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Mycoplasma Mastitis and Prevention

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Introduction

Normally, the three most prevalent contagious mastitis pathogens considered are *Staphylococcus aureus*, *Streptococcus agalactiae* and *Mycoplasma sp.* *Streptococcus agalactiae* and *Mycoplasma sp.* are more rare, with less than 5% of operations affected (APHIS, 2008). However, *Mycoplasma sp.* is increasing in prevalence and more than 21% of large dairies, greater than 500 cows, may be affected in the U.S. (APHIS, 2003). For this reason, mycoplasma mastitis appears to be an emerging mastitis problem (Fox et al., 2003)³. Recent reports also attest to its global significance, affecting areas previously unreported, as in Prince Edward Island, Canada (Olde Riekerink et al., 2006), Northern Greece (Filioussis et al, 2007), Saudi Arabia (Al Abdullah, 2006), France (Arcangioli et al., 2011), Belgium (Passchyn et al., 2011), Mexico (Miranda-Morales et al., 2008) and Iran (Ghazaei, 2006). Given that mycoplasma mastitis seems to be associated with larger herds (Pinho, 2012APHIS, 2008; Fox et al., 2008; Thomas et al., 1981), and that herd size has been increasing over time, it would seem logical that mycoplasma mastitis has become more prevalent. This would seem a most important risk factor given that the Western USA has the largest dairy farms in the nation (APHIS 2009) and is the fastest growing dairy area, especially when considering cows per dairy herd.

Two primary dairy herd risk factors for mycoplasma mastitis as stated by Jasper (Jasper, 1981) are (1) introduction of diseased animals to the lactating herd and (2) problems with milking time procedures, most notably inadequacies in hygiene. Recent reports (Punyapornwithaya et al., 2010 and 2011) suggest that failures in milking time hygiene have not been associated with mycoplasma mastitis occurrence, but that exposure to cattle with non-mastitis mycoplasma infections might be the nidus. Thus the thrust of this review will be to discuss the previous evidence that would indicate that mycoplasma mastitis was principally a contagious mastitis pathogen transmitted at milking time and the more recent evidence that describes the potential threat that symptomatic and asymptomatic carriage of *Mycoplasma sp.* by cattle has on outbreaks of mycoplasma mastitis. A brief description of diagnosis of mycoplasma mastitis will also be addressed.

Diagnosis

The simple genome and fastidious growth requirements of *Mycoplasma sp.* can be associated with their slow replication and difficult identification in many mastitis diagnostic laboratories. Given the difficulties in culture of *Mycoplasma sp.* it has been speculated that mycoplasma mastitis is not a routine procedure used in the diagnosis of mastitis.

Diagnosis of mycoplasma mastitis is most commonly done using microbiological procedures (Gonzalez and Wilson, 2003). For presumptive identification of *Mycoplasma sp.* from milk, it is

advised that milk be cultured on modified Hayflick's media, incubated at 37°C under 10% CO₂ for 7-10 days (Hogan et al., 1999). Other methods such as immuno-detection of specific antigens and nucleic acid detection (PCR technology) have been established (Fox et al. 2005). The PCR technology may have promise (Justice-Allen et al., 2012, Pinho et al., Boonyayatra et al., 2012a) , but culture based techniques are still the most common method for the detection. The advantage to the non-cultured based systems is that they can discriminate between species. *Mycoplasma bovis* is generally regarded as the pathogenic strain affecting cattle, although other strains need to be considered (Fox et al., 2012). False positive results are possible, given when other mycoplasma like organisms, mollicutes, can be confused with the pathogenic strains. The most common non-pathogenic mollicutes are *Acholeplasma sp.* The *Acholeplasma sp.* can be very effectively distinguished from *Mycoplasma sp.* by the digitonin and nisin tests using a culture based system (Boonyayatra et al., 2012b). Yet it should be kept in mind that *Acholeplasma sp.* are capable of causing mastitis (Counter, 1978).

Mycoplasma sp. isolation can be easily overlooked by mastitis diagnostic laboratories since primary isolation of mastitis pathogens is usually done using blood agar plates, 5% CO₂, for 1-2 days. Relatively few laboratories may be equipped to detect this pathogen group (Biddle et al., 2005). Indeed, Nicholas et al. (2007) argued that given the difficulty in isolation of *Mycoplasma sp.* that mycoplasma mastitis was often under diagnosed. Thus situations described in this review might be representative of a greater problem than is apparent.

Dissemination of *Mycoplasma sp.* Within and Between Cattle

Experimental infection. Perhaps one of the first reports on the effect of experimental inoculation of cattle with disease causing *Mycoplasma sp.* on infection was done by Jain and coworkers (1969). In this study, four Holstein-Fresian cows received inoculations with different strains of mollicutes. Two of the four, were strains from cases of mastitis, one was isolated from the vagina and believed to be *M. bovis genitalium* and the third believed to be *A. laidlawii*. One of the strains from a case of mastitis, when inoculated into mammary quarters of 3 cows, caused intramammary infection in the inoculated quarters and also caused infection in non-inoculated quarters. Moreover, that strain of *Mycoplasma sp.* was found in the blood, nasal fluid, mucosal surface of the eye, vagina and rectum within days after the inoculation was made. Also, one inoculated cow gave birth to a female calf and that calf shed the mastitis strain, as it was found in the mucosal surface of her nose, eye, and vagina. In one cow, the pathogen spread only to a mammary quarter not inoculated on the homo-lateral side of the gland. A systemic antibody response was observed in response to this infection. An attempt to inoculate the non-infected mammary half was successful, despite the antibody response. The authors clearly demonstrated that the infection could spread from organ to organ, and that the systemic antibody response might not be sufficient to prevent and/or clear the infection. Jain and coworkers (Jain et al., 1969) suggest that there is a complex method of spread within the body that might not only be hematogenous, but involve the lymphatic system. They note that there was marked enlargement of the supramammary lymph nodes, and that other lymph nodes were often involved. In total, these authors provided excellent findings of the nature of the response to intramammary mycoplasma mastitis, and immune response after the establishment of infection. They established that mycoplasma could migrate to different body sites after establishing infection in the mammary gland and that previous antibody response was not sufficient to prevent new infections. The possible development of vaccines to prevent the disease would have to consider augmentation of arms of the immune system other than the antibody mediated component.

Natural infection. Within cow and between cow dissemination of *Mycoplasma sp.* that cause mastitis has also been seen in a study reported more recently. Djordjevic and coworkers (2001) reported on the diversity and dissemination of *Mycoplasma species* bovine group 7 associated with disease on 3 related dairy herds. *Mycoplasma species* bovine group 7 have not been classified into a specific species (Manso-Silva et al. 2007). Apparently the characteristics of this mycoplasma group have not been well defined, and some of the known characteristics seemed to be shared sufficiently with other species, thwarting this group's precise taxonomic classification. Manso-Silva et al. (2007), suggest that *Mycoplasma species* bovine group 7 be classified as a subspecies of *M. capricolum*. This research group has more recently indicated other designations which are pending. Djordjevic and coworkers (2001) indicate that *Mycoplasma species* bovine group 7 have been isolated from various body sites of healthy and diseased cattle. Specifically, they found that *Mycoplasma species* bovine group 7 have been found to cause mastitis, polyarthritis and pneumonia in cattle, as well as having been associated with aborted fetuses from 3 different dairies over 15 months. These dairies were managed and owned by one operator. They examined the heterogeneity of the *Mycoplasma species* bovine group 7 isolates by genetic analysis, and compared the heterogeneity to isolates obtained from other research groups at different global locations. Isolates from one farm that experienced the abortion outbreak were indistinguishable. These isolates were obtained from various body sites including joints, pericardial fluid, lymph node, stomach, and spleen; and from milk. Isolates from fetal tissue were similarly indistinguishable. Isolates from milk and joints, 18 months after the initial outbreak, were also indistinguishable. The authors demonstrated that nucleic acid fingerprinting analysis could readily distinguish source of isolates as those obtained from world-wide colleagues had significant heterogeneity with those in the Australian outbreak. This report clearly demonstrates the ability of a single clone of bovine *Mycoplasma sp.* could affect and cause disease in multiple body sites, with a single strain causing disease over several months in cattle of all ages. Thus the earlier work of Jain et al. (1969) which found multiple body site dissemination after involving the mammary gland using an experimental model was confirmed in a field study (Punyapornwithaya et al., 2010) using molecular biology and fingerprinting.

Biddle and coworkers (2005) reported on internal dissemination of *Mycoplasma sp.* in 7 cows with clinical mastitis. *Mycoplasma sp.* isolates were fingerprinted similar to that by Djordjevic and coworkers (2001). Milk samples were collected daily for 28 days. Ante mortem swabbing solution samples were collected from the mucosal surfaces of the nares, eye, ear, vagina, and rectum at weekly intervals for 4 weeks. Then postmortem samples were collected from all cows. Tissue samples were taken from: mammary parenchyma and supramammary lymph node, pharyngeal tonsil, retropharyngeal tonsil, primary bronchus, tertiary bronchus, lung parenchyma, sinus, nasal turbinate, pleura, bronchial lymph node specimens, vaginal, vestibular fossa, and suburethral diverticulum specimens, conjunctiva, urinary bladder, knee joint, hock joint, pericardial sac, mesenteric lymph node, spleen, and auditory tube. Swabbing solutions and tissue samples were incubated for isolation of *Mycoplasma sp.* The fingerprint patterns of all isolates were compared. Within cow, all the mammary parenchyma samples had the same fingerprint as those causing mastitis. The respiratory system had the most heterogeneity. Although 90% of ante mortem sample isolates of the respiratory system had the same fingerprint as the mammary gland isolates, less than 25% of the postmortem samples were similar. All of the urogenital isolates had the same fingerprint as the mastitis isolates, and greater than 90% of all other isolates had the same fingerprint as the milk isolates. The data from the study clearly confirmed that *Mycoplasma sp.* that cause mastitis can disseminate through out the body to other tissue sites. It also demonstrates that other isolate types can be present, but save for the respiratory system, the large majority of isolates are the same type.

What this study and that of Djordjevic and coworkers (2001) do not show is the direction of dissemination. It is not clear if the *Mycoplasma sp.* moves from the gland to other tissue sites, or if the nidus of colonization or infection initially occurs at an extramammary site. Nor does it show how cow to cow transmission might occur, whether infection starts with a respiratory disease in one cow, the agent is transmitted to another, where it is carried asymptotically at an extramammary site and then transferred to the mammary gland where it causes mastitis. Data from Jain et al. (1969) using an experimental model indicates dissemination can occur from the mammary gland to an extramammary site.

In field studies there is evidence that suggests that mycoplasma mastitis outbreaks can originate from asymptomatic carriers. In one study the evidence indicates that an outbreak of mycoplasma mastitis originated during the dry period. *Mycoplasma bovis* mastitis affected 16 of 99 cows and appeared to start with thirteen dry cows and one periparturient cow (Jackson and Boughton, 1991). An explanation for cow to cow, udder to udder, transmission during the dry period is difficult. Mackie and coworkers (2000) describe an outbreak of mycoplasma mastitis in periparturient cows with a mixed infection of *M. californicum* and *M. canadense*. Given that the urogenital tract appeared to be colonized by both pathogens, they suspect that the nidus of the mastitis outbreak was not an initial intramammary infection. Their data would indicate that asymptomatic carriage coincided, perhaps preceded, intramammary infections. The research group previously had reported on an outbreak of mastitis that appeared to involve systemic transfer of the mycoplasma agent (Mackie and coworkers 2000). Jasper et al., (1966) also noted that in one herd with a mycoplasma outbreak cows were also suffering from mycoplasma arthritis, suggesting that the disease agent was systemically transferred. Additionally, some cows had no signs of clinical mastitis but shed *Mycoplasma sp.* and leukocytes in milk in abnormally high levels. Pinho et al. (2012) recently reported that from a survey of farms in Portugal, 20% of cows with mycoplasma mastitis intramammary infections had negative California Mastitis Test scores. This would indicate that even when diseased, a noticeable minority of cows with mycoplasma mastitis have subclinical infections.

Wilson and coworkers (2007) reported on an outbreak of mycoplasma disease in first lactation cows in a closed commercial dairy herd. The investigation began with the presentation of a first lactation Holstein cow to the Veterinary Diagnostic Laboratory with polyarthritis. The cow died and a postmortem exam indicated the involvement of *Mycoplasma sp.* An examination of the herd and an interview with the herd owner indicated that 8 other first lactation cows had been affected with arthritis, three of the 9 cows affected had died of pneumonia, and 3 had been infected with clinical mastitis. *Mycoplasma sp.* was found to be associated with the affected animals. The outbreak did not appear to have spread beyond the 9 first lactation animals. Similarly it was reported that cases of mastitis and arthritis that appeared to be connected (Houlihan et al., 2007). In one herd of 120 milking cows, the arthritis was the prominent feature, although an abortion with *M. bovis* was noted as well as nasal discharge of some arthritic cows. Clinical cases of mastitis due to *M. bovis* followed the arthritis. In the second herd, an organic dairy of 84 cows, mastitis was the most prominent feature with some cows affected with arthritis. Cows that failed to resolve were culled, and that control method appeared to be sufficient.

There is sufficient evidence to indicate that mycoplasma mastitis outbreaks are generally associated with other forms of disease by this agent (Houlihan et al., 2007, Wilson et al. 2007, Jasper et al., 1966; Mackie and Finlay, 2000; Mackie et al., 1986). Wilson et al. (2007) reported that it appeared that lameness preceded the mastitis problem, suggesting internal transmission of the disease from one organ site, in this case seemingly extramammary, to another organ site, mammary. The findings

of the clinical report by Wilson and coworkers (2007) also indicate that the agent may be endemic to the herd given that the outbreak was in a closed herd, and infected a select group of related animals. In aggregate, findings indicate that lactating cattle may be the reservoir of the multi-site infections. But there is evidence that calves may be diseased or asymptomatic carriers of the agent.

Mycoplasma sp. is carried in calves, and it appears the nares might be the most readily colonized site. Bennett and Jasper (1977) examined the nasal prevalence of replacement cattle in herds with and without mycoplasma mastitis. They were almost six times as likely to find the agent in the nasal passage of apparently healthy calves of mycoplasma mastitis herds. *Mycoplasma sp.* was isolated from 6% of calves in non-mycoplasma mastitis herds. This could suggest that the agent was more likely to be present in asymptomatic carriers, calves, and that carriage was a function of a prevalence of disease in the herd. Moreover their findings suggest that herds that fed milk were more likely to have carrier calves. Latter, Springer and coworkers (1982) reported that 80% of herds, 19% of calves, carried *Mycoplasma sp.* in their nares in herds without apparent problems with respiratory disease. Thus replacement animals of dairies could be asymptomatic carriers of the agent, or they themselves can be diseased with the mycoplasma mastitis agent.

Hum et al. (2000) reported on an outbreak of mastitis polyarthritis and abortion caused by *Mycoplasma species* bovine group 7 in 3 dairy herds that were centrally managed. Each herd had approximately 1000 lactating cows. Calves were removed from dams within 24 h of birth and fed colostrum. Calves from all 3 farms were co-mingled on one farm at 3 days of age. Mycoplasma disease in the form of polyarthritis was first noticed in the calves, at approximately 2 weeks of age. Approximately a third of all calves at the rearing site were diseased and most were culled or died. An increased abortion rate was reported at one dairy and suspected to be caused by *Mycoplasma species* bovine group 7. Milk samples from cows with clinical mastitis and bulk tank milk samples were found to have *Mycoplasma sp.* bovine group 7. Later (Djordjevic et al., 2001) it was found that fingerprints of the *Mycoplasma species* bovine group 7 isolates were found to be indistinguishable, suggesting all isolates were from the same clone. However, *Mycoplasma sp.* were never isolated from colostrum samples. Hum et al. (2000) suggest that the source of the outbreak was the colostrum fed to calves, and that the organism was resident in the herd causing disease in other animals. Given the early age that the calves became diseased suggests that this might have been the case. Yet given the fact that the colostrum did not appear to contain the disease agent, and that the agent was implicated in causing abortions and thus infecting the reproductive tracts, an alternative explanation is possible. It could be that the *Mycoplasma species* bovine group 7 was disseminated to a calf or calves during parturition and spread to other calves in the calf rearing unit. Regardless, calves were implicated as carriers of disease and the agent appeared to be disseminated in the adult population as well.

Punyapornwithaya and coworkers (2010) reported on a mycoplasma mastitis outbreak in a herd with no history of the disease. A calf with pneumonia was culled a month before the first cow with mycoplasma mastitis was discovered. Almost coincident with the first case of mycoplasma mastitis was a second case of mycoplasma pneumonia in a calf. *Mycoplasma bovis* was isolated from the lung tissue of that second calf. Both calf and cow were culled. Shortly thereafter a second cow was found to have *Mycoplasma bovis* mastitis and an investigation was initiated. Swabbing solution samples were collected from accessible mucosal surfaces (nares, eye, ear, and vagina) from all animals on the farm. Additionally, milk samples were collected from all lactating cows. One hundred and sixty three animals were sampled and *Mycoplasma bovis* was isolated from 72 animals, primarily the nares (n=57). Calves were slightly more likely to carry the clone of *Mycoplasma bovis*

endemic to the herd than cows as determined by swabbing solution cultures. One cow was found to have mycoplasma mastitis at the first whole herd sampling. The fingerprint patterns of electrophoresed chromosomal digests were indistinguishable, suggesting the same clone was carried by all animals. The herd was sampled as described at quarterly intervals for a year. During that time, two new cases of mycoplasma mastitis were identified, but the percentage of animals with perceptible carriage of *Mycoplasma sp.* was less than 10%, and most often the *Mycoplasma sp.* identified appeared to be different than the original. No new cases of mycoplasma mastitis were found during the last 6 month period. Carriage and disease by this agent seemed to “run its course” and had almost disappeared from the herd. *Mycoplasma sp.* was not cultured from the swabbing solutions of mucosal sites from the cows which prior to their development of mycoplasma mastitis. Thus asymptomatic carriage did not appear to precede mastitis. In total this case report reinforces the concept that the mycoplasma agent causing mastitis can colonize multiple extramammary body sites, stay resident for several months in a closed herd, and that carriage may not pose a threat to the herd as evidenced by the limited number of outbreak mastitis cases.

Two recent articles present evidence that the calf may develop mycoplasma mastitis and act as a reservoir for the disease in lactating cattle. Roy et al., (2008) indicate that a 7 week old heifer calf on farm on the University of Montreal’s veterinary service was found to have septic arthritis of the left tarsus. Upon full physical exam it was noted that the right rear mammary gland was inflamed. *Mycoplasma bovis* was isolated from a mammary gland inflamed quarter, but not from the tarsus. *Mycoplasma arginini* was isolated from the nares but no other body sites were positive for *Mycoplasma sp.* The dam of the calf did not appear to suffer from mastitis, nor did mycoplasma mastitis seem to affect other cows in the herd as determined from weekly cultures of bulk tank milk samples. The calf was kept in the herd and the septic arthritis and the mastitis resolved without treatment. The authors conclude that infected calves could play a role in the epidemiology of mastitis in a herd, although apparently in this case the disease did not pose a threat to the calf or herd mates. The findings are clear that calves can act as carriers of the mycoplasma mastitis agent.

In the second recent report (Fox et al. 2008), it was found that intramammary infections with *Mycoplasma sp.* occur in Holstein heifer calves prior to puberty. Three heifers on two dairies with mammary nodules were investigated. The attending veterinarian identified these nodules on the calves at the time of vaccination and removal of supernumerary teats. Lacteal fluid from mammary gland quarters with nodules had *Mycoplasma sp.* The agent was also isolated from organ tissue aseptically collected from calves after euthanasia. Strains were identified as *Mycoplasma bovis* and were fingerprinted. Swabbing solutions from accessible body site mucosal surfaces of the dam of the heifers, or a herd mate of the dam in one instance where the dam had been culled, as well as milk and blood samples, were collected. Samples from the respiratory system and the mammary tissue of one calf had the same chromosomal digest fingerprint pattern. This pattern was also indistinguishable from the milk sample from a cow in the herd with mastitis. In the second herd, both the dam’s blood and milk sample were positive for *M. bovis*, the same strain as found in the calf’s mammary gland. In aggregate the data indicate that *M. bovis* maybe carried in cows and calves in a herd. Hematogenous dissemination is indicated by the presence of the agent in the blood of the dam of one calf. The dam in this case was shedding *Mycoplasma bovis* in the milk although her mammary gland seemed healthy and functional, her 305 day mature equivalent production for the lactation was 12,274 kg of milk and her somatic cell count was consistently lower than 100,000 cells/ml of milk. Since the dam was a symptomatic carrier, and the manifestation of the problem in the calf occurred at an early age, the most plausible explanation is that the reservoir of the agent was the cow. Similarly, in the other herd, a cow with mastitis was found to be infected with the same

clone of *M. bovis* as a calf, and that clone had colonized or infected several body sites of the calf. Again, it is more plausible that the older animals were the reservoir for the agent in this herd. The data from this study also indicate that not all isolates of *Mycoplasma sp.* associated with the samples collected were of the same fingerprint. Thus several strains of *Mycoplasma sp.*, some with the ability to cause mastitis, may be present on a herd simultaneously. Lastly, heifer calves may present at the time of pubertal health and vaccine check, with mammary nodules infected with *Mycoplasma bovis*. Such infections may pose a risk to the herd at a time when those heifers come into lactation.

All of these studies beg the question, how can mycoplasma mastitis be better controlled? The data presented herein indicates that the disease causing agent can remain in the herd for months and be asymptotically carried by cows and calves. In a study of 18 herds (Punyapornwithaya et al., 2012, in press) with a new case of mycoplasma mastitis, we attempted to identify the control points that could be applied prevent an outbreak from erupting. The majority of herds were ostensibly free of mycoplasma mastitis within 1 month. No evidence suggested an advantage of preferential culling in control of mycoplasma mastitis as Fast Recovery herds, herds that were apparently cleared mycoplasma mastitis, were split evenly between preferential and non-preferential culling, and all Slow and Non-recovery herds, herds that took longer than 1 month to clear mycoplasma mastitis, culled cows preferentially. There was little variation between herds with respect to MTH practices and thus no specific practice was linked to time to clearance. Thus testing and preferential culling of cows with mycoplasma intramammary infections did not appear to hasten the apparent clearance of mycoplasma mastitis from the herd as determined by BTM cultures. It would seem that dairy operators and their veterinary practitioners should consider the importance of culling cows with mycoplasma mastitis as part of a control strategy. The importance of monitoring the mycoplasma mastitis status by culturing bulk tank milk is recommended.

In a follow up study we examined the role of a hospital pen for control of *M. bovis* clinical mastitis (Punyapornwithaya, et al., 2012). The overall incidence rate of mycoplasma mastitis in the hospital pen approached 100 fold greater than the incidence rate in the milking pens. The hospital pen was created to isolate mycoplasma mastitis cows and keep them from infecting the non-infected cows. It appeared that 3 new episodes of mycoplasma mastitis were created when cows with true mycoplasma mastitis infections were added to the hospital pen and transmitted their pathogens to cows which had clinical mastitis cases, and therefore suspect mycoplasma mastitis cows, but were initially free of the disease. The lag in time between collection of a sample and the culture result, 10 d, accounted for increased exposure to the incident cases of mycoplasma mastitis. Although it is possible that cows had subclinical mycoplasma intramammary infections prior to their entry into the hospital pen and then developed clinical mastitis, the evidence from our study suggested that new cases of mycoplasma mastitis occurred in the hospital pen and that the addition of cows with clinical mycoplasma mastitis appeared to be the nidus for additional infections in the hospital pen. Three months after creation of the hospital new cases of mycoplasma mastitis subsided suggesting that establishment of the hospital pen may have contributed to control of this disease. But future studies enrolling more herds should be directed to determine if formation of a hospital pen contains the spread of mycoplasma mastitis and/or accelerates transmission of this disease.

Recent cases: A report. It should be noted that the author has recent experience with two herds with mycoplasma mastitis outbreaks. The first herd was the Washington State University herd of 150 cows which had a history of being mycoplasma mastitis free for 25 years as determined by bulk tank milk cultures. When a first bulk tank culture appeared positive, milk samples were collected and cultured from all cows currently with clinical mastitis and all cows with recent cases of clinical

mastitis. None of these milk cultures identified cows with mycoplasma mastitis. Next, milk samples were collected from all lactating cows and then cultured; a cow with subclinical mycoplasma mastitis was identified. This cow was kept with the milking herd for approximately 10 days and then isolated; her milk was discarded after identification. Following identification of the infected cow, nasal swabbing solutions were collected from all animals on the dairy farm and it was determined that 54/353 (15.3%) of all replacements and adult cows were shedding the same strain of *M. bovis* as that causing subclinical mastitis. Yet no cases of mycoplasma disease were noted and no additional cases of mastitis developed. The herd appeared free of mycoplasma mastitis when the cow with the subclinical case was culled.

In a second recent outbreak in a commercial herd of approximately 500 cows, 47 of 166 clinical mastitis cases were determined to be due to *M. bovis*. This *M. bovis* mastitis outbreak lasted 2 months. During the outbreak cows were culled from the commercial herd shortly after they were identified. At the beginning of the outbreak calves and cows suffered from polyarthritis and thick nasal discharge. A joint tap sample and a nasal swab sample had *M. bovis*. The outbreak was deemed to have passed when bulk tank milk sample cultures were negative for one month and when no new cases of clinical mycoplasma mastitis occurred during that time. A last report from this herd suggested that after a hiatus, new cases of clinical mycoplasma mastitis appeared but not nearly as severe as the initial outbreak.

There was a dramatic difference in the adherence to milking time hygiene techniques between the two herds. The WSU herd has a history of excellent contagious mastitis control procedures as evidenced by low milk somatic cell counts (mean less than 150,000 cells/ml) and no *Streptococcus agalactiae* and low prevalence of *Staphylococcus aureus*, consistently less than 3%. Contrarily, the commercial herd had a bulk tank somatic cell count that often exceeded 300,000 cells/ml and had a history of episodes of contagious mastitis. Clearly the *M. bovis* strain in the WSU herd was transmissible, having spread to more than 15% of the herd as evidenced by asymptomatic carriage in the nasal passages. However no new cases of mastitis developed. In the commercial herd the contagious mastitis control was specious and spread occurred amongst the lactating herd in the form of mastitis; no changes in milking time hygiene protocols were made and culling appeared to control the spread. Although it is difficult to make firm conclusions based on these two herd case histories, it does appear that in both herds the strain of *M. bovis* was transmissible and it seems that a difference in the outcome might have been tied to milking time hygiene techniques and contagious mastitis control practices. In the WSU herd the infected animal was culled, although by the time of culling the agent had spread to all age groups of animals on the farm and was carried asymptotically by more than 15% of the herd. Thus it could be argued that perhaps culling was an unnecessary control strategy in the WSU case, since widespread dissemination had already occurred. In the commercial herd where the owner/operator made no changes to contagious mastitis control procedures with the exception of selected culling of mycoplasma mastitis cows, transmission eventually diminished but was likely not eliminated. Perhaps culling mycoplasma mastitis animals helped reduce transmission. But there is more to the control of the dynamics of *M. bovis* disease and colonization in a herd than simply culling mastitis cases. Our experience in an earlier outbreak where culling cases of clinical mycoplasma mastitis and other mycoplasma diseases was that culling could not have possibly stayed ahead of transmission. In that case, the outbreak first manifested clinically as pneumonia in calves, later as mastitis in cows and as arthritis in calves, affecting a total of 8 animals clinically, but more than ten fold that number of animals as evidenced by asymptomatic carriage of the strain causing clinical disease (Punyapornwithaya et al., 2010).

A previous report questioned the importance of culling as a universal *M. bovis* mycoplasma mastitis control procedure (Punyapornwithaya et al., 2012). Clearly in both herds transmission of *M. bovis* occurred extensively before culling would have had an effect. In the WSU herd, excellent milking time hygiene could have contributed significantly to arresting the spread of the agent and isolated the case of mastitis to a single individual. But also clearly the agent had likely spread to all rearing areas on the farm as a significant number were asymptotically shedding it nasally. In the commercial herd, transmission had occurred to both calves and cows and caused disease other than mastitis, and such transmission preceded the implementation of the culling strategy.

So what arrested transmission of *M. bovis*? Although apparently the transmission on both dairies had been widespread, affecting calves and cows, the agent was only detected in a minority of animals. Either more were asymptotically affected but shedding the agent at levels below detection or most animals were not susceptible to carriage and/or disease. If the latter was true, then culling of cows could have reduced the exposure of the agent to other susceptible animals. Yet it is also possible that over time the infecting strain had changed genetically. This was seen in a more detailed case report (Punyapornwithaya et al., 2010). Alternatively, it maybe that specific immunity had developed within the animals in the herd, or perhaps a combination of induced *M. bovis* genetic alteration by immune reactions accounted for the cessation of the outbreak.

Conclusion

Mycoplasma mastitis might be difficult to diagnose and remains a problem affecting dairy cattle worldwide. Recent reports establish that replacement animals can act as asymptomatic, or perhaps symptomatic, carriers of a strain that causes mastitis in the herd. Although not conclusive, the data suggests that the strains associated with mastitis are passed on to the calf from the dam, as seen in Djordjevic and coworkers (2001) and Fox et al. (2008). Carriage of mycoplasma by cows and calves may be greatest during the outbreak, diminish over time, and thus may not be a threat to cause further disease, mastitis (Punyapornwithaya et al., 2010). The role of isolation of mycoplasma cows, either through segregation such as a hospital pen or culling, did not seem to hasten the abatement of new cases of mycoplasma mastitis in some illustrated cases. However, culling as the primary method of mycoplasma mastitis control appeared to be the most effective strategy in other reports. The initiation of an outbreak that follows the importation of cattle that occurs in herds deemed to have good to excellent milking time hygiene may be due to the fact that these intervention strategies fail to isolate a requisite number of asymptomatic carrying animals that would reduce the nidus of infection. Perhaps bovine immunity against the agent develops and is sufficient to contain the outbreak over time. *Mycoplasma sp.* in general, *M. bovis* in particular, are highly transmissible agents and the primary methods of control should focus on maintaining overall cattle health through nutrition and environment, and reducing the exposure to new strains by careful selection of how and when cattle are imported into the herd.

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Euthanasia Guidelines for Cattle

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The newest version of the AVMA Guidelines on Euthanasia is “*in press*” at the time of the preparation of these proceedings. Among numerous updates, one will notice that the revised version is more comprehensive than previous editions. Another change with this newest edition is that it will be a “living document”; that is, it will be on-line and in a format that will permit updating as new information becomes available. Other changes relative to the 2012 Guidelines include the development of separate documents for Mass Depopulation and Humane Slaughter. The Panel determined that it was necessary to develop separate documents for these topics since the techniques applicable to mass depopulation and humane slaughter do not always fit the definition of euthanasia.

In the following we have attempted to summarize the salient features of the AVMA Guidelines for euthanasia of cattle, including recent studies that did not make the deadline for inclusion in the revised version. One of these, by Dr. JN Gilliam et al., is particularly noteworthy since the information presented in this paper represents a major shift in current thinking on anatomical site selection for conducting euthanasia in cattle. A second study is that reported Dr. B. Wileman, et al. on firearm and munitions selection which supports observations from an earlier Canadian study indicating that the .22 LR loaded with a hollow point bullet lacks sufficient muzzle energy and physical characteristics to provide consistent results when used for the euthanasia of cattle.

In addition to proper application of euthanasia techniques, persons conducting euthanasia procedures need to understand the visual indicators of unconsciousness and the physical parameters that confirm death. Careful observation of these responses helps provide clues to the effectiveness of the euthanasia procedure and the possibility or likelihood of a return to sensibility. Proper interpretation of these responses is essential to assuring the welfare of animals that must undergo euthanasia.

There are many ways to induce death, but not all are humane nor would they fit the definition of euthanasia. Sometimes people resort to unapproved or unacceptable methods out of convenience and/or a failure to understand that the particular method applied does not induce a humane death. It is imperative upon all who work with livestock to be prepared for situations that might require euthanasia of an animal. But, having the right equipment and a thorough understanding of the technique does not assure humane euthanasia. Too many animals still experience horrible deaths simply because of inertia and indecision. We discuss just a few of the causes of euthanasia delays. Once the decision is made, euthanasia should be conducted with as little stress to the animal as

possible. This can be challenging as well as dangerous in some venues requiring tranquilization of some animals.

We conclude with a brief discussion of options for carcass disposal. This is no small concern as options for the disposal of carcasses have decreased markedly in many areas.

AVMA Guidelines on Euthanasia

Euthanasia means a “good death” whereby the methods applied to cause death induce an immediate loss of consciousness followed by cardiac and respiratory arrest and death without a return to consciousness. In the updated version of the AVMA Guidelines, euthanasia techniques are classified as 1) Acceptable, 2) Acceptable with Conditions, 3) Adjunctive, and 4) Unacceptable. Methods deemed “Acceptable” are those that consistently produce a humane death when used as the sole means of euthanasia. Those methods classified as “Acceptable with Conditions” are those that require certain conditions to be met in order to consistently produce a humane death. For example, techniques in this latter category might have greater potential for human error or injury and/or may require a secondary (adjunctive) step to ensure death. Although the “with conditions” qualifier suggests that these methods are less humane or not as suitable as those listed as “Acceptable”, in fact they are considered to be equivalent to those listed under the “Acceptable” category.

Methods classified as “Adjunctive” are those that should not be used as the sole method of euthanasia; rather they are to be used in conjunction with others to ensure death in animals previously rendered unconscious. And finally, methods classified as “Unacceptable” are those that are considered to be inhumane under any conditions.

Methods of Euthanasia in Adult Cattle

Methods recognized as appropriate for euthanasia of cattle are: 1) barbiturates and barbituric acid derivatives (“Acceptable”), gunshot and penetrating captive bolt (“Acceptable with Conditions”). Penetrating and non-penetrating captive bolt are suitable for euthanasia of calves. Whether used in mature animals or in calves penetrating captive bolt requires an “Adjunctive” method to assure death. These are described in greater detail below.

“Acceptable” Methods

Barbiturates and barbituric acid derivatives—Barbiturates are preferred by some because of their rapid action and ability to induce a smooth transition from consciousness to unconsciousness and death. Drawbacks to the use of these agents for euthanasia include: cost, the need for restraint to deliver the drug, necessity to maintain a careful accounting of amounts used, requirements that these agents be administered only by a veterinarian or personnel who are registered with the US Drug Enforcement Administration and finally, residues that limit carcass disposal options.

A question that frequently arises is: “*What happens to the fetus in pregnant animals euthanized by an overdose of pentobarbital*”? Research and clinical observation shows that barbiturates readily cross the placenta resulting in fetal depression; however death of the dam precedes death of the fetus by as much as 20-25 minutes. Fetal welfare is preserved by the fact that while *in utero*, the fetus is maintained in sleep-like state of unconscious. On the other hand, if removed from the uterus prior to

20-25 minutes post death of the dam, the fetus may regain consciousness. In cases involving euthanasia, any fetus removed from uterus prior to the amount of time required to cause death should be carefully observed for evidence of life and immediately euthanized if there is any doubt.

“Conditionally Acceptable” Methods

“Free Bullet” from Gunshot. A 2008 study by Fulwider found that gunshot is the most common method used for on-farm euthanasia of cattle. Death by means of a “free bullet” is caused by massive destruction of brain tissue. Despite its popularity and effectiveness for the purpose of euthanasia, those who are less familiar with firearms often find gunshot violent and objectionable. However, as stated in a previous edition of the Guidelines:

“Properly applied, “euthanasia by either gunshot or penetrating captive bolt, causes less fear and anxiety and induces a more rapid, painless, and humane death than can be achieved by most other methods.”

Penetrating captive bolt is also used for euthanasia of mature cattle in field situations. Unlike euthanasia with firearms, once the animal is rendered unconscious, an adjunctive method to insure death must be applied. Styles of penetrating captive bolt include an in-line (cylindrical) and pistol grip (resembling a handgun) versions. Pneumatic captive bolt guns (air powered) are limited to use in slaughter plant environments. Models using gunpowder charges are more often used in farm environments. Depending upon model, the bolt may automatically retract or require manual placement back into the barrel through the muzzle. Accurate placement of the captive bolt over the ideal anatomical site, energy (i.e. bolt velocity) and depth of penetration of the bolt determine effectiveness of the device to cause a loss of consciousness and death. Bolt velocity is dependent on maintenance, in particular cleaning and storage of the cartridge charges. Captive bolt guns should be cleaned regularly using the same or similar solvents used in the cleaning of firearms. Powder charges for the captive bolt should be stored in air tight containers to prevent damage from moisture in hot and humid conditions.

Non-penetrating captive bolt is not recommended for euthanasia of adult cattle. On the other hand, non-penetrating captive bolt is appropriate for euthanasia of calves when followed by the use of an adjunctive (secondary step) method to assure death.

Research on Firearm Use for Euthanasia of Cattle

Although the .22 LR is a popular caliber of firearm, results of a Canadian study suggest that it may not be the best choice for euthanasia of adult cattle because of poor penetration, deflection and fragmentation of the bullet. Standard and high velocity bullets fired from a .22 caliber rifle at a range of 25 meters (82 feet) failed to penetrate skulls of steers and heifers studied. These observations are corroborated by the results of a Kansas State University study by Wileman et al, designed to evaluate the characteristics of bullet penetration and brain tissue destruction using different calibers of firearms. In this study, researchers assigned disembodied heads of feedlot cattle to one of seven treatments: **1) .22 LR with a solid point bullet** (160 ft. lbs. or 217 Joules), **2) .22 LR with a hollow point bullet** (160 ft. lbs. or 217 Joules), **3) .223 rifle** (1183 ft. lbs. or 1604 Joules), **4) 9 mm handgun** (316 ft. lbs. or 428 Joules), **5) .45 caliber handgun** (551 ft. lbs. or 747 Joules), **6) 12 gauge shotgun with # 4 shot** (1769 ft. lbs. or 2398 Joules) and **7) 12 gauge loaded with a 1 oz. slug**

(4095 ft. lbs. or 5552 Joules). Cadaver skulls were shot from a fixed distance of 3 meters (approximately 10 feet). The anatomical site used was on the intersection of two lines each drawn from the medial canthus of the eye to the base of the opposite ear with the firearm directed toward the foramen magnum. Damage to the brain was determined by computed tomography (CT) using serial coronal scans at 3 mm intervals which were reconstructed at 1.5 mm intervals.

Results demonstrated that the .22 LR hollow point bullet had the poorest depth of penetration (107.5 mm) compared with other treatment groups which had a penetration depths of 150 mm. Only 33% of the 9 mm bullets caused damage to brain tissues sufficient to cause death. Greatest destruction of brain tissue occurred with the 12 gauge shotgun with #4 shot and the 1 oz. slug. Researchers concluded that the .22 LR with a hollow point bullet and the 9mm pistol could not be recommended based on this study.

A couple of points worthy of mention in regard to the above studies; first, when gunshot is used for the purposes of euthanasia, whenever possible the firearm should be held perpendicular to the skull and at a distance of no more than 2 to 3 feet away from the intended target. Reasons for these recommendations are to avoid ricochet and to take full advantage of the bullet's maximum muzzle energy. Obviously, this is not possible for an animal that is standing or mobile which is frequently the circumstance in feedlot conditions. In the studies cited above the distance of the shooters from their targets were 25 and 3 meters for the Canadian and US studies, respectively. As the distance away from the target increases so do the challenges for accurate shot placement, potential for ricochet and ability to maintain sufficient muzzle energy particularly when lower caliber firearms are used.

