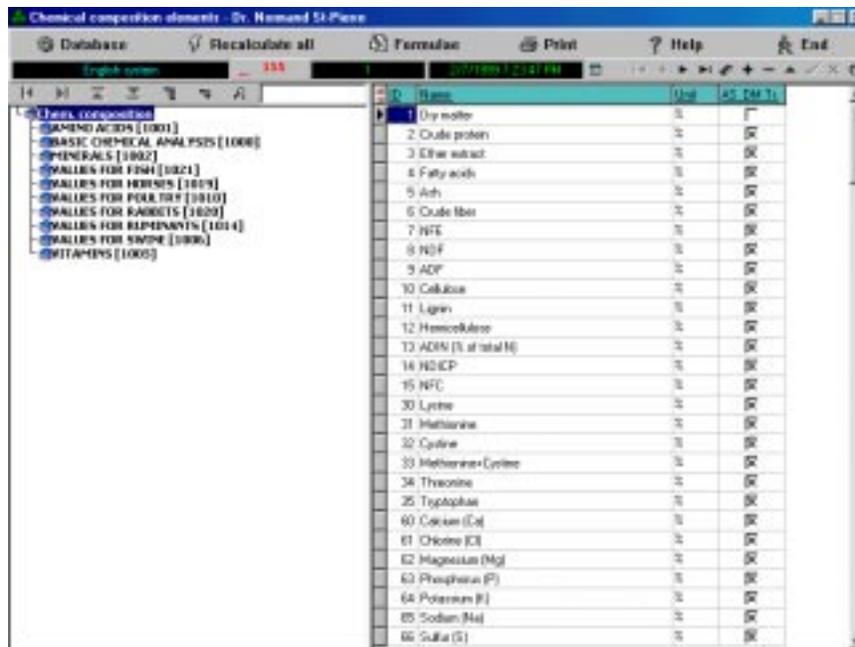


Figure 4. Chemical composition elements section showing a partial list of the more than 140 default nutrients part of the standard *SESAME*. Additional nutrients can be added using the **Formulae** section.

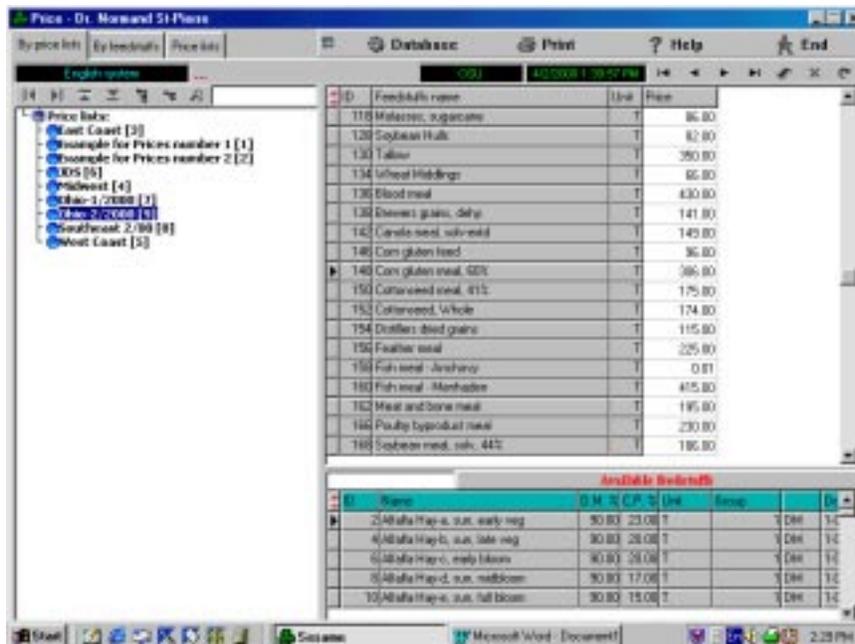


Figure 5. Price lists section showing the different price lists created and feedstuffs prices for the Ohio-2/2000 price list.

The screenshot displays the Solver software interface with three main sections:

- Available Feedstuffs Table:**

ID	Group	Feedstuff name	D.M %	C.P. %	Price	Quantity	Use
64	3	Oat Silage(25-40)DM	DH	35.00	11.50	0.000	7.3
66	3	Rye Silage	DH	32.00	12.00	0.000	7.3
68	3	Sorghum Silage	DH	30.00	7.50	0.000	7.3
70	3	Sorghum-Sudan Silage	DH	28.00	18.00	0.000	7.3
72	3	Timothy Silage (25-40)DM	DH	35.00	7.00	0.000	7.3
108	4	Bakery waste, dry	DH	92.00	18.70	32.00	0.000 7.4
132	4	Barley, green	DH	60.00	13.50	0.000	7.4
104	4	Beet pulp, dehydrated	DH	91.00	9.70	105.00	0.000 7.4
136	4	Can waste, ground	DH	87.00	9.00	0.000	7.4
138	4	Can grain, cracked	DH	69.00	18.00	0.000	7.4
110	4	Can grain, rolled	DH	69.00	18.00	0.000	7.4
112	4	Can grain, ground	DH	69.00	18.00	110.00	0.000 7.4
114	4	Can grain, high moisture	DH	77.00	18.00	87.00	0.000 7.4
116	4	Honey feed	DH	90.00	11.50	110.00	0.000 7.4
118	4	Molasses, sugarcane	DH	75.00	8.00	96.00	0.000 7.4
- Calibration set Table:**

ID	Feedstuff name	Included	Price	Use
	Bakery waste, dry	[X]	32.00	
	104 Beet pulp, dehydrated	[X]	105.00	
	112 Can grain, ground	[X]	110.00	
	116 Honey feed	[X]	110.00	
	118 Molasses, sugarcane	[X]	96.00	
	108 Soybean Hulls	[X]	82.00	
- Appraisal set Table:**

ID	Feedstuff name	Included	Price	Use
	Alfalfa Hay, var, only veg	[X]	8.00	

Figure 6. Solver section showing available feedstuffs, **Calibration** set of feedstuffs, and **Appraisal** set of feedstuffs. Tabs and buttons allow the user to select feedstuffs, nutrients, and prices part of a problem. A solution is found by pressing the “Solve problem” button.

Ohio - 2/2000 - High

4/2/2000 2:20:18 PM

Price Prediction Reliability	20.275
------------------------------	--------

Estimate of Nutrient Unit Costs		
Nutrient name	Estimate	
RUP	0.031191	
eNDF	0.039585	~
neNDF	-0.036387	**
RDP	0.015061	
U-Methionine	10.362429	**
U-Lysine	1.276768	**
NEI	0.064920	**

- A blank means that the nutrient unit cost is likely equal to zero
- ~ means that the nutrient unit cost may be close to zero
- * means that the nutrient unit cost is unlikely to be equal to zero
- ** means that the nutrient unit cost is most likely not equal to zero

Calibration set				
Name	Actual [/T]	Predicted [/T]	Lower limit	Upper limit
Bakery waste, dehy	92.000	114.137	107.954	120.321
Corn grain, ground	110.000	113.522	107.968	119.075
Hominy feed	110.000	99.180	87.947	110.413
Molasses, sugarcane	86.000	73.927	69.151	78.703
Soybean Hulls	82.000	66.831	51.946	81.716
Tallow	350.000	344.076	321.251	366.900
Wheat Middlings	66.000	89.850	81.419	98.281
Blood meal	430.000	431.863	408.581	455.146
Brewers grains, dehy.	141.000	122.546	112.235	132.858
Canola meal, solv-extd	149.000	144.462	134.621	154.303
Corn gluten feed	96.000	125.164	115.958	134.371
Corn gluten meal, 60%	306.000	302.529	285.211	319.846
Cottonseed meal, 41%	175.000	148.179	139.770	156.588
Cottonseed, Whole	174.000	176.178	153.442	198.914
Distillers dried grains	115.000	132.441	122.895	141.988
Feather meal	225.000	222.807	201.406	244.207
Fish meal - Menhaden	415.000	403.448	383.919	422.978
Meat and bone meal	195.000	209.424	200.936	217.912
Poultry byproduct meal	229.999	262.235	253.392	271.079
Soybean meal, solv, 44%	186.000	168.769	157.584	179.954
Soybean meal, solv, 48%	196.000	181.235	167.464	195.007

Appraisal set		
Name	Actual [/T]	Predicted [/T]
Alfalfa Hay-a, sun, early ve	0.000	128.051
Beet pulp, dehydrated	155.000	99.859

Calculation log	
Action	Reason
Feedstuffs "Beet pulp, dehydrated" removed	Outlier

SESAME: Regression results (Dr. Normand St-Pierre)

page 1

Figure 7. Solution screen for the example problem using 22 Ohio feedstuffs to estimate the value of seven nutrients. Actual prices were from *Feedstuffs* magazine, February 14, 2000 for the Buffalo, NY market plus \$20/ton. Lower and upper limites are based on a 75% confidence range.



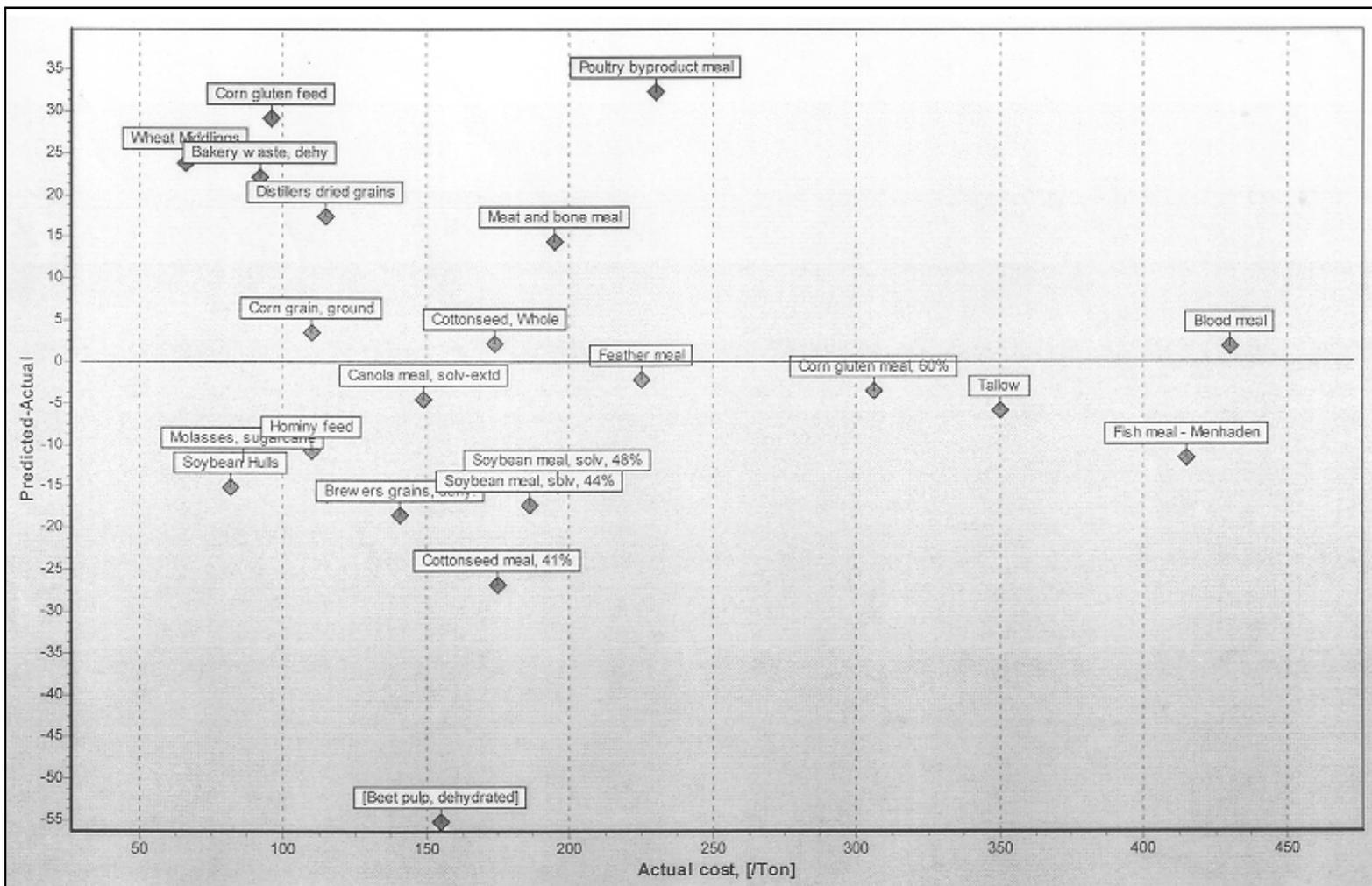


Figure 8. Graphic of predicted minus actual prices versus actual prices of 22 feedstuffs, Ohio, February 14, 2000. Composition values are on an as-fed basis.