Recommendations on Firearms for Euthanasia

Handguns. Handguns or pistols are short-barreled firearms that may be fired with one hand. For the purposes of euthanasia, handguns are limited to close-range shooting (within 1 to 2 feet or 30 to 60 cm) of the intended target. Calibers ranging from .32 to .45 are recommended for euthanasia of cattle. Solid-point lead bullets are recommended over hollow points because they are more likely to traverse the skull. Hollow point bullets are designed to expand and fragment on impact with their targets which reduces the depth of penetration. The .22 caliber handgun is not recommended for routine euthanasia of adult cattle regardless of the type of bullet used, because of the inability to consistently achieve desirable muzzle energies with standard commercial loads.

Rifles. A rifle is a long barreled firearm that is usually fired from the shoulder. Unlike the barrel of a shotgun which has a smooth bore for shot shells, the bore of a rifle barrel contains a series of helical grooves (called rifling) that cause the bullet to spin as it travels through the barrel. Rifling imparts stability to the bullet and improves accuracy. For this reason, rifles are the preferred firearm for euthanasia when it is necessary to shoot from a distance. Rifles are capable of delivering bullets at much higher muzzle velocities and energies and are therefore not the ideal choice for euthanasia of animals in indoor or short range conditions. General recommendations on rifle selection for use in euthanasia of cattle include; .22 magnum, .223, .243, .270 and .308 and others.

Shotguns. Shotguns loaded with birdshot (lead or steel BBs) or slugs (solid lead projectiles specifically designed for shotguns) are appropriate from a distance of 1 to 2 yards (.9 to 1.8 meters). Although all shotguns are lethal at close range, the preferred gauges for euthanasia of mature cattle

are 20, 16, or 12. Number 6 or larger birdshot or shotgun slugs are the best choices for euthanasia of cattle. Birdshot begins to disperse as it leaves the end of the gun barrel; however, if the operator stays within short range of the intended anatomic site, the birdshot will strike the skull as a compact bolus or mass of BBs with ballistic characteristics on impact and entry that are similar to a solid lead bullet. At close range, penetration of the skull is assured with massive destruction of brain tissue from the dispersion of birdshot into the brain that results in immediate loss of consciousness and rapid death.

One advantage of euthanasia using a shotgun is that within close range and when properly directed, birdshot has sufficient energy to penetrate the skull, but is unlikely to exit the skull. In the case of a free bullet or shotgun slug there is always the possibility of the bullet or slug exiting the skull creating an injury risk for the operator or by-standers. For safety reasons it is important that the muzzle of a shotgun (or any other firearm) never be held directly against the animal's head. Discharge of the firearm results in the development of enormous pressure within the barrel that can result in explosion of the barrel and potential for injury of the operator and by-standers if the muzzle end is obstructed or blocked.

Captive Bolt

Penetrating captive bolt. In general, captive bolt guns, whether penetrating or non-penetrating, induce immediate loss of consciousness, but death is not always assured with the use of this device alone. Therefore, an adjunctive method such as a second shot, exsanguination, pithing or the intravenous injection of a saturated solution of potassium chloride (KCl) is recommended to ensure death when penetrating captive bolt is used. A newer version of penetrating captive bolt has emerged in recent years. This device is equipped with an extended bolt with sufficient length and cartridge power to increase damage to the brain including the brainstem. If studies prove this to be an effective 1-step euthanasia method, it will eliminate the need for an adjunctive method.

Unlike techniques described for gunshot, the animal must be restrained for accurate placement of the captive bolt. And, unlike use of a firearm, proper use of the captive bolt requires that the muzzle of the device be held firmly against the animal's head. Once the animal is restrained, discharge of the captive bolt should occur with little or no delay so that animal distress is minimized. Adjunctive methods should be implemented as soon as the animal is rendered unconscious to avoid a possible return to sensibility. Thus, when conducting euthanasia by captive bolt, pre-planning and preparation is necessary to achieve the desired results.

Visual indicators that an animal has been rendered unconscious from captive bolt or gunshot include the following: immediate collapse; brief tetanic spasms followed by uncoordinated hind limb movements; immediate and sustained cessation of rhythmic breathing; lack of coordinated attempts to rise; absence of vocalization; glazed or glassy appearance to the eyes; centralized eye position with a dilated pupil; and absence of eye reflexes. Nervous system control of the blink or corneal reflex is located in the brain stem; therefore, the presence of a corneal reflex is highly suggestive that an animal is still conscious.

Anatomical Landmarks for Euthanasia of Cattle

The objective in euthanasia is to cause sufficient damage to the brain to result in immediate loss of consciousness and death. Accomplishment of this objective requires the accurate delivery of a bullet or captive bolt at an anatomical site that is most likely to cause



Figure 1. Cadaver skull from an adult Holstein cow shot with a penetrating captive bolt. The shot was placed on the intersection of 2 lines each from the medial canthus (inside corner) of the eye to the opposite horn or top of the opposite ear (black arrow). Note that the bolt failed to enter the cranial vault (white arrow). Path of the bolt is rostral to the brain (Gilliam et al., 2012).

damage to the brainstem. In the past, most recommendations suggested that the ideal site was on the intersection of two lines each drawn from the medial canthus of the eye to the base of the opposite horn or top of the ear in polled cattle.

As early as 2008, Gilliam and others suggested that this site was in fact too rostral (i.e. toward the nasal region or muzzle) and unlikely to damage the brainstem (See Figure 1). In order to confirm this observation, Gilliam instituted a study to evaluate the likelihood of brainstem damage using penetrating captive bolt at two anatomical locations. Cadaver skulls from 15 cattle were divided into one of two groups. Group 1 was shot with the penetrating captive bolt on the intersection of two lines each drawn from the medial canthus

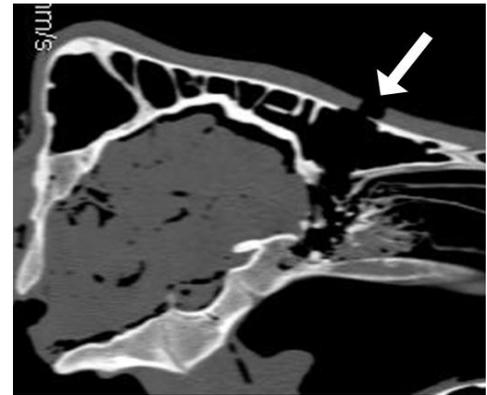


Figure 3. Computed tomography image of a bovine skull shot with a penetrating captive bolt showing the bolt path (white arrow) too far rostral to disrupt the brainstem (Gilliam et al. 2012).

of the eye to the opposite horn or top of the opposite ear. Group 2 was shot at the intersection of two lines each drawn from the lateral canthus of the eye to the opposite horn or top of the opposite ear. The actual tract (or path) of the bolt for each respective location was determined by computed tomography and physical observation of the brain and brainstem. Evaluation of the skulls from Group 1 demonstrated that the bolt failed to make contact with the brainstem in all skulls studied (See Figure 2). In Group 2, the bolt was observed to cause significant damage to the brainstem in 6 of 8 skulls studied (See Figure 3). These results, although preliminary, indicate that the higher anatomical site improves the likelihood of causing damage to the brainstem. However, these data also suggest that some adjustment of this site is still necessary to achieve consistent results. This study is continuing with plans to assess age and

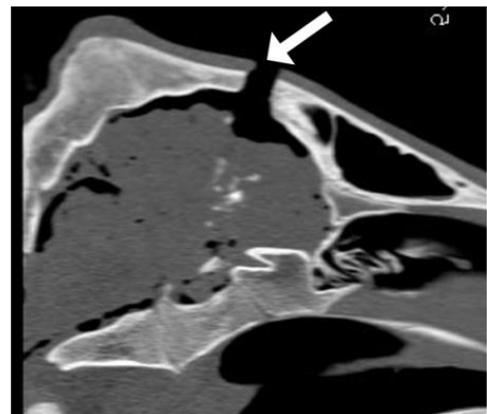


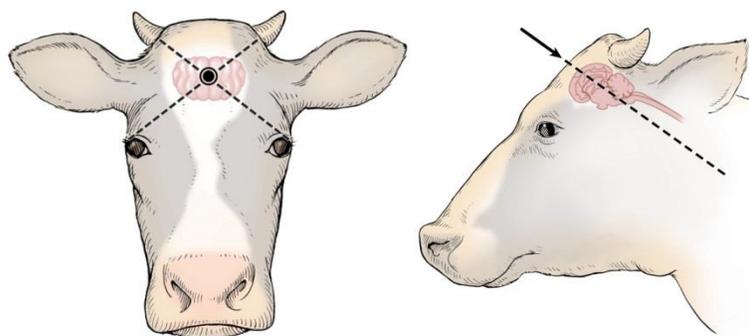
Figure 2. Computed tomography image of a bovine skull shot with a penetrating captive bolt showing the bolt path (white arrow) disrupting both the cerebral cortex and brainstem (i.e. bolt path is indicated by bone fragments pushed into the brain, Gilliam et al 2012).

breed differences for determination of the best anatomical site for conducting euthanasia in cattle.

Anatomic landmarks for use of the penetrating captive bolt and gunshot. Based upon current information in cattle, we suggest that the point of entry of the projectile should be at (or slightly above) the intersection of two imaginary lines, each drawn from the outside corner (lateral canthus) of the eye to the center of the base of the opposite horn. If a firearm is used it should be used within 3 feet of the target when possible and positioned so that the muzzle is perpendicular to the skull to avoid ricochet. When using penetrating captive bolt, operators are advised to restrain the head so that the captive bolt may be held flush with the skull.

In all cases, proper positioning of the firearm or penetrating captive bolt is necessary to achieve the desired results. As suggested earlier, persons using captive bolt are advised to prepare for the application of adjunctive methods to assure death as soon as possible following confirmation that the animal is unconscious. It is also important to consider positioning of the captive bolt device. Directing the bolt toward the foramen magnum will likely improve results particularly when placement of the device is slightly rostral.

Figure 4—Anatomic site for gunshot or placement of a captive bolt and desired path of the projectile in bovids.



Poll Stunning

Many people assume the poll (the highest point on the skull) is a proper site for conducting euthanasia procedures with either gunshot or penetrating captive bolt. In fact, this site is not advised since studies indicate that the depth of concussion in this region is less than that observed with frontal sites. Furthermore, research indicates that the use of penetrating captive bolt at the poll is more prone to operator error and misdirection of the bolt into the spinal cord instead of the brain. Conversely, for large bulls and water buffalo use of the frontal site is not always effective because of the thickness of the hide and skull in this region. Use of the poll position can be effective if the appropriate captive bolt gun is used and when the muzzle is directed so that the discharged bolt will enter the brain; but this site is not recommended for routine use.

Unacceptable Methods

The methods of euthanasia deemed unacceptable include: 1) manually applied blunt force trauma (as with a large hammer), 2) injection of chemical agents or other substances not specifically designed

or labeled for euthanasia (i.e. disinfectants, cleaning solutions, etc.), 3) air injection into the vein, 4) electrocution as with a 120 volt electrical cord, 5) drowning, 6) exsanguination of conscious animals, and 7) deep tranquilization as with xylazine or other alpha-2 agonist followed by potassium chloride or magnesium sulfate. While some have been forced out of desperation to resort to one or more of these methods, readers are strongly advised against their use. Several of these methods are known to result in a less than humane death and for others the level of pain or distress associated with these methods is unknown. For example, use of xylazine to create a deep state of tranquilization followed by the rapid administration of KCl is used by some veterinarians. The position of the AVMA is as that stated in Goodman and Gilman's Pharmacological Basis of Therapeutics, 11th Edition: "Although large doses of alpha-2 agonists can produce a state resembling general anesthesia, they are recognized as being unreliable for that purpose." Therefore, until such time as we have better information on this method in terms of its ability to cause a humane death, it is best to utilize alternate techniques.

Confirmation of Death

Regardless of method used for conducting euthanasia procedures, it is important to confirm death. It is sometimes more easily said than done. However, the most reliable criteria include lack of pulse, breathing, corneal reflex and response to firm toe pinch, inability to hear respiratory sounds and heart beat by use of a stethoscope, graying of the mucous membranes, and rigor mortis. None of these signs alone, with exception of rigor mortis, confirms death.

The Impediments to Timely Euthanasia

No one enjoys the task of euthanasia or really wants to do it. This is especially so for a livestock owner faced with the task of euthanizing his/her own animal. Employees face similar problems in conducting these procedures and for the same reasons. Some develop close attachments for the animals within their care. The physical methods of gunshot and penetrating captive bolt are inherently violent. While this is a significant deterrent in itself; in addition, many people are unfamiliar with the proper use of firearms, let alone captive bolt. Sometimes the question that prevents moving forward with timely euthanasia is related to an uncertain prognosis. Diseased and/or injured animals often exhibit conflicting signs; it's not always a black or white decision as to whether or not euthanasia is indicated. The opportunity to error on the side of waiting too long looms large.

The consequence of early euthanasia is largely economic and delaying it prolongs animal suffering. Veterinarians play a key role in assisting folks with these decisions and should be consulted whenever there are doubts as to whether euthanasia is warranted. When necessary or desired, veterinarians can intervene and relieve their clients of the burden of conducting the task on an animal to which they are emotionally attached. Euthanasia decisions can be complicated and some will undoubtedly be haunted by those lingering questions for which some might find consolation in the words of Dr. Bernard Rollin, Professor of Philosophy and Bioethics at Colorado State University, "*Better a week too early than a day too late*".

Considerations for Conducting the Procedure

Persons conducting euthanasia procedures should attempt to minimize animal distress. If animals are accustomed to human contact the presence of a familiar person may be reassuring and reduce anxiety. For animals that are not accustomed to human contact, gunshot may be the best option for euthanasia simply because it can be delivered with the least amount of human contact. In some cases tranquilization may be necessary to quiet a frightened or anxious animal.

Cattle should be approached quietly and restrained only as necessary to properly conduct the procedure. If the animal is ambulatory and able to be moved without causing distress, discomfort or pain, it may be relocated to an area where the carcass may be more easily reached by removal equipment. Dragging of non-ambulatory animals is unacceptable. In cases where movement of a down animal would increase distress or animal suffering, the animal should be euthanized first, and then moved following confirmation of death.

Euthanasia of Injured or Recumbent Cattle on Enclosed Trailers

Not all cattle requiring euthanasia are found in the farm or ranch setting. Some are the consequence of livestock truck roll-over accidents or cattle injured in the process of hauling to a market or packing plant. Whenever an animal is down and unable to voluntarily walk off of a trailer, it may become necessary to euthanize the animal prior to removal. Since entering the trailer with a fractious animal (dairy bull or beef animal) might put a person at considerable risk, and gunshot is unsafe and possibly restricted by local ordinances, tranquilization of the animal is necessary. This can be accomplished by a veterinarian with a medicated dart from either a pistol or rifle, or by use of a “pole syringe” of sufficient length to deliver the tranquilizer from across a barrier between the operator and the agitated animal. Xylazine dosed at 0.3 to 0.5 mg/lb. (3 to 5 CC of 100mg/ML /1000 lbs.) is usually sufficient to render the animal safe to approach.

Readers are cautioned that although this is a larger dose than that one would normally use, the combination of administering the drug to an anxious animal plus delivery via a dart or pole syringe makes the end result less predictable. Following administration of the xylazine, leave the animal undisturbed for the 15 to 20 minutes required for the xylazine to take full effect. Once the animal is sufficiently tranquilized it may be approached for application of the penetrating captive bolt with adjunctive procedures to ensure death. The primary concerns in these situations are human, animal and food safety.

Carcass Disposal

Euthanasia presents another issue that people frequently fail to consider – disposal of the carcass. In North America, there are plenty of coyotes, buzzards and other scavenging animals willing to assist with carcass removal. This seems a natural way to dispose of an animal carcass; it serves the purpose of disposing of the carcass and provides food for the scavengers. This practice may be acceptable on large acreages, especially those without nearby neighbors and areas containing upland woods and brush. However, this natural method isn't permitted in most areas, and some scavengers become predators when carcasses are less available. This places newborn calves and other animals weakened by disease or other maladies at risk of predation. Most cattle producers are well aware that coyotes can take a significant toll on newborns. In dairy operations, calves may be attacked at

birth or later when confined to a small pen or hutch. In either situation, they are easy prey for a coyote. Furthermore, a proper method of carcass disposal is needed to prevent the spread of infectious and/or contagious disease. Finally, as described earlier, when barbiturates are used for euthanasia wildlife may be at risk from the consumption of carcasses with drug residue that may be deadly. Penalties for the accidental killing of endangered animals are severe and include incarceration as well as huge fines for persons convicted of the offense.

The problem is that socially, economically and environmentally acceptable methods of carcass disposal have become increasingly difficult to find. In the United States the disposal of animal carcasses is regulated by state and local laws that vary widely according to animal species. The most common methods for disposal of animal carcasses are burial, composting, incineration and rendering. Less common methods would include landfills and tissue digestion.

Advances in analytical chemistry have led to increasingly sensitive assays for multiple drugs and antimicrobials. The ability of these technologies to identify residue at extremely low levels has also continued to increase the scrutiny of rendered product end users. Today, acceptable levels are no longer acceptable, for many if not most, only zero tolerance will do. The result is a rendering industry that is much less accepting of the carcasses of animals euthanized by barbiturates. Therefore, the first choice recommendation for carcass disposal of animals euthanized by pentobarbital overdose is incineration or cremation; but cost precludes this from being an economically viable consideration for carcass disposal in most of today's commercial farm operations. The next best option is burial of the animal sufficiently deep to avoid being exhumed by scavengers. This must be conducted in accordance with State and local laws to assure no contamination of ground water sources. When the ground is frozen, carcasses must be carefully covered and stored until such time as burial may be possible.

Composting is another means of carcass disposal that is becoming increasingly more common. Although studies are few, most report the persistence of barbiturate residues in composted material. For these reasons, the physical methods of gunshot and captive bolt are far more attractive for euthanasia of livestock. Even when adjunctive methods such as the rapid intravenous administration of potassium chloride are used to assure death there are no worries for rendering or composting. In short, while there are many within the veterinary profession that find gunshot and penetrating captive bolt violent methods and therefore less desirable, when they are properly conducted they are very humane, cost-effective and do not pose residue risks.

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Notes:

Avoiding Residues: More than Meat and Milk

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Introduction

This paper will focus on aspects of manure management related to the fate and transport of pharmaceuticals to the environment. The intent of this summary is to bring awareness of the potential impact of manure on the environment, and practices which can minimize that risk. We have chosen to use selected publications that will highlight the complexity of addressing management of pharmaceuticals

Fate and Transport of Pharmaceuticals

Manure is a biologically active material which hosts and supports many microorganisms, and thus can seldom be considered “pathogen free”. Certain manure handling techniques and methods however can limit the production and multiplication of such pathogens. In addition, common antibiotics and hormones have also been documented in animal manures. Awareness and risk assessments must be considered in developing best management practices and policy related to manure handling.

Antibiotics. The fate of antibiotics used at concentrated animal feeding operations (CAFOs) has gained recent attention by the regulatory community. Watanabe et al. (2010) reported the occurrence of antibiotics in the environment on two dairies. Samples were collected at the points of use of antibiotics and subsequent points of manure handling. They observed that although antibiotics had been used for decades on these two dairy farms, the antibiotics seemed to be detected within farm boundaries. Antibiotics were most frequently detected at lagoons, hospital pens, and calf hutches. Some evidence of sulfonamides was found in shallow ground water, while tetracyclines were identified in soils. Each of these antibiotics has distinct physiochemical properties. Sulfonamides are known to weakly sorb to soils, while tetracyclines have a higher sorption, thus explaining the

difference in location of detection. Lincomycin was found in ground water at one dairy, but not in the lagoon water at that same dairy. The authors suggest that due to Lincomycin's environmental persistence could explain the observation since it has photochemical and microbial stability. Evaluation of field surface samples demonstrated the presence of antibiotics on fields where manure had been applied, but not in the sandy subsoil.

Davis et al. (2006) studied the potential of seven antibiotics (tetracycline, chlortetracycline, sulfathiazole, sulfamethazine, and erythromycin, tylosin, and monensin) to appear in runoff water and sediment. The seven antibiotics were applied to land that had been prepared for corn production and then exposed to simulated rainfall. They observed that monensin had the highest concentration in runoff, while erythromycin had the highest concentration in sediment. Tetracycline and chlortetracycline had the lowest aqueous concentrations, and lowest absolute losses. The results suggest that erosion control practices would minimize the loss of tetracycline, erythromycin, and tylosin; while other methods would be needed to reduce off-site transport of the other four antibiotics.

The environmental occurrence and shallow ground water detection of monensin was studied by Watanabe et al. (2008). Monensin is expected to persist in the environment since hydrolysis and photolysis is limited (cited by Watanabe et al., 2008). In addition, monensin is expected to be more mobile than tetracyclines and of similar mobility to sulfamethazine (cited by Watanabe et al., 2008). Monensin was detected in one of eight shallow ground water wells at dairy I and three of eight wells (2 – 5 meters) at dairy II. The wells affected were associated with the lagoons, but not fields where manure was applied. The lagoons at both dairies were > 30 years old, were lined with 10% clay, but had previously been identified as leaking. The authors suggest that anoxic conditions near the lagoons (lack of oxygen) may promote the stability of monensin, while aerobic field conditions would promote degradation of monensin.

Antibiotic Resistance. Resistance of bacteria to antibiotics continues to be a concern of medical health professionals and veterinarians alike. Reducing the effectiveness of proven antibiotics would be costly for meat, milk, and egg production; and, potentially increasing the risk for bacterial infections insensitive to common antibiotics in humans. West et al., (2010) documented the presence of antibiotic resistant bacteria in samples from waterways in close proximity to waste-water treatment plants and CAFOs. From 830 environmental bacterial isolates, 77.1% were resistant to only ampicillin, while 21.2% were resistant to combinations of antibiotics including ampicillin (A), kanamycin (K), chlorotetracycline (C), oxytetracycline (O), and streptomycin (S). Multi-drug-resistant bacteria were significantly more common at sites close to CAFO farms.

There has been uncertainty as to when and, therefore, in what location that bacteria gain their ability to be antibiotic resistant? Does it occur in the animal's gut or in the environment? Two recent publications (Subbiah et al., 2012; and Subbiah et al., 2011) have provided some insight. Subbiah et al. (2011) evaluated 10 different antibiotics for their ability to be bioactive in soil. When ampicillin,

cephalothin, cefoxitin, ceftiofur, florfenicol, neomycin, tetracycline, and ciproflaxin were tested in soil-water slurries. It was observed that supernatants from soil-water slurries of ampicillin, cephalothin, cefoxitin, ceftiofur, florfenicol inhibited bacterial growth. In contrast, supernatants of soil-water slurries from neomycin, tetracycline, and ciproflaxin soil-water slurries did not inhibit bacterial growth. This study suggests that some antibiotics are not bioactive after contact with soil. A more recent report by Subbiah et al. (2012) suggests that urine containing ceftiofur metabolites is degraded more readily in warm soil (23 degrees C) but persists at 4 degrees C. The persistence under cool temperatures could provide a $> 1 \log_{10}$ advantage to cef^R resistant *E.coli* populations.

Hormones. Numerous studies have documented the presence of hormones in manure and their subsequent fate when manure is stored in manure lagoons or applied to crop land (Dutta et al., 2010; Khanal et al., 2006; Lorenzen et al., 2004; Raman, et al., 2004; Hansleman et al., 2003; Arnon et al., 2008; and Zhao et al., 2008). The general concern is the endocrine disrupting effects on wildlife and aquatic life when these hormones or conjugates are transported to ground and surface water. Endogenously (naturally) produced hormones excreted by humans and livestock, along with a host of compounds in human personal care products (ibuprofen, pigments, soaps), can disrupt endocrine system and have been linked with developmental, reproductive, neural, immune, and other problems in wildlife and laboratory animals.

Zheng et al. (2008) characterized the concentration of three endogenous hormones (17 alpha-estradiol, 17 beta-estradiol, and estrone) in dairy waste water and lagoon water. The concentration of total steroid hormones in the sequential lagoons was $\sim 1 - 3$ orders of magnitude less than in fresh dairy wastewaters. The same relationship was observed for steroid hormones in manure solids. Bartlet-Hunt et al. (2011) studied the occurrence of thirteen steroid hormones and seventeen veterinary pharmaceuticals at operating swine and beef cattle facilities. The facilities had lagoons that were known from prior studies to have direct infiltration of waste water into shallow ground water and represent a worst case scenario. Steroid hormones were detected less frequently than pharmaceuticals.

Treatment of manure via anaerobic digestion or composting can decrease the amount of estrogens detected in manure (Zhao et al., 2008). While there is still much to be learned, it is apparent that hormones or their conjugates have an ability to persist in the environment. This persistence can in part be explained by the lipophilic nature of hormones as they are poorly soluble in water and therefore would be absorbed onto sediment particles (Arnon, et al., 2008).

Best Management Practices

A number of currently used management practices serve to ameliorate the movement of pharmaceuticals from the point of excretion by the cow to the intersect of surface and ground water.

Grass Filter Strips. Nichols et al (1997) demonstrated that grass filter strips were effective in reducing the concentration of estradiol originating from poultry litter by 58%, 81%, and 94% after transport through filters of 6.1 meters, 12.2 meters, and 18.3 meters.

Composting. Windrow composting of poultry manure for 139 days resulted in a 84% decrease in 17beta-estradiol content and a 90% decrease in testosterone content (Haak et al., 2005).

Identify Readily Available Alternatives. One of the standard practices when producing ethanol from grain has been the use of antibiotics to control the fermentation. When antibiotics are added to fermentation vessels it allows for more efficient conversion of starch to ethanol. The ethanol industry has shifted toward use of non-antibiotic antimicrobial products to avoid the issue of antibiotic residues in distillers grains (Olmstead, 2012).

Anaerobic Digestion. Anaerobic digestion of manure (Zhao et al., 2008) and sewage sludge has been shown to result in reductions in pharmaceuticals.

Education Resources

The following webcasts and websites are recommended for further understanding of the factors related to pathogens and pharmaceuticals in manure.

- http://www.extension.org/pages/Potential_Routes_for_Pathogen_Transport_to_Water
- Animal Science Societies (FASS) hosted a webinar titled "Antibiotics in Animals and People" on October 20, 2010. http://www.fass.org/policy_webinar.asp
- <http://www.waterbornepathogens.org/>
- http://www.extension.org/pages/Manure_Pathogen_Articles
- Webinar – Antibiotics and Hormones: Occurrence in Water, Fate and Transport, and Best Management Practices.
http://www.extension.org/pages/Antibiotics_and_Hormones:_Occurrence_in_Water,_Fate_and_Transport,_and_Best_Management_Practices
- Veterinary Medicines in the Environment - http://toxics.usgs.gov/highlights/vet_meds.html

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Innovative Sources of Labor for Dairies Panel

The panel members will be:

Richard Greaves
Dairy Manager
T & K Red River Dairy
P.O. Box 189
Stanfield, AZ 85272
redriverdairy@cgmailbox.com

T&K Red River Dairy in Arizona is a modern dry lot facility using Saudi-style housing. It currently milks 10,000 cows with another 17,500 head of replacements and steers on a feed yard operation. The company farms about 10,000 acres and produces all the forage requirements for both operations and part of its grain. They also do custom harvesting, manure hauling and have a fleet of semis. They employ about 160 people between the dairy and feed yard operations with the rest of the company adding up to 230. They employ a multination work force from Europeans, like Richard, to Africans, Asians and Hispanics.

Richard came to T&K 17 years ago as an assistant manager when it was milking 3,600 cows. Since then, they have continued to expand building in 2006 the world's first double 77 parallel parlor. Prior to that, Richard had worked in the Middle East for 10 years on various sizes of operation, the largest of which has now grown to 30,000 cows. He is originally from the UK and started out on a typical grassland Dairy farm milking about 200 cows.

Bob and Joanne LaSalle
Owners, LaSalle Dairy
10663 Avenue 7 1/2
Firebaugh, CA 93622
boblasalle@aol.com

La Salle Dairy of Firebaugh, California has utilized interns through J-1 visa programs since 1986. Over 185 interns from over 49 countries have gained experience on Bob and Joanne La Salle's 660 milking cow herd of mostly Registered Holsteins. In addition to milking, feeding, and caring for the herd, interns gain experience by helping with the genomic testing and embryo transfer program. Weekly meetings are held with the interns to discuss management practices at La Salle Dairy, educational topics, and exchange of ideas with the interns.

Bob and JoAnne La Salle have worked with numerous programs that have provided interns over the years. These include CAEP, MAST, The Global Cow, and Experience International. The programs pre-screen the interns and arrange for the proper documents including the J-1 visa for the interns to work in the United States.

La Salle Dairy maintains a rolling herd of 27,000 lbs. of milk and 950 lbs. of fat on 3 times a day milking. La Salle's also grow wheat and corn silage on their 160 acres of farmland.

Jose Rojas
Vice President, Farm Operations
PFFJ, LLC
P.O. Box 398
Split Rock Falls, Suite B
Taylor, AZ 85939
jlrojas@pffjfarm.com

Jose was born in Mexico and attended ITESM (Tec de Monterrey) graduating with an Animal Science degree. He also attended ISU (Iowa State) obtained an MS in Animal Production. He started with Murphy-Brown (Murphy Family Farms at the time) in 1994. He worked in North Carolina for nine years mainly in the multiplication area raising replacement breeding stock and overseeing semen production for AI.

He started assisting with International recruiting from Mexico and employed folks from Poland and UK. He moved to Colorado in 2003 as Operations Manager for the business. Yuma operations have 30,000 sows and produced over 600,000 pigs to mainly source Murphy-Brown finishing operations in the Midwest. He started recruiting internationally for Murphy-Brown Western Operations in 2004. He recently took a new challenge with Hormel Foods and started on December 3rd as Vice President of Farm Operations based at Taylor, AZ

Panel moderator:
Steve Larson
Consultant
Hoard's Dairyman
1721 Turtle Mound Lane
Whitewater, WI 53190
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Some contact information

Here is a sampling of organizations or agencies involved with placing people from other countries on U.S. agricultural operations either as trainees or conventional employees. They have all had experience with dairy owners and managers.

J-1 Visa trainee programs

The Exchange Visitor Program (J-1 visa) fosters global understanding through educational and cultural exchanges. All exchange visitors are expected to return to their home country upon completion of their program in order to share their exchange experiences.

Experience International

P.O. Box 680
Everson, WA 98247
360-966-3876 Phone
Email: info@expint.org
Web: www.expint.org

Experience International invites trainees to experience the U.S. through a unique practical training program within their career or academic field. It will match trainees with a host in either the public or private sector to work alongside and learn from as they conduct their 3-18 month program.

MAST International

Sue Riesgraf
135 Skok Hall
2003 Upper Buford Circle
St. Paul, MN 55108
612-624-3740 Phone; 800-346-6278 Toll Free
Email: mast@umn.edu
Web: <http://mast.cfans.umn.edu>

MAST International is an international agricultural exchange program at the University of Minnesota providing practical and academic training in American agriculture. MAST is one of the oldest ag exchange programs having operated since 1949. It brings in 200 to 250 farm and horticulture trainees each year, with 25 to 40 of them on dairies ranging in size from 50 cows up to 5,000.

Communicating for Agriculture Education Program (CAEP)

Stephanie Sternhagen
112 E. Lincoln Ave.
Fergus Falls, MN 56537
218-739-3241 Phone; 800-432-3276 Toll Free
Email: steph@caep.org
Web: <http://us.caep.org>

CAEP Dairy Training Program participants get involved in most aspects of operation-milking, feeding, cleaning, record keeping, harvesting forage and grain, treatment of sick animals, and waste disposal/sanitation. Dairy Training Program participants may be involved with the hosts' breeding and nutrition program as well. Dairy set-ups have either a tie-stall/stanchion barn or a free stall or dry lot and parlor arrangement.

The Ohio Program (TOP)

Michael Chrisman
700 Ackerman Road. Suite 360
Columbus, OH 43202
614 292 7720 Phone; 614 688 8611 Fax
Email: chrisman.1@osu.edu

Web: www.ohioprogram.org

Under TOP's Program B, interns are scheduled to arrive at various times throughout the year for a twelve-month on-the-job training period. These interns are involved mainly in living and working on a farm or horticultural enterprise. There is no academic training. A vital part of the program is the attraction of training closely with a farming family. Daily life revolves around the farm business, varying with seasonal changes as to the training and activities required. Interns can expect long hours.

Other programs

International Rescue Committee

Stephen Allen
5227 N. 7th Street
Phoenix, AZ 85014
602-361-5351 Phone

Web: http://www.refugeeworks.org/about/links_refugee_agencies_local.html

(This site provides links to cooperating agencies in each state.)

The International Rescue Committee responds to the world's worst humanitarian crises and helps people to survive and rebuild their lives. Founded in 1933 at the request of Albert Einstein, the IRC offers lifesaving care and life-changing assistance to refugees forced to flee from war or disaster.

At work today in over 40 countries and in 22 U.S. cities, the IRC restores safety, dignity and hope to millions who are uprooted and struggling to endure. The IRC leads the way from harm to home. Recipients of IRC efforts have become employed on a number of dairies in the Pacific Northwest and Southwest, as well as other areas.

NAFTA TN Visa Program

For information: http://travel.state.gov/visa/temp/types/types_1274.html

The North American Free Trade Agreement (NAFTA) creates special economic and trade relationships for the United States (U.S.), Canada and Mexico. The nonimmigrant NAFTA Professional (TN) visa allows citizens of Canada and Mexico, as NAFTA professionals, to work in the U.S. in a prearranged business activity for a U.S. or foreign employer. North American Free Trade Agreement (NAFTA) creates special economic and trade relationships for the United States (U.S.), Canada and Mexico. The nonimmigrant NAFTA Professional (TN) visa allows citizens of Canada and Mexico, as NAFTA professionals, to work in the U.S. in a prearranged business activity for a U.S. or foreign employer. Approved job titles include labels such as "agriculturalist", "animal breeder", "animal scientist" and "dairy scientist".

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Managing Worker Safety, Productivity, and Regulatory Issues

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Introduction

More and more milk in the US is produced on larger operations. Fifty percent of the US milk is produced by less than 3% of the dairies – those with 1,000 cows or larger. Expanding production has required a larger workforce, primarily comprised of non-English speaking Latino workers (>90%) with minimal experience in agriculture. Dairy farming is among the most dangerous occupations, with high rates of injury, illness, and employee turnover. Many dairy owners and managers have not had formal training in employee management or occupational health and safety. Complying with health and safety regulatory standards while simultaneously training a predominantly non-English speaking workforce is a daunting challenge. In a highly competitive global market it is critical that dairy owners and managers have the knowledge, tools, and support needed to effectively address these challenges and sustain a healthy, productive workforce.

Background and Scope of Challenge

Production and Technology Trends in US Dairy Industry

Dairy production in the US has steadily moved toward a large-herd, high-efficiency model due to associated economies of scale [Reinemann, 2001]. Currently the United States ranks second (behind EU-27) among major dairy countries, producing 14.6% of the world's milk supply with an estimated 9.2 million cows [International Dairy Federation, 2010]. Milk production in the US has essentially quadrupled since 1944, producing 59% more milk with only 36% of the cows [USDA, 2012b]. Average herd size in the US is currently around 246 cows and ranges from 122 cows per herd in Pennsylvania to 1,906 cows per herd in New Mexico [USDA, 2009]. Between 2005 and 2009, farms with 1,000 or more cows increased 20%, driven by significantly lower costs of production. In 2005, dairy farms with 1,000 cows or more had average costs of production of \$13.59 per hundredweight of milk, 15% below the average for farms with 400-999 head and 35% below the cost for farms with 100-199 head. [MacDonald et al., 2009]. In 1998, nearly 70% of milk produced in the US came from small-herd operations (<500 head). By 2011, over 63% of milk produced in the US came from large herd operations (>500 head), and 34.6% came from operations of 2,000 head or more [NASS, 2012]. Combined, only 2.7% of dairies in the US, representing large herds of more than 1,000 head, produce 50.3% of US milk [NASS, 2012] Despite the increasing size, almost

all (94%) of the dairies in the US are family owned (79.1%) or in a partnership (14.8%), while only 6.1% are structured as a corporation and the remaining 0.5% is either in the form of a trust or an estate. The shift to large operations with many hired workers is a significant change for dairy operators. Larger dairies in the US typically employ one person for every 80-100 cows, not including farm labor needed to grow forage crops. Most of those hired workers are immigrants from Mexico, Central America and South America. Most have no experience in dairy and do not speak English. Recent technological advancements have led to the mechanization and automation of the entire milking process, including the utilization of milking robots. Dairy science research has led to significant advances in dairy practice, resulting in an optimization of cow milk production and efficiency. However, little research has addressed worker health and safety or worker productivity and efficiency.

Injury, Illness and Fatality in the Dairy Industry

The industrial sector of Agriculture, Forestry & Fishing (AgFF) consistently has among the highest fatality rate in the United States, about eight times the national average for all industries (26.0 per 100,000 full-time workers in 2009) [BLS 2010]. According to national estimates, the non-fatal injury rate for the AgFF sector was 5.1 per 100 workers in 2009 [BLS 2010]. The rates of non-fatal injuries are even higher on Dairy and cattle operations - 5.4 and 6.5 respectively [BLS 2010]. From 2003 through 2009, a total of 110 people were killed while working on US dairy farms [BLS 2009]. One of the most common causes of death and serious injury on farms is related to the heavy equipment required to run a dairy farm. A high number of farming fatalities are due to tractor turnovers. Other causes of fatalities include silage bunker collapse, manure pits, tractor power take offs (PTO) and large animals such as bulls. Recent studies show the two main causes of workers' injuries (fatal and non-fatal) are incidents with machinery and animals [Mitloehner 2008]. Machine-related accidents include tractor rollovers, being run over by tractors and being entangled in rotating shafts. Animal-related injuries include kicks, bites, and workers being pinned between animals and fixed objects. Researchers have identified dairy farming as having the second highest prevalence of injuries among all US agriculture groups [Boyle 1997, Crawford 1998, NIOSH 1993]. The majority of injuries originate from interactions with dairy cattle during milking activities [Pratt 1992, Boyle 1997, Waller 1992]. Other causes of injuries include chemical hazards, confined spaces, manure lagoons, use of power tools, and improper use or lack of personal protective equipment [Mitloehner].

Researchers at the High Plains Intermountain Center for Agricultural Health and Safety (HICAHS) completed two analyses of workers' compensation data among Colorado dairy workers [Doughrate 2006, Doughrate 2009]. Results indicated dairy workers had an injury claim rate of 8.6 per 200,000 work hours, higher than the national injury rate (6.2 per 200,000 hours) as reported by the Bureau of Labor Statistics (BLS) for 2003 [Doughrate 2006]. The largest percentage of claims involved the upper extremity (33.5%), and was caused by the cow (28.9%) during animal-handling activities. A second study focused on livestock-handling injuries [Doughrate 2009]. Nearly 50% of livestock-handling injuries took place in the parlor while performing a milking task. The highest percentage (27%) of injuries was to the wrist, hand, and fingers. The majority of livestock-handling injuries involved large operations (more than 10 workers), male, young, and less experienced workers.

Recent studies focusing on respiratory disease among workers on larger modern dairies are consistent with historical studies providing evidence of an association between lung disease and both the extent and duration of exposure to aerosols in dairies [Chaudemanche 2003, Eastman 2013,

Basinas 2012, Reynolds 2012]. Dairy workers experience lung conditions such as asthma, chronic obstructive pulmonary disease, hypersensitivity pneumonitis, and chronic bronchitis. The increased scale of dairy production with significant changes in technology and work practices, have altered airborne exposure patterns among dairy workers. There is some evidence that occupational exposure to inhalation hazards and the rates of lung disease may have been reduced with modernization. There is also strong evidence that new, inexperienced workers are at greater risk for lung disease, just as they are for injuries [Reynolds 2012].