How Low Versus High Milk Prices Affect Feeding Recommendations

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Abstract

Tight times force producers and nutrition advisors to make sure they're getting a marginal return from every pound of feed or ounce of additive. The lessons learned about the "game" of feeding dairy cows during tight times can certainly save some precious dollars today. The same feeding principles apply during periods of high milk prices to allow dairy producers to make even more money. The game of designing a low-cost/maximum-return feeding program for each dairy requires careful consideration of many factors unique to each operation. Producers and advisors need to boldly challenge each other in designing feeding programs that take advantage of the farm's inventories, while remembering to take advantage of the rumen's ability to manufacture protein and energy from relatively cheap feed sources. By diligently and continually challenging each other to produce and utilize quality feed inventories, both producers and advisors play an important role in maximizing the bottom line profitability for the dairy farm, regardless of the milk price climate.

Introduction

Have you ever heard the statement, "What does not kill me will make me stronger?" As with many of the challenges that we face in life and business, there is a "silver lining" in the cloud of the low milk prices of recent months. Tight times force pro-

ducers and nutrition advisors to make sure they're getting a marginal return from every pound of feed or ounce of additive. The lessons learned about the "game" of feeding dairy cows during tight times can certainly save you some precious dollars today. The same feeding principles apply during periods of high milk prices to allow you to make even more money.

The Game

I have always viewed the economic game of feeding cows as a game of "dimes," played ten cents at a time, one cow at a time, and one day at a time. Save a dime; make a dime. Spend a dime to make two dimes. The dimes add up. Saving or making three dimes per cow per day on a 400-cow dairy nets the owner an additional \$44,000 per year. In my opinion, there are usually at least three dimes slipping away from most dairy herds (95% of them if you like estimates) across the United States.

The Rules of the Game

The rules of the game are simple: Never spend a dime that will not make you at least a dime, and never try to save a dime that loses you more than a dime. It sounds simple, and it is. In fact, \$10/cwt for milk makes the math easy: Never spend a dime per cow that fails to yield a return of at least one pound of milk (\$10/cwt = \$0.10/lb). And, just as important, never attempt to save a dime per cow that results in a

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loss of more than one pound of milk, but be bold and diligent in saving every dime you can while maintaining milk production.

Keeping Score

Although the rules are simple, there is a little more “art” required in keeping score than simply adding and subtracting dimes with a calculator. First, a pound or two of milk can be difficult to measure. Additionally, the “value” of several other performance parameters requires consideration. These include milk components, reproduction, foot health, and overall cow condition. Keeping score while considering all these factors requires not only accurate “dime counters” but also the keen eye of the dairy producer and the input of experienced and trusted advisors. Together, this team of score keepers must have a good “feel” for cows and be willing to work together to look out for the dairy farm’s bottom line.

Understanding The Game

Space

For the sake of argument, let us use the model of the average milking cow that can eat no more than 50 lb/day of dry matter (**DM**). Although most humans do not usually measure space in pounds, cows forgot to read our textbooks and use a different system. The daily intake of feed (measured in pounds) is somewhat limited by the “space” available in the unique foregut fermentation chamber of the cow that we call the rumen.

The role of the producer and nutritionist is to decide what goes into this 50 lb basket of goodies each cow, each day, and day after day that will save the most dimes (feed costs) and make the most dimes (production). Every decision made on every ounce of this space is important. Poor use of space results in money wasted and/or milk production not realized.

Inventory

The challenge of efficiently filling the 50 lb of space for each cow (what we call our “rations”) is unique to each farm due to differences in inventory. Every farm should take complete advantage of its unique inventory. The examples are endless. Farms with adequate (quality) forage inventory should avoid buying any “forage stretchers” or high fiber ingredients (Table 1). Farms with adequate corn inventory should not have to buy any “corn stretchers” (Table 2). Producers and nutritionists need to communicate about the farm’s inventories regularly to make proper decisions on how to best spend or save the dimes (purchased feed costs) to complement the “free” feed already in inventory.

I like to monitor purchased feed costs in addition to total feed costs (Table 3). Because of the extreme variation from farm to farm in forage and grain inventories, comparing purchased feed costs between farms is meaningless. However, tracking purchased feed costs over time within each farm is a great way to see how changes in inventory, forage quality, and ingredient choices affect the monthly feed bill. Now is a good time to challenge yourself to take advantage of on-farm inventories to minimize purchased feed costs.

While you are in the mindset to make the most of your inventory, it is a good time to discuss the “quality” of your on-farm feeds. Small investments made on the part of the producer to improve forage quality (discussed later), forage storage management, or grain processing (Table 4) can have a huge impact on your feed bill. To cover this topic in the detail that it deserves will have to wait for another day. However, make no mistake about it, it is in this area of quality and management of on-farm feeds that, in large part, separates the superior dairy farm from the mediocre one.

Forage Quality

No one factor plays a larger role in “saving dimes” on feed cost and “making dimes” on milk production than forage quality (Table 5). If buying forages, producers should challenge ration formulators to evaluate several scenarios to select the one which will maximize the farm’s bottom line (Table 6).

The dairy industry has done a good job evaluating and predicting performance from alfalfa using the relative feed value (**RFV**) system. The RFV system does not appear to work well, however, for corn silage (Figure 1). Understanding the “forage quality” component in corn silage is a science in its infancy, but one that will continue to get more and more attention in the coming years.

Let The Rumen Work

Many of us “ruminant nutritionists” need to step back every once in a while, look at the first word in our two-word title, and remember that we are feeding a ruminant. More than 70% of digestion of feed occurs in the rumen of cows (Satter, 1985). This process directly involves the digestion of feeds and synthesis of nutrients by the billions and billions of microbes (bugs) that make their home in the rumen of each cow we feed. In many respects, our primary role as dairy nutritionists is feeding rumen bugs.

One remarkable thing the rumen bug population does for cows is generate “energy” and manufacture “bypass protein” from fermentable carbohydrates and degradable (non-bypass) protein. Fortunately, feeds rich in fermentable carbohydrates (grains and quality forages) and degradable proteins (high protein forages, urea, soybean meal, etc.) are relatively cheap (Table 7). We need to constantly remind ourselves to take maximum advantage of the relatively cheap “pro-rumen” feeds that let the rumen work.

Unfortunately, in some instances, the feed industry has over emphasized the feeding of bypass energy and bypass protein supplements. Emphasis on bypass nutrients is not, in itself, a problem as long as it is kept in its proper perspective: playing a minor role relative to the major impact of feeds that are utilized by the rumen bugs.

Adding to the momentum of the feed industry’s over emphasis on bypass nutrients is the animal health industry’s “tendency” to blame every cow health problem from displaced abomasums to lameness on “too much corn.” Although this can certainly be the case on any farm, often the imbalance in rumen fermentation that exists would be better described as “not enough fiber digestion.” If more ration troubleshooters approached problems from the perspective of improving fiber digestion, i.e. adding or removing feeds to promote fiber digestion, rations would be cheaper and cows would be consistently healthier and more productive.

Good Moves

Here are 10 “good moves” I frequently recommend in the game of feeding cows to help maximize the bottom line for dairy farms regardless of the milk price.

1. Quality forages: buy, manage, and educate.
2. Use some urea: 0.10 lb for each 10 lb of corn silage DM.
3. Minimize size of grind and mix package.
4. Purchase higher inclusion feeds as commodities.
5. Herds over 20,000 lb RHA for milk, stay with cottonseed.
6. Use additives that promote rumen fermentation.



7. Avoid additives that hinder rumen fermentation.
8. Cow weigh backs are “free” heifer feed.
9. Don’t get too excited about “low group rations.”
10. Do not abandon bovine somatotropin (**bST**).

Summary

Extreme variation exists from farm to farm in the Midwest in cow performance, feed inventories, and forage quality. The game of designing a low-cost/maximum-return feeding program for each dairy farm requires careful consideration of many factors unique to each operation. Producers and advisors need to boldly challenge each other in designing feeding programs that take advantage of the farm’s inventories, while remembering to take advantage of the rumen’s ability to manufacture protein and energy from relatively cheap feed sources. By diligently and continually challenging each other to create and utilize quality feed inventories, both producers and advisors play an important role in maximizing profitability for the dairy farm regardless of the milk price climate.

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Table 1. Feeds typically purchased in the Midwest as “forage stretchers.”

Feed	% NDF (dry basis)¹
Wet brewers grains	42
Fuzzy cottonseed	44
Distillers grains	44
Beet pulp	54
Soybean hulls	67
Cottonseed hulls	90

¹Source: Macgregor, 1994.

Table 2. Feeds typically purchased in the Midwest as “corn stretchers.”

Feed	NE_L (Mcal/lb, dry basis)¹
Hominy feed	0.96
Corn gluten feed, wet or dry	0.87
Starch	0.95 ²
Bakery waste	0.95
Cereal fines	0.92 ²
Wet potato waste	0.95

¹Source: Macgregor, 1994.

² Estimated.

Table 3. Total and purchased feed costs for two dairy farms with different inventories.

Feed	High Inventory		Low Inventory	
	As-Fed (lb/head/day)	\$/head/day ²	As-Fed (lb/head/day)	\$/head/day ²
VTM, YST, BF, MIN, M&B ¹	1.64	0.40	1.57	0.36
Soybean meal	1.08	0.08	2.50	0.19
Roasted beans	1.50	0.18		
Cottonseed, whole	5.00	0.40	5.00	0.40
Corn, 85% DM	16.00	0.56	3.70	0.13
Corn silage, 35% DM	30.00	0.26	30.00	0.26
Alfalfa hay, 23/167 ³	20.53	0.87	12.11	0.60
Distillers grains			3.00	0.12
Corn gluten feed			8.00	0.28
Starch			2.00	0.07
Wet potatoes, 20% DM			25.00	0.12
Sweet corn silage, 20% DM			10.00	0.04
Total lb/head/day, As fed/DM	75.8/50.0		102.9/50.0	
Total feed, \$/head/day	2.75		2.57	
Purchased feed, \$/head/day	1.06		2.31	

¹ VTM = Vitamin and trace mineral supplement, YST = yeast, BF = buffer, MIN = phosphorus and calcium mineral sources, and M&B = meat and bone meal. Mix also includes 0.10 lb/head/day of urea.

² Southern Minnesota elevator and commodity prices, March 2000.

³ Crude protein/relative feed value.

Table 4. Effects of grinding and moisture on rumen degradability of corn.¹

Corn Type ²	Mean Particle Size (microns)	Rumen Degraded Starch (%)
Dry, coarse grind	4442	36.8
Dry, fine grind	810	63.2
High moisture, coarse grind	5633	47.8
High moisture, fine grind	1966	76.3

¹ Ying and Allen, 1998.

² Dry corn = 87% dry matter; high moisture corn = 65% dry matter.

Table 5. Forage quality limits milk production of dairy cows.¹

RFV²	Peak Milk (lb/day)	Milk Production (lb/lactation)
151+	100-110	20,000+
125-150	90-100	18,000-20,000
103-124	75-90	16,000-18,000
87-102	65-75	14,000-16,000
75-86	55-65	12,000-14,000
< 75	35-45	10,000-12,000

¹ Garrett (2000).

² RFV = relative feed value.

Table 6. Alfalfa quality affects purchased feed costs.

Feed	\$90/ton Hay		\$60/Ton Hay	
	As-Fed (lb/head/day)	\$/head/day ²	As-Fed (lb/head/day)	\$/head/day ²
VTM,YST,BF,MIN,M&B ¹	2.11	0.45	1.29	0.33
Soybean meal	3.65	0.27	7.55	0.57
Cottonseed, whole	5.00	0.40	5.00	0.40
Corn, 85% DM	14.68	0.51	21.40	0.75
Corn silage, 35% DM	42.92	0.37	19.33	0.17
Alfalfa hay, 23/167/\$90 ³	15.00	0.68		
Alfalfa hay, 17/100/\$60 ³			15.00	0.45
Total lb/head/day, As-fed/DM	83.4/50.0		69.6/50.0	
Total feed, \$/head/day	2.68		2.67	
Purchased feed, \$/head/day	2.31		2.50	

¹ VTM = Vitamin and trace mineral supplement, YST = yeast, BF = buffer, MIN = phosphorus and calcium mineral sources, and M&B = meat and bone meal. Mix also includes urea.

² Southern Minnesota elevator and commodity prices, March 2000.

³ Crude protein/relative feed value/cost per ton.

Table 7. Cost per pound of protein from various protein sources.

Feed	Crude Protein¹ (% As-Fed)	Undegradable (Bypass)Protein¹ (% of CP)	\$/ton²	\$/lb of CP²
Urea	280	0	250	0.045
Corn gluten feed	22	22	90	0.205
Soybean meal, 47% CP	47	35	185	0.197
Distillers grains	27	47	115	0.213
Corn gluten meal	60	55	335	0.279
Heat-treated soybean meal	42	55	240	0.286
Fish meal, menhaden	62	60	720	0.581
Meat & bone meal	50	70	238	0.238
Blood meal	80	82	486	0.304

¹ Source: Macgregor, 1994

² Southern Minnesota elevator prices, March 2000.

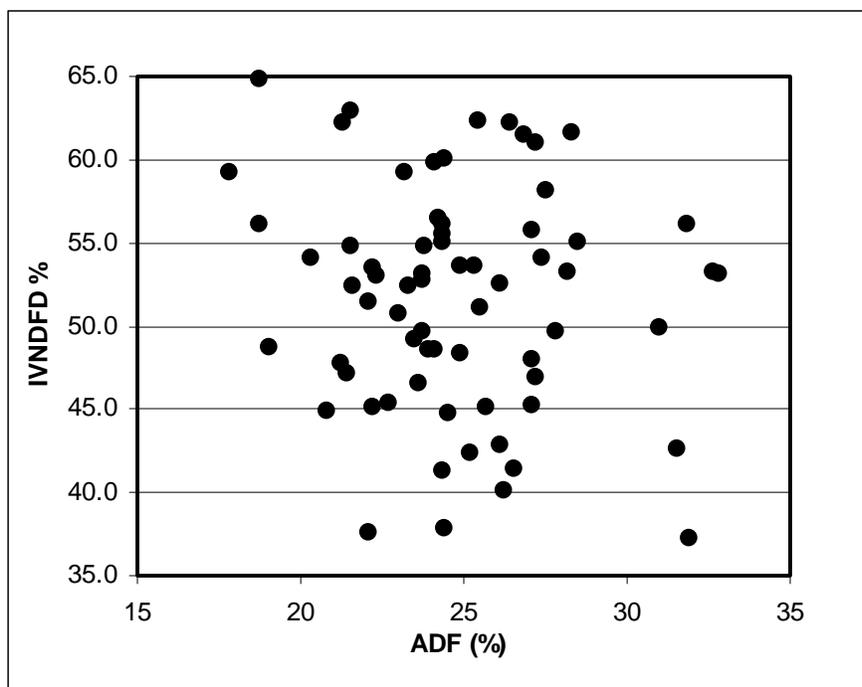


Figure 1. Relationship between ADF and 30-hour in vitro NDF digestibility (IVNDFD) for corn silage samples taken from 67 dairy farms in MN and IA during 1999. In vitro digestibility performed by DAIRY ONE laboratory, Ithaca, NY, 30-hour incubation in ANKOM Dairy II Incubator.

What We Expect from a Dairy Nutritionist

Ryan Anguilm¹

R & S Farms

Ryan Anguilm is the manager of R & S Farms located in North Manchester, IN. Ryan and his wife, Sarah, have been milking cattle in Indiana for the past four years. Prior to this, they were employed as herd managers on a large dairy farm in Michigan. R & S Farms consists of 140 cows and the resulting youngstock. The farm's dairy nutritionist is David Perry of Land O' Lakes, who has worked with the farm since 1996.

Ryan and Sarah own the cattle and are leasing the land and facilities. The feeding program is based on a combination of grown and purchased forages. Concentrate is supplied as a custom, complete pellet, and it is currently fed at 29 lb/cow/day to the high cow group. Ryan has learned that "making feed on time and putting quality forages into the rations is one of his most important jobs." The farm's total land base is 240 acres, of which 185 are tillable. Corn silage is the principle forage, and it has been custom planted since 1998.

R & S Farms makes maximum use of the limited acreage by double-cropping rye silage and corn silage. A corn silage hybrid is planted on 160 acres and corn silage is stored in a 120 x 45 ft bunker. An existing 20 x 80 ft upright oxygen-limiting silo is used as a summer and transition silo for corn silage as the bunker is being refilled and is fermenting. In 1999, which was a very dry year in parts of Indiana, almost all of the 130 acres of corn were put into the silo. Extra corn is planned to allow "flex" acres that can be

ensiled or custom harvested and sold as dry grain. Soils on the farm are very tight. Therefore, the addition of manure and fall plowing or chiseling are used to insure adequate soil tilth.

Alfalfa silage from 40 acres is harvested each year and stored in silage bags. Alfalfa silage and rye silage are tested on a weekly or by-weekly interval by Land O' Lakes and are used in formulation of lactating cow, dry cow, and heifer rations. The balance of hay crop silage and hay is purchased. Recently R & S Farms finished their own supply of alfalfa silage and are now feeding high-quality haylage delivered on a weekly basis. The dairy has also purchased third cutting hay with a relative feed value of 155 and a Ne_L of 0.71 Mcal/lb. "This hay didn't look to be the very best, but Dave took core samples and the relative feed value and protein levels were there," said Ryan. Hay is chopped in a tub grinder once each week and is kept in the 120 x 45 ft bunker silo for inclusion in the TMR.

Cow groups include 80 high cows, 40 low cows, 2 to 4 fresh cows, and 12 to 13 close-up dry cows. Groups are fed twice daily. Feed refusals are scraped daily and mixed with growing heifer rations. Cows are fed a TMR along a drive-thru, 300-foot, floor-line feed bunk that is under a tin roof. Close and far-off dry cows are fed a partial TMR along a section of this feed bunk and also have access to a round bale feeder.

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The way Ryan works with Dave has changed over the past four years. In 1996, when Ryan had just moved to Indiana from a herdsman position in Michigan, Dave's involvement with the farm included forage testing. He also worked with the Anguilm's as they were dealing with some problems with two groups of purchased cattle. Since the onset of their relationship, production has increased from around 40 to greater than 70 lb/day. Recently, Ryan has been working with Dave on more of a consulting basis to fine tune the fresh cow and close-up dry cow rations for the herd, which now has a RHA for milk of 22,000 lb.

Pre-fresh cows are fed a diet with anionic salts. One of the most recent interactions between Ryan and Dave has resulted in trying a commercial salt mixture with the thought that switching to it could help to improve DM intake of close-up cows. "It's

supposed to be more palatable, but it really didn't work that way for us" said Ryan, and he told Dave he'd like to go back to the straight salts.

There are a lot of little details that make the feeding program at R & S Farms work but the three most important things are:

- 1) Keeping quality forages a top priority
- 2) Making as few base feed changes as possible
- 3) Giving cows sufficient bunk space and a comfortable freestall surface to lie on.

Goals for the future include purchasing and upgrading the barns and other facilities at the present site or purchasing a different farm. Increasing cow numbers and productivity are also goals for the future.

What We Expect from a Dairy Nutritionist

Mike Rasmussen¹

Hillhaven Farms, Inc., Edmore, Michigan

I believe with reasonable certainty that most dairy nutritionists and feed industry people would like to have a secret formula that answers “What does this dairy farmer expect of a dairy nutritionist”. The difficulty with this is that a universal approach towards defining dairy farm nutrition does not exist. All dairy nutritionists are not the same or have the same approach once they are working on a farm. The same is certainly true of dairy farmers, who are as diversified a group of individuals that one is likely to ever encounter. The secret formula may be found by making the right fit within the given constraints that the dairy farmer will vaguely define and often quickly change. Unfortunately, sometimes the relationship between the nutritionist or feed company and the dairy farmer may deteriorate, resulting in the nutritionist or company being replaced. This may be avoided by overcoming bottlenecks, such as complacency, poor communication, timeliness, and yes, even the price of goods and services.

Hillhaven Farms Inc. is a 600-cow dairy farm located in central Michigan. It is a partnership between my father, Chris, and myself, with me being the principle manager of the dairy. The farm’s cropping enterprise consists of 450 acres of alfalfa and corn for silage. Additional forage along with corn grain is purchased from local cash crop farmers. The dairy enterprise has expanded from 150 cows in 1995 to the current 600 cows. All heifers are contract raised based on a daily fee by two different growers. Milk production is currently just over 27,000 lb/cow and

has been steadily rising. The farm employs 12 full and part-time employees.

As stated above, dairy farmers are a diverse group and approaches on a given farm can and most certainly will change over time. This has occurred with Hillhaven Farms as well. Back in the mid to late 1980’s, the rations were formulated and balanced once or twice a year by our veterinarian, the late Dr. Ed Sterner. At that time, we felt that was sufficient, but things changed. In 1988, I attended a six-week, Michigan State University-Extension, dairy nutrition shortcourse taught by Dr. Herb Bucholtz. At about the same time, we started utilizing the services of Dr. Rob Davis, a consulting veterinarian and nutritionist, to help with herd health, herd management, and nutrition. Over time, I became more aware of the importance of proper feed management and, with the encouragement of Dr. Davis, started to formulate rations for our farm using the Spartan-2 computer program.

Today, because of our dairy herd expansion and the need to precisely manage all aspects of the dairy operation, we utilize a team approach to managing our feeding program and the other aspects of herd management. Like it or not, dairying is a business, and we are in business to make a profit. That is not to say that we don’t enjoy working with cows, because we do. However, if Hillhaven Farms were not treated as a business first, then there wouldn’t be much of a lifestyle.

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At Hillhaven Farms, we weekly test forages for dry matter and monthly send feed samples for laboratory analysis. Other management tools we employ are harvesting first-cutting alfalfa according to growing degree-days and select corn hybrids both for silage and grain based on fiber and grain digestibilities, in addition to yield characteristics. We process the corn silage at harvest, use inoculants on forages, and work very hard at properly filling bunker silos and practicing good feed bunk management. Dry matter intakes of the total mixed ration (**TMR**) are monitored daily for the following groups: high-aged cows, high 2 yr-old, fresh cows, and close-up dry cows. Feed refusals from the lactating cow TMR are re-mixed daily back into the ration for the late lactation, pregnant cow group. Feed refusals for that group and the close-up dry cows are cleaned up three to four times a week, re-mixed, and fed to the far-off dry cows. The far-off dry cow bunk is cleaned, three times a week, with the feed refusal finally being discarded into the manure pit. All cows are fed a TMR through the mixer wagon, with the only exception being the far-off dry cows that have access to a round bale of hay.