HICAHS researchers conducted one of the first studies to examine the relationships between exposures to microbial containing aerosols (e.g. endotoxin from Gram negative bacteria), cross-shift changes in pulmonary function, and potential intrinsic (genetic) and extrinsic (behavior) effect modifiers of the exposure-response relationships [Reynolds 2012]. Stronger effects were observed among dairy and beef cattle workers compared to grain handlers. Evidence of larger cross-shift reductions in lung function was observed among those more highly exposed. Current smoking and the use of pesticides or herbicides increased the effects of dust inhalation on reductions in lung function. There was also limited evidence of the potential modifying effects of obesity, preexisting respiratory conditions, and the presence of genetic polymorphisms related to inflammatory reactions. New workers, who had not been exposed to these types of microbial agents, were also at greater risk of decreased lung function. Further evaluation of data from a larger population of dairy workers is under way. The results suggest that interventions to reduce lung disease among dairy workers need to include more comprehensive wellness programs in addition to exposure reduction strategies [Reynolds 2012].

Stress has also been shown to be a major concern for both dairy workers and managers [Fetsch 2009]. Suicide is among the top causes of fatalities on CO farms and ranches, and this is a consistent problem throughout US, UK, Canada, and Australia [National Vital Statistics Reports 2008]. Western mountain states have some of the highest levels suicides. In addition to contributing factors such as economic pressure and isolation, farmers and ranchers have ready access to the means to commit suicide. This was highlighted in the mid 2000's when a review of U.S. poison center data found that close to half of the fatalities from Mycotil (an injectible drug for cattle) were determined to be suicides [Von Essen 2003, NIOSH 2003, Oakes 2008]. The human and economic impact of illness, injury, and fatalities on the dairy industry is significant. In an industry with low profit margins and highly volatile global markets, reducing employee turnover, and direct and indirect costs may make the difference in survival.

HICAHS and the NIOSH AgFF Centers

Programs and Approach

In 1990 the US Centers for Disease Control and Prevention – National Institute for Occupational Safety and Health (CDC/NIOSH) launched a national effort to address the high toll of occupational hazards in agriculture, forestry and fishing (AgFF). A key component was the creation of regional centers with the mission to conduct research into the causes and programs for prevention of injury, illness, and fatalities. These centers are funded through highly competitive scientific peer review grant process. The High Plains Intermountain Center for Agricultural Health and Safety (HICAHS) was one of the earliest, initially funded in 1991, and is responsible primarily for the states of Colorado, Montana, North Dakota, South Dakota, Utah, and Wyoming

[<http://www.hicahs.colostate.edu>]. The NIOSH AgFF Centers bring together a diverse range of expertise including occupational medicine, exposure assessment, agriculture, engineering, education, economics, anthropology, veterinary medicine, dairy science, and others to provide a multi-disciplinary approach to solving the challenges in AgFF. HICAHS has been particularly known for its partnerships and engagement with Cooperative Extension.

HICAHS Dairy Programs

Over the past decade and particularly in the last five years, HICAHS has worked closely with the dairy industry to understand the causes and impact of work-related injuries and illnesses, develop and evaluate effective education and engineering interventions, and build a network of partners with capacity to address the global health and safety needs of the dairy industry. At the core of all projects and interventions has been a focus on stakeholder engagement and partnership building. The HICAHS approach to address health and safety on dairy farms is to LISTEN to dairy stakeholders, and RESPOND to expressed needs and concerns with *sound and relevant* research and outreach efforts.

Network Capacity Building

HICAHS researchers have worked diligently to engage dairy industry stakeholders to form partnerships for research, outreach, and translation/dissemination efforts. Strategic partnerships have been formed with representatives of US dairies and producer organizations. HICAHS researchers have also engaged industry-leading service and equipment companies to address health and safety on the dairy farm. HICAHS has formed collaborative partnerships to address the health and safety needs in the US as well as internationally. We are working closely with industry partners to design milking tools that will enable workers to perform milking tasks more efficiently, productively, and with reduced risk for the development of musculoskeletal disorders.

Research partnerships have been formed with domestic and international dairy researchers with the goal of increasing research capacity, and optimizing resources. We have partnered with the University of Texas Health Science Center in Tyler, TX (Southwest Ag Center), University of Iowa (Great Plains Ag Center), University of California Davis (Western Center for Agricultural Health and Safety), University of Nebraska (Central States Center for Agricultural Safety and Health), Wisconsin National Farm Medicine Center (National Children's Center for Agricultural Health and Safety) and University of Minnesota (Upper Midwest Agricultural Safety and Health Center) and with Dairy Extension programs in a number of states including New Mexico. Additionally, we have partnered with researchers at the Swedish University of Agriculture Sciences in Alnarp, Sweden, to form an International Dairy Research Consortium to address health and safety on dairy farms in the US, Europe and other dairy producing countries. New members of the consortium represent Italy, Germany, Denmark, Australia, Canada, Brazil, New Zealand, and Ireland.

Outreach to the Dairy Industry has been directed through the development and integration of three groups with expertise to assist HICAHS with research, prevention efforts and dissemination of materials. Multiple workshops have assisted with this process.

HICAHS partnered with the Southwest Ag Center to host two High Plains and Mountain Region Dairy Health and Safety Workshops in 2009 and 2011 in Denver, Colorado. Attendees included faculty from US and Swedish universities, dairy extension specialists (CO, TX, NM, SD, ND, IA,

and UT); dairy owners and managers (CO, TX, NM, and SD); dairy equipment manufacturers, workers' compensation providers, and dairy producer organizations (CO, TX, and NM). The workshop enabled the identification and prioritization of dairy worker health and safety issues, and generated recommendations and strategies for dealing with the challenges of addressing worker health and safety.

Through stakeholder engagement, the HICAHS Dairy Advisory Board has been formed. Made up of dairy producers, extension specialists, and equipment manufacturers, the Board guides and directs all HICAHS dairy-related projects, as well as serves as a medium for dissemination of findings.

In response to these workshops and in concert with the HICAHS Dairy Advisory board, a major effort is to develop a regional Dairy Health and Safety Network. Goals include: 1. Creating mechanisms for improved multi-directional communication between researchers and producers, and 2) Development of a structure to efficiently disseminate information on evidence-based practices (Research To Practice - R2P) to improve health on dairies. The Network to date consists of numerous producers and extension specialists in 10 states, equipment manufacturers, collaborating researchers at other Ag Centers, and producer organizations.

Established partnerships such as those listed above have provided opportunities for outreach efforts with dairy owners, managers and workers, enhanced HICAHS research opportunities and enabled the successful execution of R2P and dissemination efforts.

Needs Assessment

Feedback from the two regional workshops, advisory board meetings, and surveys of Dairy managers and workers has identified a number of key priority issues or needs including:

- Resources for developing health/wellness programs (e.g. immunizations).
- Community integration and acceptance.
- Communication, awareness and training in relation to chemical and drug exposures.
- Owner and worker awareness about hazards of equipment and animal handling.
- Awareness and training regarding personal hygiene.
- Awareness of transmission of infectious agents from animals to people.

Heading the list of concerns are four major areas:

- Stress affecting both managers and workers
- The need for effective worker training
- Immigration issues
- The need for management training and tools

HICAHS has refocused research and programs to address these issues, including bringing on new faculty expertise (cultural anthropology, occupational health psychology) and building new partnerships. Short term efforts have included providing training for producers on the Occupational Safety and Health Administration (OSHA) and on management approaches such as Lean Six Sigma. Longer term efforts to develop Occupational Health and Safety Management Systems and effective worker training programs are in progress. HICAHS continues to focus on building partnerships to facilitate the sharing of knowledge and resources.

A few examples of current HICAHS programs are described below. Further information, including links to resources can be found at www.HICAHS.colostate.edu

Research

Current projects focus on better understanding of risk factors associated with adverse health outcomes, and development and testing of effective interventions for prevention and control. One current intervention effort concentrates on specific milking tasks and how to most cost-effectively reduce their associated ergonomic exposures. Researchers have partnered with dairy producers, equipment manufacturers and extension specialists to identify specific ergonomic interventions (i.e. lightweight milking cluster, udder preparation tool, varying pit heights) to reduce risk factors in the milking parlor that are associated with the development of musculoskeletal disorders.

Dissemination of Knowledge

HICAHS has worked with industry partners to implement a more immediate response to the need for management training and information about regulatory activities of the Occupational Safety and Health Administration (OSHA). HICAHS partnered with the I-29 Dairy Consortium to sponsor five health and safety workshops for the regional dairy industry entitled *What You Need to Know About OSHA Before OSHA Needs to Know About You*. HICAHS enabled a partnership with Utah State University and Utah Dairy Extension to offer a two-day workshop entitled *Agriculture Safety Management Using Lean Six Sigma*. HICAHS also partnered with a leading manufacturer of dairy equipment, to offer a one-day workshop entitled *Worker Safety on Dairy Farms: How Does OSHA Apply?*

HICAHS researchers have disseminated relevant dairy-related health and safety information to producers via extension newsletters (e.g. New Mexico State University Dairy Extension Newsletter, Utah State University Dairy Extension Newsletter), Ag Center newsletters (e.g. AgConnections), and producer trade publications (e.g. DeLaval Environmental, Health & Safety Newsletter). Additionally, HICAHS researchers have published dairy-related research findings in several high-impact, peer-reviewed academic journals.

HICAHS has also collaborated with the Southwest Ag Center and New Mexico State Dairy Extension to develop and evaluate a safety training DVD (in English and Spanish) entitled *Considering Human and Animal Safety—Dairy Safety Training for New Mexico Dairy Producers*. HICAHS provided funding and personnel to collaborate with the Colorado Livestock Association to develop and evaluate the DVD *Creating Safety Culture in Livestock Operations*, English and Spanish Versions. Another effort of importance for the dairy industry is the development and implementation of training programs and materials for agricultural users of ATVs in partnership with Montana Extension.

These programs have been informed by HICAHS research into effective training methods and their impact on injury reduction. A key study of workers interviewed on 15 volunteer large dairies found that safety information presented within the context of task-related training, rather than provided as a separate training experience had an apparent protective effect against injury [Roman-Muniz 2006]. Safety information seen as valuable, meaningful and relevant to everyday experiences should enhance adult learner motivation, and aid with the processes of memorization and recollection in

older students. This study also suggests that incorporating appropriately trained co-workers into training efforts could be very beneficial to training programs. The effectiveness of these interventions should be assessed by conventional objective data (injury rates and the severity of work-related injury pre- and post-intervention) as well as by querying participant workers and dairy operators on such parameters as scope and depth of training, continuation of training, language of delivery, and the cultural sensitivity of delivery.

Worker training programs, OSHA awareness and compliance are important steps to managing occupational health and safety risks, but they are only components of a more systematic approach that is needed to sustain a healthy, productive workforce at the same time that cow health and productivity are addressed.

Risk Management

Occupational Safety and Health Regulation – OSHA

The Occupational Safety and Health Administration (OSHA) was created by the US Congress with the OSHA Act in 1970. The agency is part of the US Department of Labor and is tasked with helping to sustain a healthy U.S. workforce through development and enforcement of occupational health and safety regulations, and through provision of consultation services. About half of U.S. states operate their own OSHA programs, and state programs may go beyond the basic federal program. The OSHA Consultation programs are not as well known as the regulatory aspects of programs, but have become a valued asset in many states. The OSHA Voluntary Protection Program (VPP) provides recognition of companies where management, labor and OSHA work cooperatively and proactively to prevent fatalities, injuries and illnesses through a systematic program.

VPP participants are exempt from OSHA programmed inspections while they maintain their VPP status. While there has been a widespread belief that OSHA does not regulate agriculture, that perception is certainly changing as farms and ranches grow into operations with large workforces.

The California Occupational Safety and Health Administration has been particularly active in engaging the Dairy industry for more than a decade. Nationally OSHA (both federal and state agencies) has become much more active in the past few years, particularly following fatalities. A recent article in the Hoard's Dairyman (March 2012) summarized the most common dairy violations in California, based on inspection reports from CAL-OSHA:

1. Not having a written and active Injury Illness Prevention Program that workers are aware of, trained for, and kept informed about.
2. Not having a written and active Heat Illness Prevention Program that workers are aware of, trained for, and kept informed about.
3. Not having employee washing and toilet facilities that are in good working order.
4. Open electrical boxes and circuit breakers, missing wire insulation, or circuits not properly labeled.
5. Not having adequate sanitary and accessible first aid supplies.

6. Not immediately (within eight hours) reporting any serious worker injury or death to the district OSHA office.
7. Failing to provide hazardous materials training and protection devices to employees or not maintaining material safety data sheet (MSDS) binders.
8. Failing to have and display a copy of the Permit to Operate Air Compressor sheet at each permanent and portable pressurized vessel on the farm.
9. Not having a written and active Control of Hazardous Energy Program that workers are aware of, trained for, and kept informed about.
10. Failing to operate and maintain equipment safety. Typical violations include not having PTO guards, rollover protective structures, or seat belts; jumping off equipment; and having extra riders on equipment.

These are similar to violations on dairies in other states. Prevention of most of these violations is straightforward. Fines can be costly – in some cases exceeding five figures. Fatalities related to manure handling in California dairies gained national attention through a series of article in the NY Times in 2004. In an extreme example one dairy farmer was charged with involuntary manslaughter in the 2001 deaths of two workers, based upon alleged violations of California's permit-required confined space regulations. After a 3 year trial the dairy farmer was acquitted. The Times showcased this prosecution in a three-part front page series in 2004. Although this scenario is rare, it does demonstrate the extreme emotional and financial impact that severe injury or fatality has on a dairy operation and its people.

OSHA attention to the dairy industry nationally is accelerating and it is important for the Dairy industry to not only understand how OSHA operates, but to become proactively involved in helping craft regulations that are appropriate and applicable to dairy operations. It is important note that compliance with OSHA is setting the risk management bar low.

Comprehensive/Integrated OHS Management Systems

Occupational Health and Safety Management Systems (OHSMS) have gained wide acceptance in many industries, and are becoming mandated on a global level. OHSMS programs share characteristics and should be integrated with other accepted management systems such quality and environmental management. The goal of OHSMS programs is to achieve safety and health excellence including continuous quality improvement. They are driven by management commitment and employee involvement, and must be a part of every task so that health and safety becomes a way of doing business. Health and safety management *systems* are different from S&H *programs*. Systems are performance-based, programs focus on compliance. Systems have an evaluation feedback loop to improve performance. OHSMS follow the Plan-Do-Check-Act (PDCA) model of continual improvement. PDCA, as defined by the EPA includes:

- Plan: Planning, including identifying environmental aspects and establishing goals
- Do: Implementing, including training and operational controls
- Check: Checking, including monitoring and corrective action
- Act: Reviewing, including progress reviews and acting to make needed changes to the system.

A successful OHSMS depends on full management commitment to achieving S&H excellence and relies on the creation of a culture of safety and health encompassing beliefs, norms, values, and work practices of managers and employees.

There is evidence that OHSMS or Environmental Health and Safety Systems make good business sense, although there is little critical evaluation in the peer reviewed literature and no published evaluation of OHSMS in Dairies [Linhard 2005]. Effective management and implementation of workplace safety and health programs add significant value to individuals and companies by reducing the extent, severity and consequences of work-related injury and illness. Workplaces that establish safety and health management systems reduce their injury and illness costs by 20 to 40 percent. Businesses spend \$171 billion a year on costs associated with occupational injuries and illness, expenditures that come straight out of company profits and can comprise as much as 5 percent of a company's total costs. Achievements of a successful OHSMS include: Lowering injury and illness rates; Decreasing workers' compensation costs; Reducing lost workdays; Limiting equipment damage and product losses; Increased productivity; Higher quality products; Increased morale; Better labor/management relations; Reduced turnover; Better use of human resources.

A number of tools developed for other industries allow an employer to calculate the average cost of an injury or illness and project the number of sales the organization would have to make to cover the indirect cost of an injury or illness, and to determine the impact and profitability to her/his organization. In addition, there is software available to organizations that also includes environmental aspects that can be used to show how ES&H affects the bottom line. One resource is OSHA's Safety Pays Program that can be found at www.osha.gov. This site also allows the employer to download and use OSHA's "Safety Pays" Expert System. This program was not designed for the dairy industry, but the basic components should be useful.

Federal OSHA has indicated that their top priority for the near future is to pass regulations requiring all U.S. establishments to develop and implement an OHSMS. CAL OSHA has required a version called the Injury and Illness Prevention Program (I2P2) since 1991. The OSHA OHSMS will likely be based on the American Industrial Hygiene Association (AIHA) and the American National Standards Institute (ANSI) voluntary standard Z10-2005 and OSHA's 1989 guidelines. From a risk management standpoint OSHA is a minimum "bar" – international competition and the challenges facing the dairy industry will require a higher bar. Worker health/productivity must be an essential component of Animal health/productivity, Food Safety, Environmental compliance, Profitability and Sustainability of the business.

Conclusion

As modern dairy operations around the world expand, farmers have become increasingly reliant upon immigrant workers to milk cows and perform other essential tasks on the farm. Optimal dairy farming management should address milk production that is sustainable and responsible from the animal welfare, social, economic and environmental perspectives (*Guide to Good Dairy Farming Practice*) [FAO and IDF 2011]. Each of these aspects is interdependent with each other and with a sustainable, healthy, productive workforce. Physical health and well-being of owners, managers or hired labor are not often proactively addressed on modern dairy farms. There are very few studies addressing effective risk management in the dairy industry. Managers on expanding dairy farms struggle with the transition to human resource management, expressing difficulty and low

satisfaction with this aspect of farm management. There have been a few limited studies suggesting that labor management practices are a potential competitive advantage for dairy farms, but the connection with productivity and profitability has not been clearly demonstrated. The Transformational leadership style (exhibiting: idealized influence, inspirational motivation, intellectual stimulation and individualized consideration) has been associated with improved safety climate and reduced incidence of injury. On the contrary, non-positive or passive leadership styles have opposite effects on safety climate and safety consciousness, and are associated with increased safety events and injuries. Lower education levels, illiteracy and limited language proficiency increase the possibility of injury or death associated with higher risk occupations such as dairy. There is a need to develop and evaluate the effectiveness of safety-specific transformational leadership among dairy managers and supervisors. A systematic approach to risk management should address worker health and safety as an integral component of production, food safety, and animal welfare. A successful program must address the cultural and linguistic barriers associated with immigrant workers. The U.S. Dairy industry needs to be proactively involved with OSHA to help craft standards and approaches that make sense for the industry.

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Monitoring Negative Energy Balance in Transition Cows for Better Dairy Herd Results

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Introduction

Most transition dairy cows visit a state of negative energy balance (NEB) due to increased energy demands after parturition coupled with lagging dry matter intake (Hayirli et al., 2002). The ability to partition available energy for milk production early in lactation (Bauman and Currie, 1980) has made the role of energy balance a key factor in the study of milk production, reproductive performance, and disease occurrence. The metabolites non-esterified fatty acids (NEFA) and/or β -hydroxybutyrate (BHB) are common measures of NEB and/or ketosis in transition animals (Duffield et al., 2009). Although some elevation of these metabolites is normal as these animals balance energy intake and energy demands, excessive elevation can indicate poor adaptation to NEB (Herdt, 2000). Identification of an objective level where NEFA and/or BHB are excessive and cause detrimental effects on health, reproduction and milk production, has been difficult due to individual animal variations, normal metabolite elevations during the transition period, and the multiple herd-level factors that can affect the outcomes of interest.

The objectives here were to: 1. identify critical thresholds above which NEFA and BHB concentrations increase the risk of disease and affect production and reproductive performance at the individual animal level; 2. investigate the magnitude of these associations in free-stall, TMR-fed herds; 3. evaluate herd-level outcomes associated with the proportion of animals sampled which were above NEFA and BHB critical thresholds; 4. evaluate sampling schemes to estimate herd level outcomes; 5. intensively measure the incidence of early lactation subclinical ketosis in high performing herds; 6. identify dry period risk factors for cows that develop ketosis; and 7. evaluate the cost:benefit of various testing schemes for subclinical ketosis and subsequent treatment of positive cows with propylene glycol.

Materials and Methods for multi-herd study

A convenience sample of 104 farms in the Northeast USA were selected to participate in a prospective cohort study. All farms consented to participate, and this study was approved by the Cornell University Institutional Animal Care and Use Committee. To be included in the study a

herd must have: 1) had greater than 250 milking cows, 2) free-stall housing, 3) fed a total mixed ration (TMR), and 4) participated in DHIA and/or use Dairy Comp 305 (Valley Ag. Software, 2009).

All farms received a standardized consent form, a survey, and case definitions for diseases of interest. The survey collected information on: farm demographics, feeding times in relation to blood collection, voluntary waiting period, and ovulation synchronization protocols. Farm personnel were instructed to document any incident cases of the diseases of interest: displaced abomasum (DA), clinical ketosis (CK), and metritis (MET) and/or retained placenta (RP).

Farms were visited once, and during the farm visit, two cohorts of animals were identified: those 14-2 days pre-partum and 3-14 days post-partum. Within each cohort, convenience samples of 15 apparently healthy animals were evaluated. The evaluation included simultaneous blood collection and body condition scoring (BCS) (Ferguson et al., 1994). Guidelines for blood collection and sample handling were based on previous studies (Stokol and Nydam, 2006). Briefly, a plain evacuated red-top tube was used to collect 10 ml of blood from the coccygeal vein or artery. The sera from the pre-partum cohort were analyzed for NEFA and hemolysis. The sera from animals sampled post-partum were analyzed for NEFA, BHB, and hemolysis. For animals sampled, the incidence of the diseases of interest within 30 DIM, time to pregnancy within 70 days post voluntary waiting period and Mature Equivalent 305 (ME 305) milk at 120 DIM were recorded.

Data analysis

Statistical analyses of data were performed using SAS version 9.1 (SAS Institute, Inc., Cary, NC 2004) and ROC curves were obtained using MedCalc (Schoonjans, 2008). Data from the pre- and post-partum cohorts were analyzed separately. Initially data was stratified by parity group (parity =1 or >1), but if the effect of the predictors on the outcome was similar between the two groups they were pooled in the final analyses.

In summary, the analytical approach was done in three stages. The first stage was to identify significant risk factors with a multivariable model where the outcome was the development of any combination of the diseases of interest (DA or CK or MET and/or RP). The second stage, analyzed the continuous significant predictors from the multivariable model with receiver operator characteristic (ROC) curves to identify critical thresholds for prediction of individual diseases (e.g. DA) and any combination of the diseases. Once the range of critical thresholds predictive of disease was identified, the covariates were treated as categorical variables within this range. In the final stage, the magnitudes of the associations between these categorical predictors with disease, reproduction and production were evaluated. For each of these outcomes, three full models were evaluated: pre-partum NEFA and covariates; post-partum NEFA, BHB and covariates; and BHB with covariates.

At the herd level; the proportion of animals sampled that were above the critical thresholds was evaluated as the predictor variable and the herd level outcomes were: incidence of DA or CK in sampled animals; herd PR; and average ME 305 from sampled animals.

Evaluation of significant risk factors

The metabolites, NEFA and/or BHB were the main risk factors and at this level of analysis and were treated as continuous predictors. Parity, season, BCS, time of blood collection, and all biologically plausible 2-way interactions were evaluated as covariates in the model. They were modeled with PROC GENMOD using a Poisson distribution, a log link function, p-scale option for over-dispersion, and an exchangeable correlation matrix (Spiegelman and Hertzmark, 2005, Ospina et al., 2012). This statistical method allows for clustering of cows within herds (i.e. including herd as a random effect) while adjusting for continuous or categorical covariates. There was no adjustment for varying time spans (offset term) because the length of the time interval at risk was the same for every individual in the sample (Allison, 2007).

ROC curves

The continuous, significant risk factors identified in the multivariable model were evaluated using ROC curves to determine the critical threshold for predicting disease. The point on the ROC curve that has the highest combined sensitivity and specificity was considered the critical threshold. Interpretation of this critical threshold depends on the area under the curve (AUC), such that if the $AUC > 0.7$ the test is considered accurate (Swets, 1988).

Effect on disease risk, reproduction, and production at the individual animal level

Disease risk

Once the critical thresholds for prediction of disease (DA, CK, MET/RP, or any combination) were identified with ROC analysis, the covariates were dichotomized at the critical threshold. The risk of disease, given these categorical covariates, was evaluated with PROC Genmod, using a poisson distribution, log link function, p-scale option for over-dispersion, and an exchangeable correlation matrix (Ospina, 2010a).

Effect on reproduction

The effects of elevated NEFA and/or BHB concentrations on reproductive performance were evaluated with time-to-event analysis (PROC Phreg). Cox proportional hazard models (Cox, 1972) were analyzed accounting for clustering of cows within herds. The covariates were: BCS, parity, and ME 305 milk at 120 DIM. ME 305 data was dichotomized based on the median production of the pre- or post-partum group. Animals culled before the end of voluntary waiting period were excluded from the analysis and those not pregnant by the end of the follow-up period were right censored. The proportional hazards assumption was checked statistically by evaluating time dependent covariates and non-informative censoring was evaluated with sensitivity analysis (Allison and SAS Institute, 1995). The categorical metabolite value selected from within the range of critical threshold predictive of disease that resulted in the smallest chance of committing a type I error was kept in the final model (Ospina 2010b).

Effect on milk production

The effects of elevated NEFA and/or BHB concentrations on ME305 milk were evaluated with mixed effects models with herd as a random effect. The covariates were: BCS, season, and when applicable both parity, and the interaction between parity and the metabolite level. In all models, the metabolites, NEFA and BHB were dichotomized and evaluated within the range of values identified as critical thresholds for prediction of disease. The categorical metabolite value that resulted in the smallest chance of committing a type I error was kept in the final model (Ospina, 2010b)

Effect on disease, reproduction and production at the herd level

The herd alarm level

Once estimates of the metabolite thresholds were established at the individual animal level, the herd alarm level, i.e., the proportion of sampled transition cows per herd with elevated pre-partum NEFA, postpartum BHBA and NEFA concentrations that was associated with herd-level incidence of diseases, decreased pregnancy rate, and milk production was evaluated. The interaction between parity and the level of the metabolite was evaluated and the analysis was stratified by parity (parity =1 or >1) if there was a difference in the effect.

The herd alarm level consists of two numbers: 1) the metabolite (NEFA or BHBA) concentration threshold above which detrimental downstream outcomes are most likely to occur and 2) the proportion of animals with metabolite concentrations above this threshold that is associated with herd-level downstream outcomes. To establish the herd-alarm level both of these parameters were evaluated concurrently. The lowest metabolite concentration and smallest proportion that yielded the smallest chance of committing a type I error and had the largest change in the outcome of interest was kept in the final model (Ospina, 2010c). The metabolite concentrations were evaluated within the range identified as critical thresholds associated with individual-cow health effects reported above in Ospina et al., 2010a.

Sampling scheme to estimate herd level outcomes

Number of animals to sample

Based on empirical data, further data sets were simulated to estimate herd level sensitivity (**HSe**), specificity (**HSp**), and positive/negative predictive value of the herd alarm level for subclinical ketosis. The true prevalence of the condition was evaluated at several levels, starting with a very conservative 10% and up to 40%. These analyses were performed using formulas presented by Martin et al., 1992. The critical threshold used to decide whether a herd was positive was 15%, and the BHB concentration was > 12 mg/dL (which is approximately equal to 1.2 mmol/L).

Results of multi-herd study

Study population

Of the 104 herds, 4 were excluded from the study due to missing data. 2758 cows from the remaining 100 herds were included in the study and of these cows, 1440 were sampled pre-partum

(35 % heifers and 65% cows) and 1318 were sampled post-partum (37% heifers and 63% cows). The number of milking cows per herd averaged 840.

Multivariable analysis

In the three multivariable models, the metabolites were the only significant predictors of any of the diseases of interest: pre-partum NEFA ($p=0.028$), post-partum NEFA ($p=0.0005$) and when BHB was the only main predictor in the model ($p=0.005$) it was also the only significant predictor. No other covariate or interaction term in any of the three multivariable models had a p -value <0.1 .

ROC- critical thresholds for prediction of disease

The critical thresholds identified with ROC analysis are summarized in Table 1 with their AUC values. Briefly the NEFA critical thresholds for predicting any of the diseases of interest in the pre- and post-partum cohort were 0.29 and 0.6 to 0.7 mEq/L, respectively and the BHB critical threshold was 10 to 12 mg/dL. Figure 1 is a graphical representation of an ROC curve with DA as the outcome and concentrations of post-partum NEFA as the test.

Risk of disease

The risk of disease based on NEFA and BHB concentrations greater than or equal to critical thresholds are also summarized in Table 1. For example, experiencing elevated metabolite levels post-partum increased the risk of developing a DA by up to 10 times, and elevated levels of post-partum NEFA contributed the greatest risk of disease development.

Effect on reproduction

Table 2 summarizes the results of elevated metabolite levels on reproduction with estimates for metabolites and significant covariates reported. Animals with elevated metabolite levels (within the range identified as predictors of disease) took longer to get pregnant; the hazard ratio for pregnancy within 70 days post-voluntary waiting period decreased. Figure 2 is a graphical representation of a Kaplan-Meier curve, where animals with elevated pre-partum NEFA levels took longer to get pregnant.

Effect on production

The results of elevated metabolite concentrations are reported separately for heifers and cows sampled post-partum because the effect of the elevated metabolite thresholds on ME305 milk was different between these two groups. Generally, elevated metabolite levels predicted a decrease of several hundred kilograms of ME 305 milk; however, in heifers sampled post-partum elevated metabolites levels predicted an increase in ME 305 milk. The results of this analysis are summarized in Table 3 with metabolite results and significant covariates reported.

Herd alarm levels

Table 4 summarizes the herd alarm levels, i.e., the proportion of animals sampled with NEFA or BHB concentrations above which negative downstream outcomes are more likely. The outcomes

evaluated were: DA and CK incidence in sampled animals; pregnancy rate at the herd level; and ME 305 milk based on 4 test days. If more than 15% of the animals sampled had NEFA or BHB concentrations above the threshold, herds had an increase in disease, decrease in pregnancy rate, and decrease in ME 305 milk compared to herds that were below the herd alarm level.

Herd level sampling

The HSe and HSp are very sensitive to the true prevalence of the condition of interest, the number of animals tested, and the critical threshold used to decide whether a herd is positive. Given a 15% cut-point for calling a herd positive; the HSe increases as the herd true prevalence increases, but it is largest when the sample size is 15. The Hsp does not depend on the underlying true prevalence; however, it is affected by the cut-point used to call a herd positive. Both the HSe and HSp are above 0.90 when the true prevalence is ≥ 0.3 , 15 animals are sampled, and the cut-point for calling the herd positive is ≥ 2 animals with NEFA or BHB concentrations above the cut-point.

The herd predictive value positive (**HPV+**) and herd predictive value negative (**HPV-**) depend on the HSe, Hsp, and both the within and between herd prevalence. The HPV+ increases as the sample size and cut-point used to determine whether a herd is positive increases and it is ≥ 0.90 when the true within herd true prevalence is ≥ 0.30 regardless of between herd prevalence. The HPV- increases as within herd prevalence increases, but it generally decreases as the prevalence of positive herds increases. The HPV- is most sensitive to this change when the within herd true prevalence < 0.30 . Both the HPV+ and HPV- are above 0.90 when both the within herd true prevalence are > 0.30 and 15 animals are sampled.

Conclusions from multi-herd study

The work to this point demonstrates that excessive negative energy balance (as measured by NEFA and BHB concentrations) in the transition period are strong predictors of clinical disease, and negative reproductive and productive performance in cattle from free-stall, TMR-fed dairies averaging 840 milking cows. The magnitude of the association between elevated NEFA and/or BHB and diseases of interest, measured by risk ratios, was large (range: 2.0-10 times more likely to get a metabolic disease when preceded by elevated NEFA or BHBA). The effects of elevated metabolite levels on reproduction decreased the hazard of pregnancy within 70 days post-voluntary waiting on average by 20%, with parity as the only other significant covariate (cows took longer to get pregnant than heifers). Milk production, showed mixed results, and although further investigation about homeorhesis in heifers is warranted, there was strong evidence of significant ME305 milk loss in cows sampled post-partum and all animals in the pre-partum cohort. When evaluated at the herd level, high levels of NEFA and BHBA were detrimental to milk production in heifers. The herd alarm levels for the concentration above which detrimental outcomes were likely were similar to individual animal levels and the proportion of animals was on average only 15%. When evaluating herd level factors associated with sampling, it appears that at least 15 animals in that at risk group should be sampled.

It is important to note that these herds were not chosen to participate in the study due to any issues with metabolic disease. Within herds, only cows that appeared healthy were sampled, i.e., in order to be included in the study a cow could not have already developed a DA, CK or metritis. Despite these selection criteria, the prevalence of herds above the herd alarm level was 40%. Being above

the herd alarm level means that more than 15% of sampled animals had BHB concentrations > 1.2 mmol/L. The distribution of herds having a given percent of sampled animal above the cow-cut point of 1.2mmol/L is in Figure 3.

Management programs focused on minimizing the risk of these diseases and minimizing negative effects of decreased reproductive and productive performance may consider the following as general guidelines for monitoring NEFA and BHB concentrations in cattle should sample at least 15 animals to determine if more than 15% of than animals sampled had NEFA concentrations ≥ 0.3 mEq/L for cattle 14-2 d pre-partum; and NEFA concentrations ≥ 0.6 mEq/L and BHB ≥ 12 mg/dL for those 3-14 d post-partum.

Introduction to intensive study of high performing herds

Some amount of both NEFA and BHB are normal in early lactation ruminants; however, excessive amounts of either can lead to increased risk of disease, decreased reproductive performance, and decreased milk production. When compared to NEFA, ketone monitoring and evaluation can be less expensive and more practical even though NEFA concentrations are a bit more predictive. Additionally, some cow-side ketone tests also offer a high degree accuracy. The most common fluids used for ketone tests, presented in order of increasing accuracy, are: urine (e.g. Ketostix®), milk (e.g. KetoTest™), and blood (e.g. Precision Xtra™ Meter). The blood meter, a hand-held device originally designed for use in humans with diabetes, costs about \$30 and the test strips cost around \$1.50 per sample when purchased through your veterinarian. This test is very accurate ($>96\%$ sensitivity and 99% specificity) and gives a cow-side answer in about 10 seconds.

Prevalence estimates existing cases of disease - it is like a snapshot in time. In the above mentioned study, prevalence was used to evaluate the effect of SCK on herd performance. Estimating herd prevalence can be done very quickly, and it is recommended to sample at least 15 to 20 healthy animals between 3 to 14 DIM and record how many of the animals sampled have BHB concentrations ≥ 1.2 mmol/L. For example, if 20 animals are sampled and 4 have a BHB concentration ≥ 1.2 mmol/L, then the prevalence is 20% ($4/20$) and the herd is considered to be at increased risk for the negative downstream outcomes mentioned previously.

Although prevalence is a very useful measurement, the incidence of a condition sometimes gives different information. Incidence is defined as the number of cows that develop a new case of SCK divided by all the animals at risk. If, for example, 15 cows within a group of 50 sampled cows develop a new case of SCK sometime from 3 to 16 DIM, the incidence is 30% ($15/50$). The incidence of SCK is approximately twice the prevalence.

Results and Discussion of intensive study in high performing herds

A more recent study by researchers at Cornell and the University of Wisconsin followed 1,717 cows from 3 to 16 DIM in 4 free-stall, total mixed ration fed herds (McArt et al., 2011, 2012b). Using the Precision Xtra meter, all cows that calved within the study period were monitored for SCK, defined as a BHB concentration of $1.2 - 2.9$ mmol/L. Cows were tested on Mondays, Wednesdays, and Fridays, and given this testing scheme each cow was sampled 6 times, beginning at 3, 4, or 5 DIM and ending on 14, 15, or 16 DIM. The highest incidence of SCK occurred at 5 DIM, with 75% of cows that developed SCK testing positive for the first time from 3 to 7 DIM (Figure 4). Cows that

tested SCK positive from 3 to 7 DIM were over 6 times more likely to develop a DA, 4.5 times more likely to be removed from the herd, 0.7 times as likely to conceive to first service, and made almost 5 pounds less milk per cow per day for the first 30 DIM than cows first testing SCK positive between 8 and 16 DIM. Thus it is important to identify these SCK cows early in lactation in order to reduce the risk of negative downstream events.

The above study also looked at risk factors in dry cows to help predict which cows went on to develop ketosis between 3 and 5 DIM, as most cows first develop SCK during this time and, as mentioned above, these cows are at a higher risk for negative events than cows first developing SCK later in lactation (McArt et al., 2012c). Cows with pre-calving NEFA ≥ 0.30 mEq/L were almost 2 times more likely to develop ketosis than cows with NEFA < 0.30 mEq/L; similarly, cows birthing male calves were 1.8 times more likely to develop ketosis than cows birthing female calves. In addition, cows with a calving ease ≥ 3 on a scale of 1 to 5 were 2.6 times more likely to develop ketosis than cows with a calving ease < 3 , cows that gave birth to a dead calf were 2.2 times more likely to develop ketosis than cows that gave birth to a live calf, and parity ≥ 3 cows were 3 times more likely to develop ketosis than their younger herdsmates. Thus for herds that chose to focus their ketosis testing rather than test all fresh cows, special attention should be paid to cows with high pre-calving NEFA, older cows, and cows that have had difficulty birthing.

The same study evaluated the benefits of daily oral drenching of propylene glycol in cows diagnosed with SCK (McArt et al., 2011, 2012a). The first time a cow tested positive for SCK she was randomized to either the treatment group where she received 300 mL (10 oz) of propylene glycol by oral drench once daily until she tested < 1.2 mmol/L or the control group where she was not given propylene glycol. Most cows were treated for 5 days. The SCK positive cows treated with propylene glycol were almost half as likely to develop a DA, half as likely to be removed from the herd, and on some farms made more milk (3 pounds per cow per day) in early lactation than SCK cows not given propylene glycol. In addition, SCK cows treated with propylene glycol were more likely to conceive at first service. Based on this study and the expected duration of SCK, treatment of SCK positive cows with a 5 day course of daily propylene glycol drenching is suggested.

A partial budget was developed to assess the benefit:cost ratio of different SCK testing scenarios and treatment with propylene glycol. On a herd level, the most cost-effective method depends on the herd SCK incidence. This analysis evaluated 4 different testing and treatment strategies at varying herd SCK incidences. Results indicate that at herd SCK incidences above 50%, blanket treatment of all fresh cows with 5 days of oral propylene glycol starting at 5 DIM is the most cost-effective strategy. At incidences between 15 and 50%, testing cows that are 3 through 9 DIM two days per week (e.g. Mondays and Thursdays) and treating SCK positive cows with 5 days of oral propylene glycol is the most cost-effective strategy; although testing all cows that are 3 through 16 DIM one day per week (e.g. Mondays) will also provide a positive return on investment. For a herd with a 40% incidence of SCK that freshens 1,000 cows per year, choosing to test cows two days per week and treating the positives will benefit \$10,000 to \$25,000 per year.