Haylage, corn silage, and high moisture corn are all stored in bunker silos. A commodity shed holds the dry ingredients, which include whole cottonseed, dry ground corn, and large square bales of hay. We use a custom formulated protein-mineral-vitamin pellet based on my specifications which is currently being fed to the lactating cow groups at an 18-lb inclusion rate. In the past, we had a feeding system that utilized separate piles of commodities and protein sources mixed with a trace mineral pack, major minerals, and buffers. These were all added to the mixer separately. We realized that despite possible cost savings, at least on paper, the excess shrinkage and inventory management concerns did not outweigh the benefits of the high inclusion custom pellet that we now use. In addition, the custom pellet results in less shrinkage, greater convenience, mixing simplicity, and over all better quality control.

I rely heavily on a number of people to help fine tune rations and to supply ration ingredients. Dry corn, some bagged products, and cottonseed are handled by a local feed cooperative. Another feed company supplies an anionic, close-up, dry cow mineral-protein pack and some bagged ingredients. A third feed company supplies the custom pellet. This may appear to be a rather complex system of feed purchasing, but we think that the competition is healthy and profitable for Hillhaven Farms. Remember, dairy farmers, just like nutrition consultants and feed companies, are in business for a profit. The relationships that we have developed with our consultants and suppliers is healthy, and their input is appreciated because the conversation is not always directed toward sales. The people that work with Hillhaven Farms know that if they are going to be asked to come back, they must be willing to be part of our team, and I am the team's manager. We all work on problem solving and fine-tuning. Body condition scoring, particle separation, fresh cow troubleshooting, and nutrient management are just some of the items that may be worked on by one or more parties of this team. Members of this team know that bad-mouthing the competitor is not done. An attitude of cooperation is much better than trying to low-ball the competition just to try to "buy ration space". We also like to see our nutrition team members stay current on the developments in dairy nutrition.

In the future, I would like to see all the information that is generated on the farm being tied together. Currently, we have dry matter intakes, feed analysis reports, and body condition scores in separate paper folders. The PC-Dart DHIA data are on our barn office computer, along with Spartan-2. Another barn office computer has the Surge milking system that contains milk production and other herd data. The farm also has paper folders of soil test results and manure nutrient analyses, along with faxes from our milk cooperative. We have weekly herd health visits that generate paper files for health and repro-

duction, as well as observations on manure consistency and a cud-chewing index.

Hillhaven Farms has a tremendous amount of good and useful data that unfortunately are in too many separate places. We see the need for consolidating the data into an easy to use computer management system that can be utilized by our staff and our management team. This is a potential service area that a consultant or feed company could provide.

Summary

In these times of fluctuating milk prices and cash flow challenges, we don't always want to hear a

sales pitch, but instead, we are looking for support people to pitch in and help. We have gone from separate feeding of forage and grain in the 70's, to feeding a TMR and periodic ration balancing in the 80's, to a highly involved, business-like approach to feeding in the 90's. As we start the new decade, there will be more fine-tuning, more research, and more emphasis on environmental concerns with nitrogen and phosphorus. Information is abundant and software to organize the whole picture is, for now, pretty basic. We look forward to tackling the challenges before us, and with the help of a concerted effort of our team members, we will be in this business for a long time.





What's Unique About Working with Large Herds

Rob Davis, DVM¹

Progressive Dairy Management

Introduction

In order to discuss large dairies, it is first useful to define just what we mean by large. In fact, this term will mean different things depending on which part of our country you live. Out in the western states, for instance, dairies milking more than one thousand cows are fairly common. The other extreme can be seen in the northeast states where the 60-cow herd is more standard.

Large Dairies

What constitutes a “large” dairy is in fact a moving target in today’s industry. Just 10 years ago, I would have characterized farms with over 200 lactating cows as large. Now in the upper mid west, at least 500 and above seems a more appropriate benchmark. There is little doubt that in a few more years, this number will need re-assessment. So, for the sake of discussion, we will arbitrarily talk about herds milking 500 or more cows.

The first aspect of large dairies that is unique to them is the sheer task of accumulating the livestock and building the facilities. Most, but not all, of the “large” herds are expansions of existing farms. These herds are increased in size by purchasing cattle, invariably from more than one source. So, the first unique aspect of these operations is unfortunately increased biosecurity risk. The opportunity, especially for the veterinary community, is to be pro-

active in reducing risks. Vaccination protocols and Johnes, Tuberculosis, and contagious mastitis detection are just a few areas where expansion farms need help at minimizing risks. Cows coming from various sources and their sheer numbers make disease control a major job for expanding farms.

The need to produce, store, and purchase larger and larger amounts of feed is an ongoing challenge for newly expanded dairies. Forage management, including inventory management, storage, and harvesting, is an area that consultants and feed industry people can get more involved. Land-limited dairies need new strategies to manage feeding, cropping, and manure disposal. Opportunities abound here. Big farms tend to use commodities, and having knowledge of how these can fit in rations, how they can help to stretch forage supplies, and their impact on profitability are all areas that clients expect us to know about. An even more challenging aspect of commodities is the forward contracting feeds to limit risk. Many farms are looking for advice in contracting of feeds.

Another unique aspect of large dairies is that along with a lot of cows, there are a lot of employees. At about 500 cows, there begins the appearance of a “middle management” team. Owners now have the need to delegate some authority to others and have the income to hire skilled management-oriented people. This frees the owner to “macro-manage” the big issues of the dairy, while others tackle

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the day-to-day details in their area of responsibility. Ideally, there is regular interaction and information exchange between owners and “key personnel”. When this communication is lacking, there are invariably more problems.

Challenges of Large Dairies

Both opportunities and challenges exist in providing nutritional and management consulting to these dairies. A challenge is that we need to develop communication with more people than just the owner on these farms. Success will depend on how well we interact with the entire staff. The perception of us by key employees will directly effect our level of success. It is not unusual when visiting a large farm to meet briefly with the owner, then go to find the herd manager, and then to the feeder to get a real understanding of what is happening on the farm. An opportunity, of course, is to be able to work well with all these people and achieve real changes that favorably impact profitability. Success takes time, effort, and good communication skills.

Technology is ever present on large dairies. “In house” computer monitoring systems are common on these farms. Familiarity with these systems and the ability to extract real information is a big plus to these herds. Unfortunately, there are many varieties of software out there, and it is an ongoing challenge to be able to use them all. Further, the daily monitoring systems on farms are separate from the record keeping systems and interface between them is poor or non-existent. The next decade will see better, more user friendly integrated software that does it all.

Large operations tend to be more willing to pay for information. This is partly because they have a larger budget to work with but also because they more clearly see the need for outside opinions and viewpoints to stay current. The owners and managers of large dairies readily see the value of “specialty” people in keeping them informed and offering

input on decisions. Like in any financially successful business, these owners understand that having information is the key to decision making. We need to be willing and open minded enough to accept the input of other “experts” who work with us to form the dairy management team.

Still another unique aspect of large dairies is the dramatic difference that tiny money savings or production gains can make. I have a client that likes to remind me that saving them just \$0.02/cow/day returns \$12,000 to the dairy each year and the gain of just 0.5 lb of milk increases gross income by more than \$35,000. These producers then are more than willing to invest time, effort and money to realize these gains, however small they seem at first.

An unfortunate down side to the large dairies from a nutritionist’s point of view is that more and more cows contribute to greater liability risk. That is, an unhappy client that milks 1,000 or more cows and decides that the nutritionist is to blame for a given problem can ask for damages that can get astronomical. While this is a worst nightmare for any of us in nutrition, it can usually be avoided by simply not advising in areas where our knowledge may not be adequate and most importantly maintaining good communication.

While there are many aspects of large dairies that make them unique, it should be kept in mind that there are many more similarities than differences in dairies of varying size. Those who provide nutrition and consulting services should not be intimidated by their size but rather welcome the opportunity to expand from ration balancing into the variety of new services that these ever-increasing expansion farms need.

Contracting for Forages

Dan Undersander¹

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Abstract

Increasing capital costs and shortage of labor are forcing many dairy farmers to reevaluate the way they operate. One opportunity is to contract for forage harvesting. This provides labor at a needed time and reduces the equipment the farmer must own. The reduced equipment can greatly reduce capital investment. Custom harvesting also provides a large supply of uniform quality forage rather than variable quality resulting from harvesting small land areas over longer periods of time. This paper considers the reasons for using a custom operator, the economics of custom harvesting, and the appropriate methods of working with custom harvest operators. A second opportunity is to contract for forage either delivered as hay, haylage, or a premixed TMR.

Introduction

One of the most frequent concerns of dairy farmers is the difficulty of finding needed labor. Contracting for forages can alleviate this problem because the major labor crunch on most dairy farms is caused by trying to harvest forages while still maintaining the dairy herd. An additional factor is that, as sophistication of machinery is increasing, the quality of the labor needs to improve. However, finding qualified labor on a seasonal basis is more difficult as farm populations are declining. Why not simply hire the job done rather than trying to hire labor to do the harvesting?

A second concern of dairy farmers is rising capital costs. Most farmers are fully aware that they are replacing \$20,000 tractors with \$60,000 tractors and \$15,000 choppers with \$30,000 choppers. This means that production costs per acre are rising unless the equipment use is spread over more acres. Figure 1 indicates the cost to harvest one acre of alfalfa haylage, assuming a pull-type mower, chopper, blower, and two wagons. The cost declines rapidly as the equipment is used more often during the season (e.g. for one versus two cuttings). More importantly, the cost to harvest one acre declines as acreage is increased. To remain competitive, farmers must spread harvesting capital costs over more acres. This can be done by increasing harvested acreage or by contract harvesting.

An additional consideration is the variability in forage quality caused by harvesting small acreages spread over many days. Harvesting over more than four days causes significant variability of forage dry matter (**DM**) content and quality that makes balancing rations difficult. Figure 2 shows an example of the variation that can occur. Samples were taken from a vertical silo of corn silage and analyzed for DM and forage quality at approximately every three feet. Note that the DM varied by as much as 10% in consecutive samplings. Similarly, acid detergent fiber varied up to 4.5% from consecutive samplings (Figure 3). These changes in forage quality make balancing rations difficult because by the time a forage has been analyzed and the ration rebalanced,

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a different forage is being fed. High milk production could be achieved with a ration balanced around a more constant forage quality, even if some sacrifices were made in overall forage quality.

Should You be Using Custom Harvesting or Contracting Purchase of Forage?

Using the services of a custom harvest operator or contracting forage purchases allows the dairy producer to capture the efficiencies of large-scale harvesting equipment without incurring the high costs of machinery ownership. It eliminates the need for seasonal labor and allows dairy farmers to direct their labor towards the dairy herd. However, it requires some changes in operating practices and must be considered carefully before such changes are made. You may wish to consider the change if:

- Milk production suffers due to time commitments of field work,
- Crops are planted and/or harvested late,
- Your machinery is old and needs replacing or is too small for timely harvesting,
- You would rather work with cows and leave field work to someone else,
- You have limited labor,
- You need or want to spend more time with your family, or
- You are willing and able to give up control of your cropping systems.

If you answered 'yes' to several of the above statements, you should consider contracting for custom harvesting or for forage purchases.

Selecting a Custom Harvest Operator For Your Farm

Selecting a custom harvest operator for a farm is a major decision that will have great consequences for the dairy operation and should be considered carefully with decisions being made only after

some study. Begin by visiting with other farmers who use custom harvest services. A reputable custom operator should be willing to provide a list of references. Ask references the following questions:

- Were you generally satisfied with the custom operator's service?
- Did the custom operator have a business-like approach?
- Did they have a printed price sheet and contract?
- Did the custom operator offer payment options?
- Did the custom operator seem to have a general sense of control over his/her business?
- How timely was the custom operator?
- How well did the custom operator deal with machinery breakdown, weather delays, etc.?
- Did the custom operator let you know when to expect arrival?
- Did the custom operator have machinery in good working condition?
- Did the employees have a good attitude and moral?
- Was the custom operator willing to listen to any of your concerns?
- Has your forage quality improved, stayed the same, or declined since using the custom operator?
- How satisfied were you with the quality of the silo packing?

Next, arrange an off season visit of the custom operator. They need to see your feed storage facilities, learn field locations, etc. Ask if they can meet your needs in a timely manner. Have a complete set of field maps available with identifying land marks (air photo copies are available from the Farm Service Agency). In addition, discuss the following:

- What labor and equipment you are expected to provide (e.g. hauling, unloading, packing, etc.).
- Ask the custom operator about capacity per hour?

Is it adequate for your needs?

- If you agree to do packing, what tonnage will be delivered per hour and can you pack that fast?
- Will the operator assure an accurate count of loads off each field so that yields can be estimated? Who will supply the forms to record the loads?
- Do you want an inoculant or preservative applied? A specific one? Who pays?
- Is kernel processing desired for corn silage? How are rollers set to assure good processing?

Lastly, the custom operator may want to interview you. Be prepared to provide personal and credit references, just as you asked of the custom operator.

Custom operators are in business just like the dairy farmer and need to have firm commitments so that they can schedule operations and determine crew size needed. Signing a contract for services is strongly recommended. A written contract will protect both parties and prevent either from failing to meet obligations. Read the contract carefully and clarify any issues before signing. If you have concerns, perhaps the custom operator will be willing to modify the contract to meet your needs.

The contract should specify how hours are determined, if charge is by hour, or how acreage is measured, if charged by acres. Note that acreage on Farm Service Agency maps will not always match that determined by acre meters on field equipment. Deciding in advance how acreage will be measured and putting this in the contract will avoid disputes.

A few additional considerations when working with custom harvest operators are:

- 1) Good communication is especially important during the harvesting season. The custom operator is expected to have the equipment ready to go.

The dairy producer is expected to keep the custom operator informed of field conditions, progress of crop growth, weather, etc. Be accurate when giving the operator a crop maturity report. Use a moisture tester or microwave oven to accurately determine moisture content of crop. If field or weather conditions change before the operator arrives, let him or her know as soon as possible. If the operator arrives and is unable to harvest, the operator has lost time that could have been spent harvesting elsewhere. Be prepared for the custom operator to leave if conditions on arrival are not as last described.

- 2) Custom operators do not stop for milking; therefore, if you are required to provide labor, be prepared to do so or to pay for extra help.
- 3) Do not expect the custom operator to arrive the instant your crop is ready. Operators have a set rotation and will work you in as quickly as they can.
- 4) If you purchase or rent additional land, be sure that the custom operator is made aware of the extra acreage to be harvested.
- 5) Clear your field of hazards that might cause breakdowns, and clearly mark the hazards that cannot be removed. The custom operator will likely be harvesting faster than you did and will be unfamiliar with the fields. Be sure that low tree limbs are removed, unless the area underneath is not to be harvested. Mark washouts, large stones, and other large hazards to prevent damage to the harvester.
- 6) Smooth fields for fast harvesting before planting. When planting, remove stones and other hazards. Combine fields where possible for faster harvesting with larger machinery.



How Much Should I Pay a Custom Operator?

Cost is a key consideration when going to custom harvesting. While the hourly costs of a custom operator may seem high, it will generally be less than if you did the harvesting yourself. An example budget for a farmer to harvest his or her own forages is presented in Figure 4 (this spreadsheet by Gary Frank is available on the web at: <http://www.wisc.edu/dairy-profit/tools.html>). Note that if the farmer has average size (and cost) equipment, as presented in Figure 4, and is using this on 300 acres of haylage and 150 acres of corn silage, the farmer will lose \$5,819 annually compared to custom harvesting at the specified costs. If acreage is less, costs to the farmer increase (because capital item cost, interest, and depreciation is spread over fewer acres), so smaller farms would see greater advantage from custom harvest.

Figure 5 lists the same calculations for a custom harvest operator. With the larger machinery and charging \$43 per acre for haylage and \$90 per acre for corn silage, the custom operator needs to harvest approximately 4450 acres of haylage and 600 acres of corn silage to break even. The custom operator's costs are very sensitive to acreage, as shown in Figure 6. So if the operator harvests more acres, the costs go down and profits go up.

It is important for both the custom operator and the user of the services to understand their own and each other's costs. A dairy farmer should make the decision based on labor and cost savings to their operation and, if the custom operator is to stay in business, he or she must cover their costs and provide some income for themselves (Figure 6). Therefore, custom harvest arrangements must be fair to both parties. In this context, it should be pointed out that custom rate guides published by the National Agricultural Statistical Service should not be used because these guides do a great disservice to the custom harvesting and planting operators. The rates published

in the custom rate guides are survey rates of largely farm-to-farm custom rate charges. These rates are always too low to cover depreciation, interest, and wear and tear on the machinery.

Contract Forage Production

An option to growing your own forages is to contract for forage purchase. This option has the advantage of allowing the dairy farmer to concentrate on dairy management while someone else is specializing in the forage production. A further advantage is that labor does not need to be trained for both the dairy and cropping operations. Purchased feed minimizes price risk since both parties agree to a price for a set amount of delivered feed. Financing then becomes easier since the lender knows what the dairy farmer's feed costs and income will be. If arrangements for feed purchase are made locally, the crop producers can provide land for manure disposal from expanding dairy farms, and this will reduce fertilizer costs for the crop producer.

However, the following points should be kept in mind when considering purchasing or selling forage:

- Prices set in contract must be fair to both parties if the arrangement is to last.
- If yields are less than expected, the crop producer is still expected to deliver the guaranteed amount of forage.
- The dairy producer is obligated to purchase the amount of feed specified in the contract, even if a cheaper source is available.
- The crop producer must take great care to monitor moisture of forage during dry down, either wilting haylage or standing corn. The dairy farmer should specify a range of moisture that they want and have the right of refusal if moisture is below the specified amount.

There is no standard contract that could cover

all situations (though examples of contracts are presented at the end of the article in Appendices 1, 2, and 3). It is a good idea to develop a purchase/sell arrangement with someone you know or who has good references. The contract is only as good as those signing it. Quality loss can be accounted for to some extent by using forage analysis with a price premium/discount schedule, but any attempts to cover all other possible scenarios will result in lengthy and cumbersome contracts.

Whatever the arrangement, make sure that it is in writing. This will cause both parties to discuss many aspects of the sale/purchase and reduce the number of surprises as the contract is carried out. Also, in some states, contracts above certain dollar amounts are not enforceable unless they are in writing.

Setting the prices for the forage is often the most difficult part of the arrangement. Some have used current market prices, but this causes problems when the commodity price dips below production cost. It is important for the seller to have an understanding of their production costs and know what they need to cover costs and provide some return. Similarly, the dairy farmer must know what the production costs are for forage (if they are thinking of stopping producing their own forage) and what they can afford to pay based on costs in the dairy operation.

What else should be in the contract? Listed below are some guidelines (not all factors are included and it is generally wise to have an attorney look over the contract):

- Names of all parties involved
- Name of commodity
- Base price per unit of feed at a specified moisture level
- Acceptable ranges for quality, moisture, etc.

- Specify price adjustments for moisture, quality, etc.
- “Right of refusal” clauses
- How will feed be sampled and tested? Who will pull samples, where will it be tested, and who will pay?
- Who will haul the crop?
- Specify preservatives, inoculants, additives, etc.
- How and where will feed be weighed?
- Payment method and interest rates
- Cancellation clause - what happens if the seller can't deliver?
- Arbitration clause - in case of dispute, identify a third party to help resolve the dispute.
- Date and signatures

Following this are examples of some contracts provided by Joe Stellato, University of Wisconsin, Shawano County Extension Agent (Appendices 1, 2, and 3). They are simple and usable but not perfect or fool proof. Note that they may not cover all of the issues listed above, but hopefully, all of the above will be considered before signing one of the contracts. It is always wise to have an attorney look over the contract and make suggestions. The fee spent with an attorney now may save much grief and expense later.

Acknowledgment

The author would like to recognize Joe Stellato, University of Wisconsin, Shawano County Extension agent for his significant contributions to this article.



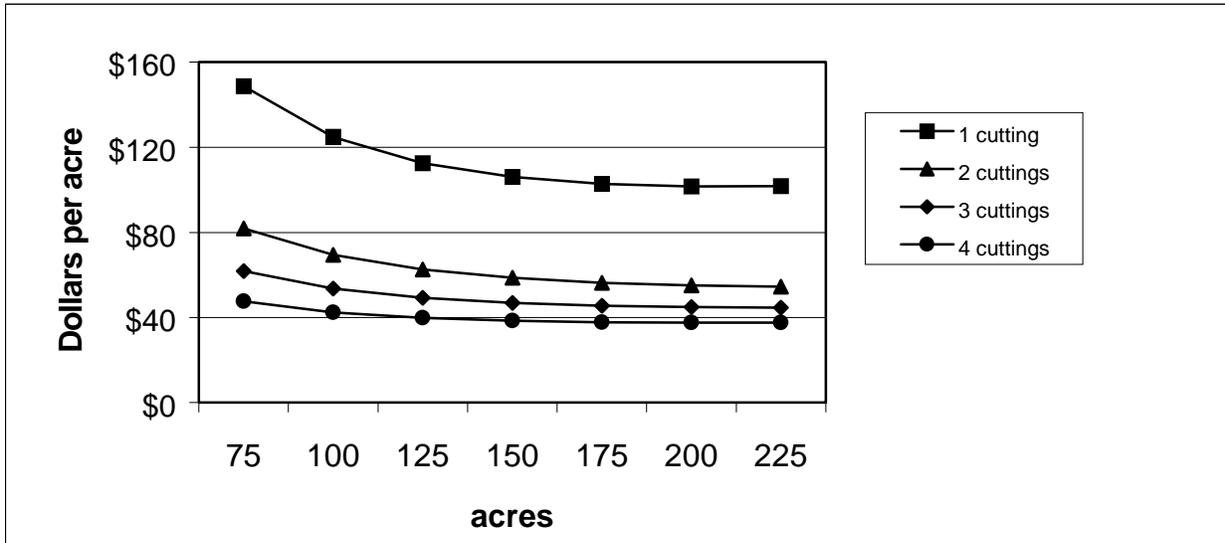


Figure 1. Cost to harvest one acre of alfalfa haylage.

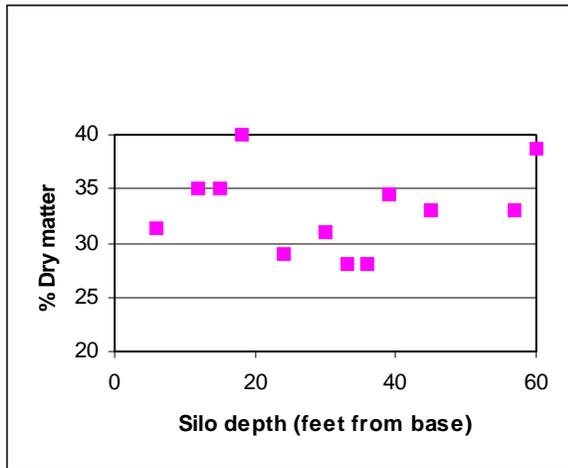


Figure 2. Change in dry matter of corn silage with depth in vertical silo.

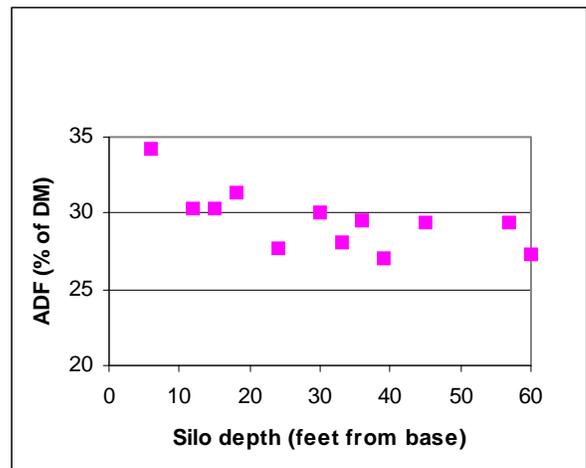


Figure 3. Change in ADF of corn silage with depth in vertical silo.