It may be easier to first conduct a SCK prevalence test (sample 15 to 20 cows) on a herd in order to approximate the herd incidence and determine the best testing and treatment plan. For those herds with an estimated incidence greater than 50%, where blanket treatment with PG is initiated, repeated prevalence testing may be necessary after management changes to determine if treating all fresh cows remains the best option. For herds with an incidence from 15 to 50%, either the one day per

week or two day per week testing strategies will allow for repeated monitoring of herd incidence, however it is important to remember that herds that choose to test cows from 3 to 9 DIM should assume they are only identifying 80% of the cows that will develop SCK between 3 and 16 DIM. Repeated incidence or prevalence testing is recommended in order to evaluate changes in transition cow management and allow appropriate adjustment of farm SCK testing and treatment protocols. Remember the goal is to not treat many, if any, cows with propylene glycol, but rather have transition cow management strategies in place such that the prevalence of SCK is lower than 15%.

Conclusion of intensive study in high performing herds

In well managed TMR fed freestall herds in the northeast and upper Midwest, the incidence and thus prevalence of SCK is high. SCK is a condition not recognized clinically until it predisposes cows and herds to higher incidences of transition cow diseases, lower milk production, and lower milk production. Thus it is a costly condition. Work with your management team to develop a testing strategy to assess your level. Treating SCK cows with propylene glycol is cost effective in almost all scenarios until preventive management strategies can be put in place.

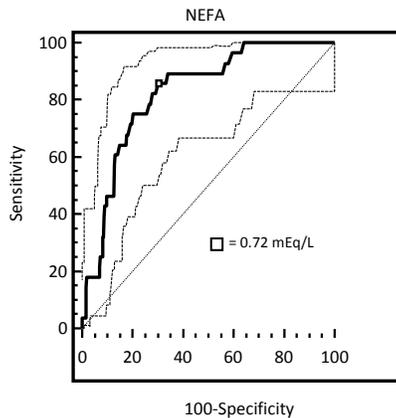


Figure 1. ROC curve determination of critical threshold (upper most left hand corner) for NEFA concentrations predicting DA in animals sampled post-partum.

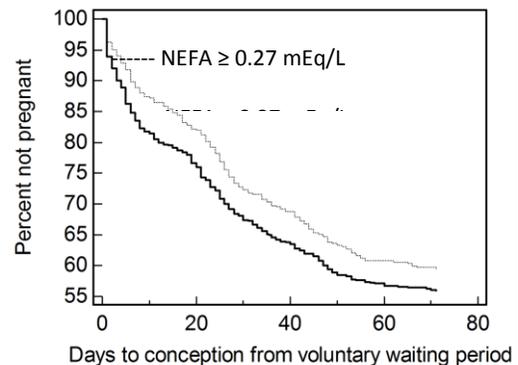


Figure 2. Kaplan-Meier curves of time to pregnancy of cows and heifers with NEFA ≥ 0.27 mEq/L or < 0.27 mEq/L measured in serum 14-2 days pre-partum.

Figure 3. Prevalence of herds showing the percent of sampled animals within herd above BHB ≥ 1.2 mmol/L (~12mg/dl). 40% of herds were above the herd alarm level of 15% of sampled animals.

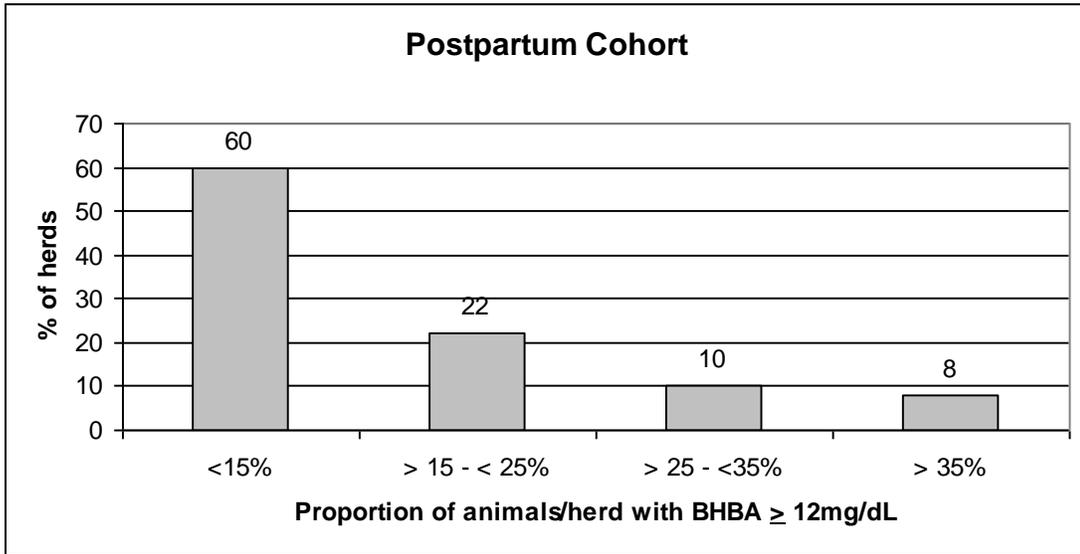


Figure 4. Incidence of subclinical ketosis (B-hydroxybutyrate ≥ 1.2 mmol/L) by days in milk of test.

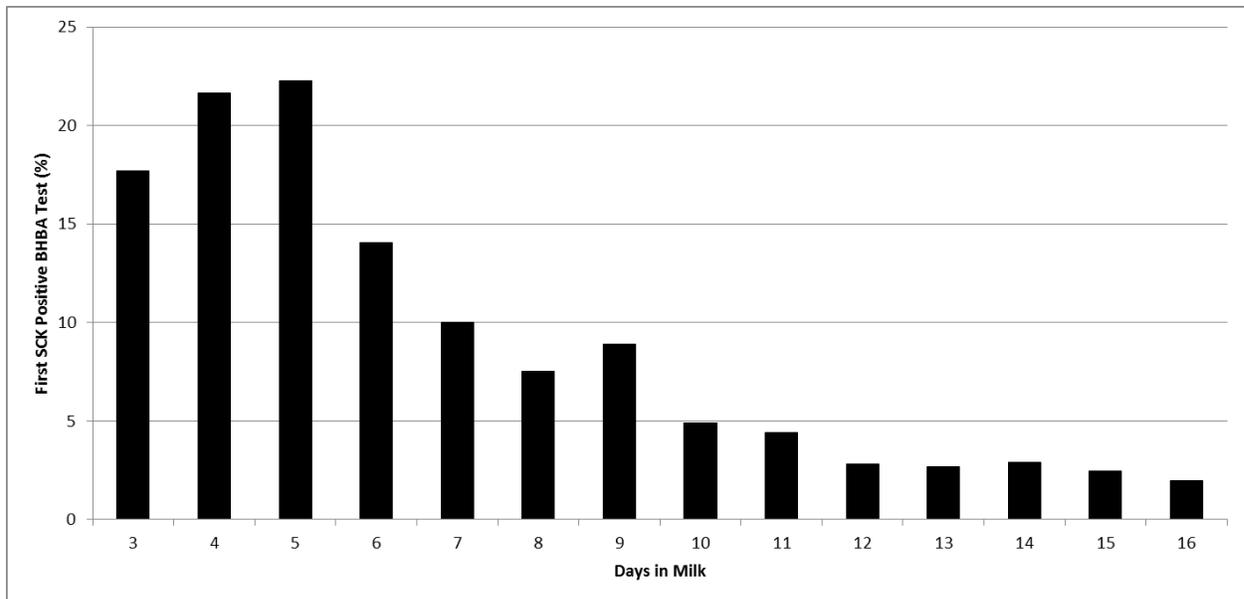


Table 1. Receiver operator characteristic (ROC) curve determination of critical NEFA (mEq/L) and BHB (mg/dL) thresholds as predictors of disease and risk ratios of disease based on these critical thresholds.

Animals sampled pre-partum					
Disease	Critical NEFA threshold ¹	AUC ²	Risk Ratio	95% RR CI ³	p-value
DA	0.27	0.6	2.0	1.1 – 3.7	0.03
CK	0.26	0.6	1.8	1.2 – 2.5	0.001
MET	0.37	0.6	2.2	1.6 – 3.0	<0.0001
and/or RP					
Any 3	0.29	0.6	1.8	1.4 – 2.2	<0.0001
Animals sampled post-partum					
Disease	Critical NEFA threshold ¹	AUC ²	Risk Ratio	95% RR CI ³	p-value
DA	0.72	0.8	9.7	4.2 – 22	<0.0001
CK	0.57	0.7	5.0	2.3 – 11	<0.0001
MET	0.36	0.6	17	2.0 – 133	0.008
Any 3	0.57	0.7	4.4	2.6 – 7.3	<0.0001
Disease	Critical BHB threshold ¹	AUC ²	Risk Ratio	95% RR CI ³	p-value
DA	10	0.8	6.9	3.7 – 12.9	<0.0001
CK	10	0.7	4.9	3.2 – 7.3	<0.0001
MET	7	0.6	2.3	1.1 – 5.1	0.037
Any 3	10	0.7	4.4	3.1 – 6.3	<0.0001

¹ Highest combined specificity and sensitivity

² Area under the curve

³ Risk ratio confidence interval

Table 2. Cox proportional hazard model of the effect of NEFA (mEq/L), and/or BHB (mg/dL), covariates, and animals clustered within herds on days to conception after voluntary waiting period.

Sampled Population	Variable	Hazard Ratio	Pvalue
Pre-partum cohort	NEFA \geq 0.27	0.81	0.01
	Parity	0.73	0.0004
Post-partum cohort	NEFA \geq 0.72	0.84	0.05
	BHB \geq 10	0.93	0.40
	Parity	0.81	0.01
Post-partum cohort	BHB \geq 10	0.87	0.09
	Parity	0.80	0.01

Table 3. Mixed models for the effect of NEFA (mEq/L), and/or BHB (mg/dL), covariates, and herd as a random effect on milk production measured by 120 DIM ME 305 (kg).			
Sampled Population	Variable	Difference in ME milk yield (kg)	Pvalue
Pre-partum cohort	NEFA ≥ 0.33	-683	0.001
	Parity	-556	0.01
Post-partum cohort- heifers	NEFA ≥ 0.57	488	0.02
	BHB ≥ 10	-143	0.5
Post-partum cohort-cows	NEFA ≥ 0.72	-647	0.001
	BHB > 10	-165	0.40
Post-partum cohort-cows	BHB ≥ 10	-393	0.04

Table 4. Herd level effect of elevated NEFA or BHBA concentrations on outcomes*				
Herd alarm level				
Proportion of animals	Metabolite level	Effect on outcomes*	P-value	
15%	Pre-partum NEFA: 0.27 mEq/L	+ 3.6% Disease	0.006	
		- 1.2 % in PR	0.006	
		- 282 kgs of ME 305	0.002	
15%	BHBA: 12 mg/dL	+ 1.8 % disease	0.03	
		-0.8 in PR	0.03	
	BHBA: 10 mg/dL in cows [#]	-358 kgs of ME 305	0.0004	
15%	Post-partum NEFA: 0.70 mEq/L	+1.7% disease	0.04	
		0.60 mEq/L	-0.9 PR	0.05
		0.70 mEq/L in cows [#]	-593 kgs of ME 305	<0.001
*Disease: incidence of displaced abomasum or clinical ketosis in sampled animals; PR: herd level pregnancy rate; ME 305: Estimated mature milk equivalent 305 at 120 DIM (4 test days)				
[#] cows = parity ≥ 2				

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Don't be so lame- Time to Implement Solutions to Sore Feet

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Introduction

Despite increased awareness of lameness in dairy cattle over the last decade, it remains a major concern for the industry. Lameness control is fundamental to the successful management of the dairy herd, because it impacts how a cow rests, eats and behaves, thereby reducing the ability of the cow to produce milk efficiently, reproduce and survive.

Table 1 documents the peer-reviewed surveys of lameness prevalence published over the last 20 years. With a few exceptions, it should be noted that lameness prevalence is higher in freestalls compared to tiestalls, compost barns or bedded packs and grazing herds, higher in larger compared with smaller herds, and higher in higher milk producing herds.

Most notably, in the most recent large scale survey of North American dairy herds, lameness affected one third to one half of the cows in larger, high producing freestall housed herds.

In Wisconsin, I have been working on lameness prevention programs for more than a decade and recently we launched The Dairyland Initiative (www.thedairylandinitiative.vetmed.wisc.edu) with a focus on facility designs for dairy cattle that promote excellent hoof health. I believe that it is possible to manage high producing dairy cows in freestall housed herds with high standards of health and well-being and this paper will detail the progress being made to achieve that goal, highlighting the essential management steps necessary to maintain low levels of lameness in confinement housed dairy herds.

Table 1. Lameness prevalence surveys published in peer review 1993-2013.

<i>Study</i>	<i>Country</i>	<i># Herds</i>	<i>Housing/Management</i>	<i>Herd Size</i>	<i>Milk Production (lb)</i>	<i>Lameness Prevalence</i>
Wells et al.,	US	17	Mostly Tiestall	50	17,906	13.7 (summer)
Clarkson et al., 1996	UK	37	Freestall/Grazing	?	?	20.6
Cook, 2003	US	30	Freestall/Tiestall	121	23,060	21.1 (summer) 23.9 (winter)
Haskell et al., 2006	UK	37	Grazing and Zero-grazing freestall	?	?	15% grazing 39% zero-grazing
Espejo et al., 2006	US	50	Freestall	?	83	24.6
Amory et al., 2006	Netherlands	19	Freestall/Grazing	76	18,566	16.5 (arch back only)
Barberg et al., 2007	US	12	Compost Barns	74	23,005	7.8
Rutherford et al., 2009	UK	80	Organic v Conventional, Fstall/Bedded Pack	147	16,084 (O) 18,559 (C)	16.0-18.0 (O) 19.1-23.1 (C)
Dippell et al., 2009a	Austria	30	Freestall/Grazing	35	18,062	31
Dippell et al., 2009b	Germany/Austria	103	Freestall/Grazing	48	17,633	33
Barker et al., 2010	UK	205	Freestall/BP/Grazing	163	15,844	36.8
Ito et al., 2010	Canada (BC)	28	Freestall	177	22,955	28.5
Lobeck et al., 2011	US	15	Crossvent/Conventional Fstall/Compost Barn	121-1000	24,879*ME	4.4 (CB) 13.1 (CV) 15.9 (NV)
Von Keyserlingk et al., 2012	Canada and US	121	Freestalls in British Columbia, California, New York and Pennsylvania	42 (BC) 1796 (CA) 826 (NY)	25,815 *ME (BC), 26,464 (CA), 26,924 (NY)	28 (BC), 31 (CA), 55 (NY/PA)

Wisconsin Cluster Analysis Survey

In the summer of 2012, we used the AgSource Cooperative Services (Verona, WI) herd database to identify herds over 200 cows (likely freestall housed) in Wisconsin and neighboring states with monthly DHIA tests records. Using a principle components analysis of DHIA data from these herds, we identified 16 variables that were able to characterize performance variation between herds and subjected the 557 herds to a cluster analysis. Herds were clustered into 6 groups and we visited 22 herds in each of groups 1, 2 and 6 (66 total herds). These clusters were representative of the highest milk production. For each herd we evaluated the physical well-being of the high producing mature cow group(s) and measured lameness using a 5-point locomotion scoring system where scores >2 qualified as 'lame'. Overall, mean lameness prevalence was 13.1% - lower than recent reports of high producing housed dairy herds in the US and Europe, and lower than we had found previously in similar herds (Table 2). Sixty four percent of herds used sand bedding and lameness prevalence was significantly lower in these herds compared to herds using mattress stalls.

Table 2. Lameness prevalence comparison between freestalls with sand bedding and rubber crumb filled mattress beds in herds located in the Upper Midwest.

Free stall herd comparison	Cook, JAVMA 223:1324, 2003	Espejo et al., JDS 89:3052, 2006	Cook et al. Unpublished 2013
No. Herds (sand/mat)	16 (9/7)	53 (16/37)	61 (41/20)
% Lameness: Sand Herds	19.8	17.1	11.0
% Lameness: Mattress Herds	30.2	27.9	17.5

So, how can these herds manage cows successfully in large scale freestall housed dairy operations and still achieve excellent standards of lameness control? Obviously there is no one pathway that all herds follow, but there are some consistent features that I shall focus on here.

1. Sand bedded stalls
2. Time available for adequate rest
3. Excellent hoof health management
4. An effective footbath program
5. Good flooring to avoid the risk of slipping, wear and trauma
6. Adequate heat abatement

I will briefly summarize the relative impacts of each of these critical steps to lameness control.

1. Sand bedded stalls

Sand bedding appears to benefit the cow with respect to lameness management in several different ways.

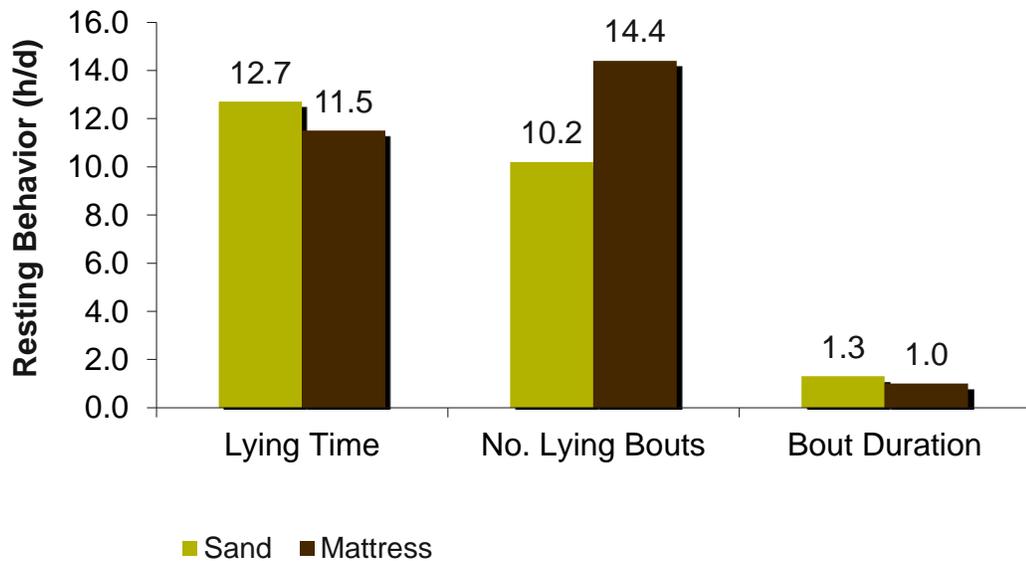
1. Creates more secure footing in alleys

Sand unquestionably reduces the risk for slipping and trauma to the foot in the alleys, reducing the risk for white line lesion development.

2. Promotes long lying bouts and fewer bouts per day

Sand, because of its ability to conform around the bony prominences of the cows' hips and hocks promotes longer lying bouts compared to rest on rubber crumb filled mattresses (Figure 1). Since cows are motivated to rest for around 12 h/d, cows on sand take fewer lying bouts per day to achieve their resting goal compared to cows on mattresses. This behavioral change is of little consequence for young fit non-lame cows, but it is of great significance for older lame cows, since they do not have to shift position as much on sand.

Figure 1. Differences in lying behavior between cows on sand and cows on rubber crumb filled mattresses (from Gomez and Cook, 2010).

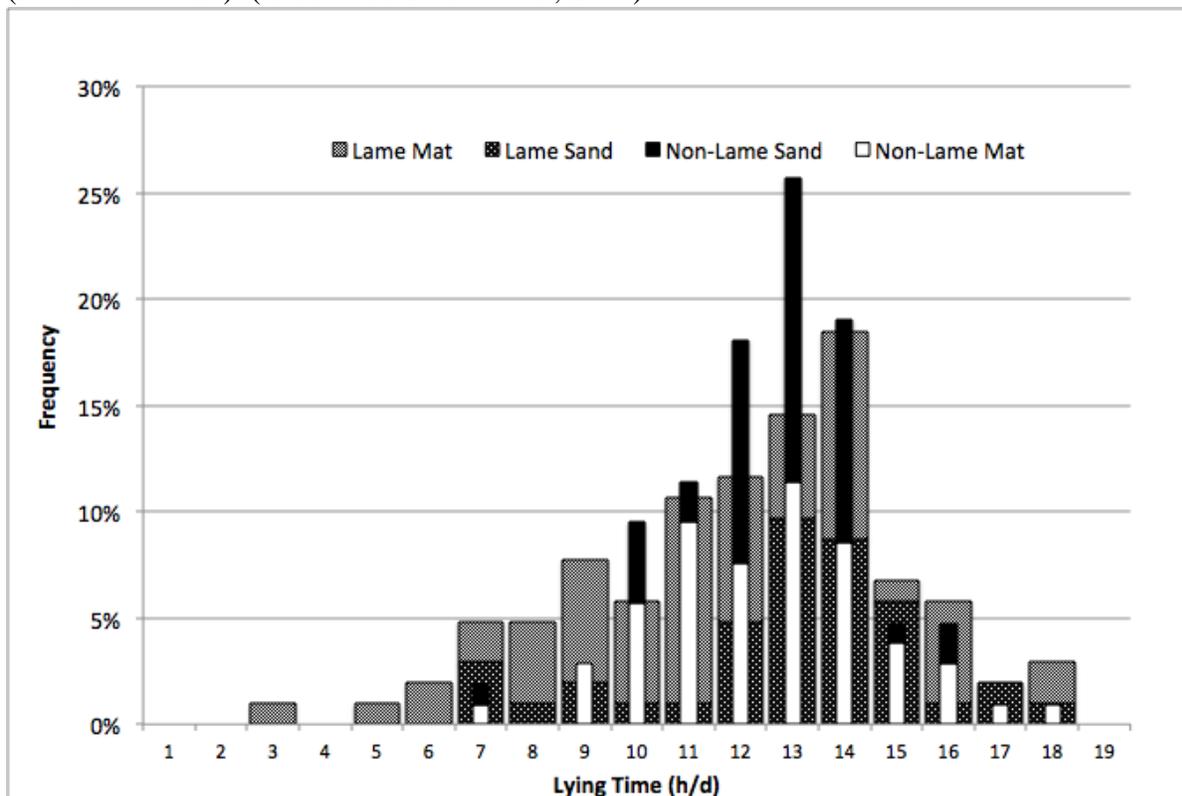


3. Improves the ability for lame cows to rise and lie down

The primary behavioral change observed in stall use by lame cows most consistently is an increase in the time standing in the stall - either perching or standing with all four feet on the platform, to between 4 and 6 h/d.

This change is indicative of a reluctance of the cow to rise and lie down in the stall and we have hypothesized that the painful forces at the claw stall surface interface are the reason for this change in lame cows. Ultimately, in stalls that do not provide the lame cow cushion, traction and support during rising and lying movements, resting behavior is further impacted. Lame cows get ‘stuck’ standing in the stall, reluctant to lie back down, or get ‘stuck’ lying down, reluctant to stand back up again. These challenges are magnified on firm mats or rubber crumb filled mattresses, because on this type of surface, resting is predicated by a greater need to rise and lie down more frequently. Figure 2 shows the difference in lying time frequency for lame and non-lame cows housed on mattress or sand stalls. Note that the distribution for lame cows is skewed toward both extremes, with a greater frequency of very short lying times and very long lying times observed, compared to non-lame cows. The effect of sand on lame cows is also obvious, there are many fewer lame cows with very short lying times than on mattresses, and there are more lame cows with longer lying times, suggesting that sand ‘normalizes’ lying behavior in lame cows. This normalization may have an impact on the ability for lame cows to rest and recuperate and improvements in hoof lesion score have been shown after 21 weeks of sand stall use compared to straw bedded freestalls.

Figure 2. Distribution of lying times (h/d) for 208 lame and non-lame cows by stall surface type (mattress or sand). (from Gomez and Cook, 2010).



Whether or not lame cows lie down more or less than non-lame cows is also likely affected by the time available for rest, which is also a critical issue for lameness prevention.

2. Time available for adequate rest

The time available for rest can be impacted by:

1. Stall design
2. Time milking
3. Time spent in lock-up
4. Overstocking
5. Heat stress

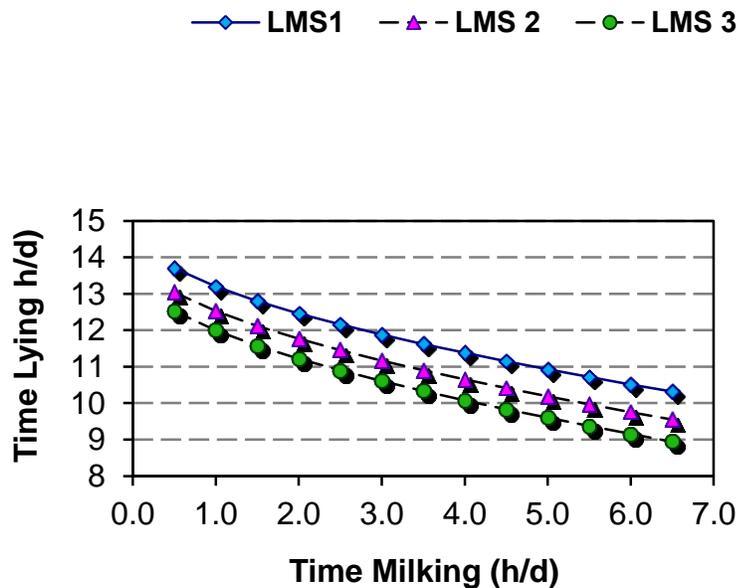
In confinement freestall facilities we target 12 h/d as a minimum target for lying time per day.

The effect of lameness and stall surface type has already been discussed, but other aspects of stall design may impact resting time, such as stall width, brisket locator presence and height, and lunge obstructions.

The time it takes to move the cow from the pen to the parlor for milking and back again has been associated with lameness. There are obvious impacts on the cow's time budget, but time spent in the holding area may also exacerbate the effects of heat stress during the summer. It is unlikely that a cow will be able to maintain a lying time target of 12 h/d if time spent milking each day exceeds 3 h/d. In our survey of 66 herds, mean time out of the pen milking was 90 minutes, suggesting that many herds are missing this goal, due to undersized parlors, poor parlor throughout, oversized pens, inefficient transfer lanes and too great a distance from the parlor to the pen of origin.

Time spent milking also impacts lame cows greater than non-lame cows, as they are often the last to return to the pen. Coupled with the resting behavior changes described, the impact of increased time milking can have a significant impact on the time available for rest. Figure 3 shows the relationship between time milking and time lying by locomotion score (1-3) for cows housed on rubber crumb filled mattresses. Note that only non-lame (LMS1) cows can be milked for 3 h/d and still maintain 12 h/d of lying time and that long milking times significantly impact the time available for rest for lame cows.

Figure 3. Impact of prolonged time spent milking (h/d) on time lying (h/d) by locomotion score (LMS1=sound, LMS2=slightly lame, LMS3=moderately lame) (from Gomez and Cook, 2010).



There has been no research on the time spent in lock-ups on the time budget of lame cows. However, since it has been shown that cows fail to recoup lost lying time when access to a place to rest is removed for more than 2-4 h/d, and since fresh cows are frequently locked up for prolonged periods on larger dairy herds, the impact of lock-up time on lameness should be considered. We have shown that lame cows appear to behave differently at calving time - with an increase in standing bouts on the day of calving (implying increased discomfort), and an increase in post-partum lying times, which was also associated with elevated BHBA levels (Calderon and Cook, 2011). Lame cows are high risk fresh cows with an increased risk for treatment or removal by 30DIM, so we recommend that they be managed appropriately. Lame cows benefit from housing on a bedded pack immediately post-partum and we advocate maintaining milking frequency at 2 times a day rather than 3 or more times a day milking, to ensure that these cows be given the time they need to rest and recover after calving.

Similarly, the effect of overstocking on lame cow behavior has not been examined. Since stocking at more cows than available stalls has been shown to reduce lying times, increased competition likely impacts lame cows disproportionately.

Finally, in order to thermal pant and dissipate heat, it has been shown that cows increase standing time per day under conditions of heat stress. Under conditions of moderate heat stress, standing time may increase 2-3 h/d, resulting in a proportionate drop in time available for rest.

3. Excellent hoof health management

Excellent hoof health management involves preventive routine hoof trimming and the early identification and treatment of lame cows.

Functional hoof trimming serves to balance the inner and outer claws of the rear feet, reducing the overload of the outer claw, and restores a more upright claw angle. These steps largely reduce the risk for sole hemorrhage and ulcer formation. The effects of trimming typically last ~ 4 months, before claw overgrowth returns balance to pre-trimming levels. Recommended trimming protocols suggest trimming for heifers prior to first calving, all cows at dry off and lactating cows around 80-150 DIM. However, this basic advice may need modification in larger herds, where hoof wear may be an issue.

Because cows with white line disease and sole ulceration have altered claw architecture and blood supply, I recommend that cows with pre-existing conditions are trimmed more frequently at around 90 day intervals. Trimming should be performed by a competent, well-trained professional working in a favorable environment with the right equipment.

While the detection of lame cows is relatively simple in smaller herds, it is more challenging when herds increase in size. I recommend that one or two trained caregivers have the responsibility of locomotion scoring cows each week by pen, as the cows are moved to the holding area for milking, in order to identify cows for treatment. Veterinarians should play a role in the detection of lame cows as they are released from lock-ups after post-partum checks and pregnancy checks and all cows at dry off should be locomotion scored, in order to identify lame cows that may have been missed.

The total trims required per year should be calculated based on historic lameness rates and the preventive program and the required trimmer visits per year determined. I would expect no more than 50 trims per trimmer/assistant per day if we are to give the trimmer enough time to do an excellent job for each cow, and the quality of the work needs to be monitored regularly.

4. An effective footbath program

An effective footbath program serves to assist in the control of infectious hoof disease, principally foot rot and digital dermatitis (DD or hairy heel warts). It is almost impossible to eradicate DD once it is present within the dairy herd and the goal is to find the 'manageable state of disease'. The two critical control points for the control of DD are:

1. The early identification of lesions and effective topical treatment
2. The use of a footbath program to reduce the risk for chronic DD lesions to recrudescence into active painful lesions

Note that the footbath is NOT used to treat active lesions. An antibacterial agent, with efficacy against *Treponema* species, should be applied to the feet as frequently as necessary to maintain control of the disease. A reasonable goal is to maintain the proportion of cows infected with DD to less than 5% at dry off trims. The median herd footbaths three times per week, but some herds may need more or less frequent bathing depending on the level of leg hygiene and the degree of the problem.

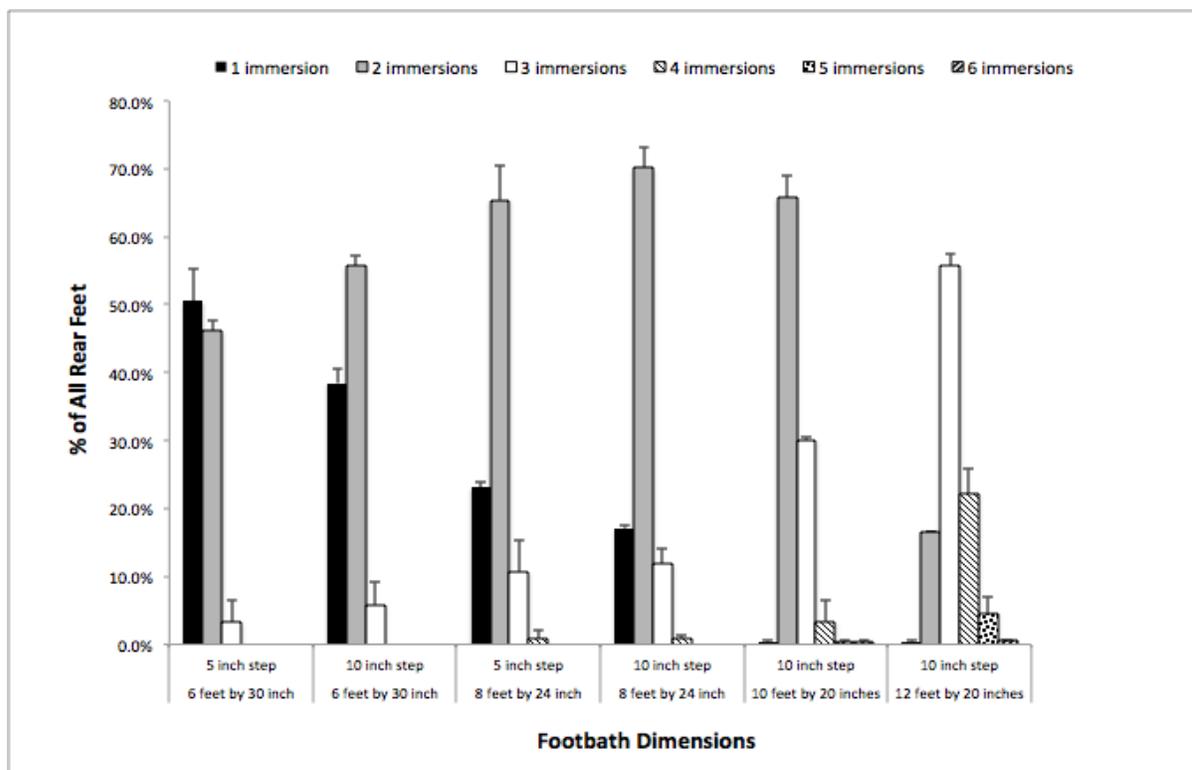
Two thirds of dairy herds use copper sulfate and one third use formalin as the antibacterial agent of choice. 42% of farms use more than one chemical and there are a wide range of commercial products that are available to address the chief concerns of the use of formalin, which is a potent carcinogen, and the disposal of copper on farmland, where plant toxicity is a potential risk.

The use of an acidifying agent to reduce the concentration of copper sulfate being used to 2-3% has become commonplace, with the goal of maintaining a bath pH of 4.0. Among the options are sodium bisulfate (pHMinus) added 1 oz at a time and a number of proprietary chemicals.

Recommendations on the need to replenish the solution so that it remains active are at best empirical. 200-300 cow passes are commonly used as a reasonable goal, but residual activity will depend on time of use, temperature and the degree of manure contamination, which may vary from farm to farm and day to day.

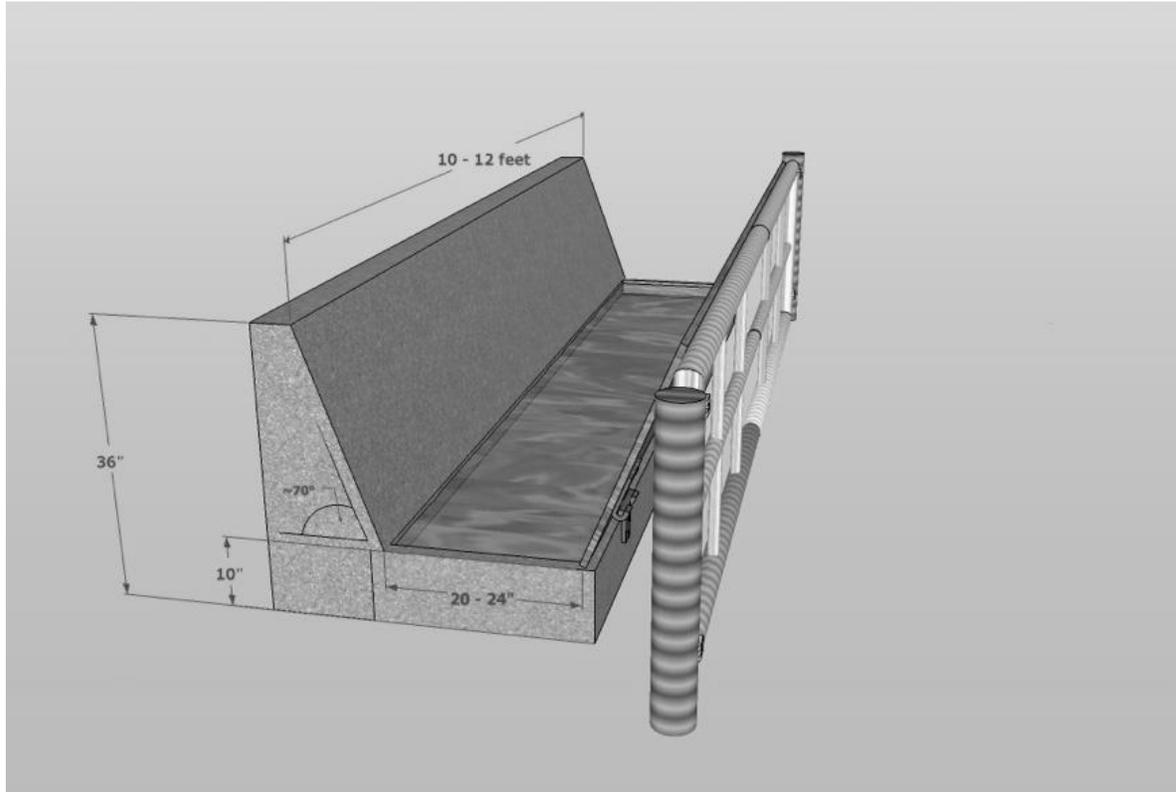
Whatever chemical agent is used, the delivery system must ensure that the feet are adequately exposed when the cow passes through the bath. Typically, farms install 50 gallon footbaths 6 feet in length and as wide as the transfer lane. We have shown that this design of bath does not optimize foot immersions per pass. Figure 4 shows that for an effective bath, where each rear foot receives at least 2 immersions per pass, the bath length must be 10 feet. Indeed, a recent study showed that a longer bath was three times as effective as a short bath with the same chemical.

Figure 4. Immersion profile for footbaths of different dimensions (from Cook et al, 2012).



We advocate footbath designs that are 10-12 feet in length with a 10 inch high step-in, as narrow as 24 inches, with sloped enclosed side walls (Figure 5). When filled to 4 inches in depth, this bath still maintains a final bath volume of around 50 gallons. We do not recommend the use of wash baths.

Figure 5. An ‘ideal’ footbath design.



5. Good flooring to avoid the risk of slipping, wear and trauma

In order to reduce the risk for wear and white line lesions and provide a comfortable surface when the cow is forced to stand idle, we advocate the use of rubber flooring in transfer lanes, holding areas, parlor return lanes and parlors. The type of rubber chosen is critical. On level floors firmer, less compressible recycled rubber products that tend to be cheaper may be used. However, on sloped floors and around the parlor a more compressible rubber with less recycled product in it with a heavy pattern to afford good traction is preferred. These products tend to be more expensive.

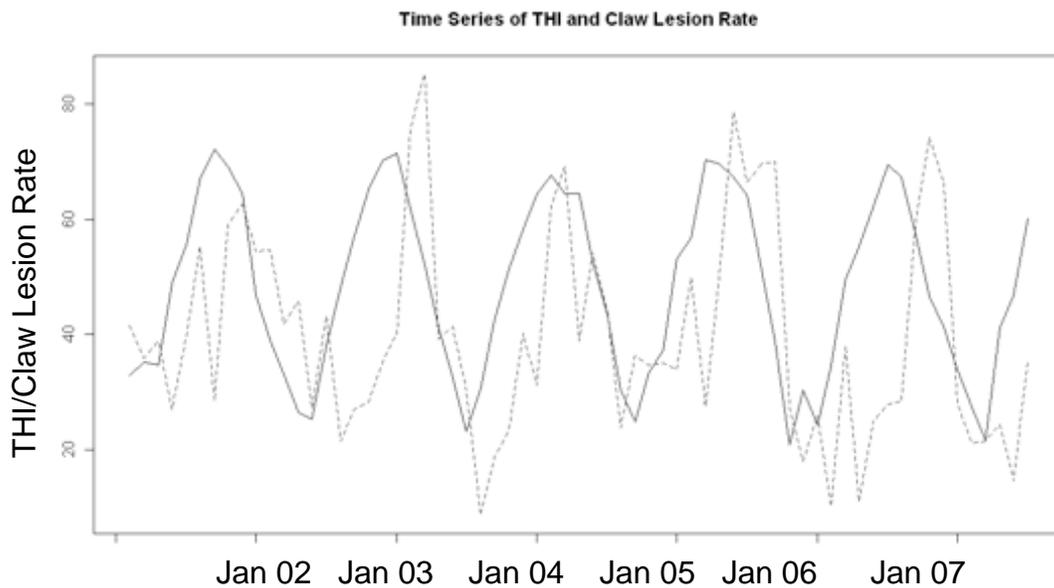
The use of rubber in freestall pens is not recommended for mattress herds and I do not believe it is needed for sand herds. In peer review two articles claim a lameness benefit for rubber in the alleys, two articles show that it makes lameness worse, and three were equivocal, with no clear effect. This may be due to the behavioral effect observed when rubber is used in the alleys in mattress stall pens, where cows choose to stand more on the rubber and lie down for less time in the stalls.