	Salary	Number	Ownership & Operating Cost		
Managers	\$0.00	0			Cash
Office Help	\$0.00	0	<u>Item</u>	<u>Profit</u>	<u>Flow</u>
Wages (\$/Hour) for Additional Employees	\$7.00		Management	\$ 0.00	\$ 0.00
			Labor	\$ 3,077.00	\$ 3,077.00
			Fuel	\$ 1,650.00	\$ 1,650.00
			Repairs	\$ 3,675.00	\$ 3,675.00
			Insurance & Misc	\$ 1,470.00	\$ 1,470.00
Custom Harvesting Charge, (\$/Acre)	Haylage \$43.00	Corn Silage \$90.00	CRC Interest ¹	\$ 4,749.00	
			Depreciation	\$ 5,250.00	\$ 5,886.00
Total Custom Harvesting Charges (Income) if billed at the above rates		\$26,400	Tractor & Truck Rental	\$12,348.00	\$12,348.00
			Total	\$32,219.00	\$28,106.00
Hours Chopper Base Used/Year		75.66	Custom Harvesting Charges		\$26,400.00
Billing Rate, \$/Hour		\$210.00			
Income if billed hourly		\$29,750			
Acres Harvested	Haylage 300	Corn Silage 150			
Harvest Rate, Acres/Hour	4.5	2.0			
Fuel, \$/acre	\$ 3.00	\$ 5.00			

Return above Costs (Profits from ownership)	- \$ 5,819.00
Short Term Cash Advantage	- \$ 1,706.00

Item	Cost	Units	Total Cost	Useful Life (years)	Depreciation per year	Simple Interest	Repairs at: 5% of 'Cost'
Chopper	\$20,000.00	1	\$20,000.00	7	\$1,428.57	\$1,200.00	\$1,000.00
Hay Head	\$ 5,000.00	1	\$ 5,000.00	7	\$ 357.14	\$ 300.00	\$ 250.00
Corn Head	\$ 5,000.00	1	\$ 5,000.00	7	\$ 357.14	\$ 300.00	\$ 250.00
Haybines	\$12,000.00	1	\$12,000.00	7	\$ 875.14	\$ 720.00	\$ 600.00
Merger	\$ 2,500.00	1	\$ 2,500.00	7	\$ 178.57	\$ 150.00	\$ 125.00
Blower	\$ 5,000.00	1	\$ 5,000.00	7	\$ 357.14	\$ 300.00	\$ 250.00
Hauling	8,000.00	3	\$24,000.00	7	\$ 1,714.29	\$1,440.00	\$1,200.00
Totals			\$73,500.00		\$ 5,250.00	\$4,410.00	\$3,675.00

¹CRC = Capital recovery charge.

Figure 4. Estimate of the cost for a dairy farmer harvesting their own forage relative to using a custom harvest operator. Please note that the format of this spreadsheet has been altered slightly to accommodate the format of this publication.

	Salary	Number	Ownership & Operating Cost		
Managers	\$40,000	1			Cash
Office Help	\$20,000	0.5	<u>Item</u>	<u>Profit</u>	<u>Flow</u>
Wages, \$/Hour for Additional Employees	\$12.00		Management	\$ 50,000.00	\$50,000.00
			Labor	\$ 35,400.00	\$35,400.00
			Fuel	\$16,200.00	\$16,200.00
			Repairs	\$26,000.00	\$26,000.00
			Insurance & Misc	\$10,400.00	\$10,400.00
Custom Harvesting Charge, \$/Acre	Haylage \$43.00	Corn Silage \$90.00	CRC Interest ¹	\$35,141.79	
Total Custom Harvesting Charges (Income) if billed at the above rates		\$243,200	Depreciation	\$57,500.00	\$92,688.89
			Truck & Tractor Rental	\$13,928.57	\$13,928.57
			Total	\$244,570.36	\$244,597.46
Hours Chopper Based Used/Year		464.285714	Return above costs - \$ 1,570.36 (Profits from ownership) Net Cash - \$ 1,379.46		
Billing Rate, \$/Hour		\$475.00			
Income if billed hourly		\$220,535.71			
Acres Harvested	Haylage 4400	Corn Silage 600			
Harvest Rate, Acres/Hour	14	4			
Fuel, \$/Acre	\$ 3.00	\$ 5.00			

<u>Item</u>	<u>Cost</u>	<u>Units</u>	<u>Total Cost</u>	<u>Useful Life (years)</u>	<u>Depreciation per year</u>	<u>Simple Interest</u>	<u>Repairs at: 5% of cost</u>
Chopper	\$225,000.00	1	\$225,000.00	7	\$28,125.00	\$13,500.00	\$11,250.00
Hay Head	\$ 15,000.00	1	\$ 15,000.00	7	\$ 1,875.00	\$ 900.00	\$ 750.00
Corn Head	\$ 45,000.00	1	\$ 45,000.00	7	\$ 5,625.00	\$ 2,700.00	\$ 2,250.00
Haybines	\$100,000.00	1	\$100,000.00	7	\$12,500.00	\$ 6,000.00	\$ 5,000.00
Merger	\$ 15,000.00	1	\$ 15,000.00	7	\$ 1,875.00	\$ 900.00	\$ 750.00
Hauling	\$ 40,000.00	3	\$120,000.00	7	\$ 7,500.00	\$ 8,400.00	\$ 6,000.00
Totals			\$520,000.00		\$57,500.00	\$32,400.00	\$26,000.00

¹CRC = Capital recovery charge.

Figure 5. Estimate of the cost of custom harvest operation. Please note that the format of this spreadsheet has been altered slightly to accommodate the format of this publication.

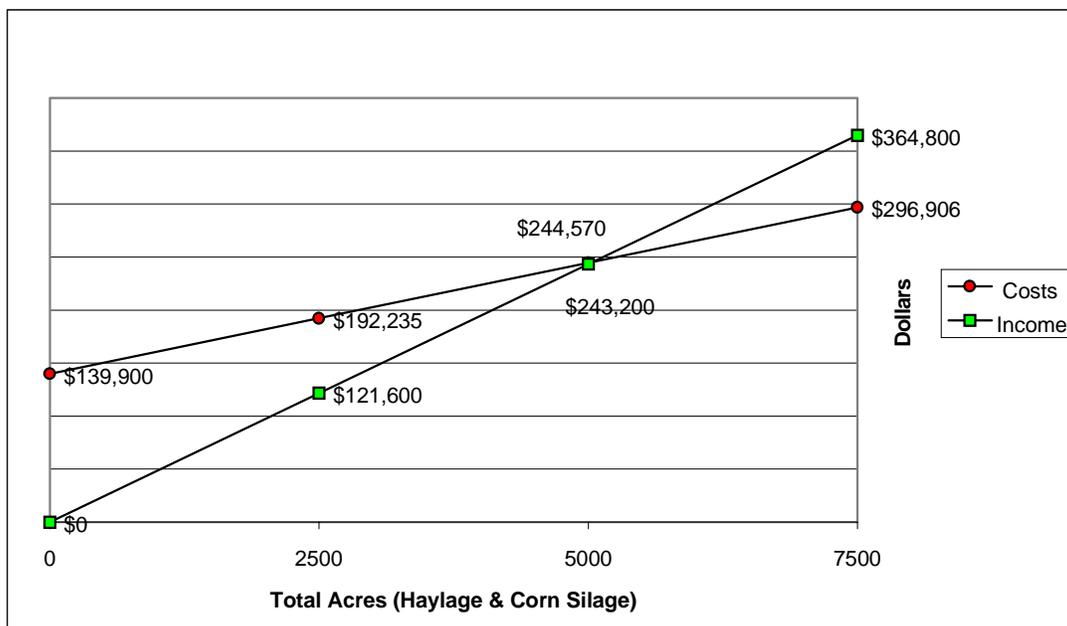


Figure 6. Cost and profit of custom operation.

Appendix 1. Sample Contract for Corn Silage Custom Harvesting.***CORN SILAGE CONTRACT******Between******CHOCOLATE MILK DAIRY and YELLOW DENT GRAIN FARMS***

Yellow Dent Grain Farms will sell 2000 tons of standing corn for silage to Chocolate Milk Dairy during the harvest of 1999. Yellow Dent Grain Farms will be responsible for all costs, both fixed and variable, necessary to the production of this corn. These costs include, but are not limited to, the cost of seed, fertilizer, chemicals, crop insurance, tillage operations, fertilizer application, chemical application, planting, fuel, labor, land rent, interest charges, and overhead expenses. Chocolate Milk Dairy will be responsible for all harvesting, hauling and ensiling costs associated with converting 2000 tons of standing corn into corn silage.

The price of this standing corn for silage will be \$17.50 per ton at 65% moisture. Final price adjustments for moisture will be made using the calculation procedure shown on Attachment 1 of this contract. A minimum of every third truckload of harvested silage will be weighed on a state-certified scale to be selected by mutual agreement of both parties to this contract. Scale tickets will be presented by Chocolate Milk Dairy to Yellow Dent Grain Farms for each load that is weighed. Any costs of weighing the corn will be shared equally by both parties. Corn testing below 61% whole plant moisture will not be accepted by Chocolate Milk Dairy Farm.

Both parties reserve the right to have moisture tests independently analyzed for the purpose of determining a final price per ton. If moisture samples taken by each party differ, an average will be computed to determine a final price. Corn silage samples will be submitted to the AGSOURCE Soil and Forage Analysis Lab in Bonduel for final moisture determination. Each party to this contract will pay for the cost of having their own corn silage samples analyzed.

Payment for the corn silage will be as follows: Chocolate Milk Dairy will pay for the corn silage in twelve equal monthly installments, with the first installment due on October 1, 1999. Each successive payment will be due on the first day of each month for the following eleven months. The equal monthly installments will include accrued interest at an annual rate of 9% amortized over the eleven-month period. Interest will begin to accrue on the unpaid balance starting on October 2, 1999. In the event of late payment in any given month, interest will continue to accrue at the annual rate of 18% on the unpaid balance for that month.

If a dispute arises during the course of this contract that cannot be resolved by referring to the language of this contract, both parties hereby agree that an arbitration process will be used to resolve that dispute. The arbitration process will be as follows:

Each party to this contract will select one arbitrator of their own choosing to work on the dispute resolution process. Arbitrators so selected shall not have any ownership or investment interest in the farm business operations of Chocolate Milk Dairy or Yellow Dent Grain Farms. The two arbitrators selected will, in



turn, select a third arbitrator to serve on a three-person arbitration board. Rulings made by this arbitration board will be accepted as final and binding upon both parties to this contract.

Signed this day of _____, 2000

Yellow Dent Grain Farms

Chocolate Milk Dairy

ATTACHMENT 1: Price Adjustments for Corn Silage Moisture Content

Example: Corn silage base price is \$17.50 per ton of corn silage at 65% moisture (35% dry matter)

Step 1: Calculate price per ton of 100% dry matter corn silage:

$$\frac{\$17.50}{\text{ton 65\% corn silage}} \times \frac{\text{ton 65\% corn silage}}{0.35 \text{ tons dry matter}} = \frac{\$50}{\text{ton dry matter}}$$

Step 2: Calculate price per pound of 100% dry matter corn silage:

$$\frac{\$50}{2000 \text{ lbs dry matter}} = \frac{\$0.025}{\text{pound dry matter}}$$

Step 3: Corn silage harvested at 70% moisture contains 30% dry matter.