For concrete, we recommend a groove 3/4" wide, 1/2" deep, 3 1/4" on center. This wider groove, located closer together ensures that when a cow stands on the floor, each foot is always over a groove. The edge of the groove grips the claw and the groove allows for liquid manure to transfer from under the claw, improving contact with the concrete. In high risk areas for slipping, where cows have to make sharp turns, an additional groove 4" on center may be placed to create a diamond pattern.

6. Adequate heat abatement

As discussed earlier, when cows are heat stressed, they stand more and attempt to cool through the use of thermal panting. There are physiological changes that increase the likelihood of lameness associated with heat stress (such as SARA), but there are also behavioral changes that start at around 68 °F (Cook et al., 2007). Whatever the inciting cause, sole hemorrhage and ulcers peak ~ 2 months after the peak in heat - usually around September/October each year. Figure 6 shows the time series for a 450 cow dairy over a 5 year period, showing the relationship between monthly average ambient THI and claw lesion development. Note the two month lag each year between the peak in temperature (black solid line) and the peak in lesion development (red dotted line).

Figure 5. The relationship between average monthly ambient temperature humidity index (THI) (black solid line) and the rate of claw horn lesion development (red dotted line) for a 450 cow dairy in Wisconsin over a 5 year period (from Cook et al., 2006).



The primary goal of heat abatement is to reduce the risk for increased standing time in the alleys and around the milking center, by assisting cow cooling in high risk areas of the farm.

Therefore, I believe that the critical control points for heat abatement are:

1. Providing sufficient air movement in the holding area
2. Using effective soakers in the holding area
3. Providing adequate air movement in the resting area of the pens
4. Provide adequate access to water

We have developed a novel concept for holding area cooling using positive pressure ventilation systems that we hope will improve upon the current state of the art using recirculation fans, which struggle to provide the air speeds necessary to achieve optimal cooling and serve only to recirculate

stale warm humid air from inside the barn. Similarly, in freestall pens we are searching for improved ways to supply fast moving cooled air over the lying area.

Currently, we recommend at least two waterers per pen for pens over 20 cows and a minimum of 3.5 inches of accessible perimeter per cow.

Conclusion

The development of large confinement housed freestall facilities for dairy cattle has been associated with an increase in the prevalence of lameness. However, it does not have to be this way and we can maintain very low levels of lameness in high producing dairy herds if we apply the 6-steps outlined in this article. Welfare concerns will only increase in the coming years and the dairy industry must act now to reduce the impact of this costly problem.

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Scientific Data for Developing Water Budgets on a Dairy

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Introduction

The water needs of lactating cows, milk parlor usage, and other functions on the dairy require a minimum water supply of 40 to 50 gallons per day per cow (gpd/d; Allen et al., 1974; Bailey et al., 1993; Beede, 1992; MWPS-7, 1997). Ten to 20 percent of the daily water requirements of a dairy cow can come from feed (Ishler, 1998), but lactating cows require anywhere from 25 to 40 gallons of drinking water per day (gpd). Brouk et al (2001) metered water flow into water troughs located on several freestall dairies and found that Holsteins' water requirements ranged from 30 to 40 gpd/cow and less than 25 gpd/cow for Jerseys.

Water Consumption by Dairy Cows

Dairy cows require large amounts of daily water. Sources of water for the dairy cow include: 1) drinking or free water, 2) water (moisture) in feed, and 3) metabolic water. Metabolic water is insignificant compared with water ingested freely or contained within feeds. Some major factors affecting water intake by dairy cattle are dry matter intake, milk production, dry matter content of the diet, temperature and environment, and sodium intake (NRC, 2001).

Brouk et al (2001) studied the difference in water consumption based on the location of the water trough in a freestall building during summer months on three dairies in northeast Kansas. Results showed that more water was consumed at the center cross alleys than end cross alleys (Table 1). McFarland et al (1989) reported similar results in an earlier study. Brouk et al (2001) also found that cows consumed about 8 percent of their daily water needs at watering troughs located near the parlor exit. In addition, daily refilling of water troughs after tipping was equal to 10 to 15 percent of the daily drinking water requirements. They reported average water consumption ranged from 35.0 to 45.2 gpd/cow when cows were housed in the 4-row freestall barns. The ratio of water consumption to milk production ranged from 3.6 to 5.4 lbs of water per lb of milk, while average milk production per pen ranged from 56 to 98 lbs/cow/day. Water consumption ranged from 24.2 to 28.1 gpd/cow in the 2-row freestall, and the water to milk ratio ranged from 2.6 to 3.5. These values did not include water drunk at the milk parlor exit. Approximately 9 percent of the drinking water requirements were met from the two additional water troughs located along the back alley of the free stall. On a third dairy, water consumption ranged from 28.8 to 30.3 gpd/cow with milk production ranging from 64.3 to 85.6 lbs/cow/day. The water to milk ratio ranged from 2.9 to 3.8, while the water to feed ratio averaged 4.2. The general trend showed decreased total water usage as milk production increased. The water to milk ratio generally ranged from 3 to 4 lbs of water per lb of milk. When the

water requirements for the milk parlor and heat abatement were included, the values are similar to those reported by Reinemann and Springman (1992).

Table 1: Percentage of drinking water utilization at various locations within pens in a dairy containing two water troughs in each cross-over alley

Location of Water Trough	Location in Cross-over	Percentage of Total Utilization	Percentage of Location within Cross-over	Percentage of Total Water Utilization by Cross-over
Pen Exit Cross-over	Feedlane	12.0	62.2	19.3
	Stall	7.3	37.8	
Cross-over between exit and middle	Feedlane	16.1	62.2	25.9
	Stall	9.8	37.8	
Middle Cross-over	Feedlane	15.9	58.2	27.3
	Stall	11.4	41.8	
Cross-over between middle and end of pen	Feedlane	10.9	62.3	17.5
	Stall	6.6	37.7	
Pen End Cross-over	Feedlane	5.5	55.0	10.0
	Stall	4.5	45.0	

Peak water intake for cows occurs during the hours when feed intake is greatest. When given the opportunity, cows tend to alternately consume feed and drink water. Ideally, fresh, clean water should be available within 50-60 ft of the feeding area whenever the cows consume feed. If a cow's water consumption declines by 20%, then dry matter intake will decrease by 1 to 2.5 lb/d; this reduction in water intake could suppress milk yield up to? 5 percent.

Andersson and Lindgren (1987) studied cows' water consumption by restricting access to water during feeding. The treatments included a control (in which cows had free access to drinking water), no drinking water for one hour after feedings, and no drinking water for two hours after feedings. They reported that cows prefer to have water available during feeding. However, cows will consume 60 to 80% of total water intake within a few hours after feeding. There were no differences in water intakes between treatments once water was made available; however, the cows with free access to drinking water drank within 15 minutes after eating (Andersson and Lindgren, 1987).

Severe water restrictions can have a profound impact on productivity and feeding behavior of cattle. Steiger Burgos et al. (1999) evaluated the impact of 50 and 75% restrictions of water intake for 8 days. Restricting water intake by 50% resulted in a 21.3% decrease in 24-h feed intake, a 57.4% reduction in the size of the first meal, and a 41% increase in the number of meals per 24 hours. The 75% reduction in water intake resulted in an 11.3% decrease in 24-h feed intake, a 53% reduction in the size of the first meal every day, and a 31% increase in the number of meals per 24 hours. A reduction in the size of the first meal each day by greater than 50% accounted for most of the suppression in feed intake.

Data collected during a study comparing the impact of fiber (Dado and Allen, 1995) indicated cows drink about 1.5 gal of water per trip to a watering trough at a 1.27 gallons per minute (gpm). Dado

and Allen (1995) results showed t cows will consume their daily water requirements in 12 to 16 minutes (Dado and Allen, 1995).

Dry matter content of the diet has been shown to affect the free water intake. Holter and Urban (1992) showed a decrease in ration dry matter from 50 to 30 percent resulted in a decrease in free water intake by 8.75 gpd. Ration dry matter percent can have a negative impact when considering total water intake. When ration dry matter percent increases, free water intake increases but total water intake decreases. Murphy (1992) attributed for this because of the need to excrete more N and K in urine when feeding wet diets. Holter and Urban (1992) concluded that this is only relevant to cows on high protein pasture or succulent silage. Table 2 shows the ration water (gpd) available as a function of dry matter and ration moisture content. For example, 6 gallons of moisture (water) are available if a ration is formulated for 50 lbs of dry matter intake and has a moisture content of 50 percent.

Table 2: Gallons of ration water available as a function of dry matter intake and ration moisture content (%)

Ration MC (% wet basis)	Dry Matter Intake (lb/c/d)		
	40	50	60
	Feed Water Intake, gal/d		
40	3.2	4.0	4.8
45	3.9	4.9	5.9
50	4.8	6.0	7.2
55	5.9	7.4	8.8
60	7.2	9.0	10.8
65	9.0	11.2	13.4

Dewhurst et al. (1998) performed an experiment to examine the effects of silage characteristics on water intake. In this study, 16 silages were used with dry matter ranging from 15.9 to 28.0 percent. Free water intake ranged from 5.3 to 23.8 gpd, total water intakes from 12.8 to 32.8 gpd, and milk production from 36 to 85 lb/d. They found that free water intake increased with increasing silage dry matter concentration. Their study also confirmed other reports suggesting that free water intake replaces silage water at a rate less than 1:1.

Winchester and Morris (1956) found water intake per unit of dry matter intake remained constant from 10 to 40°F. From 10 to 40°F, cows consumed about 0.16 gal (1.36 lb) of water per lb of dry matter intake. At the peak of 90°F, cows consumed 0.38 gal (3.18 lb) of water per lb of dry matter intake.

Andersson et al. (1984) looked at the effect of 0.5, 1.8 and 3 gal/min water flow rates on water consumption of Swedish Red and White Breed cows in tied stalls. Using flow rates of 0.5, 1.8 and 3 gal/min, they reported the cows drank 2.5 and 3.3 gpd more water with the increased flow rates, while each group's time spent drinking decreased from 37 min/d on the low flow rate to 7 min/d on the high flow rate. The cows also had more drinking events per day with low flow rates (40 times/d) than with high flow rates (30 times/d). While the cows spent more time drinking, the flow rates did not affect milk production or dry matter intake. However, at the high flow rates there was a tendency

for increased milk production. These results indicate that cows will adapt to slower flow rates by changing their drinking behavior (Andersson et al., 1984).

Murphy et al. (1983), Holter and Urban (1992), Little and Shaw (1978), Stockdale and King (1983), Castle and Thomas (1975), and Dahlborn et al., (1998) have published formulas for predicting water consumption. The Murphy et al. (1983) formula is as follows:

$$FWI = 15.99 + 1.58 \times DMI + 0.90 \times MY + 0.05 \times SI + 1.20 \times Temp_{min}$$

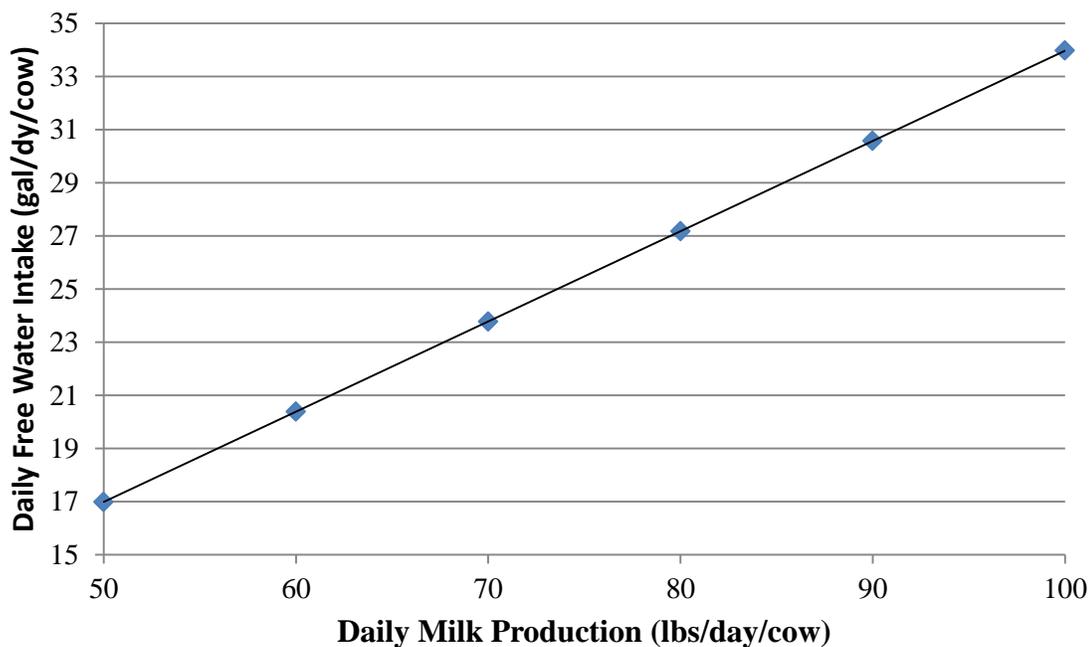
Where: FWI is free water intake (kg/d),
 DMI is dry matter intake (kg/d),
 MY is milk yield (kg/d),
 SI is sodium intake (g/d) and
 Temp_{min} is minimum temperature (°C).

The 2001 NRC recommendations used the formula developed by Murphy et al. (1983) to estimate free water intake. This formula shows that drinking water changes 1.58 kg for every 1 kg of change in dry matter intake (DMI), .90 kg for every 1 kg in milk yield, 0.05 kg for each 1 g change in Na intake, and 1.20 kg for every 1°C change. This also shows that dry matter intake, minimum temperature, and milk yield have more influence on drinking water intake than sodium intake. Potts (2012) developed a meta-analysis using data from 50 individual studies recording water intake by dairy cattle. Ration water intake (RWI) was calculated from the dry matter intake and percent dry matter reported. Table 3 reports the actual free water intake from the data set and what the prediction equations estimate for FWI using the meta-analysis data points. Using the 116 data points, the ratio of free water intake to milk yield averaged 2.82, and Figure 1 shows the relationship between daily milk production and free water intake based on this average, as reported by Potts (2012). Daily water requirements are proportional to increased milk production.

Table 3: Comparison of four prediction equations of FWI¹ regarding actual water intakes and milk efficiency from all data points (116) where dry matter intake, ration water intake and milk yield were reported

Data Source	Estimated Free Water Intake (gal/cow /day)	Predicted milk efficiency (lb water/ lb milk)
Actual	21.4	2.82
Little and Shaw (1978)	20.1	2.64
Stockdale and King (1983)	10.2	1.35
Potts et al. (2012)	21.4	2.82
Castle and Thomas (1975)	22.6	2.92
Dahlborn et al. (1998)	18.7	2.46

Figure 1: Relationship between daily milk production and free water intake assuming an average water intake to milk ratio of 2.82 across all milk production levels (Potts, 2012)



Overall Water Usage on Dairies

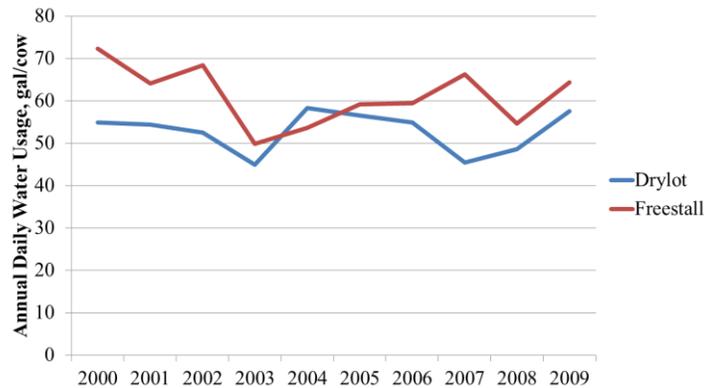
Brugger and Dorsey (2008) compiled total dairy farm water usage from January 1, 2005 to December 31, 2006. This study was conducted on a 1,000 cow dairy farm in northwest Ohio where the average high temperature was 60°F and the average low temperature was 39°F. Over 2 years, the total farm water usage (parlor, drinking, cooling, etc) averaged 29.6 gpd/cow. Free water intake by the dairy cows was lowest at 11.6 gpd/cow during the month of December 2005 and highest at 33.8 gpd/cow in July 2005. The cows alone consumed an average of 23.3 gpd/cow of free water intake over the entire study. No information on milk yields, dry matter intakes or ration moisture content was provided.

Bray et al. (2008) published water budgets for Florida dairy farms by using the equation shown previously from Murphy et al. (1983) to predict water intakes. The estimated average consumption was 25 gpd/cow. It was noted that cows under heat stress can require 1.2 to 2 times more water per day. The study by Brugger and Dorsey (2008) showed peak summer water consumption was 1.45 times the annual average.

In the state of Kansas, dairies diverting more than 15 acre-feet of water are required to have meters on their wells to monitor and regulate fresh water pumping (KDHE, 2008). Potts (2012) evaluated dairy farms that were using 15 acre-ft or more of water located in western Kansas. Fresh water pumping records were accessed from the state's Division of Water Resources in Topeka, KS. Twenty-four dairy farms consisting of 10 dry lot dairies, 12 freestall dairies, and 2 dairies using both freestalls and drylots were used to compile 10 years (2000-2009) of fresh water pumping records (Figure 2). The dry lot dairies' average size was 4,387 cows and the freestall dairies averaged 3,632 cows. During this time, all of the farms together averaged 57 gpd pumped/cow. The dry lot dairies

averaged 52.6 gpd/cow and the freestall dairies averaged 61.4 gpd/cow. The variation in water usage by facility may be caused by differences in parlor water usage, milking frequency, cow cooling, wash pens, herd size, heifer production and water recycling.

Figure 2: Comparison of average use of water by DL and FS facility over 10-year period with outliers removed



Zuagg (1989) summarized the daily water usage on five dairies in Arizona (Table 4). Early lactating cows drank between 29 and 35 gpd/cow while late lactating cows drank 25 to 28 gpd/cow. This was a function of milk production and feed intake. Water consumption was less than 20 gpd/cow during the dry cow period on all of the farms. Water usage on a dairy varied from 72 to 186 gallons per lactating cow per day and averaged 127 gpd/cow. In reviewing the data in Table 4, wash pens accounted for 37.5% of the total water usage per cow on average. Comparing water usage on Dairies B, C, and D, where some form of heat abatement was implemented and heifers beyond 6 months were not raised on the dairies, the average water usage was 89.3 gpd/cow when considering the water used in a wash pen and 58.6 gpd/cow when the water used in the wash pen was omitted. For the 5 dairies, the wash pen water usage ranged from 19 to 93 gpd/cow and averaged 50 gpd/cow. However, on dairies B, C, and D, the water usage in the wash pen averaged 30.6 gpd/cow. Water usage in the milk center, excluding the wash pen, ranged from 2.3 to 18.3 gpd/cow and averaged 11.2 gpd/cow. Dairies A and E (Table 4) utilized about 6 gpd/cow with the vacuum pump.

Brugger and Dorsey (2008) conducted the most thorough study metering water at 13 different locations on a dairy in northwest Ohio. The average fresh water usage was 29.6 gpd/cow. However, milk production and feed ration composition were not included in this paper. In addition, only 1 gpd/cow was used for cooling so there was minimum heat abatement on the dairy.

Table 4: Summary of daily water usage on five dairies (adapted from Zaugg, 1989)

	Dairy Identification and Milking Frequency				
	A(3X)	B(3X)	C(2X)	D(2X)	E(3X)
Calf include from 0 to 6 month	No	Yes	Yes	Yes	Yes
Heifers include from 6 to 22 months	No	No	No	No	Yes
Dry & Close-ups cow (D–dry * C- close ups)	D	D & C	No	No	D & C
Cooling (M – Milk Center & P – Pen)	M only	M & P	M & P	M & P	M & P
Total Water Usage per Lactating Cow (gpd)	186	101	95	72	182
Wash Pen Usage per Lactating Cow (gpd)	93	49	19	24	65
Drinking Water per Lactating Cow (gpd)*	71.2	32.2	59.3	40.1	81.1
Milk Center Usage per Lactating Cow (gpd)**	18.3	2.3	7.7	3.3	14.5

* Includes water for dry cows, close-ups, calves and heifers

** Includes water reported usage for vacuum pump

Water Usage at the Milk Center

The milking parlor facilities in a dairy have been shown to use the largest amounts of water (Sweeten and Wolfe, 1993; Gamroth and Moore, 1995, Meyer et al. 2006). Meyer et al. (2006) evaluated parlor water use on 16 dairies to calculate the amount of water flowing into dairy lagoons and holding ponds. The data for this study was collected over a 9 to 12 month period from August 1998-August 1999. Parlor water use was based on readings from the milk house, milking parlor, and sprinkler pens, and included water used for udder hygiene, milk equipment sanitation, parlor cleaning, plate coolers, and ice makers. They found parlor and udder hygiene water comprised an average of 56% of the total water entering the farms' lagoons. The water usage ranged from 45 to 194 gpd/cow with an average of 78.5 gpd/cow, showing the variability among farms and the large amounts of water that are used in milking facilities. Like the other studies, they reported that parlor water use was consistent throughout the year on each farm (Meyer et al., 2006). A second study in California (Castillio and Burrow, 2008) measured parlor water use in Merced County dairies. They chose 3 different dairies and installed 64 water meters. The average water use in the parlors on the 3 farms was 44, 51, and 49 gpd/cow. It should be noted that water usage tends to be higher in Western states since irrigation is required to raise crops. Dairies tend to utilize the pumped water first for an application on the dairy and then the water is recycled with nutrients onto cropland. . In this scenario, the net water depletion may be neutral depending on irrigation scheduling and crop water utilization.

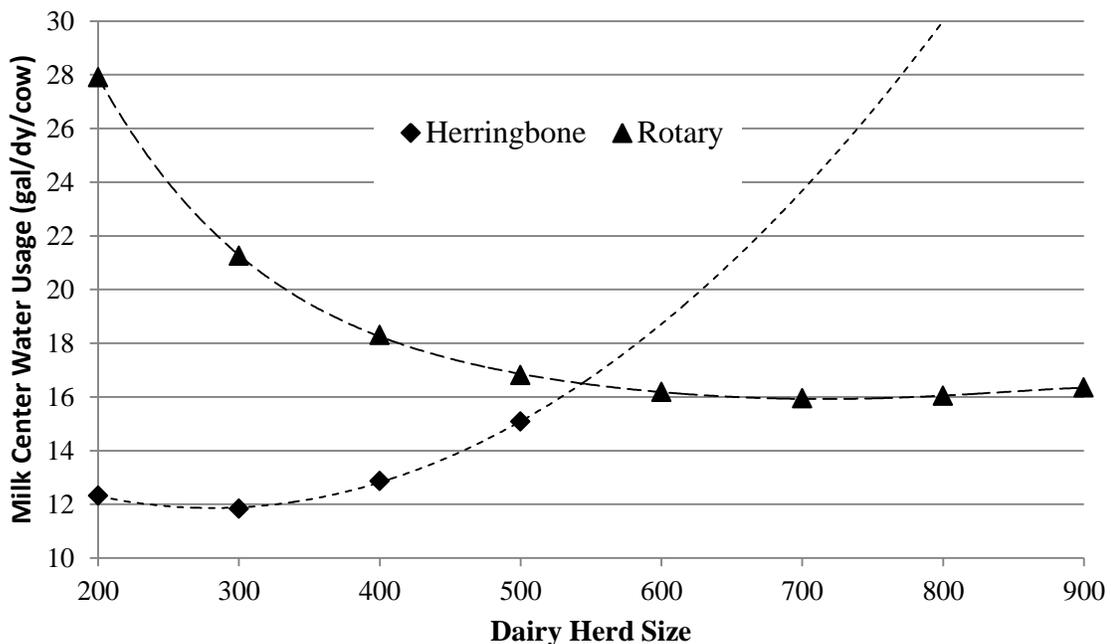
In contrast to the previous warm climate California studies, Janni et al. (2009) measured parlor water use on 16 Minnesota dairy farms. These dairies were much smaller in size, ranging from 41 to 130 milking cows. A range of 2.3 to 9.86 gpd/cow was used in the parlor, similar to the values reported by Zaugg (1989) on dairies B, C, and D in Table 4.

In Northwest Ohio, Brugger and Dorsey (2008) found that the average water intake was 6.3 gpd/cow for parlor water. They also noted that this was a consistent annual usage rate without seasonal variation. Bougie (1993) studied milk house waste water characteristics on 5 farms in Wisconsin and reported average usage ranging from 3.0 to 5.5 gpd/cow (Bougie, 1993).

Meyer et al. (2006) reported that dairies with wash pens averaged 80 gpd/cow, while dairies without averaged 53.4 gpd/cow. This data is similar to the findings of Zaugg (1989). On Texas dairies, Sweeten and Wolfe (1993) found that milk centers with flush systems used 47 gpd/cow and scrape systems used 20 gpd/cow.

The most comprehensive study involving water usage in the milk center was conducted in Victoria, Australia, where water usage on 780 dairies was analyzed (Williams, 2009). Water usage varied among herds of similar size, as noted in previous studies. Figure 3 shows the predicted 75th percentile recommended water usage for dairies based on herd size, defined by the industry as the “upper limit of what is ‘reasonable’ dairy water use for Victorian dairy farmers.” Figure 3 show with herringbone parlors use more water per cow as herd size increases. With rotary parlors, water usage tends to level out after 500 cows at 16 gpd/cow. This extensive data suggest an upper limit of ‘reasonable’ dairy water use equal to 16 gpd/cow in the milk center.

Figure 3. 75th percentile recommended reasonable water usage for Australian dairies based on parlor type and herd size.



Many dairies have reduced water usage in the milk parlor by changing udder prep procedures. Dairies using hand-operated wash hoses or automatic prep systems utilize between 1 and 4 gallons per cow per milking. Water usage can be reduced to less than ½ gallon per day when using low water techniques such as single service towels. Ludington and Sobel (1992) reported hot water usage dropped from 3.4 gpd/cow to 0.69 gpd/cow when changing to dry prepping with pre and post dip. Reinemann and Springman (1992) recommend sizing the water requirements of plate coolers based on 1 to 2 lbs of water per lb of milk. Water usage may be less than 1 to 1 if no attempts are made to control water and milk flow. Spencer (1992) also notes water usage with a pre-cooler may be twice as much as the milk production while accounting for 30 to 50 percent of the cooling requirements.

Fresh or clean water is required when flushing the parlor platform and holding pen. Water can be recycled from the plate cooler to perform this task. Weeks (1992) reported that 7.5 gpd/cow was required for flushing the milk parlor and holding pen. However, the milk parlor was only used several hours per day. Some data suggest an adequate flush can be obtained using 1.3 gallons per sq. foot per flush (Moore, 1989).

Heat Abatement

Low pressure sprinkler systems are used to wet the cow's skin surface for evaporative cooling and can be used in the holding pen and along the feed lane. Bray et al. (1994) reported water usage for low pressure systems ranging from 18.6 to 56 gpd/cow. They referred to a study by Montoya (1992) which found that 23 percent of the water was generally evaporated and 15 percent of the total water applied evaporated from the cow's body. This rate of evaporation equaled about 1.1 gallon per cow per hour. Bray and Bucklin (1995) recommend applying 0.05 inches per cycle when sprinkling cows. This converts to 0.03 gallons per square foot of wetted area. A cow will have about 12 square feet of wet area based on 2 ft along the feed line and 6 ft for cow length.

Sprinkler water usage was also recorded in a study by Meyer et al. (2002). This study was conducted over a 70-day period on 156 Holstein cows in August and September on a commercial dairy in Kansas. Three different cooling systems were studied to determine which was the most effective. Axial fans were used over freestalls and feed line, ceiling fans were used over freestalls, and poly tube cooling was also used over freestalls. Sprinklers were set up on 15 min cycles of 3 min on and 12 min off and were activated above 75°F with a rate of application of 16 gpm. Total water usage from the sprinklers from across all experiments came to 2,651 gpd or 17 gpd/cow.

Lin et al. (1998) also recorded sprinkler water usage over a 2-year study during the summer months. During the first summer, maximum daily temperatures ranged from 81.5 to 90.5°F and the sprinklers used 11.3 gpd/cow. During the second summer, daily temperatures ranged from 89.4 to 99.5°F and the sprinklers used 27.2 gpd/cow. Sprinklers were set to run 3 min out of every 15 min and turned on when ambient temperature exceeded 82°F (Lin et al., 1998).

Evaporative pads are another method used to cool cows. Evaporative pads are designed to cool the air around a cow's body to reduce heat stress (Harner et al., 2007). Harner et al. (2007) presented their findings on the water usage of evaporative pads. The water usage data in this presentation were collected from a cross ventilated barn which housed 1,200 dairy cows in the upper Midwest. Water measurements were taken from July 1 to July 31. Total water used during this time was 480,000 gallons and average use per cow was 13 gpd/cow (Harner et al., 2007).

Developing Water Budgets based on Scientific Data

Scientific data collectively may be used as an initial step to developing a water budget on a dairy. The following assumptions are based on the data presented in this paper and routine mathematical calculations:

- Milk production per cow is 80 lbs/d
- Feed consumed is 52 lb dry matter at 50% dry matter

- Water consumption is 3X milk production.
- Plate cooler water is 1.5X milk production.
- Milk center water is 6 gpd/cow, excluding deck flushing.
- Decking flush requires 12 gpd/cow.
- Dry cows are 20% of lactating cows and drink 15 gpd.
- Water troughs are cleaned daily at 10% of free water intake. Most will only clean once per week unless the water is used to flush the cross-over.
- Free water intake is 90% of total water requirements.
- Heat abatement lasts 120 days and requires 15 gpd/cow during abatement season.

These assumptions were used in developing the water budget for a dairy, as shown in Table 5. The total clean or potable water required per day was equal to 72.0 gpd/cow; however, 14 gpd/cow used for milk cooling were assumed to be used for drinking water or flushing the decks.

This results in an annual average daily net water usage (pumped from groundwater or purchased) of 57.2 gpd/cow. If milk inspection allows decks to be flushed with non-potable water, then the plate cooling water would be used for drinking purposes and the net requirement is only 43.2 gpd/cow. The water budget in Table 5 shows that the three biggest uses of water are for drinking, plate cooling, and deck flushing. Immediate water uses include parlor cleaning and heat abatement. There are limitations in using the data for developing water budgets, however, since data on water used for calf and heifer production and in hospital areas are not included. The data may provide a realistic estimate of water usage on a dairy, though, and a starting point for developing a water footprint for a dairy based on scientific data.

Table 5: Average water budget for a lactating cow based on stated assumptions in the text and current scientific data

	Annual Daily Water Required per Lactating Cow (gallon/day)	Percentages	
		Net Water Pumped Required*	Total Clean Water Required**
Free Water Intake	28.8	50.0	40.0
Ration Water Intake	3.2		
Total Water Intake	32.0		
Dry Cow Allowance	2.2	3.9	3.1
Water Trough Cleaning	2.9	5.0	4.0
Parlor Usage	6	10.1	8.4
Decking Flush	12	21.1	16.9
Heat Abatement	4.9	8.7	6.9
Plate Cooler	14.4		20.2
Total Clean Water Required	71.2		
Clean Water Reused	14.4		
Net Water Required	56.9		

*Newt water is the percentage of water pumped from ground water or purchased

** Total clean water is the percentage of total clean water required per day and assumes the plate cooler water is recycled and used in an application where potable water is required such for drinking

Summary

Many scientific controlled and field studies have explored water usage on dairies and water intake by dairy cattle. Unfortunately, comparing data is difficult due to the uniqueness of each study. Based on information reviewed, the following is a summary of the water data supported by multiple studies.

- **Drinking Water & Cooling**
 - 80 to 90 % of water consumed is free water.
 - 3 lbs of free water are drunk per 1 lb of milk produced.
 - Depending on milk production, cows will drink 25 to 40 gpd.
 - Water consumption is higher during the summer months and may be 1.5 to 2 times more than in cooler months.
 - 50% of water is consumed within 1 hour after eating.
 - Heat abatement, while dependent on location, requires 15 to 20 gpd/cow during summer months.
 - Cows will consume 8% of drinking water requirements at watering trough located near the milk center when exiting.
 - If water troughs are tipped and cleaned daily, assume increase in drinking water requirements of 10%.

- **Wash Pens**
 - Wash pen usage ranges from 20 to 100 gpd/cow and, depending on the study, averages 50 to 75 gpd/cow.
 - Reasonable usage may be 30 to 40 gpd/cow.
 - Wash pens on average account for 30 to 40% of total water used on a dairy.

- **Milk Center**
 - Water usage is variable, but 15 gpd/cow seems to be upper reasonable limit.
 - Many dairies are operating milk centers using less than 5 gpd/cow, so a reasonable target is 5 to 10 gpd/cow.
 - Water flow through plate coolers should be monitored and reduced on many dairies.
 - Reasonable plate cooler ratio is 1 to 2 lbs of water per lb of milk with a target of 1.5 or lower.
 - Dairies using water for cooling milk should recycle the water for other clean water applications such as flushing decks or drinking.

- **Overall**
 - Total water usage on dairies is 4 to 5 lbs of water per lb of milk but with a target of 4 if parlor decks are scraped and 5 if parlor decks are flushed with potable water. The water/milk ratio will be higher for dairies using wash pens.
 - Without wash pens, water usage should be less than 60 gpd/cow with a reasonable target of 50 gpd/cow. For herds with lower milk production, 40 gpd/cow may be reasonable.
 - Water usage on dairies will be 50% in housing areas and 50% in the milk center; however, the actual ratio is dependent on milk center procedures, manure handling,

housing of non-lactating animals such as heifers or dry cows, heat stress management etc.

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Notes:

Guidelines for Successful Dairy Heifer Development

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Success for a dairy heifer development program means that the growing phases of a heifer's life were managed to achieve high milk production early in first lactation with minimal variation or negative health events. It means managers managed the immune system to maximize immune-competence, controlled body condition scores and weights, and monitored desired hip height, feed efficiency and average daily gains at key target points based on mature cow height and weight.

However, heifer development programs have not traditionally been a major focus for dairy producers. As long as the cost per day for growth seemed reasonable and death rates remained below 5%, producers were satisfied. Dairy producers commonly state that more intense management systems for heifers require too much effort and are not cost effective.

Intensive management systems are not for all dairy operations; however, changes in the dairy industry over the past three to four years are driving change. Furthermore, operations that have intensified their management over time are experiencing reduced disease incidence and mortality losses, reduced treatment and labor costs and improved average daily gains through the first 70 days of age and beyond.

The industry is currently in a situation where there are higher feed costs, yardage costs, land values, cull cow values, sexed semen technology, dairy heifer inventory and beef prices. Currently, there is also a shortage of feeder replacements and the realization that currently you can purchase a springing heifer for \$200 – \$400 less than actual rearing costs. Therefore, one must focus more on the heifer business enterprise. Today's economy does not automatically give every heifer a lactation career opportunity. The earlier culling decisions can be made, the more profitable the heifer rearing program.

As an industry, managers monitor important performance indicators, but generally track those with far too much lag-time to be immediately useful. First lactation milk production, age at first calving and age at first breeding are just a few of these interesting, but lagging, measures. The industry has been reluctant to record and monitor early life indicators like birth weights, passive transfer, average

daily gains to 70 and 150 days of age, and disease events such that culling decisions can be made prior to investing in completely rearing an animal.

This reluctance carries significant performance and economic costs. For example, research from Cornell and other institutions shows that passive transfer has life-long effects on average daily gain and feed efficiency (Faber et al., 2005).

Growth rates within individual herds exhibit a remarkable amount of variation. For instance, track the days of age that Holstein heifers in a well-managed operation take to reach a hip height of 51 inches. On farms where weight and hip height are actually measured, variations of plus or minus 60 days from the average have been observed. This variation results from factors like passive transfer, genetics, disease incidence and environmental conditions. This variation demonstrates that dairy producers can no longer set a target age for first breeding without minimally monitoring hip height.

Heifer management without recording and monitoring the most relevant key performance indicators would be like managing your lactating herd without milk weights or bulk tank records.

The purpose of this paper is to focus on key areas of nutritional management, especially the first 100 days of age, and to suggest new key performance indicators that most heifer management programs either do not record or use to their full potential. From field experience, the following eight bottlenecks or phases of heifer development are areas where heifer development programs are often inadequate.

Phase 1—Colostrum Harvest and Delivery – Day 1

Harvesting and delivering an adequate volume of clean, high-quality colostrum in a timely manner must be the foundation of all successful dairy heifer development programs. Nutrients in colostrum, especially energy, are critical for generating body heat, maintenance and growth. There are also hormones and growth factors related to expression of genes involved in weight gain, reproduction and mammary development.

In addition, colostrum also contains components that transfer immune function to the calf. These components are immunoglobulins (IgG, IgA and IgM), white blood cells (macrophages, neutrophils, T and B lymphocytes) and other factors like cytokines, growth factors, vitamins, minerals and tripsin inhibitors plus nonspecific antimicrobial agents like lactoferrin and lysozyme (Godden, 2012).

Success or failure of passive transfer is dependent upon the dam's plane of nutrition and previous exposure to vaccines and environmental pathogens during gestation. The timeliness, cleanliness, amount and quality of colostrum harvested and delivered are the most important factors.

Colostrum quality is highly variable, especially from first-lactation heifers. Currently, producers must rely on a colostrometer or Brix refractometer to monitor quality. Large dairy operations with protocols in place for administering colostrum have found that it is easier to manage by feeding larger volumes sooner in a hygienic manner. The current recommendation is to feed 10% of the calf's body weight within 30 minutes of birth followed by 5% of body weight in 8 – 12 hours. For a 90-pound Holstein calf that is 9 pounds of colostrum at birth (4 quarts) and 4.5 pounds (2 quarts) 8 – 12 hours later. If esophageal feeders are used properly, passive transfer can be accomplished quicker and with less labor than bottle feeding of colostrum.

Cleanliness affects absorption of IgG. Colostrum is easily contaminated by preexisting intramammary infections or via fecal material during harvest. Common pathogens often found in colostrum are *E. coli*, *Salmonella spp.*, *Mycoplasma spp.*, Bovine Leukosis Virus, *Listeria monocytogenes*, *Campylobacter jejuni*, *Staphylococcus aureus*, *Mycobacterium bovis*, *Brucella abortus* and *M. avium susp. paratuberculosis* (MAP). Microbes may block passive transfer of IgG and these microbes can proliferate during storage and in feeding equipment.

The pathogen exposure for newborn calves can be minimized by following these recommendations:

- Do not let calves suckle their dam
- Clean and disinfect the udder before milking
- Sanitize milking, storage and feeding equipment
- Feed colostrum within 1 – 2 hours of birth
- Do not store colostrum in refrigerator more than 48 hours. Freeze it as soon as possible if you are not going to use it immediately.