Calculate total pounds of dry matter per ton of 70% moisture corn silage:

$$\frac{2000 \text{ lb 70\% corn silage}}{\text{ton 70\% corn silage}} \times \frac{0.3 \text{ lb dry matter}}{\text{lb 70\% corn silage}} = \frac{600 \text{ lb dry matter}}{\text{ton 70\% corn silage}}$$

Step 4: Multiply price per lb of dry matter from Step 2 times the pounds of dry matter per ton of 70% corn silage:

$$\frac{600 \text{ lb dry matter}}{\text{ton 70\% corn silage}} \times \frac{\$0.025}{\text{lb dry matter}} = \frac{\$15.00}{\text{ton 70\% corn}}$$

Appendix 2. Sample Contract for High Moisture Corn Custom Harvesting.***HIGH MOISTURE CORN CONTRACT******Between******CHOCOLATE MILK DAIRY and YELLOW DENT GRAIN FARMS***

Yellow Dent Grain Farms will deliver to Chocolate Milk Dairy 420 tons of high moisture shelled corn during the harvest of 1999. The 420 tons is equivalent to 15,000 bushels of dry shelled corn at 15% moisture, with a test weight of 56 lbs. per bushel. The targeted moisture level of the corn will be 25%. Corn testing below 22% moisture will not be accepted by Chocolate Milk Dairy. Yellow Dent Grain Farms will be responsible for all costs, both fixed and variable, necessary to the production of this corn. These costs include, but are not limited to, the cost of seed, fertilizer, chemicals, crop insurance, tillage operations, fertilizer application, chemical application, planting, fuel, labor, land rent, interest charges, hauling costs, harvesting costs and overhead expenses.

The base price will be \$2.40 per bushel on a dried basis of 15% moisture, which equates to \$75.65 per ton at 25% moisture. Final price adjustments for moisture will be made using the U.W.-Extension chart entitled "Equivalent Price Per Ton of High Moisture Shelled Corn" (Attachment 1). Every load of corn delivered to Chocolate Milk Dairy by Yellow Dent Grain Farms will be weighed on a state-certified scale to be selected by mutual agreement of both parties to this contract. Scale tickets will be presented by Yellow Dent Grain Farms to Chocolate Milk Dairy for each load delivered. Any costs of weighing the corn will be shared equally by both parties.

Both parties reserve the right to have moisture tests independently analyzed for the purpose of determining the final price per ton. If moisture samples taken by each party differ, an average will be computed to determine a final price. The sampling procedure for moisture testing will be as follows: Several hand samples of corn will be taken from each load of harvested grain to be delivered to Chocolate Milk Dairy. These hand samples will be combined into one 5-gallon pail or similar container and mixed. When an entire field has been harvested, one composite sample for laboratory analysis will be taken from the pail to represent that field. Corn samples will be placed in a sealed plastic bag and submitted immediately to the AGSOURCE Soil and Forage Analysis Lab in Bonduel, Wisconsin. The lab will perform a moisture test on the corn, and the moisture test results will be used to compute a moisture-adjusted price per ton for corn from each field harvested and delivered to Chocolate Milk Dairy. Each party to this contract will pay for the cost of having their own corn samples analyzed.

Payment for the grain will be made as follows: Chocolate Milk Dairy will pay for the corn in twelve equal monthly installments, with the first installment due on November 1, 1999. Each successive payment will be due on the first day of each month for the following eleven months. The equal monthly installments will include accrued interest at an annual rate of 9% amortized over the twelve month period. Interest will begin to accrue on the unpaid balance starting on November 2, 1999.

In the event of late payment in any given month, interest will continue to accrue at the annual rate of 18% on the unpaid balance for that month.

If a dispute arises during the course of this contract that cannot be resolved by referring to the language of this contract, both parties hereby agree that an arbitration process will be used to resolve that dispute. The arbitration process will be as follows: Each party to this contract will select one arbitrator of their own choosing to work on the dispute resolution process. Arbitrators so selected shall not have any ownership or investment interest in the farm business operations of Chocolate Milk Dairy or Yellow Dent Grain Farms. The two arbitrators selected will, in turn, select a third arbitrator to serve on a three-person arbitration board. Rulings made by this arbitration board will be accepted as final and binding upon both parties to this contract.

Signed this day of _____

Yellow Dent Grain Farms

Chocolate Milk Dairy



Appendix 3. Sample Contract for Haylage Custom Harvesting.

HAYLAGE CONTRACT

Between

CHOCOLATE MILK DAIRY and YELLOW DENT GRAIN FARMS

Yellow Dent Grain Farms of Green Bay, Wisconsin agrees to provide Chocolate Milk Dairy of Shawano, Wisconsin with the entire haylage harvest from 110 acres of first cutting, 140 acres of second cutting, and 140 acres of third cutting alfalfa during the 1999 growing season. Yellow Dent Grain Farms will be responsible for all costs, both fixed and variable, necessary to the production of this alfalfa. These costs include, but are not limited to, the cost of seed, fertilizer, chemicals, crop insurance, rent, interest charges, and overhead expenses. Chocolate Milk Dairy will be responsible for all harvesting, hauling and ensiling costs associated with converting the specified standing alfalfa crop into alfalfa haylage.

Chocolate Milk Dairy will pay a base price of \$90 per ton of 100% dry matter haylage at RFV of 140 to 160, which includes mowing, raking and chopping costs. Chocolate Milk Dairy agrees to pay all transportation and bunker silo packing costs to contractors within 30 days of receipt of invoice. The price will be adjusted by a deduction of \$1.00 per ton (100% dry matter basis) per point of RFV for haylage testing less than 140 RFV. The price will also be adjusted by a premium of \$1.00 per ton (100% dry matter basis) for haylage testing greater than 160 RFV, up to a maximum RFV of 180.

Both parties reserve the right to have forage samples analyzed by the AGSOURCE Soil and Forage Analysis Laboratory in Bonduel, Wisconsin for the purpose of determining a final price per ton according to forage quality. If forage sample RFV taken by each party differs, an average will be computed to determine a final price. A minimum of every other truckload of harvested haylage will be weighed on a state certified scale to determine final tonnage harvested. In the event that dry hay is harvested, every load shall be weighed on a state certified scale.

Payment for haylage (or dry hay) will be made as follows: Chocolate Milk Dairy will pay in 12 monthly installments. Monthly installments will begin on June 5, 1999 and will be \$5000 per month for the first 3 months, to be adjusted upon completion of harvest. Each successive payment will be due on the fifth day of each month for the following eleven months. Interest shall accrue on the unpaid balance starting on June 6, 1999 at the rate of 12% amortized over a period of one year. In the event of late payment in any given month, interest will continue to accrue at the annual rate of 18% on the unpaid balance for that month.

If a dispute arises during the course of this contract that cannot be resolved by referring to the language of this contract, both parties hereby agree that an arbitration process will be used to resolve that dispute. The arbitration process will be as follows: Each party to this contract will select one arbitrator of their own choosing to work on the dispute resolution process. Arbitrators so selected shall not have any ownership or investment interest in the farm business operations of Chocolate Milk Dairy or Yellow Dent Grain Farms. The two arbitrators selected will, in turn, select a third arbitrator to serve on a three person arbitration

board. Rulings made by this arbitration board will be accepted as final and binding upon both parties to this contract.

Signed this day of _____, 1999

Yellow Dent Grain Farms

Chocolate Milk Dairy

Feeding Management for Cows Entering a New Herd

Dean L. Hefner¹

Abstract

The movement of dairy cows and heifers into new operations is occurring at an increasing frequency. Cheap feed prices in the past year has encouraged dairy producers to maximize milk production on their operations, which may include the addition of new cows or heifers. New feed management techniques have to be developed to reduce the stress that a cow or heifer encounters before, during, and after relocation. The available research on management methods for relocated dairy animals to allow them to optimize their productivity is very limited. Of critical importance is to get the relocated dairy animal quickly back to pre-shipment dry matter (DM) intake. This requires that bunk management, feed palatability, water availability, and grouping pressures be considered. Customized receiving rations should be formulated, with nutrient density for a known dry matter intake a necessity. Data generated from studies done on beef calves may be a useful comparison for shipped cows and heifers, with inferences drawn for ration concentrations of energy, protein, zinc, selenium, and vitamins. Nutrient fortification beyond compensation for these factors must be individualized for a particular dairy operation, depending on environment, degree of animal stress, and facility availability.

Introduction

Consolidation of dairy cows onto fewer dairy

operations has occurred rapidly during the last decade. In 1992, there were 9.7 million cows on 131,535 dairy operations, while in 1999, nearly 9.2 million cows were on only 87,669 dairies (Halladay, 2000). That's a 33% decrease in the number of dairies, with only a corresponding 6% decrease in the size of the United States dairy herd. Cow movement across regions of the country has become common due to expansion of existing dairies, as well as the construction of new dairies. With the aging of production facilities and encroachment of urbanization, we see migration away from existing dairy centers to new areas. One only has to look at the dramatic dairy industry growth in the state of Idaho in the last decade to understand this occurrence. Historically, dairy herd growth occurred slowly over time due to the retention of a higher percentage of home-raised heifers. However, we now see the specialization of heifer raisers, often geographically removed from associated dairy operations. Cow and heifer relocation has become a way of allowing herd consolidation to occur. In 1996, the USDA reported that 18.5% of all dairy operations brought bred heifers into their herd, and 19.9% of operations brought lactating cows. This movement of cattle has caused herd managers to reconsider methods for reducing stress in these transported animals, allowing them to optimize their lactation potential and profitability as quickly as possible.

The topic assigned has broad reaching implications. Cows entering a new herd can be either cows or heifers, and they may range in stage of production

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from dry, fresh, midlactation or late lactation. These animals may enter a variety of production facilities. For purposes of this discussion, the animals moved will be considered to have been shipped for several hours, possibly commingled from multiple locations, and enter the new facilities in a highly stressed state.

Health Management Considerations

Whenever you bring new animals onto a dairy, you have a number of management considerations that need to be evaluated. A rigorous pre-shipment vaccination and health testing program should be developed by a veterinarian. Numerous health management standards have been published for cows that are to be relocated (Tomsche, 1999; Wallace, 1998) and won't specifically be addressed here. At the very least, Linn (2000) suggests that a bulk tank milk sample be taken on the herd of origin to prevent the introduction of contagious mastitis organisms to the new herd.

From the swine and poultry industries, we have learned about herd biosecurity issues. While "biosecurity" encompasses consideration of any possible vector that might transfer health challenges (human, vehicle, animal, etc.) to an animal population, we must admit in the dairy industry that the movement of animals is probably our largest concern. No one disease may be more injurious to the dairy industry than Johne's disease, due to its easy transfer and effect on older dairy cows. However, in the real world, often animals are moved without any pre-shipment health protocol.

Most recommendations would suggest that animals new to a dairy should be isolated away from the existing herd for at least a one to two week period. This isolation also provides a means so that the group can be closely watched for any health challenges that might occur. However, logistically on many dairies, this is not feasible. Either physical facilities do not exist to allow for isolation or the number of

animals is too small to handle as a group. Cow comfort for newly received cows must also be a consideration to allow adequate space for stress recuperation.

Effect of Transportation

There is limited information describing changes in production traits associated with relocation of lactating dairy cows. Early studies of farm records (Norell and Applemen, 1980; Speicher et al., 1978) suggested there was no effect on yearly milk production the first year following relocation. Varner et al. (1983) studied the effects of transporting lactating cows either into new facilities or merged into existing herds. Milk yield was decreased at the first milking post-movement, but subsequent milk yields were similar to yields pre-relocation. However, in these studies, the cows were only moved 328 feet or 4.35 miles. Studies evaluating the stress of long distance transportation on dairy animals are difficult to find.

Dry Matter Intake

Beyond health, probably the main feeding concern for nutritionists and managers for newly received animals is working to get dry matter intake back to pre-shipment levels, or higher if those levels were not within normal ranges. Many dairy diet formulation recommendations are provided as relative quantities; however, actual weight of nutrients should be considered when intakes are depressed (Table 1). Management considerations for new animals should include all items to maximize intakes: adequate bunk space, feed availability, feed quality, and water availability (Quaife, 1995). Also, environmental considerations must be considered, especially if animals are transported across geographic regions. The faster we get animals back to at least pre-shipment dry matter intake, the greater the ability of the group to withstand health challenges.