Vaccination programs administering antigens for *E. coli*, Roto and Corona viruses in late gestation and again more than five weeks prior to freshening stimulate colostrum antibodies for these specific diseases. Well-balanced diets 30 days prior to freshening that meet the dam's metabolizable protein and energy needs, as well as preventing hypocalcemia, have been shown to reduce the incidence of fresh cow disease and to enhance the fetus' immune system as well as that of the dam.

The benefits of achieving successful passive transfer of IgGs are reduced treatment and mortality rates (NAHMS, Wells, 1996), improved growth rates and feed efficiency (Fowler, 1999; Gaber et al., 2005; Nocek et al., 1984; Faber, 2005), decreased age at first calving (Faber et al, 2005), and increased first and second lactation milk production (DeNise, 1989; Faber, 2005).

Critical data to record for later determination of individual and pen level outcomes include:

- I.D. number
- Birth date
- Birth weight
- Twin+/-

- Breed
- Sex
- Calving ease
- Dam Identification

Additional information about the dam includes days carried calf, days in close-up pen, lactation number, previous lactation mature equivalent milk production and mature body weight. If available, dam mature body weights can be used to set target weights for breeding and first calving for offspring. It is also recommended to record total serum protein at 48 hours and results of the BVD ear notch test.

Phase 2—Ramping Up Milk Intake – Metabolizable Energy & Protein – Week 1

The first decision management must make is what to feed and how much. The composition of whole milk on a dry matter basis for both Jerseys and Holsteins is shown in Table 1.

Table 1. Milk Composition: Average Milk Components from 2010 CDFA Herd Survey n=14/112

As Fed	Jersey Milk	Holstein Milk
Butterfat %	4.74%	3.57%
True Protein %	3.65%	3.10%
Total Solids Non-fat %	9.36%	8.81%
Total Solids %	14.10%	12.38%
Water %	85.90%	87.62%
Dry Matter Basis	Jersey Milk	Holstein Milk
Butterfat %	33.62%	28.84%
True Protein %	25.89%	25.04%
Total Solids Non-fat %	66.38%	71.16%
Total Solids %	100.00%	100.00%
Water %	0.00%	0.00%

What to feed?

If a calf is left on its mother, it will nurse between six and 10 times per day and consume somewhere between 16 and 24% of its body weight per day as milk (Corbett, 2012). A 100-pound calf would then consume 16 – 24 pounds of whole milk per day (1.9 to 2.8 gallons). If whole Holstein milk is 12.5% total solids, 16 – 24 pounds of whole milk equates to 2 – 3 pounds of total milk solids per day. Two to 3 pounds total milk solids can result in daily gains of 2 – 3 pounds, depending upon environment conditions, calf size and daily gain.

Most milk replacer companies recommend that 1 pound of dry powder be added to 1 gallon of water and that 1 gallon of mixed product be fed to each calf per day ($1/9 = 11.1\%$ solids). This amount is only one-third to one-half the amount that a calf would normally consume if left on its mother.

Table 1 shows that whole milk is 25 – 26% true protein. Most milk replacers are 20 – 22% protein. A traditional milk replacer program compared to a calf left on its mother is providing the calf with one-third to one-half the volume and one-third the protein. It is clearly evident if you are going to feed milk replacer, one must formulate for at least 12.5% solids and 25 – 26% protein and feed a minimum of 6 quarts volume. The higher protein milk replacers promote more lean tissue gain as well as improve efficiency of gain.

Table 2 summarizes the current information about the requirements for growth of the calf based on the body composition data derived since the 2001 NRC was published (Drackley, 2005). This table shows the updated nutrient requirements of a 100 lb calf under thermo neutral conditions.

Table 2. The energy and crude protein requirements of calves from birth to weaning (Van Amburgh and Drackley, 2005)					
Rate of Gain lb/d	ME^a mcal/d	DMI lb/d	ADP g/d	CP g/d	CP %DM
0.45	2.4	1.2	87	94	18.0
0.90	2.9	1.4	140	150	23.4
1.32	3.5	1.7	193	207	26.6
1.76	4.1	2.0	235	253	27.5
2.20	4.8	2.4	286	307	28.7

Normal fat content of milk replacers is 15 – 22%. Whole milk from Table 1 shows Holstein milk at 29% fat (DMB) and Jersey milk at 33% fat (DMB). Individual producers have reported feeding fat at up to 25% levels during cold winter months.

Some producers report success by increasing solids up to 18%. My experience has been that exceptional management must be in place to eliminate variation from batch to batch and the added solids must mirror the osmolality of whole milk at 271 mOsmol/kg. It is mandatory that calves have access to fresh water at all times if the strategy is to increase solids. Stools will be softer even with proper osmolality.

How much to feed?

Traditionally, the industry feeds 2 quarts twice a day. Even when whole milk is fed at 2 quarts twice a day, calves receive less than one-half of what a calf nursing its dam would consume. Managers on several calf ranches have switched to 3-quart bottles and some have switched to three-times-per-day

feeding. From a practical standpoint, it's recommended to feed 3 quarts twice a day at a minimum and 3 quarts three times a day at the maximum if you are using 3-quart bottles. It is also recommended that solids be at 12.5% to 14% for most operations because of concerns about batch-to-batch variation. Very good management can go up to 18% solids.

Pasteurized hospital milk is another other source of milk commonly used. It is recommended that you check each batch for solids as variation from 8% to 14% solids have been observed—depending on source and type of animals in the hospital pens. Larger operations have also had success identifying high somatic cell count cows, placing them in a separate pen, and sending this milk to the calf ranch where it is pasteurized.

These decisions increase the daily inputs for feed and labor, but have resulted in improved heifer average daily gains and significant decreases in scours and pneumonia. Reduced morbidity and mortality also result in lower pharmaceutical and labor costs.

Bucket feeding is another option that some calf ranches use. It is easier to feed larger volumes of milk, but more of a challenge from a sanitation standpoint.

Keep in mind that one program does not fit all operations. Different programs require different input costs for feed, labor, and yardage. Most calf ranches are paid on a cost per head per day basis which is not as conducive to good performance as if one is paid on a cost per pound of gain basis.

The industry should consider analyzing wet calf performance using the partial budget below.

In this example, calves are feed 2 quarts of a 26% CP and 20% fat milk replacer mixed at 12.5% total solids either two or three times a day. The milk replacer costs \$2,600 per ton. Daily feed cost increases from \$1.38 to \$2.07. The example increased the yardage/labor cost \$0.15 per head per day for the extra labor for the extra feeding. In order to breakeven in this scenario, producers would need an extra 0.6 pounds of average daily gain. No value has been placed on the reduction in disease incidence and the reduced drug and labor costs that would be expected.

	2 Times a Day Feeding	3 Times a Day Feeding
Ration Description	26/20 Milk Replacer	26/20 Milk Replacer
Cost/Ton DM	\$2,600.00	\$2,600.00
Cost/Ton AF	\$325.00	\$325.00
% Dry Matter/Solids	12.50%	12.50%
Intake DM	1.06	1.59
Yardage/Labor	\$0.75	\$0.90
Daily Feed Cost	\$1.38	\$2.07
ADG	1.50	2.09
Cost/hd/day	\$2.13	\$2.97
Cost/lb. gain	\$1.42	\$1.42

One cannot do an analysis like the one above without average daily gain (ADG) numbers. This is why it is suggested that producers record individual birth weights and individual weights out of the hutch. They can then calculate ADG by subtracting birth weights from weight out of hutch and dividing by days on feed (days in hutch). Managers can then look at performance of cohorts or groups of calves by week, month, season, source or disease incidence.

In addition to recording individual weights out of the hutch, it is recommended to record disease events like scours and pneumonia, number of days for the health event, and treatments used. If the operation records this information, one can consider early culling based on individual average daily gain and number of disease events. Marketing opportunities are usually better for early culling at 150 days on feed than at 70 days.

In the dairy industry today, optimal rumen development is the goal but not at the expense of reduced performance during the milk-feeding phase. Reducing milk intake with the intent of driving up dry feed intake at an earlier age is not the objective nor is it economically justified. The objective should be to transition from milk protein and energy to plant protein and energy as quickly and as efficiently as possible. In younger animals, the plant protein and energy is less digestible (metabolizable). The dairy industry has lengthened the days on milk in response to the performance lag they experience when transitioning to dry feed too early. Calf starter grain mixes containing highly digestible protein and energy sources have allowed some operations to reduce days on milk up to a point.

Phase 3—Weaning – Week ~8

Weaning is the time in a dairy calf's life when management asks the calf's digestive tract to switch from milk protein and energy to plant protein and energy. Milk and milk replacers are more costly than starter feeds on a per ton basis but the feed efficiency of milk solids is better than plant sources. The younger the calf (5 – 6 weeks), the lower the digestibility of the plant source protein and energy. We now have modeling programs for young calves, but they are not capable of accurately predicting the metabolizable protein and energy actually available to the very young calf during the weaning process (<10 weeks).

Experience has changed weaning recommendations and weaning should be based on calf starter intake vs. days of age. It can be cumbersome to measure calf starter intake in large operations but it can be done. Do not wean an animal until it is consuming 2.5 to 3.0 pounds of calf starter for three consecutive days. All schedules for transitioning from milk to starter feed need to be adjusted by each operation based upon calf performance. Performance is driven by your colostrum program, the volume and solids of milk fed, the environmental conditions and disease incidence.

There is variation in the number of days of age when calves are ready for removal of milk. Producers cannot afford to keep all calves of a cohort or age group on milk until the last one is ready to wean. It is recommended that you have a protocol in place that allows the slower developing animals to stay on milk at least an extra 7 to 10 days. These animals need to be recorded in your record-keeping system as delayed weaning. This is another factor to consider for later culling decisions.

Free choice water is essential for calf starter dry matter intake. Calves will generally double their starter intake in the 7 days following complete removal of milk. Do not introduce hay until in group pens for at least 2 weeks.

All calf starter grain mixes are not formulated equally! Crude protein (CP) and energy are not as important as metabolizable protein and energy. Some ingredients are more palatable than others. Palatability and digestibility of the properly formulated calf starter, as well as the development of the calf's digestive system, are keys to a successful transition to plant protein and energy.

In my opinion, the main source of protein should be soybean meal. Calves transitioning from milk to dry feeds cannot utilize poor quality bypass proteins such as corn distillers grains. The grains should be processed and heat treated for better gelatinization of the starch, thus better digestibility. A coccidiostat should be included in the formula at a proper dosage level. An example of a calf starter grain mix is shown below.

Example: Calf Starter Grain Mix

<u>Ingredient</u>	<u>% Ration</u>	<u>% Pellet</u>	<u>% TMR</u>
*Hi-Pro Soybean Meal	33.25%	70.74%	
*Diamond V® XP	4.00%	8.51%	
*FERMENTEN®	2.75%	5.85%	
*Fine Ground Wheat	4.50%	9.57%	
*Calf Starter Mineral-Vit	2.25%	4.79%	
*Extra Bond	0.10%	0.21%	
*Flavor	0.10%	0.21%	
*Mold Inhibitor	0.05%	0.11%	*47.00%
Steam Flaked Corn	31.50%		31.50%
Steam Flaked Barley	15.00%		15.00%
Vegetable Fat	0.50%		0.50%
Molasses Cane	6.00%		6.00%
	100.00%	100.00%	100.00%
<u>Ration Analysis</u>			
Crude Protein %DM	25.20%		
Sugar %DM	8.57%		
Starch %DM	37.80%		
EE %DM	3.46%		
Lasalocid mg/lb	23.33		
FERMENTEN gms/lb	11.24		
<i>*Ingredients are Pelleted with vegetable fat sprayed on pellet prior to adding corn, barley & molasses to total mix.</i>			

Calf starters are often purchased on price rather than quality. Instead, this decision should be based on calf performance.

Average daily gain while in the hutch is one of the key numbers to base your decision upon. The Ration Comparison spreadsheet shows the relative value of two starter feeds. The example compares an 18% calf starter grain mix to a 22% CP as fed. The difference is \$40 per ton. The example assumes that dry matter intakes are the same as well as yardage/labor. The 22% CP calf starter requires the calves to gain 0.12 pounds more per day in order to break even. Without performance numbers, one usually makes an error by choosing the lower performing, less expensive feed.

Ration Compare Spreadsheet

Ration Description	18% CP	22% CP
Cost/Ton AF	\$ 400.00	\$ 440.00
% Dry Matter	87.43%	87.57%
Intake DM	6.76	6.76
Yardage/Labor	\$0.75	\$0.75
Daily Feed Cost	\$1.55	\$1.70
ADG	1.9	2.02
Cost/hd/day	\$2.30	\$2.45
Cost/lb. gain	\$1.21	\$1.21

Phase 4—Group Lag – Week ~9 to~17

Many calf operations experience a “lag phase” when calves are moved from the hutches to group pens. Operations that require calves to consume about 7 – 8 pounds of calf starter grain mix before leaving the hutch experience less lag and/or better performance during the transition to groups.

Consider the initial group size as well; as smaller groups translate into less stress. Groups of 10 – 20 head per pen on large operations seem to work well. Not all animals like to eat in lockups so it is advantageous to provide some starter grain mix inside the pen.

In addition, a dry, draft-free bedded area is required to assure that calves lie down. Temperature, moisture, hair coat and wind velocity have a large impact on daily maintenance requirements. Today’s nutritional models demonstrate this very nicely.

Adequate fresh water close to the feeding area is also essential. Do not introduce hay in the ration until the animals are in group pens for at least 2 weeks. Mixing 10 – 15% of good quality chopped alfalfa hay with the calf starter seems to work well for most operations. This can be fed until the animals have been in group pens for approximately 4 weeks. Table 3 below shows the timeline for ration changes.

Table 3. Example Ration Changes by Weeks of Age

GROUP LOCATION	SMALL GROWER PENS 10, 20 or 40			LARGE GROUP PENS 160						
	Week 11-12	Week 13-14	Week 15-18	Week 19-22	Week 23-26	Week 27-30	Week 31-34	Week 35-38	Week 39-42	Pre- Breed
RATION - LBS/HD/DAY AS FED										
CSGrain Mix	8	8								
Grow Pellet			3	3	3	3	3	3	3	3
Flaked Corn			3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
Alfalfa Hay		0.8	1.1	1.6	2.1	2.5	3	3.66	4	4.33
Oat Hay			2.20	3.20	4.20	5.00	6.00	7.33	8.00	8.66

Phase 5—Grower Grain Mix – Increasing % Forages – Week ~16

At approximately 15–16 weeks of age (110 days), the calves can be transitioned to a grower ration. A grain mix or grower pellet that contains protein, vitamins, minerals and coccidiostat/growth promoter can be mixed with good quality forages.

In response to higher feed costs, the industry has gradually increased the amount of forage fed (lowered digestibility) and decreased the quality of dry concentrate fed (lowered digestibility at an earlier age). This management decision has moderated feed costs, but what has been the production response? Most managers are not monitoring ADG or total cost per pound of gain during the growing phase (weight out of hutch to 150 days of age). Without these performance indications, it is not possible to make good management decisions.

Capturing body weight information at 5 months of age can solve this dilemma. This is a time when vaccines are normally administered; animals are already being handled and you can maximize labor efficiency.

With this information you can make better ration decisions as it is an opportune time to make early culling decisions. Under present marketing conditions, this is a good opportunity to allow your underperforming heifers to make a future career change. Beef feeder markets are good and ~400 lbs. is a good time to market dairy animals for beef production programs.

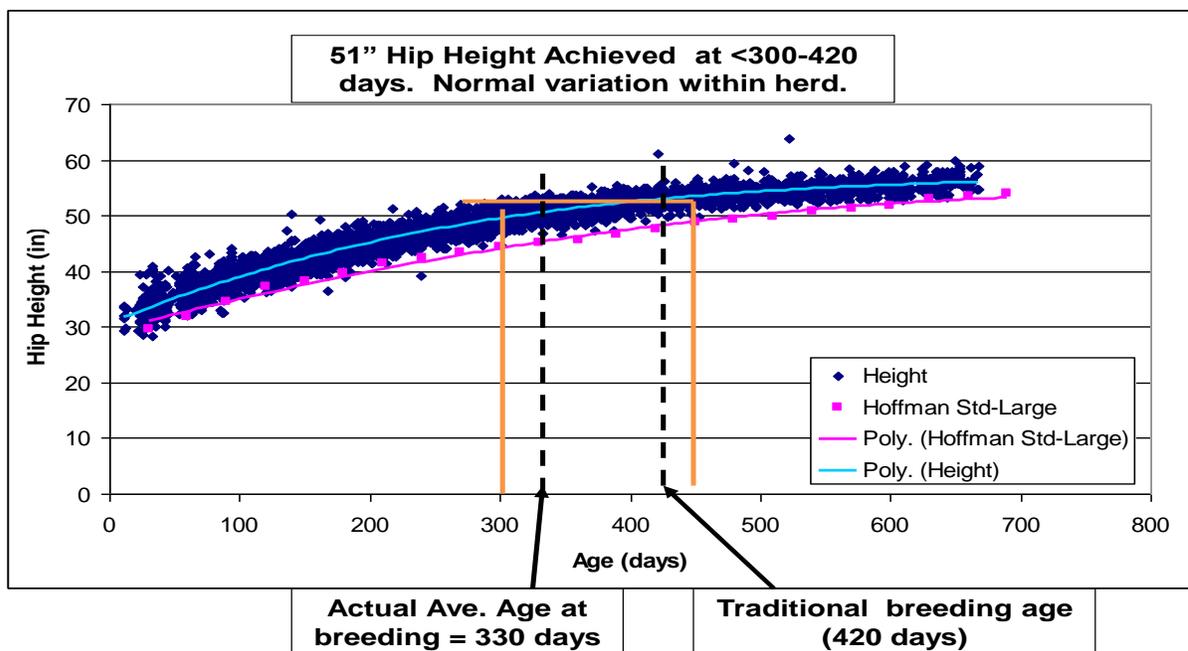
Phase 6—Introduction to Breeding Pen – 10 Months/51-52” Hip Height

Movement to the breeding pen must be based primarily upon accurate hip heights and body weight measurements, with age as a secondary parameter. Holsteins should be 51 – 52 inches at the hip when entering the breeding pen. It is recommended that you do not breed Holstein heifers before 10

months of age even if they have achieved the hip height and weight targets. In well-managed programs, approximately 20% will be adequate size by 10 months of age.

Variation in age of animals attaining target hip height and body weight is greater than most people realize. A normal, well-managed Holstein heifer development program will have more than 90% of the animals at an adequate size to breed between 10 – 14 months of age. This variation is normal and is due to genetics, growth rate, feed efficiency and disease. Age at conception is the key performance indicator to monitor for heifers in the breeding pen. It is also important to record movement to breeding pen so that 21-d pregnancy rates and insemination risks are calculated correctly.

Waiting too long to initiate breeding results in wasted days on feed and, often, over-conditioned heifers. Frame growth slows down as heifers mature. Older heifers tend to gain excessive body condition. This results in more calving difficulties and metabolic disease. The graph below is from more than 7,000 measurements in a Holstein heifer herd. Note that even though the same rearing program was followed throughout, several animals were 51 inches at the hip at less than 10 months of age while others were 14 months of age before attaining desired hip heights.



Phase 7—Movement to Close-up Pen – 3 Weeks in Close-Up – DCC<250

The most common mistake in this phase is not getting springing heifers on the close-up diet for more than 21 days before freshening. Move heifers to the close-up pen before they reach 250 days carried calf. The key numbers to monitor are days in close up pen and dry matter intake. Monitor variation as well as averages. Days in close up pen should be greater than 21 and the average dry matter intake for Holstein heifers greater than 24 pounds.

The second most common mistake is not feeding the rumen microbes to provide ~1200 gms metabolizable protein. The fetus and mammary gland are developing at a very fast rate as the end of gestation nears, resulting in increased requirements for metabolizable protein and energy, while dry matter intake is declining. The heifer also has requirements for her own maintenance and growth as well as the immune systems of both the fetus and dam. When requirements for metabolizable protein and energy are not met, the animal begins to mobilize protein and fat.

If metritis is a concern with fresh heifers, feed a negative DCAD diet to increase serum calcium levels around freshening. Low blood calcium (hypocalcemia and subclinical hypocalcemia) has been shown to increase the incidence of fresh cow diseases (Santos et al., 2012).

Phase 8—Animal Comfort and Welfare – Animal Husbandry – Day 1 to Lactation

This paper would not be complete without briefly touching on animal comfort and welfare—animal husbandry.

In today's society, consumers want the ideal. If you say you are doing it, you had better be able to prove it. Leadership is about taking your operation to where it needs to be. Therefore, protocols must be in place for housing, feeding, breeding, moving, and handling and treating all ages of livestock on the farm.

There must be written consequences for individuals who do not follow protocols. Protocols must be in writing and training programs must be documented. These records are the only way to defend the practices on your farm.

What will your message be when asked to explain castration or dehorning on your operation? Don't allow your organization to think "if" we are audited. Rather, be prepared for when you are audited so you can communicate and demonstrate that you have a realistic plan in place. The dairy industry's success depends on our ability to assure consumers that we are doing the right thing and our ability to prove it (Walker, 2012).

Conclusion

In today's dairy industry, heifer development is essential and should be considered an opportunity area for most herds. Today's input costs are requiring more intense management. This management style requires different key performance indicators than we have traditionally used. Average daily gain and feed efficiency numbers are required to make the management decisions that yield the best return on your heifer development dollars.

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An Economic Comparison of Conventional vs. Intensive Heifer Rearing

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Introduction

Dairy replacement heifers are often viewed as simply another cost-of-doing business on a dairy. While replacement heifer programs usually rank as the second largest cost of producing milk, usually trailing only feed costs, the expense associated with feeding and rearing heifers should be more properly viewed as an investment towards the future. Much like any other investment, money is spent today for a return that will not be realized until the heifer calves and enters lactation.

Within the dairy heifer growing period, the highest daily expense is during the preweaning period and is a consequence of the liquid diet and the high labor costs associated with liquid feeding. As a result of the high up-front costs, many producers adopt management and feeding strategies that appear to save money up front, but result in greater opportunity costs in the future.

Conventional wisdom regarding the feeding of neonatal calves has been that one should slightly limit or restrict the caloric intake from the liquid diet in an effort to stimulate consumption of calf starter. The belief is that hungry calves will begin consuming starter grain earlier and in larger amounts than if early liquid nutrition is sufficient to meet or exceed their daily needs. However, while it is true that feeding larger amounts of starter grain costs less than milk or milk powder as traditionally fed, dairymen that choose this approach are not capitalizing on the tremendous growth efficiency that young calves possess, if fed adequately, and they usually will see much higher morbidity and mortality in the young calves.

The typical dairy that follows a conventional approach feeds a milk replacer that contains 20-22% protein and 15-20% fat at the rate of about 1 lb of milk solids per day (DM basis). Under thermoneutral conditions, this level of milk feeding allows approximately 200 g of body weight gain per day for a 90 lb calf but during more stressful conditions such as cold, windy or wet weather, results in a state of semi-starvation¹. Calves fed these traditional diets often suffer from significant weight loss or stunted growth. Additionally, there are often outbreaks of diarrhea at 7-10 days of

age and preweaning respiratory disease that are caused (or at least worsened) by a compromised immune system and inadequate caloric and protein intake.

A major complicating issue to the conventional approach is the low protein content of the calf starter. The marginal level of calories serves to stimulate earlier and higher levels of starter grain consumption and can allow producers to wean calves at an earlier age, but these calves often crash afterward because of the low protein content. Remember, even if a conventionally reared calf increases its consumption of starter grain and is consuming the identical level of crude protein as a calf on a diet that provides a higher level of milk volume and/or solids, the digestibility of the two diets is usually not comparable. Milk and milk replacer is generally more digestible than the proteins commonly found in most calf starters. Calves on a conventional diet usually have smaller frames and often have health issues that follow them through the remainder of the growing phase and into lactation. Also, with conventional rearing systems, typical age at first calving is usually between 25 and 28 months and the impact is a large delay in positive cash flow (milk production) and requires a greater number of youngstock to fill the gaps created by culling poor producing animals.

Intensive management programs have begun receiving a lot of attention in the last few years. These programs involve the feeding of rations that are higher in metabolizable protein without enough extra energy to promote fattening²⁻⁷. During the milk feeding period, calves are provided with larger volumes of more nutrient dense milk or milk replacer. Typical formulations are 28% protein and 18-20% fat and are fed at a rate of 0.3-0.37 lbs of milk solids/ liter with a total of 4-10 liters of fluid volume depending upon the size and age of the calf. Feeding higher levels of nutrients will allow 1.7 to 2.5 lb or more of body weight gain per day, depending on environmental conditions and volume of milk provided. Also, the higher level of nutrients can allow calves to withstand more environmental stressors without resulting in weight loss.

The downside of the approach is that the feed cost during the liquid feeding period is significantly higher and calves sometimes are slow to begin eating calf starter. The increased feed costs continue through the entire replacement rearing period. As calves grow and move through the various diet and pen changes, they are provided with rations that continue to be higher in metabolizable protein than comparable conventional rations and these larger heifers eat more feed per day due to their larger body size and higher growth rates. However, these well-fed heifers usually experience the advantages of a reduction in both morbidity and mortality, reduced impact of cold weather stress, an earlier age at first service and first calving, and improved feed efficiency since total days on feed is reduced but rate of gain is increased. In addition, there should be a reduction in the number of heifers required to enter the replacement stream since fewer animals are lost during the rearing process. One very impressive benefit that cannot go unmentioned is the higher levels of milk yield during the first and subsequent lactations that is the result of improved nutrition and management as heifers⁶.

Economic Modeling

A partial budget was created using Microsoft Excel[®] and the objective was to model and compare a conventional heifer rearing program with an intensive program from birth through calving. The model is divided into age groups based on feeding, housing and management needs and consists of six different stages: 1) birth to 2 months of age, 2) 2 to 4 months of age, 3) 4 to 10 months of age,

4)10 months through breeding, 5) gestation, and 6) the last two months prior to calving. During all but the final stage, there are significant differences in nutrient composition, quantity consumed, and cost of feeds. During the final stage, there are no significant differences in nutrient composition, but there are still large differences in level of feed intake based on the difference in size of heifers between the two management approaches. One primary difference is the age at which the intensive heifers exit the 4th stage and enter subsequent stages when compared to conventionally reared heifers. Many management issues such as vaccination protocols and housing needs are not different between groups, but are included in the model in order to more accurately calculate the true cost of heifer rearing.

The major management difference between the two heifer rearing approaches is the nutrition program. Throughout all but the final stage, intensive heifers receive rations that are higher in metabolizable protein, yet similar in energy density. As a result, the projected growth curves of the two groups are assumed to be different. The growth curve for the conventional program is based on data collected by Coleen Jones and Jud Heinrichs from Penn State University and was fit to mimic the growth characteristics of the median of the population⁸. The growth curve for the intensive program was fit from data collected by Dr. Robert Corbett from an intensively managed herd in the western U.S. This particular herd has been following the nutritional advice of Dr. Corbett and has fed for an intensive rate of gain for a number of years. The growth curve for each approach was derived by selecting the best fitting polynomial regression equation for each data set.

In stage 1, calves in both groups are assumed to weigh 88 lbs at birth and are fed 3 liters of colostrum at birth and again within 12 hours via an esophageal feeder. All calves are housed in individual fiberglass hutches and have free choice water and calf starter available beginning at 3 days of age. Calves in the conventional group receive 4 liters per day, divided into 2 feedings, of 20% protein, 20% fat (DM basis) milk replacer containing 1 lb of milk powder per gallon. Calves receive the same amount of milk daily for 7 weeks and then they are weaned from liquid feeding. Calf starter is an 18% crude protein (as fed basis) and initially, the amount consumed per day is only a trace amount, but increases over time such that over the 7 week liquid feeding phase, starter grain intake averages approximately 2.3 lbs/d. For the final 2 weeks of stage 1, conventional calves consume an average of 4.4 lbs/d and by 63 days, these calves are projected to weigh 155 lbs.

In the intensive group, calves are fed a 28% protein, 18% fat (DM basis) milk replacer containing 1.25 lb/gallon but the volume fed varies over time. During the first week, calves are fed 1.25 gallons/d, but over weeks 2-6, calves receive 1.75 gallons/d. With higher levels of liquid feeding, calves often do not consume as much grain starter and in order to encourage adequate consumption of grain prior to withdrawing milk completely, calves are cut back to 0.88 gallons/d for the 7th and final week of liquid feeding. The calf starter for this group contains 22% crude protein (as fed basis) and costs more than the conventional starter. As with the conventional feeding approach, calves do not usually consume significant amounts of feed during the first week of life and due to the higher nutrient intake from the intensive approach throughout the milk feeding period, these calves only consume about 0.8 lbs of starter/d on average during weeks 2-7. However, with the reduction in milk feeding during week 7 and the increasing body weight, starter intake increases and for weeks 8 and 9 in the hutch, grain intake increases to about 3.8 lbs/d. it is worth mentioning that in both the conventional and intensive approaches, weaning should occur once calves are eating sufficient dry feed to make a successful transition from the liquid diet to a grain-based diet. Standardizing the

weaning time is necessary to accurately model the costs and opportunities associated with each approach. Upon exiting the 1st stage, these calves are projected to weigh 192 lbs.

Another key difference within stage 1 between the two approaches is the projected morbidity and mortality estimates. With conventional feeding and management, 30% of calves are projected to experience a case of diarrhea and 25% are expected to be treated for pneumonia. The mortality risk for this preweaning period is 7%. Due to improved nutrition, the intensive calves only experience 9% diarrhea risk and 8% pneumonia risk with a period-specific mortality risk of only 3%. Due to a reduction in respiratory disease in the first 2 months, the intensive group is projected to experience a reduced incidence of pneumonia over the subsequent stages and an overall mortality risk of 6% vs. 12% in the conventional group for the entire rearing period.

At 63 days of age, calves move into the 2nd stage and are moved into small group pens and fed a ration consisting of mostly grower grain with about 10-15% good quality hay. The intensive group's grower grain is higher in crude protein and costs more per kg of dry matter than the conventional grain. Calves enter this stage weighing 155 lbs and 192 lbs for conventional and intensive, respectively, and in 2 months, weigh 266 lbs and 320 lbs. The predicted dry matter intake per day is a function of body weight and energy density of the ration and is estimated using the Nutrient Requirements of Dairy Cattle: Seventh Revised Edition, 2001.

Calves move into larger group pens and are fed a total mixed ration (TMR) beginning at 4 months. This move is the beginning of the 3rd stage and it lasts until 10 months. Due to higher protein levels, the intensive group's TMR costs more, and these calves eat more based on a larger body weight and frame. At the end of this stage, calves weigh 588 lbs vs. 705 lbs for conventional vs. intensive, respectively.

The 4th stage is the period that encompasses the breeding period. Heifers enter at 10 months of age, but the time that they leave depends primarily upon when they reach the desired breeding height/weight and then successfully complete the breeding program. Both groups are eligible for breeding at 825 lbs of body weight, but due to a faster rate of growth, the intensive heifers start breeding at an average of 12.2 months of age while the conventional heifers begin breeding at 15.1 months. Both groups are eligible for breeding for 8 21-d cycles and there is no difference in reproductive performance assumed between the two groups. The overall insemination risk is 65% and the overall conception risk is 50% for both groups. The average heifer conceives approximately 45 days after entering the breeding program and is confirmed pregnant 45 days later when she is then moved into the next rearing stage. Approximately 6% of the heifers that entered the breeding program are culled for failure to become pregnant. Thus, the total length of time in this stage is dependent upon the time required to reach breeding weight, the time required to become pregnant and the time required before pregnancy can be confirmed. Conventional heifers leave this stage at an average of 18 months weighing 966 lbs while the intensive heifers leave at 15.1 months weighing 1017 lbs.

The 5th growth stage contains the pregnant heifers and lasts for 5-6 months. The ration for the intensive heifer group continues to be higher in metabolizable protein and there is a corresponding difference in cost/ lb of ration dry matter. The intensive heifers' daily feed cost continues to be higher due to the higher level of feed intake and the higher cost per lb. Heifers are moved into the final group at 1-2 months prior to calving weighing 1195 lbs and 1347 lbs for conventional vs.

intensive, respectively, and the ration composition and cost is the same for both groups during the 6th and final stage. The major cost difference in this final month is the different level of feed intake predicted due to the difference in body weight. Conventional heifers are predicted to calve weighing 1267 lbs while the intensive heifers should weigh 1459 lbs.

Throughout each of the cycles, a variety of costs are assigned to the heifers other than feed costs and reproductive management fees. Specific costs that are included in the model include the upfront purchase cost of each heifer; the feeding, housing, equipment, reproductive management, labor, and health management costs of each heifer; and the interest or opportunity costs. All costs, including the costs attributed to the rearing expenses of the calves that die, are adjusted to the net present value expected at calving using a preset interest rate of 8% and are distributed over the heifers that actually survive to calving. In other words, all expected costs for every calf that enters the rearing enterprise is redistributed over the surviving heifers. Thus, heifers from the conventional system that survive and calve carry more interest and mortality costs due to the longer time to calving and the higher mortality associated with this group. There is an initial investment cost per calf that is assumed to be the same between groups and the final investment cost is also time adjusted to the time of calving.

One benefit of intensive heifer programs that has been summarized by Van Amburgh and by Soberon, et al. is the potential for increased milk production in the first lactation^{2,6}. Heifers reared via an appropriately managed intensive approach are projected to produce an extra 1700 lbs of milk during the first lactation. The model incorporates the extra milk as a source of value for intensive heifers but makes adjustments for the returns that will occur in the future and for culling that occurs during the first lactation.

Results and Discussion

Throughout each growth stage, the intensive system costs more per day, as shown in Figures 1 and 2, but the conventional system results in a higher total cost per heifer due primarily to the longer feeding period. The total rearing cost is estimated to be \$2449 and \$2415 for conventional vs. intensive heifers, respectively. The \$35 advantage for intensive rearing does not include the value of the extra milk predicted in the first lactation for the intensive heifers. After accounting for the delayed return for the extra milk production (after calving for first time), for the additional feed cost associated with the extra milk, and for the impact of culling during the first lactation, the net value per heifer is estimated to be \$180 as shown in table 1.

Based on the assumptions used in this model, the intensive approach results in \$73 higher feed costs, but results in savings in labor (\$29), health and vet med costs (\$11), interest costs (\$10), reproductive cull costs of (\$9), costs of dead or culled calves (\$13), and housing costs (\$36) for a net result of a “savings” of \$35 per calf for the intensive program, not including the value of the additional milk. Addition of the predicted time-adjusted value of the extra milk results in a total economic advantage of \$205 for the intensive program.

Within this model, attempts have been made to represent the true estimated costs and returns of each program as carefully as possible. As more systems implement the intensive heifer rearing approach, more data will be generated to help validate this model. Many people will likely be surprised at the total estimated cost of rearing heifers in either system, but this model reflects the current high feed costs that many have not considered over the entire rearing period. A key take-home message from

this work is that while the individual cost/d may be higher, capitalizing on improved growth efficiency that is possible with higher metabolizable protein rations, especially early in the growth and development of calves, results in a lower cumulative cost that is realized at calving.

Many people are skeptical of the projected increase in milk production that is attributed to the intensive program. However, the literature actually shows increased milk production not only in the first lactation, but also carrying over into the second lactation for heifers fed for intensive growth during the rearing period and this value is not captured by the model². Even without the projected additional milk in the first lactation, the advantage is still tilted towards intensive rearing.

Another benefit not currently captured is the ability to either maintain fewer heifers in the replacement pipeline or to grow extra heifers for potential marketing benefits. By growing heifers faster and with reduced morbidity and mortality, fewer calves need to be placed each month in order to meet the required number for replacement each year. If additional heifers were maintained above the basic replacement needs, producers would have the luxury of either selling additional springing heifers or calving these animals and then culling more heavily from the lactating herd in order to make more rapid genetic progress. These additional marginal benefits were not considered in this version of the model and yet the advantage is still clearly in favor of intensive rearing vs. the more conventional approach.

The model presented in this paper and its results were based on a combination of published data and from data generated on a large commercial dairy that works with Dr. Corbett. This private dairy generated thousands of calf weight data points that were used to develop an intensive management growth curve. Use of this curve allowed for the prediction of average growth expectations using specific milk and grain feeding approaches. However, the results presented here are quite conservative for the intensive calf rearing approach. Since this early work, Dr. Corbett has further refined his feeding approach and is now feeding even larger volumes of more nutrient-dense milk replacer and higher levels of protein in his heifer diets. As a result, Holstein calves are averaging over 2.2 lbs of body weight gain per day, morbidity and mortality are substantially lower than reflected in the current model, and approximately 90% of the calves have reached breeding weight and height by 11 months of age. Results such as these further increase the advantage of the intensive heifer rearing program. However, even with what some would consider to be an overly conservative approach to modeling the two programs, there should be no doubt to the economic advantage of the intensive approach to rearing dairy replacement heifers.

Figure 1. Cumulative costs throughout the heifer rearing period for conventional vs. intensive dairy heifers.

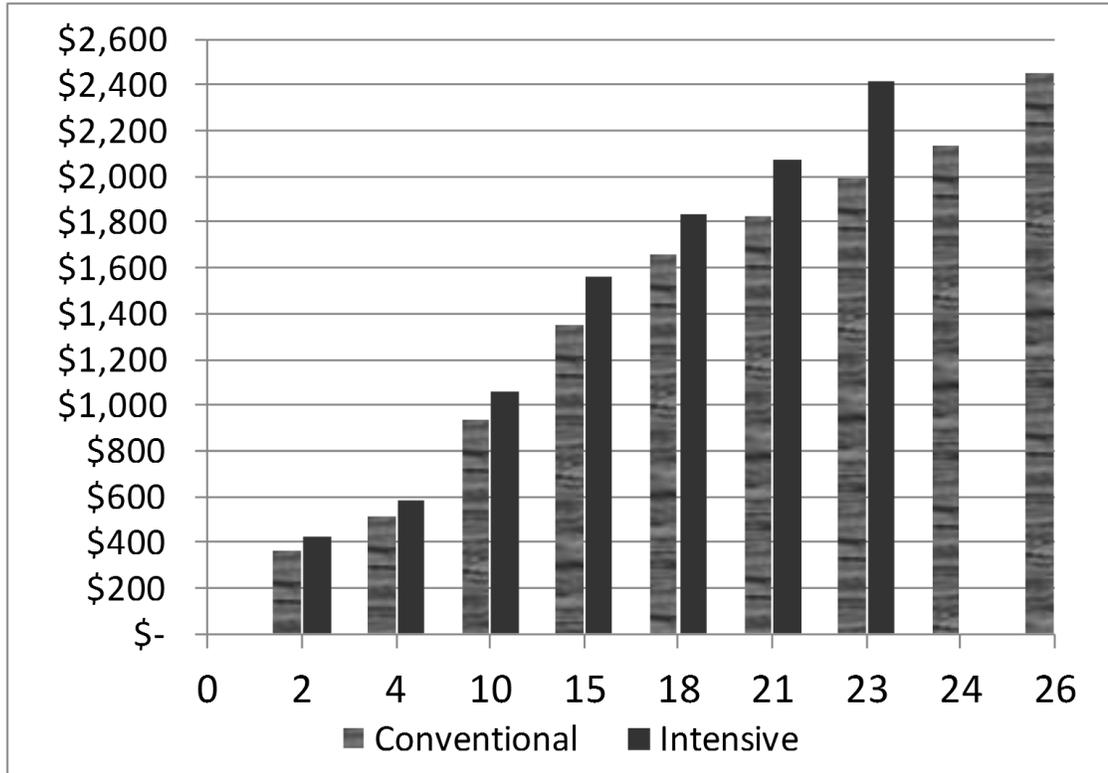


Figure 2. Total costs for conventional vs. intensive heifer rearing by category for the entire rearing period.

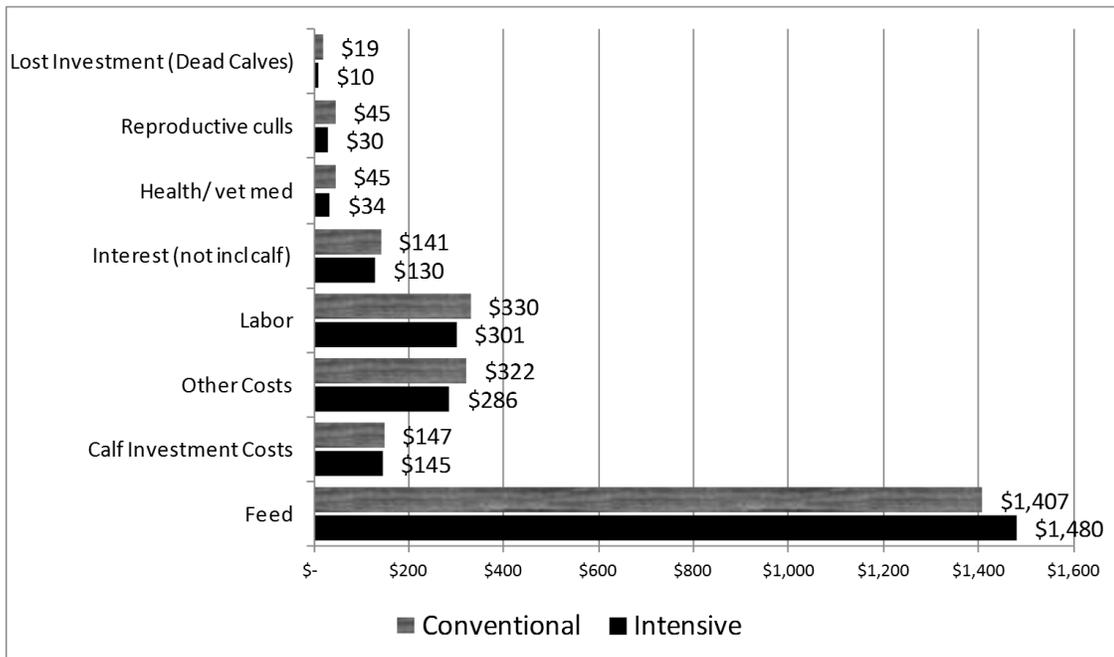


Table 1. Summary of the net results for conventional vs. intensive rearing systems assuming an initial calf value of \$125, interest cost of 8%, and other previously described assumptions.

Outputs:	Convent. System:	Intensive System:
Calf Invest. Cost at Calving	\$ 147	\$ 145
Age at First Service	15.1	12.2
Average Age at First Calving	25.8	22.8
Average Daily Gain (lb/d)	1.50	1.97
Total rearing cost/ heifer (incl. interest + initial value + repro culls)	\$ 2,449	\$ 2,415
Avg Cost/ Day	\$ 3.12	\$ 3.48
Additional milk in first lact		1700
Culling risk - first lactation	28%	28%
Add. milk value (lact = 1)	\$ -	\$ 171
Net cost/ heifer	\$ 2,449	\$ 2,244
Additional profit for Intensive		\$ 205

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Group Housing and Feeding Systems for Calves - Opportunities and Challenges

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Introduction

Group housing of preweaned calves is gaining in popularity in the U.S. This practice has been adopted for several reasons. Research at the University of British Columbia and in Europe has documented potential benefits to animal welfare. Dairies view the practice as a means to improve labor efficiency in feeding the pre-weaned calf. Upon initial consideration, the practice of group feeding calves seems to contradict many of the commonly accepted tenets for feeding and management of young calves which includes:

- Isolation to minimize calf to calf contact and disease transmission
- Feeding limited amounts of milk to encourage starter intake and early weaning
- Feeding twice daily

However, research has demonstrated that there are many desirable features of the group feeding systems which merit careful consideration by dairies. It is important to realize that consideration of management of group feeding systems is multi-faceted. Successful adoption of this concept requires knowledge of:

- Dairy calf nutrient requirements to support gains of 1.5 to 2.0 lb. per day
- Feeding system operation and management
- Differences in dairy calf behavior of group fed calves
- Human behavior to adapt to a different approach to calf management

Each component is necessary to assure that the benefits of the system are achieved.

A short review of recent changes in calf feeding helps to establish the potential advantages and limitations of group housing systems. It has become more popular to feed calves increased levels of liquid diets. When the basic principles of ration balancing are applied to dairy calf nutrition, it is evident that feeding calves limited amounts of milk solids (~1 lb.) is barely sufficient to meet maintenance requirements with little remaining to support calf growth. At 32°F, a 100 lb. calf must consume 1.2 gallons of whole milk to solely to maintain body weight. Low intake of milk or milk replacer solids is especially a problem for calves during the first 3 weeks of life when starter intake is limited. Higher feeding rates of milk or milk replacer solids results in higher daily feed costs but improved feed efficiency of body weight gain and lower cost per unit of weight gain. Additionally, higher intake of solids in the liquid diet by dairy calves is associated with significant reductions in

morbidity and mortality (Godden et al, 2005). However, increased feeding rates (up to 2.5 lb. of milk solids/day) have been resisted by some dairy producers and practitioners and have been associated with a perception of increased diarrhea and possibly abomasal bloat. Evidence is circumstantial and bloat is more commonly observed under conditions of poor sanitation, irregular mixing of milk replacer powder, low or irregular liquid diet temperatures and irregular feeding schedules.

An additional potential benefit of group fed calves is the implementation of more frequent feeding. Several studies (Sockett et al., 2011; Kmicikewycz et al, 2011) indicate that increasing feeding frequency from twice daily to three or four times daily results in improved body weight gain, starter intake, feed efficiency and an increase in survival of calves through their first lactation. These responses seem logical given that, given the opportunity, calves will nurse more frequently than twice daily. This likely results in more consistent nutrient flow and improved efficiency of utilization of protein and energy by the calf (van den Borne et al., 2006). More frequent feeding may be critically important in situations when milk solids are fed at rates less than 1.5 lb. / day. Under these conditions of limited intake and with long intervals between the evening and morning feeding, calves may be mobilizing body fat stores to maintain body temperature. If body fat is limited as occurs in limit-fed calves, it's not uncommon for body fat to drop to 2% of body composition in calves less than 2 weeks of age. Unfortunately, most individual housing calf management systems are not well suited to more frequent feeding of calves. Surveys of dairy farms and calf growers reveal that only 8 – 14% of farms fed calves three times daily.

Group housing of calves has not been widely adopted on U.S. dairies. There are several ways to deliver the liquid diet to group housed calves.

- Mob feeding
- Free choice acidified milk or milk replacer
- Computer controlled automatic feeders.

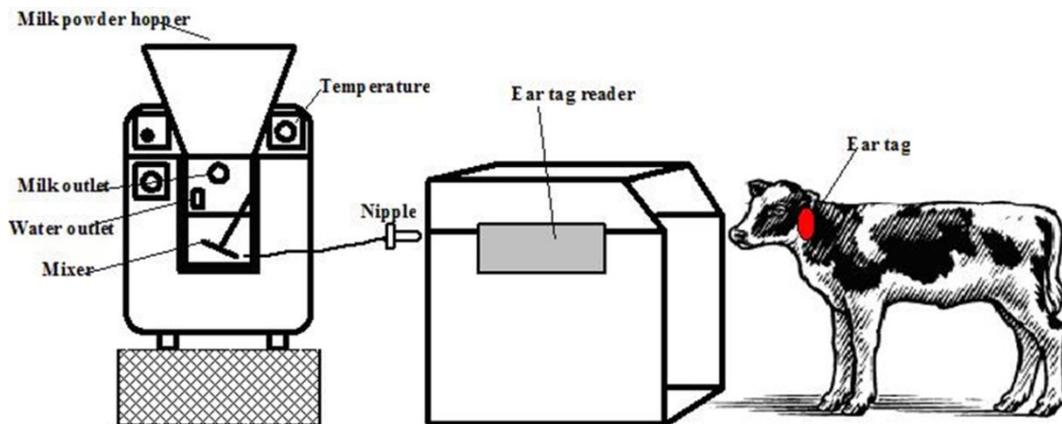
Mob feeding of calves is a common practice in grazing dairies practicing seasonal calving. This practice involves placing larger containers with multiple nipples in the calf pen until all the liquid is consumed, which is generally less than 30 minutes. Sufficient liquid is added to provide the average calf with the desired amount of liquid. Although it encourages labor efficiency, there are some challenges with this system. The most common problem is cross sucking which is a greater problem if the feeder is removed from the pen shortly after calves have finished eating.

More elaborate systems using acidified milk or milk replacer to preserve and limit liquid intake are gaining popularity on some dairies in more northern climates. These systems are very labor efficient but there is a lack of control of intake by individual calves, and minimal sanitation of nipples and feeding equipment. Systems developed in Canada utilize formic acid which is illegal in the U.S. The reader is encouraged to read the publication by Anderson (2008) for further information on free access acidified liquid feeding systems.

Computer controlled automatic calf feeding systems are gaining rapidly in popularity as a means of accurately delivering the liquid diet while controlling meal size and frequency. More sophisticated systems provide valuable management information to enable the calf manager to monitor diet consumption by individual calves and make timely intervention for calves becoming ill. This paper will focus most on the research and practical implications involved with automated calf feeding systems.

Basic components of calf autofeeders

Calf autofeeders involve the basic components shown in the illustration below (Biotic Industries, Bell Buckle, TN).



These systems vary widely in sophistication and price ranging from systems which record minimal data and have simple feeding programs to more involved systems with extensive capabilities to program different feeding plans for individual calves in a group and monitor calf performance. The essential features of autofeeders include a feeding stall and feed box which contain a device enabling electronic identification of calves. Most new systems utilize the RFID ear tags. The nipple is connected via a flexible tube to a mixing bowl where defined amounts of powder and water are mixed as prescribed by the system. Calves are limited by meal size, number of meals per day and time intervals between meals. Additional features of systems will be described later in this manuscript.

Behavior of group-housed calves with autofeeder systems

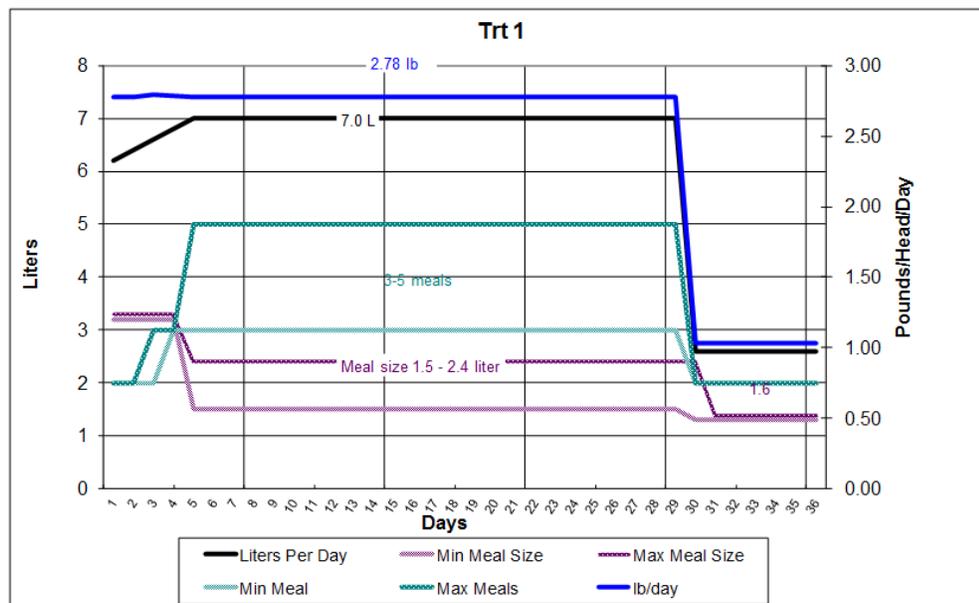
Workers in Denmark and Canada have conducted numerous behavioral studies which have enabled the development of recommendations for management of autofeeder systems. A common problem observed in calves housed individually is the “post weaning” slump which is apparently related to the adjustment of calves to group housing and the competition for feed. Studies by Chua et al (2001) found that calves raised in pairs continued to gain weight normally during the week of weaning while those housed individually experienced the “growth check” commonly observed in traditional calf rearing systems. This suggests that group housing calves prior to weaning promotes development of social skills and reduces fear of interaction with other calves. Another significant concern of group-housed and fed calves is the occurrence of cross sucking. Jensen (2003) found that feeding calves via nipple buckets as opposed to open buckets resulted in a significant reduction of cross sucking. Cross sucking tends not to be a problem in calf autofeeder systems as compared to mob feeders. However, the author has noted increased cross sucking in some operations with very high daily allocations (over 3 lb. of milk solids/daily) or large meal sizes (>3 liters/feeding). Reductions in flow rate of milk to prolong milk feeding also seem to satisfy the calves urge to suck after completing the liquid feeding meal. The work conducted by Jensen (2004, 2005) and von Keyserlingk et al (2004) has resulted in the recommendations for stocking rates given by major manufacturers of calf autofeeder systems. General relationships are what would be expected in group housing situations. More calves per feeder results in greater competition for the nipple and an

increased rate of intake. A second important factor governing autofeeder management recommendations is the milk allowance per day and per feeding. When calves are limit-fed milk (less than 1.5 lb. per day) calves spent more time in the feeder without being rewarded with additional milk. Similarly when milk allowances per feeding session are small (one pint or less) calves remain in the stall longer without being rewarded.

General recommendations and features of calf autofeeder systems

- Age when calves are introduced to the autofeeder system is strongly dependent upon fresh cow and newborn calf management. Aggressive colostrum management programs are essential to successful adaptation to the autofeeder. Consider routine monitoring of serum proteins during the first week to assess success of the colostrum program. Most farms house calves in individual housing systems for at least the first 5 days to ensure that the calf is eating well.
- Calves are trained to feeders by leading them to the nipple when they are moved into the group housing. Eliminating the morning feeding the day that calves are moved into the autofeeder group encourages adaptation to the system. Research by Svennson and Liberg (2006) and Jensen ((2008) shows that moving calves onto the feeder at less than 6 days requires more effort to train calves to the feeder. Research by Jensen (2006) has shown that calves introduced to feeders at day 14 required less training time. Calves introduced to the feeder at day 6 spent less time in the feeder after ingesting milk and ingested less milk. They were less successful in competing for milk feeder access, particularly when there is a wider range in age of calves in the pen and with higher stocking rates per feeding station (>25). There also appears to be less risk of respiratory disease when entrance into the feeder is delayed until 10 – 14 days of age.
- Stocking rates of no more than 25 calves per nipple are advised.
- Milk allowances range from 1.5 to as much as 2.7 lb. (680 – 1225g) of milk solids per calf per day. On a volume basis this amounts to 1.4 to 2.3 gallons (5.3 – 8.7 L) of liquid per day.
- Meal sizes vary from 1 pint to 2.6 quarts (.5 to 2.5 L) each. In many systems, calves must earn enough credits to be able to receive milk or milk replacer from the feeder. As an example, if a calf is allocated 9 liters of “milk” per day, they will earn about .4 liter allocation for each hour of the day. They must accrue enough credits to achieve their minimum meal size specified by the system which might be 1.5 liters. This would mean that there must be a minimum of about 3 hours and 45 minutes between feedings.
- When milk replacer is used, powder is diluted with water to approximately 13 – 15% solids. Caution is advised when specifying dilution as most autofeeding systems express the grams of milk replacer to add to each liter of water. Therefore 150g added to a liter of water is not 15% solid but 13% (1,000 ml of water + 150 g of powder = 1150 final weight. Therefore 150g of powder/1150g of total weight = 13% solids) .
- Number of meals per day varies by the system. Some basic calf autofeeders have a small mixing bowl and provide meals of 1 pint per visit. In these systems milk allowances exceeding 1 to 1.5 gallons daily require numerous daily visits to obtain the daily allowance (>12) In other systems calves are limited to a maximum amount per visit and the feeder will mix multiple batches of liquid up to the maximum. Typically calves nursing from more sophisticated systems consume ~4 – 5 meals per day.
- Feeding programs vary considerably depending upon the system. The basic systems are frequently programmed to provide all calves with similar meal sizes and daily allowances,

regardless of their age. However, the more sophisticated systems enable feeding a defined feeding program in which milk allowance is gradually increased over several days and then decreases to accomplish a “soft” weaning which is felt to reduce the stress of weaning. An example of such a feeding program is shown below. (Courtesy: T.J. Earleywine, Land O Lakes Animal Milk, Shoreview, MN). In more sophisticated systems multiple feeding programs can be in effect within one pen so that smaller calves or those of a different breed may be accommodated.



More sophisticated systems also enable use of pasteurized waste milk in addition to milk replacer.

- More sophisticated systems enable medicating calves with either dry or liquid medication. This enables the manager to administer additional electrolytes, antibiotics or other therapies on an individual basis.
- More advanced computer controlled stations will also delivery calf starter grain. These systems will trigger “soft” weaning from liquids when calf starter grain intake reaches levels indicated by the computer. However, research has shown that these systems don’t encourage intake and many users don’t use this feature and provide small open feed bunks with free choice calf starter.
- Sanitation is automatic in some systems and manual in others.

Virginia Tech Calf Autfeeder Survey

During the summer of 2011, eleven dairies in Virginia and North Carolina were visited and administered a survey to determine calf feeding and management practices prior to and after implementing the autfeeder and the cost of systems implemented. During the initial and later visits, duplicate samples of the liquid diet were obtained aseptically by disconnecting the line to the nipple and retrieving the sample when half of the liquid in each mixing bowl had left the feeder. Temperature of the liquid was determined immediately by an electronic thermometer. Solids levels were estimated by use of a brix refractometer (Moore et al., 2009). (The Brix or digital

refractometer will show changes in solids levels that are valid within a given milk replacer or whole milk. However, they do not provide valid estimates of total solids between different milk replacers or when compared to whole milk.) Samples were immediately cooled, transported to the laboratory and frozen until later analysis for standard plate counts using the 3M petri film system (3M, St. Paul, MN). Calf autofeeders were classified as basic or sophisticated. Basic systems delivered preset amounts of milk replacer and had minimal retention of calf feeding data from day to day. Sophisticated systems employed more detailed feeding programs as described above and retained intake data as long as desired with management information geared towards more intensive evaluation of calf liquid intake. These systems also incorporated many of the features described previously. Three dairies using each system were selected for repeat visits for three consecutive months.

The objective of this field study was to determine how dairies implemented these systems and to evaluate performance of these systems under field conditions.

What We Learned

General information. Herds ranged in size from 125 to 3,100. In the largest herd, autofeeders were used to feed calves in excess of the calf hutches already present on the dairy. One 1,300 cow dairy constructed two new facilities containing 8 basic calf autofeeders. Calves per feeder ranged from 11 – 35. All farms used only milk replacer which varied from 20:20 to 28:20 (protein: fat). Farms indicated that physical characteristics of the powder were important to assure that the powder flowed freely from the storage bin to the mixing bowl and that it mixed quickly.

Cost. Due to limited numbers of herds, it was difficult to estimate total costs of establishing the calf autofeeder system. Basic calf autofeeder systems cost approximately \$1,600 - \$2,400 per unit with each unit capable of feeding up to 25 calves. More sophisticated systems cost ~\$15,000 – 18,000 for a unit that includes two feeding stations, software and is capable of feeding two more stations with slightly more cost. Such units could feed up to 60 calves with 2 feeding stations on one central unite. Additional costs include construction of group housing or adaptation of existing structures to accommodate the feeders. Autofeeders must be protected from weather and freezing. There was a wide range in these costs.

Standard plate count. A goal for SPC for pasteurized waste milk systems is <20,000 cfu/ml. Previous work by our group and others has found this to be an achievable goal. The SPC of liquid samples in this study ranged from <10⁵ to > 10⁷ cfu/ml. There was considerable overlap between systems, but mean counts were higher in the basic systems which were manually cleaned. Nearly all farms cleaned the mixing bowl daily, but cleaned the lines or nipples less frequently. Newer sophisticated systems enable all liquid delivery lines and mixing bowls to be automatically cleaned daily or as often as desired.

Brix refractometer. Brix readings varied from 7 to 18. Average and range of readings were similar for both systems. This indicated the need to adequately calibrate the delivery of milk replacer solids and water on a frequent basis. Owing to the newness of these systems in Virginia and North Carolina, technical support varied considerably in installation and maintenance of the equipment. Our work would indicate that routine monitoring of total solids is advised on at least a weekly basis. Once again, more sophisticated autofeeders weigh powder and water during mixing and delivery and feature auto calibrating on a daily basis.

Temperature. Liquid temperature varied from 81 to 118°F (27 – 48°C). Recommended delivery temperature would be 100 – 105°F (38 – 40°C). Colder temperatures impede adequate mixing of the powder and water which can lead to clogging of lines and possibly enhance bacterial growth. Cold temperatures also “cold stress” calves. Higher temperatures impede consumption of the liquid and definitely don’t encourage calves to adapt to the system.

Calf management

1. Age when calves transitioned from individual housing to the autfeeder ranged from 3 to 14 days of age. Three days is probably too early given that the drive to consume liquids is still fragile.
2. Calves were not hand fed their AM liquid diet allowance the morning before putting them on the feeder. Farms recommended that calves must be good, vigorous eaters prior to putting them on the feeder. Minimum meal size was set at 1.2 L for the first few days and set for 3 meals per day initially. These levels are probably lower than desired.
3. Range in age of calves within a pen should be minimized. This presents a problem for smaller farms with few calves. Each farm in our study had at least two pens of calves regardless of herd size. Pens were depopulated and cleaned and feeders were extensively cleaned prior to adding new calves. Ranges in age exceeding three weeks would be discouraged as younger animals would not compete well at the feeder.
4. Weaning was achieved with an abrupt drop in liquid diet and continued at this low level for 7 days. This appeared to strongly encourage starter intake.

Facility management. In many cases older facilities were adapted to group calf housing with varying degrees of success. In other cases three-sided or green house buildings were utilized.

- Ventilation to minimize accumulation of moisture is essential.
- More liberal space allocation /calf contributes to drier bedding. Farms in this study provided 30 to 50 sq. ft/calf.
- Feeding stalls should be located within 3 ft of the autfeeder to facilitate more effective cleaning of milk lines between the feeder and nipple.
- Feeding stalls should be solid sided and of minimal width to discourage multiple calves from trying into access the feeder.
- Do not restrict the area leading up to the feeding stall.
- Provide plenty of fresh clean water. Clean waterers daily and locate the waterers several feet away from starter bunk.

Miscellaneous. This section includes advice based upon our observations of the study farms and previously published information.

- Equipment varies in how they determine when a calf is eligible to receive their next meal. In some of the lower priced machines the times are the same for all calves. This results in a rush to the machine when calves realize that they are eligible for another meal. This is particularly a problem when meal sizes are small. More sophisticated machines determine meal availability for each calf with the result that stall use is more uniform.

- Agitation of milk replacer and warm water is less aggressive in some machines resulting in clumps of powder moving down the line from the mixing bowl to the nipple. These feeders tended to have more residual milk remaining in the lines.
- More sophisticated machines handle waste milk in addition to milk replacer. This creates a new set of management challenges as waste milk should be pasteurized prior to storing, cooled and then warmed again prior to feeding. Some systems given the known solids content will automatically add milk replacer powder and water to achieve the desired final solids level in the diet. Given the variable supply of waste milk and the variable solids content of waste milk it is challenging to maintain consistency in the feeding program and to adequately sanitize the equipment.
- Dairy producers interested in adopting this technology should have the proper management mindset. These individuals should have the following skills and management behaviors:
 - They are data oriented and should evaluate the intake and other management information provided each morning and periodically throughout the day.
 - Calf managers should “walk” the pens periodically to evaluate calf behavior and detect illnesses that are not indicated in computer reports.
 - There is an opportunity for improved labor efficiency. However, many producers in this survey noted that time formerly spent feeding was spent reviewing reports, walking pens and cleaning the feeder.
- Calf behavior will be dramatically different. When calves are fed twice daily in individual pens, they respond to people entering the barn through increased activity and vocalization. Calves fed via an autofeeder system will not respond to people entering the pen. If a calf does so, it usually means that they have not been trained to the feeder or there is an equipment malfunction.

Conclusion

Calf autofeeders are a proven technology that offers some attributes which are very positive for calf nutrition and management. More frequent feeding is probably less stressful for the calf and appears to promote more efficient feed utilization. It’s easier to feed more without stressing the calf with large meal sizes or higher percentages of milk solids required for intensive feeding systems confined to twice a day feeding of three quart bottles.

The survey of Virginia and North Carolina farms using this technology emphasizes the need for routine monitoring of temperature, solids delivery calibration and sanitation. Although SPC were higher than expected in the farms surveyed in this study, calf health did not appear to be impaired. Future studies are planned to identify the predominant organisms and the impact of cleaning and sanitation on bacterial growth.

Although they are marketed for their labor saving, this field study indicated that although routine labor is reduced, increased emphasis needed to be placed on monitoring the equipment, evaluating calf consumption, sanitation and in monitoring calf health.

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Notes:

Impact of Global Dairy Development Panel

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The IFCN – International Farm Comparison Network - is a global network of dairy researchers from 91 countries cooperating with over 93 companies representing the dairy chain. The IFCN has a Dairy Research Center (DRC) with 19 dairy researchers coordinating the network process and dairy research activities. The IFCN is independent from third parties and committed to truth, science and reliability of results. The main research focus of the IFCN and its core competence is in the field of milk production, milk prices and especially dairy farm economics.

This article summarizes the key findings of the IFCN work in 2012 and the recently published IFCN Dairy Report 2012.

1. The Top 20 milk producing countries 2011

The IFCN as research network was established in the year 2000 to create a better understanding of milk production world-wide. IFCN is focusing on this segment of the dairy chains as it is the most important element of the chain once it comes to I) the costs, II) resources used, III) emissions created and IV) the political challenges.

It is quite important for the dairy industry to have a solid method to rank countries by milk volumes. The IFCN provides one standard concept and consistent data collection. These data have been collected and validated by the IFCN research partners in the countries since the year 2000. Moreover, the list has standardized national milk production figures (cows and buffalos) to 4% fat and 3.3 % protein by using the Energy Corrected Milk (ECM) concept described below.

World milk production 2011

World milk production (cow and buffalo milk) 2011 was in natural fat/protein content 708.7 mill t. As the average natural content of the milk is higher than 4% fat and 3.3% protein the ECM milk

volume is 721.4 mill t which is 12.4 mill t more. Once it comes to milk deliveries IFCN is estimating that only 62% of world milk production is delivered to milk processors. The remaining 38% are consumed on the farms or sold informally.

IFCN top 20 milk production and processing countries 2011

No.	Country	Milk production in mill t ECM	Milk production in mill t natural content	Milk delivered in mill t ECM	Milk delivered in mill t natural content
1	India	137.5	121.2	23.0	20.5
2	USA	84.3	89.0	83.8	88.5
3	Pakistan	41.6	35.6	1.3	1.1
4	China	33.9	37.4	29.2	32.8
5	Brazil	32.0	33.0	21.8	22.5
6	Germany	31.1	30.3	30.1	29.3
7	Russian Federation	30.1	31.7	15.5	16.4
8	France	25.2	25.3	24.6	24.7
9	New Zealand	21.3	18.9	21.3	18.9
10	United Kingdom	14.1	14.1	13.8	13.8
11	The Netherlands	12.7	12.0	12.4	11.6
12	Turkey	12.2	12.8	6.7	7.1
13	Poland	12.0	12.1	8.9	9.0
14	Argentina	11.4	12.0	10.2	10.7
15	Italy	11.3	11.6	10.5	10.8
16	Mexico	11.1	11.1	7.7	7.7
17	Ukraine	10.2	11.1	4.3	4.6
18	Australia	9.8	9.6	9.5	9.3
19	Iran	9.8	9.7	7.2	7.3
20	Canada	8.9	9.2	8.6	8.8
	World	721.4	708.7	447.0	453.2

ECM correction: As the dairy farms operate with very different fat/protein contents of the milk the IFCN is using the energy correct milk (ECM) approach to standardised milk volumes to 4% fat and 3,3 % protein. The use formula is the following one: ECM milk = (milk production * (0.383 * % fat + 0.242 * % protein + 0.7832) / 3.1138).

Top 5 milk production countries 2011 – 4 developing countries among the top 5

The top 5 countries: 1. India, 2. USA, 3. Pakistan, 4. China and 5. Brazil

Top 5 milk processing countries 2011 – China is no.3 milk processing country in the world

The top 5 countries: 1. USA, 2. Germany, 3. China, 4. France and 5. India

2. IFCN Top 20 milk processors list 2012

Introduction: To better understand the future of milk production the IFCN has started to benchmark milk processors by milk intake in 2008. We have created a top 20 milk processors list in 2012 and have also estimated a turnover which can be associated to the milk intake.

Concentration of milk processing 2012: Based on the table below the Top 20 milk processing companies process 24% of world cow and buffalo milk production. Measured by milk deliveries they account for 39% world-wide. The largest milk processor Fonterra is processing 3.0% of world

milk production or 4.8% of world milk deliveries (cow and buffalo milk). **In comparison to the Global dairy top (Rabobank)** in the IFCN ranking cooperatives are important as they usually have a higher milk intake in relation to their turnover compared to private companies. Private companies often create higher value products and so have higher turnover to milk volume ratios.

IFCN Top 20 milk processors list 2012

Rank	Company name	Country	Dairy processing plants main location	Market share in % of world milk production	Milk intake, in mill. t	Dairy turnover, US-\$ bill.
1	Fonterra Co-operative Group	New Zealand	international	3.0%	21.6	16.4
2	Dairy Farmers of America	USA	USA	2.4%	17.1	13.0
3	Groupe Lactalis (Parmalat)	France	international	2.1%	15.0	16.9
4	Nestlé	Switzerland	international	2.1%	14.9*	19.1
5	Dean Foods	USA	USA	1.7%	12.0	13.1
6	Arla Foods/MUH/Milk Link	Denmark/Sweden	DK/SE/DE/UK	1.7%	12.0	12.0
7	FrieslandCampina	The Netherlands	NL/DE	1.4%	10.1	13.4
8	Danone	France	international	1.1%	8.2	15.6
9	Kraft Foods	USA	international	1.1%	7.8	7.5
10	DMK	Germany	Germany	1.0%	6.9	6.4
11	Saputo Inc.	Canada/USA	Canada/USA/Argentina	0.9%	6.3	7.0
12	Glanbia Group	Ireland	international	0.8%	6.0	3.9
13	Land O' Lakes Inc.	USA	USA	0.8%	5.9	4.3
14	California Dairies Inc.	USA	USA	0.6%	4.6	3.0
15	Unternehmensgruppe Theo Müller	Germany	international	0.6%	4.4	6.5
16	Groupe Sodiaal	France	France	0.6%	4.1	5.7
17	Mengniu Dairy Company Ltd.	China	China	0.6%	4.1**	5.8
18	GCMMF (Amul)	India	India	0.6%	4.0	2.5
19	Yili Group	China	China	0.6%	4.0**	5.8
20	Bongrain SA	France	international	0.5%	3.6	5.5
Sum of Top 20				24%	172.8	183.4

Source: IFCN analysis and estimates. Data represents in most cases the year 2011. *2010, ** estimated. Explanation: Milk intake represents milk volume collected, commodity purchase (in milk equivalent) for main company and its subsidiaries. Milk intake figures in mill tons. In some cases recalculated from litre (1litre = 1.033 kg). Dairy turnover represents turnover which belongs only to processed milk and not to other activities. Turnover figures in US-\$ bill, in some cases converted to US-\$ by using the annual average exchange rate. Turnover directly validated by companies or taken from annual reports. Comments: Amul (India): milk with high fat content. Arla incl. MUH and Milk Link: IFCN estimate. Danone: Fresh Dairy Direct only. Nestlé: Dairy products and ice cream, milk intake figure represents the year 2010. 50% of DPA milk intake and turnover allocated to Fonterra and Nestlé each. California Dairies: milk intake 60 % of total milk collected, 40% is directly shipped to other companies. FrieslandCampina: milk intake excl. supplier milk outside NL/DE. Sodiaal: uncertainty whether milk intake includes all purchased products. Müller: total milk processed (including all subsidiaries), turnover represents groups turnover, including non dairy activities. DMK: Deutsches Milchkonotr. GCMMF (Amul): Gujarat Cooperative Milk Marketing Federation Ltd. Mengniu and Yili: milk intake figures estimated, uncertainty about proportion of fresh milk and milk powder intake. Double counting of milk intake possible (purchased products).

Top milk processors 2012: The global top five dairy processors are Fonterra (NZ), Dairy Farmers of America (USA), Lactalis (FR), Nestlé (CH) and Dean Foods (USA). 50% of all companies included in the list are originally from Europe, 30% from the USA/CA and 20% from other world regions including Fonterra, which is originally from Oceania. Half of the companies are cooperatives and half are private companies.

Compared to the IFCN ranking 2011 there were the following major changes in the ranks:

- Moved up in this ranking: Arla and Lactalis– mainly via mergers / acquisitions.
- Newcomer in this ranking: Bongrain, Glanbia and Müller via the acquisition of Wiseman.

Turnover per kg milk intake: This indicator can be interpreted as “dairy value creation”. To find a meaningful match of milk intake and dairy turnover which is also comparable between companies is challenging. Initial calculations show that the turnover per kg milk differs significantly between companies (range: 0.65 -1.53 US-\$ per kg milk, excl. outliers). Details on method and results are

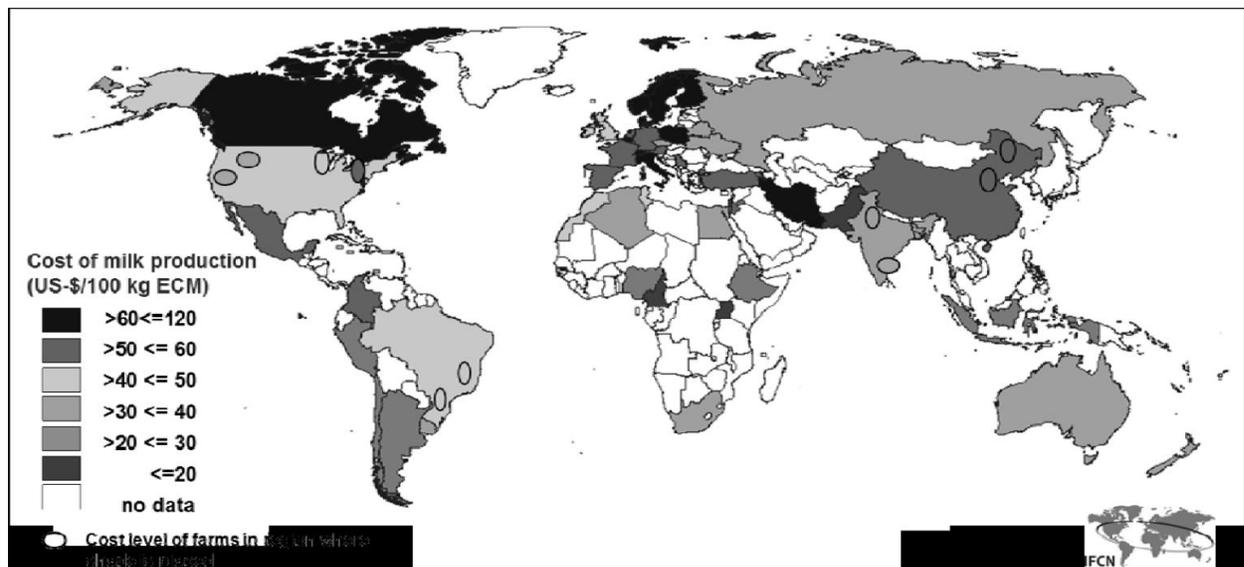
published in the IFCN Dairy Report as special study. The IFCN plans to refine the method and welcomes any feedback especially in this difficult field.

3. IFCN Cost of milk production in 2011

IFCN concept: Since 2000 the IFCN has been comparing typical farms around the world. In 2012, 171 typical farms from 61 dairy regions in 51 countries were analyzed. The analysis is based on the concept of typical farms and has used the model TIPI-CAL to have standardized calculation across the countries. The data collection and validation has been done by researchers in the countries, by researchers in the IFCN Center and also during the IFCN Dairy Conference held in June 2012 in Kiel.

IFCN cost indicator: The IFCN uses the indicator cost of milk production only which can be directly related to a milk price. This cost includes all costs from the profit & loss account of the farms and also opportunity costs for own labour, land and capital. From this cost level the non-milk returns from sales of cull cows, heifers, calves, manure, etc. and also direct payments have been deducted. For creation of the world map, the cost levels on average sized farms have been used.

Cost of milk production in average sized farms per country in 2011



Cost range: Cost of milk production ranges from about 5 US-\$ per 100 kg milk in extensive farming systems in Cameroon to 100 US-\$ on an average sized farm type in Switzerland. The average cost over all countries analysed was 45 US-\$/100 kg milk.

The countries can be grouped in the following cost categories: Costs below 30 US-\$: Argentina, Chile, Peru, Indonesia, Pakistan, and countries in central Africa. Costs 30 -40 US-\$: Oceania, South Africa, India, selected countries in Northern Africa and Eastern Europe. Costs 40 -50 US-\$: USA, Brazil, UK, Ireland, Morocco and Tunisia. Costs > 50 US-\$: A wide number of countries in Western Europe, Poland, Mexico, Colombia, Israel, Jordan, Iran, Turkey and China. Most likely, Japan and Korea are also in this segment. It is worth mentioning that economies of scale

were significant in almost all countries, especially in Western Europe and the variation in farm sizes was quite high.

Key developments in 2011: Cost of milk production increased on average by 5 US-\$

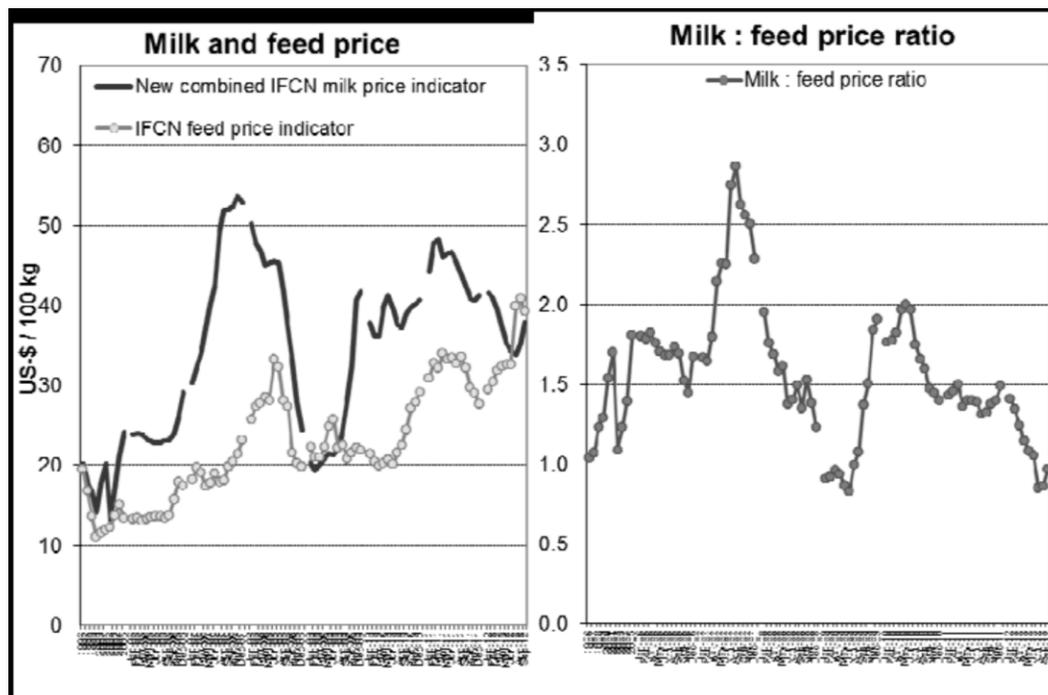
In the year 2011, the costs have increased on average by 5 US-\$ per 100 kg milk. A key driver was the 38% increase in feed price (based on the IFCN world feed price indicator). Moreover, dairy farms in emerging dairy countries are facing strong increases in wages. A third driver for costs is the increasing energy and fertilizer prices.