Grouping Strategies

It may be less stressful to move cows and heifers long distances during the early dry period and to maintain animals within the same group. Heifers within several weeks of parturition ideally should be grouped separately and adapted to their early postpartum environment. Cows that are forced to deal with abrupt environmental changes during the periparturient period can exhibit aberrant feeding behavior, leading to more metabolic disorders (Grant and Albright, 1995). We know that social behavior within a group can alter dry matter intake and productivity. Dairy cattle are social animals and readily form dominance hierarchies, especially at the feedbunk (Friend and Polan, 1974; Grant and Albright, 1995). Any dairy cow that moves into an existing group of cows must quickly find her place in the social hierarchy in the group to maximize dry matter intake. This situation becomes even more critical for cows in early lactation. With prolonged reduced dry matter intake, the potential not to reach peak milk and maximum production becomes greater. It is just as important that bunk space must not be limited for groups that receive new cows. Research suggests that the maximum effect of dominance hierarchies in groups is greatest the 30 to 45 minutes after delivery of fresh feed. If bunk space is restricted, submissive cows may not be receiving maximum dry matter intake. This situation is even greater if you consider fresh cows that may enter groups in a weakened state, more vulnerable to dominance.

Receiving Rations

There is not a great deal of information regarding the dietary manipulation of receiving rations for cows and heifers that are new to a dairy. Besides isolation, there are suggestions of inoculants and feed additives that can be used to minimize reduced feed intake from the stress of relocation or to improve rumen fermentation. Without specific research, it is difficult to make accurate dietary addi-

tions. As discussed previously, there are two primary concerns with any stressed ruminant: 1) get them back to pre-stressed dry matter intakes as quickly as possible and, 2) during periods of depressed dry matter intake, make sure density of nutrients is adequate. As a means of comparison, a review of the recently transported dairy animal can be most logically compared to the feedlot animal that may be transported long distances and challenged with a number of stressors. There has been considerable data collected on nutrient recommendations that may help alleviate stress, reduce health challenges, and get feedlot animals on feed quickly, with a reduction in both morbidity and mortality. Figure 1 demonstrates that depressed prepartum intake in dairy cows can be directly correlated to postpartum complications (Zamet et al., 1979).

Energy-Protein Ratios

Lofgreen (1983) showed that in stressed calves, voluntary intake of low-energy (high-roughage) diets is less than that of high-energy (> 60% concentrate) diets. Pritchard and Mendez (1990) reported increased dry matter intake during a 28-day receiving period by calves fed a high energy (> 60% concentrate) receiving ration. Feeding good quality hay plus protein supplement has worked well (Cole, 1996). Feedstuff quality is obviously important for newly received animals. Similarly, Fluharty and Loerch (1995) conducted three trials with newly arrived cattle to assess protein needs. Daily gain in calves increased linearly during the first week after arrival as crude protein increased from 12 to 18%. Based on several trials, it can be concluded that increased crude protein concentrations are needed early in the receiving period when dry matter intake is low (Galyean et al., 1999). Differences in source of cattle, distances transported, pre-shipment nutrition, time of year, and management are unknown factors on the amount of dry matter intake suppression that will occur and the needs for increased energy:protein density. Intakes by newly received animals must be measured. In dairy



rations, there should be adequate protein and energy for relocated cows or heifers as long as intake corrections are considered. As a base recommendation for dry cows and heifers, a minimum of 14% crude protein should be considered in the receiving ration.

Vitamins

The B-vitamin supplementation experiments on newly weaned or received cattle have resulted in a variety of different animal responses. Vitamin combination packs have been tested that include supplemented thiamin, riboflavin, pyridoxine, pantothenic acid, niacin, choline, and B₁₂. In a review of several experiments, Cole (1996) noted that B-vitamin supplementation resulted in a 3% decrease in morbidity caused by bovine respiratory disease. Differences in feed intake could be a reason for variable responses. Ruminal production of B-vitamins would be greater in animals with high than in those with low feed intakes, potentially influencing results of supplementation (Galyean et al., 1999). The B-vitamin supplementation for newly received dairy animals should be considered for severely dehydrated, thin cattle or those with prolonged dry matter intake reductions.

Supplemental vitamin E can be beneficial for decreasing morbidity and improving performance of stressed cattle, due to effects of vitamin E on the immune system (Coehlo, 1996). Unlike some of the vitamins, vitamin E is not stored in the body in appreciable amounts. In feeder cattle, because of possible injection-site reactions, injection of vitamin E may be less desirable than dietary supplementation (Galyean et al., 1991). Hays et al. (1987) reported that injection of 3,000 IU of vitamin E for newly received steers on arrival increased sick days per morbid calf when compared to feeding 800 IU of vitamin E per animal per day in a 2 lb supplement. While it is unknown what definitive level of vitamin E provides immune system support for stressed dairy cows, it is assumed that if they receive standard dry cow levels

of 1000 IU/head/day, their intake would appear adequate. Smith et al. (2000) recommends that cows at calving have alpha-tocopherol concentrations in their plasma of at least 3 to 3.5 g/ml. The interaction of vitamin E with selenium is discussed further below.

Minerals

Research would suggest that for stressed animals, mineral requirements are not different from those of nonstressed cattle (Orr et al., 1990), at least in research using calves. Again, decreased dry matter intake of stressed cattle may require increased concentration of minerals in the diet. Cattle subjected to stresses of marketing and shipping lose weight - primarily loss of water from the digestive tract as well as intracellular fluid. When intracellular water is lost, deficiencies of potassium and sodium can occur (Hutcheson et al., 1980). In feeder cattle, the potassium requirement of stressed calves is increased 20% (Hutcheson, 1984). Data suggest that 1.2 to 1.4% potassium in the diet for two weeks is the optimum concentration for newly arrived, stressed calves (NRC, 1996). Typical levels of potassium and sodium in dairy lactation diets should be adequate to support stressed cows. However, for cows or heifers shipped before parturition, it may be difficult to adequately increase the potassium or sodium level without post-calving difficulties. Utilization of anionic commodities may be considered, but they too can suppress dry matter intake.

Suttle and Jones (1989) reviewed the possible involvement of zinc in immune functions of ruminants. Zinc supplementation may be needed for stressed calves with a propensity to succumb to bovine respiratory disease. Also, several studies indicate that the source or availability of zinc may be important for immune response. Zinc methionine has been shown to return calves back to dry matter intakes faster (Chirase et al., 1991) and lower rectal temperatures quicker (Blezinger et al., 1992).

There has been increased research on utilization of zinc in combination with other trace minerals for stressed animals (Clark et al., 1996; Engle et al., 1997; George et al., 1997). The data are inconclusive.

The research on selenium has been closely tied to vitamin E, most notably on the effect of the mammary gland response to invasion of a pathogen. Both vitamin E and selenium research shows that when fed in combination, there is an improved neutrophil response to mastitis pathogens. Selenium in the diet should be supplemented at the maximum allowable supplementation rate of 0.3 ppm for dairy cows. If necessary, blood tests could be conducted on newly received animals to measure their selenium status (Smith et al., 2000; Table 2). Feeding diets with 0.3 ppm of supplemental selenium to all classes of cattle and feeding 1000 IU/day of supplemental vitamin E to dry cows and springing heifers and 500 IU/day to lactating cows improves immunity and reduces the incidence of clinical mastitis and reduces somatic cell counts (Smith et al., 2000).

Additives

Yeast culture was studied for its effect on prepartum and postpartum intakes and milk production in Jersey cows (McCoy, et al., 1997). Yeast culture was a dry product topdressed at 60 g/d for 14 days prepartum and 140 days postpartum. Dry matter intake was increased by yeast culture during the last seven days prepartum and during the first 42 days of lactation. Cows supplemented with yeast culture increased dry matter intake more rapidly than non-supplemented cows and lost less body weight. As a tool for newly received dry cows, yeast culture should be beneficial in a receiving ration for getting them to maximum dry matter intake and maintaining that intake.

Other additives, such as probiotics or nutraceuticals, can be considered, but limited data exist to suggest they will have an impact on receiving cattle.

Summary

There is a limited amount of research data on the effects of stress due to relocation and the impact on the dairy cow or heifer. There are a number of factors to take into consideration, including pre-transit health and nutrition status, distance shipped, restriction of water and feed intake, social and grouping effects, commingling of animals from multiple locations, and environmental variations. These factors have different effects relative to the stage of lactation or dry period when the animals are received at the new location. Facilities for isolation of new animals are recommended, but for many operations, facilities may not be available. A pre-shipment health assessment is strongly suggested, but if not possible, a receiving program must be implemented. Close observation of newly received animals is highly necessary. Ration formulation for newly received animals should compensate for decreased feed intake and known nutrient deficiencies. Energy and protein intakes should follow standard recommendations, while concentration of these nutrients should reflect the lower intakes. Other nutrient fortification beyond compensation for decreased feed intake should be carefully evaluated.

Here are some standard feed management guidelines that should be considered:

1. Know the pre-shipment nutrition and body condition of animals.
2. Have a veterinarian-prescribed health assessment pre-shipment and eliminate animals not meeting criteria.
3. Move cows and heifers as early as possible pre-calving.
4. Have health check on arrival.



5. Isolate newly received animals away from the rest of the herd.
6. Measure dry matter intake and observe frequently. Provide adequate bunk space. Provide fresh, clean water.
7. Minimize newly arrived cow movement to reduce social conflicts. If possible, keep heifers separate from cows.
8. Formulate nutrient density according to intake. Feed high quality forage. Meet industry specifications for nutrients based on stage of production.
9. Provide at least 1% potassium in receiving ration. For close up dry cow rations, this may require inclusion of anionic salts to prevent milk fever.
10. Provide at least 0.3 ppm selenium in the daily ration, and feed vitamin E at the rate of 500 or 1,000 IU/head/day to lactating or dry cows, respectively.
11. Consider inclusion of zinc methionine to the diet.
12. For newly received animals near parturition, add yeast culture to the ration.
13. Maintain newly received animals as a group if possible.

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Table 1. Effect of intake on energy and protein concentrations for a 1320 lb cow producing 80 lb of milk at 3.7% fat.

Dry Matter Intake (lb/day)	Energy (NE _L)		Protein	
	Required (Mcal)	Calculated (Mcal/lb)	Required (lb)	Calculated (%)
40.88	37.75	0.92	7.87	19.25
43.29	37.75	0.87	7.87	18.18
48.10	37.75	0.78	7.87	16.35
52.90	37.75	0.71	7.87	14.88
55.30	37.75	0.68	7.87	14.23

¹Adapted from Zamet et al., 1979.

Table 2. Recommended concentrations of selenium in plasma (or serum) and whole blood of dairy cows.

Classification	Plasma or serum (µg/ml)	Whole blood (µg/ml)
Adequate	> 0.075	> 0.20
Marginal	0.05 to 0.075	0.14 to 0.20
Deficient	< 0.05	< 0.14

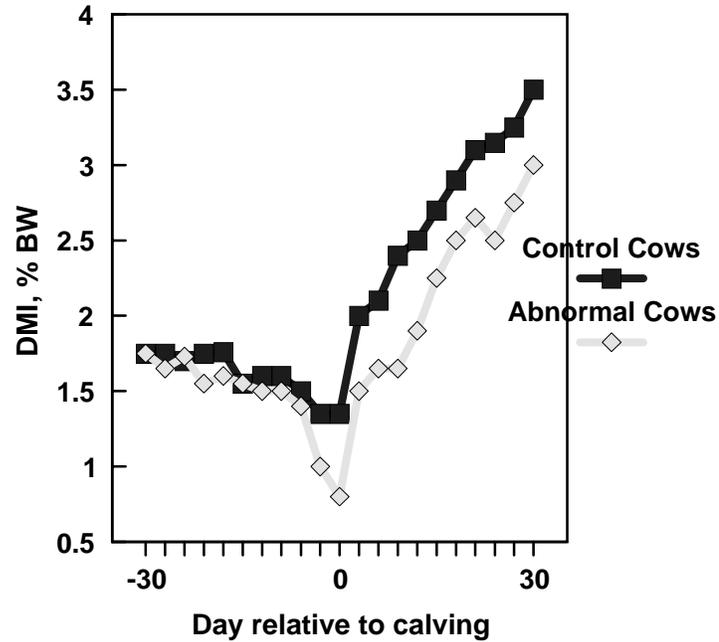


Figure 1. Prepartum dry matter intake of cows having postpartum complications. Adapted from Zamet et al., 1979.



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