Outlook for cost developments in 2012

In 2012, costs are expected to increase by about 5% compared to 2011. The main drivers for cost increase are: increasing feed prices, high energy costs, increasing competition on land market worldwide (affecting prices). From the return side, the average milk price from January to August has dropped by 24% in 2012 compared to the same period in 2011. Therefore, profitability of dairy farms is expected to decline significantly in 2012, compared to 2011. More details will be available in IFCN Dairy Report 2013.

4. Developments of feed prices and the impacts on dairy

World milk and feed prices



IFCN feed price indicator:

*Source: International Monetary Fund. Specification: Soybean meal: CME futures first contract forward, Corn: FOB US Gulf. Calculation: 0.3 * soybean meal price + 0.7 * corn price.*

New combined IFCN milk price indicator:

*Weighted average of IFCN milk price indicators: 35% SMP&butter, 45% cheese&whey, 20% WMP
Milk : feed price ratio: Milk price divided by the calculated feed price.*

Feed prices have almost tripled since 2006

Almost tripling prices since 2006 from 13 US-\$ to now 42 US-\$/100 kg feed. There have been three phases and in each phase, the price level increased by 10 US-\$ per 100 kg feed.

- **January 2006 to November 2007:** +70% from 13 to 22 US-\$ / 100 kg feed driven by high oil price and biofuel policies
- **August 2010 to February 2011:** +50% from 22 to 32 US-\$ / 100 kg feed
- **April 2012 to August 2012:** +30% from 32 to 41 US-\$ / 100 kg feed driven by forecast supply shortage, which in turn was driven mainly by extensive drought in the USA. In September, a slightly lower feed price was observed.

Price of 1 kg feed > price of 1 kg milk since July 2012

Similar to 2009, the price of feed is currently higher than the price of milk, even though on a higher level. The milk feed price ratio is below 1. This very simple indicator illustrates when dairy farm economics come under pressure due to transmission of world market prices to the farm level. Farming systems based on high concentrate feed input are affected to a larger extent.

Effects of high world feed prices over a longer period on farm economics

- **Step 1:** Transformation of world feed price into national price for concentrates.
- **Step 2:** Purchase feed costs rise depending on the amount feed bought and duration of forward contracting of farmers.
- **Step 3:** Land values increase especially for arable land for cash crops. This transforms into increasing land rent costs depending on the local land markets and also the land rental contracts
- **Step 4:** Opportunity costs for own land increases as the farmers might make a better profit from selling the crops they produce instead of feeding them to their cows. A cost increase out of this depends on the perception and decision of each dairy farmer.
- **Steps 5:** If feed prices stay longer on the currently high level, the prices for pastureland would also increase, which would in turn lead to an increase in costs of grazing systems.

Summing up

In times of high feed prices, dairy farms having low concentrate intake (like in Ireland) have a competitive advantage. Adaptation of the farming system by either increasing milk yields (maximize output) or by decreasing yields (minimize input) could help high input systems to improve their farm economics.

Notes:

Notes:

Managing Heat Stress and Its Impact on Cow Behavior

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Summary

- Heat stress affects several aspects of the dairy industry including cattle behavior.
- Heat stress will increase an animal's standing time as it tries to dissipate heat over its entire body surface.
- Increasing standing time or decreasing resting time reduces milk production.
- Prolonged standing further increases the risk of lameness.
- Understanding environmental and physiological parameters that affect standing behavior will improve industry efforts to minimize heat stress in dairy cattle.
- Core body temperature is correlated standing behavior, with cattle more likely to stand above a 102.07 °F (39.2 °C) core body temperature.
- Correlation between thermal heat index and cattle behavior has also been evaluated, although predictive capacity has yet to be established. However, cattle are more likely to stand above a THI of 68.

Introduction

The issue of environmental impacts on dairy production and cattle welfare has long been of interest to the industry. One environmental stressor which has commanded considerable research attention within the past several decades has been thermal stress. Production loss due to heat stress has been estimated at \$900 million annually to U.S. dairy herd (St. Pierre et al., 2003). This interest in heat stress has coincided with the spreading demographic of the United States dairy industry from the Midwest to warmer and more arid climates, such as the desert Southwest, as well as an increase to heat sensitivity due to a doubling of average production per cow. Improvements in warm weather dairy housing have provided more efficient technologies for cooling animals exposed to hot climates. However, heat stress remains an important environmental stressor on dairy cattle.

Heat stress directly and indirectly affects feed intake, cow body temperature, maintenance requirements and metabolic processes, feed efficiency, milk yield, reproductive efficiency, cow behavior, and disease incidence (Thatcher, 1974; Cook et al., 2007; Tucker et al., 2007; Rhoads et al., 2009). These effects are well documented. It is only recently that researchers have attempted to understand the correlation of one of the most understood outcomes (increased body temperature) to one of the least understood outcomes (modified cow behavior) and its possible effect on bottom line production.

Heat Stress and Dairy Cattle

Domestic animals have a core body temperature (CBT) range in which metabolism functions without modification, termed the thermoneutral zone. Typically, core body temperature is higher than ambient temperature to ensure that heat generated by metabolism flows out to the environment (Collier et al., 2006). Deviation outside of this range – which is relatively narrow – leads to increases in resting metabolism, modifications to the biochemistry and cellular physiology as well as the behavior of the animal (Shearer and Beede, 1990). The thermoneutral zone lies between 41 and 77 °F (5 and 25 °C) for dairy cattle (Roefeldt, 1998). Above 77 °F (25 °C), the body must modify physiology and behavior to keep CBT above the environment temperature.

Heat Stress and Thermal Humidity Index

Temperature is not the only environmental factor that affects the intensity of heat stress. The temperature humidity index (THI) measures the combined effects of ambient temperature and relative humidity (RH) to ascertain heat load intensity (Berry et al., 1964). This index was later categorized into heat stress levels with an index above 72 THI [75 °F (23.9 °C) with 65% RH to 90 °F (32.2 °C) with 0% RH] established as the lower threshold of heat stress (Whittier, 1993; Armstrong, 1994). However, because of the increased milk production per cow since the development of the THI, a 22 lbs/d (10 kg/d) increase will decrease the threshold for heat stress by 9 °F (5 °C; Berman, 2005). A recent re-evaluation of the THI has suggested that due to this improvement of milk production, the THI heat stress threshold should be lowered to 68 THI [72 °F (22.2 °C) with 45% RH to 80 °F (26.7 °C) with 0% RH; Zimbelman et al., 2009].

Heat Stress and Reproduction

Elevated core body temperature (CBT) in dairy cows caused by heat stress can have detrimental effects on reproductive performance. An increase in rectal temperature of 1.8 °F (1 °C) occurring 12 h post-insemination decreased pregnancy rates by 16% (Ulberg and Burfening, 1967). Gwazdauskas et al. (1973) reported an increase in uterine temperature of 0.9 °F (0.5 °C) on the day of or the day after insemination resulted in decreased conception rates by 13% and 7%, respectively. Badinga et al. (1985) attributed decreased conception rates of lactating cows to their inability to maintain normal body temperature at high environmental temperatures [> 86 °F (30 °C)]. Ealy and colleagues (1993) further support this hypothesis by reporting that bovine embryos become more resistant to adverse effects of maternal heat stress as pregnancy progresses. Embryos are sensitive to deleterious effects on d 1 following artificial insemination but develop substantial resistance by d 3. Expression of estrous behavior is also depressed when cows become heat-stressed.

Prolonged heat stress negatively affected reproduction by increasing estrous cycle length and decreasing duration of estrus (Abilay et al., 1975). A decrease in the frequency of pulsatile release of luteinizing hormone on d 5 of the estrous cycle was observed in heat-stressed cows compared to cooled cows (Wise et al., 1988). Follicular dynamics are altered and follicular dominance is depressed by heat stress (Wolfenson et al., 1995). Furthermore, fetal growth is negatively affected due to decreased uterine blood supply and the insufficiency of the placenta to provide maternal nutrients (Collier et al., 1982).

Heat Stress and Milk Production

When cows are subjected to heat stress, feed intake decreases. Simultaneously, maintenance requirements are increased due to activation of the thermoregulatory system. There is need to expend energy to maintain homeothermy that would otherwise be available for useful production (e.g. milk; Buffington et al., 1983). Mild to severe heat stress in dairy cattle has been estimated to cause an increase in maintenance requirements by 7 to 25% (NRC, 2001). By definition, heat-stressed cows are in a state of negative energy balance (NEBAL) since feed intake is not meeting energetic demands of maintenance and lactation.

Decreased intake accounts for approximately 36% of the decrease in milk production due to shifts in postabsorptive metabolism and nutrient partitioning (Rhoads et al., 2009). Under thermoneutral conditions, cows experiencing NEBAL have increased rates of lipolysis. This is characterized by the presence of elevated plasma nonesterified fatty acid (NEFA) concentrations, while glucose is partitioned to the mammary gland for milk synthesis. However, heat-stressed cows have lower NEFA concentrations and a higher rate of peripheral glucose utilization, suggesting that glucose uptake by other tissues reduces the amount of glucose available for milk synthesis (Rhoads et al., 2009).

A reduction in feed intake precedes a decrease in milk production when cows are subjected to heat stress (Rhoads et al., 2009). Spiers et al. (2004) showed that feed intake decreased within 1 d after initiation of heat stress, while milk yield decreased after d 2 of heat stress. Collier et al. (1981) demonstrated that maximum decrease in milk yield during heat stress occurs 48 hours after the initiation of the stress.

Prolonged thermal stress negatively impacts somatotropin (growth hormone or GH) secretion from the anterior pituitary (Mitra et al., 1972). Depressed GH concentrations result in slower growth rates, reduced nitrogen retention, and contribute to decreased lactation performance in dairy cattle (Mitra et al., 1972).

Johnson et al. (1963) reported that milk yield decreased by 4 lbs/d (1.8 kg/d) per cow for every 1 °F (0.55 °C) increase above a daily rectal temperature of 101.5 °F (38.6 °C). More recently, Igono et al. (1985) reported that a cow with a mean rectal temperature of 102.4 (39.1 °C) produced 1.54 lbs/d (0.7 kg/d) less milk than a cow with a rectal temperature of 101.8 °F (38.8 °C). Zimelman et al. (2009) also reported a negative relationship between rectal temperature and milk production. This is relationship is further complicated with higher internal heat production in high producing cows compared to low producing cows, regardless of environmental influence (Purwanto et al., 1990).

Heat Stress and Production Efficiency

There are a number of behavioural, physiological and metabolic mechanisms which are employed by the cow to keep CBT above environmental temperature. Some of these are shown in Figure 1.

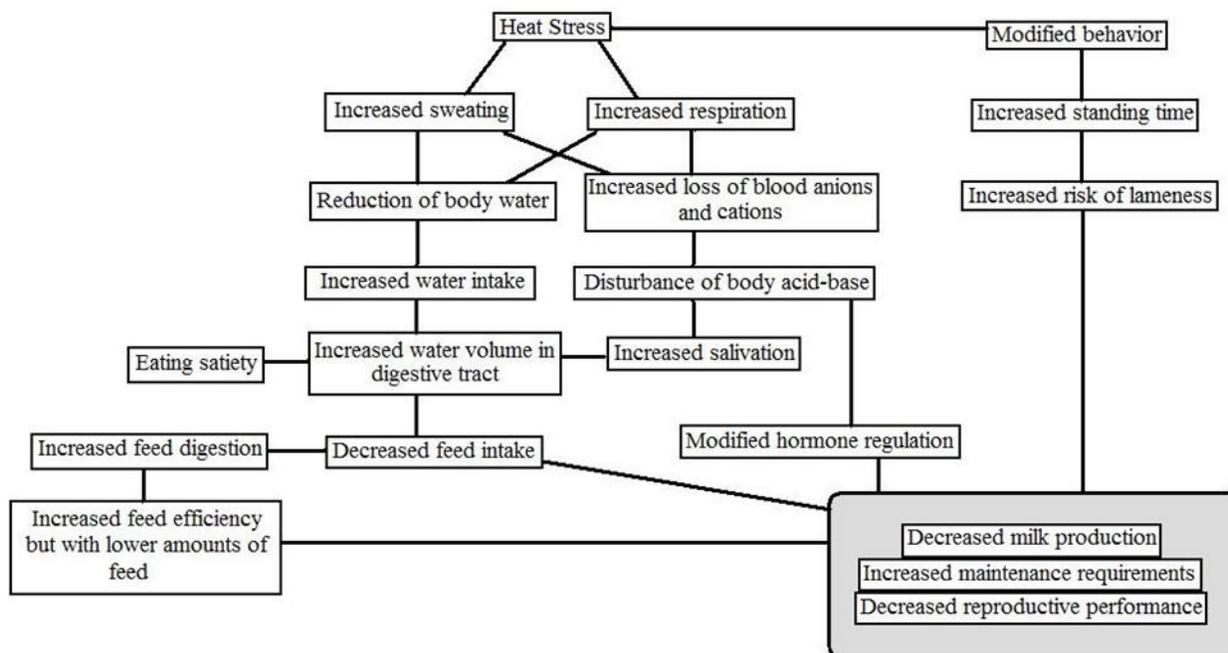


Figure 1. Schematic of the general effects of heat stress in dairy cows. (Adapted from Atrian and Shahryar, 2012).

Energy production and expenditure through cellular maintenance produces excess metabolic heat. Thus, heat exchange from the animal to environment is necessary to maintain optimal CBT (Kadzere et al., 2002). A negative correlation between metabolic hormones (thyroid hormones, somatotropin, prolactin, etc.) has been reported (Mitra et al., 1972; Johnson et al., 1988; Lu 1989; Collier et al., 2006). These hormones are responsible for energy expenditure and heat production, including gut motility and blood flow to the digestive system (Hales et al., 1984; Johnson et al., 1988). A decrease in gut motility leads to slower passage rate, decreasing feed intake. West (2003) reported a 1.9 lbs (0.85 kg) decrease in dry matter intake with every 1.8 °F (1 °C) increase in ambient temperature above a cow's thermal neutral zone. While digestion is improved, the lowered amount of feed within the digestive system is unable to meet requirements (Kadzere et al., 2002), decreasing feed efficiency.

Physiological mechanisms which improve heat dissipation also lead to an increase in maintenance requirements because of an increase in nutrient needs. Examples include increased respiration rate, increased sweating, increased heart rate, and increased salivation (Atrian and Shahryar, 2012). These in turn lead to increased body fluid loss which further increases maintenance requirements to abate dehydration and blood homeostasis (Collier et al., 2006). While these actions may seem futile, 15% of total body heat loss can be realized through normal respiration (McDowell et al., 1976), and increased respiration rate can and does increase heat loss potential (Campos Maia, et al., 2005).

Together, the cow's adaptation to minimizing heat production and maximizing heat dissipation leads to economic issues. Milk production will decrease, but energy and nutrient usage by the cow will increase. With an increase in maintenance requirements compounded by a decrease in dietary nutrients, nutrients are diverted from systems not necessary for survival. Rhoads and others (2009) reported a significant repartitioning between dietary and body nutrients utilized for milk production

during heat stress, with decreased feed intake accounting for only 36% of milk production loss. Smith and others (2008) calculated that at a milk price of \$18/cwt (\$39.50/100 kg), a 2 to 12 lbs (0.9 to 5.5 kg) drop in milk production per cow per day due to heat stress could cost an operation between \$32 [2 lbs/d (0.9kg/d) loss for 90 days] and \$324 [12 lbs/d (5.5 kg/d) loss for 150 days].

Heat Stress and Health

Other than the physiological issues that arise from heat stress adaptation, there is ample research linking heat stress to particular aspects of an animal's health. Specifically, lameness incidence increases with an increase in ambient temperature (Cook et al., 2007). This coincides with the change of seasons as well; lameness prevalence is lower in cool months as compared to warm months (Sanders et al., 2009). These climatic and seasonal effects are also correlated to mastitis (Dohoo and Meek, 1982; Elvinger et al., 1991). Several trials have reported an increase of disease, particularly reproductive issues, during warmer months of the year due to the acceptable environment for pathogens and vectors (Collins and Weiner, 1968; Silanikove, 2000; Kadzere et al., 2002). Death losses also increase with an increase in THI (Vitali et al. 2009). Recent interest has also hinted at the effect of cow behavior on increased risk for locomotive diseases.

Heat Stress and Cow Behavior

Within the last decade, research efforts have turned to welfare of cattle experiencing heat stress. With an increase in ambient temperature or solar radiation, cattle are more likely to seek shades or other cooling structures (Tucker et al., 2008; Atrian and Shahryar, 2012). This change in behavior, aside from the physiological changes to decrease heat production mentioned above, suggests that dairy cows will also seek micro-environments that have a lower ambient temperature. Furthermore, cattle are more likely to seek optimum environments that have maximized cooling capacity. For instance, a recent study reported cattle were more likely to choose shade over a cooling system directed away from the shade, but were also likely to take advantage of shade that included a cooling system (Anderson et al., 2012).

To maximize heat loss regardless of environment, dairy cattle in areas with elevated temperature often stand to increase available surface for heat dissipation (Igono et al., 1987; Anderson et al., 2012, Smith et al., 2012). Even a mild increase in ambient temperature can invoke an increase in standing time (Smith et al. 2012). Highest incidence of lameness (new cases) occurs when cattle stand longer than 45% of the day (Galindo and Broom, 2000), and locomotion scores increase during summer months relative to winter months (Cook et al., 2007). A negative correlation between time spent lying and incidence of lameness as well as time spent lying and temperature humidity index has also been reported (Leonard et al., 1996; Privolo and Riva, 2009). This suggests that cattle exposed to higher temperatures are more likely to stand to improve heat dissipation but are also more likely to experience periods of lameness during the same time frame. Reducing resting time has been reported to reduce milk production (Bach et al., 2008, Grant 2007). It was estimated that for each hour of increased resting time that milk production increased 3.7 lbs (1.7 kg).

The effects of lameness on dairy production are compounded by and just as disconcerting as heat stress effects. Lameness affects resting and feeding behavior (Cook et al., 2007), decreases reproduction efficiency (Garbarino et al., 2004), and increases the likelihood for early removal from the herd (Collick et al., 1989). In hot climates, cattle are forced to risk lameness or risk overheating.

CBT and Cow Behavior

To further our understanding of behavioral conditions of heat stressed dairy cows, we combined three different data sets from heat stress trials conducted in Arizona (Anderson et al., 2012), California (S. Rungruang, unpublished), and Minnesota (Smith et al., 2012). In each trial, lactating dairy cows were fitted with 2 data loggers: one recorded CBT intra-vaginally, and one recorded angle of leg to determine lying status. All data were standardized to 5-minute intervals for CBT or 15-minute intervals for ambient conditions, and 2 hours per each milking period were removed to eliminate human interference and subsequent feeding.

While mild temperatures in the Minnesota trial resulted in higher lying CBT, the 2 other climates revealed greater incidence of heat stress and higher standing CBT compared to lying CBT (Figure 2). Table 1 shows the narrow CBT range (0.11 °F or 0.06 °C) of cattle standing compared to cattle lying. Altogether, CBT during posture shift (lying to standing or standing to lying) was equal (Table 2), suggesting that dairy cattle may be cognizant of their fluctuating CBT and are reacting preemptively to battle a dramatic shift in CBT, regardless of time of day (Figure 3).

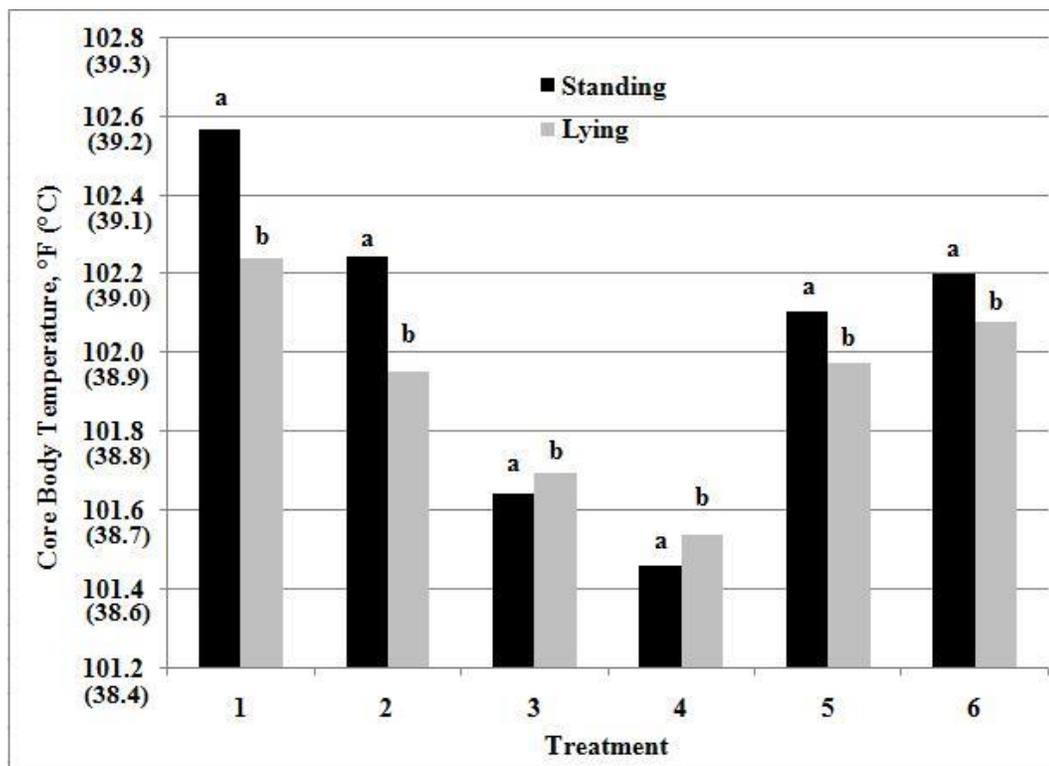


Figure 2. Cumulative core body temperature relation to posture in lactating dairy cows. Treatments are designated as follows: 1 = Arizona with fixed fans and misters under drylot shade; 2 = Arizona with adjustable fans and misters under drylot shade; 3 = Minnesota within a cross-ventilated building; 4 = Minnesota within a cross-ventilated building with evaporative pads; 5 = California with feed-line soakers and fans; and 6 = California with hydrothermally cooled freestalls without feed-line soaking or fans. A treatment effect is observed ($P < 0.0001$). Columns within treatment with different letter designations differ ($P < 0.01$).

Table 1. Core body temperature of lactating dairy cows in relation to posture¹

Item:	Posture		SEM	P Value
	Standing	Lying		
Core Body Temperature, °F (°C)	103.834 (39.908)	101.912 (38.840)	0.0025 (0.0014)	0.0001

¹ Data is representative of cows in Arizona (n = 56), California (n = 37), and Minnesota (n = 64).

Table 2. Core body temperature of lactating dairy cows in relation to posture¹

Item:	Posture			SEM
	Initial Stand	Continuance of Stand	Initial Lying	
Core Body Temperature, °F (°C)	102.144 ^a (38.969)	101.916 ^b (38.842)	101.847 ^c (38.804)	0.0085 0.0047

^{a,b,c} Letters in the same row with a different superscript differ ($P < 0.0001$).

¹ Initial lying is representative of the period in which the animal has transitioned from a standing to lying posture; continuance of lying is representative of the period after the animal has initially lied down. Data is representative of cows in Arizona (n = 56), California (n = 37), and Minnesota (n = 64).

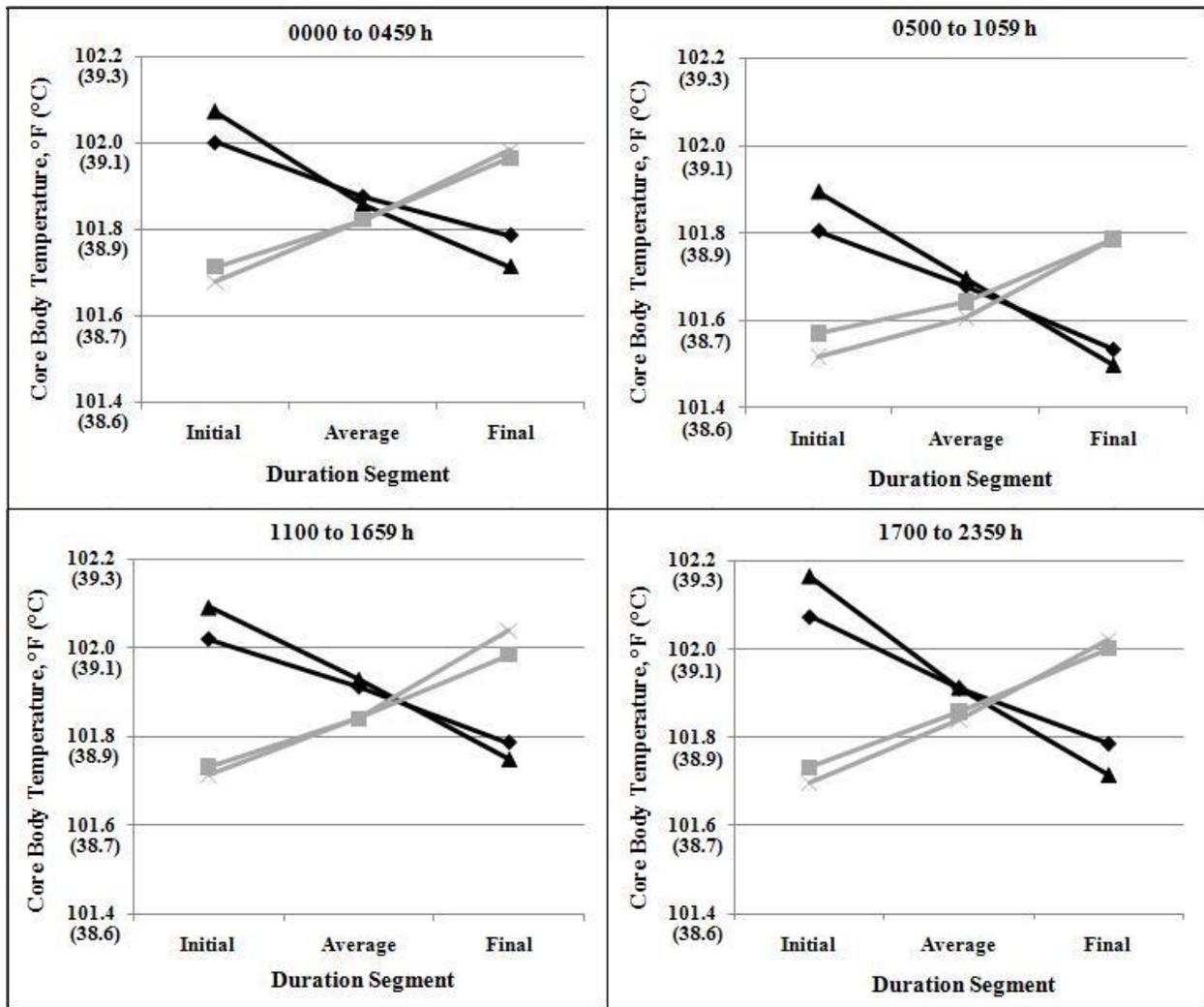


Figure 3. Effect of period of day on core body temperature of standing and lying bouts (Period effect: $P < 0.01$)

An analysis of the entire data set (> 260,000 data points) provided a correlation ($r^2 = 0.56$, $P < 0.0001$) between CBT and cow posture, giving researchers and producers a more specific CBT in which to focus their attention when managing dairy cattle for heat stress and cow comfort. In this data set cattle were more likely to be standing at a CBT greater than $38.93\text{ }^{\circ}\text{C}$ ($102.07\text{ }^{\circ}\text{F}$; Figure 4).

This does not suggest that cows with a CBT below this mark do not experience heat stress. However, with increased standing behavior as an indicator of heat stress, this CBT provides a point at which to improve our management efforts to alleviate the negative affects of heat stress, particularly in decreasing the amount of time a cow stands to dissipate body heat.

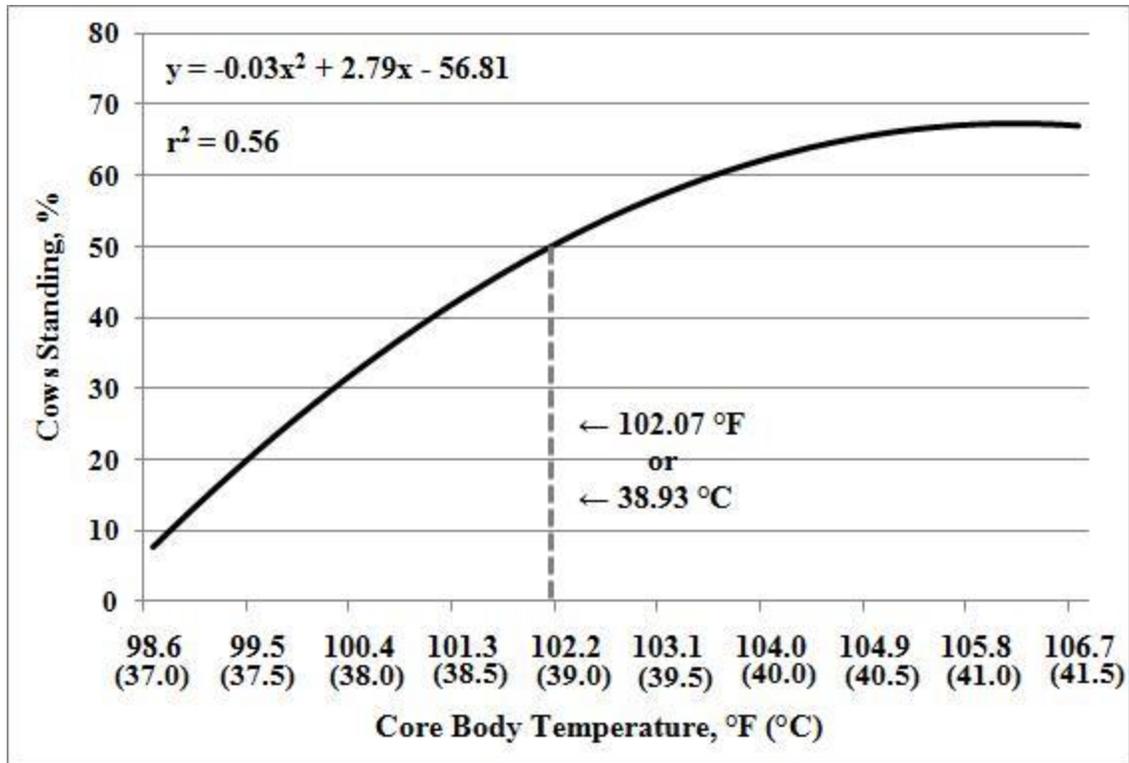


Figure 4. Percent of animals standing in relation to core body temperature. Data is representative of cows in Arizona (n = 56), California (n = 37), and Minnesota (n = 64).

Data using THI as a predictor of stance were limiting in predictive power ($r^2 < 0.20$). This may be in part to the diminished number of THI data points (< 90,000) as compared to the CBT data points (> 260,000). However, the impact of THI on cattle behavior is measurable (Table 3) and appears to follow the same pattern as CBT. Although not specified, the 50 percent mark would occur just above a THI of 71, which is just above a THI of 68, the established threshold where heat stress begins in high producing dairy cows (Zimbelman et al., 2009).

Table 3. Percent of cattle standing within THI categories¹

Item:	THI Category ²						SEM
	< 68	68 to 71	72 to 79	80 to 89	90 to 98	> 100	
Animals							
Standing, %	43.6	49.8	53.0	68.2	49.7	52.2	1.6

¹ P < 0.0001. Data is representative of cows in Arizona (n = 56), California (n = 37), and Minnesota (n = 64).

² Categories defined as thermal neutral (< 68), heat stress threshold (68 to 71), mild-moderate heat stress (72 to 79, moderate-severe heat stress (80 to 89), severe heat stress (90 to 98), and extremely severe heat stress (> 100).

Summary

Heat stress is a major economic issue in the dairy industry. Its effects reach beyond milk production into reproduction, health, and welfare arenas through physiological and behavioral changes. Modifications to cow behavior are linked to overall production performance and should not be overlooked. Improving the cow's comfort by reducing the amount of time it stands to dissipate heat can ultimately reduce the effect of heat stress on milk production.

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Notes:

Animal Care Certifications: What, Who, and Why

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There is no question the public is concerned about how farm animals are treated. In a recent Purdue survey of a thousand participants, consumers put “produced on farms with animal welfare and handling standards in place” right behind fat and protein content in their selection criteria. Other surveys have reported that about 80% of people feel animals have rights related to pain and suffering.

People’s attitudes are shaped in part by local and national news programs that show animals unable to walk and being dragged onto trucks. Opinion documentaries like “Food, Inc.” and “Death on a Factory Farm” create doubts in public minds about the care animals receive on farms and ranches. Covert videos of animal mishandling go viral on the web before they even make it into traditional media. Concerns about animal care are not just public perception; there have been documented cases of abuse on farms.

Based on these public concerns, the food industry has become involved by specifying how animals are treated on farms where meat, eggs, and milk are produced for their suppliers. United Egg Producers has increased the cage space for laying hens and a 2011 state law in Ohio established a livestock regulatory board to establish space and care standards for livestock. At the same time the legislation phases out veal crates, gestation crates, and tail docking. Some progressive farmers would like their operations inspected and certified as “animal friendly” as a market tool. However, the movement to assuring proper animal care before selling your product is fast becoming a market-access issue, not an opportunity for a niche market.

Most producers recognize the payback of comfortable, healthy cows. And many of the practices on dairies are exceptional efforts when you consider the frequency and size of jobs performed regularly. Grooming freestalls and open lots takes a lot of time in a busy dairy schedule. By far, the majority of dairy farmers have a good story to tell and sound animal care evaluation and audit programs can help. Producers and consumers are at a crossroads. We have an obligation to care for the animals and consumers need reassurance animals are cared for properly.

The essence of animal care and welfare is providing comfortable, safe facilities and maintaining healthy animals that can have relatively normal social interaction. The American Veterinary Medical Association has defined the nebulous term “welfare” as:

“Welfare is a wide term that embraces the physical and mental well-being of an animal. Any attempt to evaluate welfare, therefore must take into account the feelings of the animals that can be derived from the structure and functions and also from their behavior.” (http://www.avma.org/issues/animal_welfare/default.aspx)

Animal care discussions are not new. Welfare ideals were published almost 50 years ago, based on a group of scientists and veterinarians in the United Kingdom that were charged with investigating and defining livestock husbandry standards (Brambell report, 1965). These ideals focused on the “Five Freedoms” for farm animals:

1 FREEDOM FROM HUNGER AND THIRST - We do this by providing access to fresh water and a balanced diet to maintain full health and vigor that is appropriate for stage of growth or level of production.

2 FREEDOM FROM DISCOMFORT - Providing an appropriate environment including shelter and a comfortable, clean resting area.

3 FREEDOM FROM PAIN, INJURY OR DISEASE - Providing safe facilities and by prevention or rapid diagnosis and treatment of disorders.

4 FREEDOM TO EXPRESS NORMAL BEHAVIOR - Providing sufficient space, proper facilities, and company of the animal’s own kind.

5 FREEDOM FROM FEAR AND DISTRESS - Providing secure, calm, and relatively quiet conditions and handling which avoid mental suffering.

The majority of the livestock industry is providing these five freedoms in good husbandry practices to animals in their operations; however, what consumers are bombarded with are the exceptions that are exposed by various agendas. So what are the options are there for the industry to tell its story and reassure consumers? Doing nothing has not worked. Reports of animal abuse and misconceptions will continue. Certification within the industry by producers or their processors is seen as “the fox watching the hen house” by the public and doesn’t provide any aggregate data to determine overall successes and challenges in the industry. Systematic verification of practices and animal condition by someone not associated with individual farms has credibility with consumers and can provide the assurance important in their purchase decisions. These can be done through assessments, evaluations, or audits.

Assessments. Evaluating animal care is simply measuring animal condition and care practices against recognized standards. These standards are developed by individuals knowledgeable in care practices and how they affect animals. This evaluation can be done in an “Assessment” or “Evaluation.” An assessment reviews animal condition and care against standards to establish strengths (meeting or exceeding standards) and challenges (subpar conditions needing improvement). These are usually consultative sessions where reasons for challenges and possible

solutions are discussed. Assessments can enable a facility to develop an action plan and timeframe to conform to standards in a more formal certification process, such as a third party audit.

Audits. An animal care audit evaluates the client's facility against the same recognized standards to verify conformance or non-conformance to these specified requirements. Non-conformances need to be addressed by the client and are re-evaluated when the problem is corrected. Some criteria must be corrected immediately for the certification process to continue, such as colostrum to bull calves or lack of adequate feed or water. These are Critical Control Points. Neither assessments nor audits specify management of the farm, recognizing there are a lot of ways to reach compliance with the standards. When possible, outcomes are measured. For example, using body condition scores of cows can measure the effectiveness of the nutrition management on the farm.

So what happens during a third-party, external audit? If you are just starting a program, you contact the auditing program. They will provide a list of standards and request information on the numbers of animals by age or production status. Once you are in a program, your next audit is scheduled by the program. The auditor may contact you prior to the visit so management is available and records are up-to-date.

The day of the audit you need to schedule about 90 minutes for a short explanation of the audit process, an interview with the auditor, the review of written protocols and training materials, and reviewing animal numbers and locations. The interview is a friendly series of open-ended questions to help the auditor understand procedures he or she should see later in the audit. Then the auditor will begin evaluation of animals and the facilities.

The auditor will gather "evidence" that your farm meets or exceeds criteria which are a defined set of external or internal requirements that must be adhered to assure good animal care. The evidence is used to verify that audit criteria are being met (or not). Evidence can be gathered from documents such as treatment/processing protocols, records, interviews and observations with employees, and measurements of cow condition. All the evidence gathered is confidential and is simply used to support compliance with criteria.

Observing the housing and handling conditions are important basics, but cows tell a pretty good story. Are they in proper body condition for their stage of production? Are they relatively clean? Are they alert, but calm? Is there evidence of injury? Do they have sound feet? As cow measurements are recorded the auditor will observe work area cleanliness, pen/stall conditions, equipment use and wear, gates and fences, and hanging or other documentation to which employees can refer.

The auditor will review the farm mission statement for mention of animal well-being, the treatment/processing protocols that establish the consistent care given each animal, and the farm's emergency action plan for loss of power, fire, employee injury, and catastrophic animal loss and disposal.

A week or two after the visit you will receive a report of assessment strengths and challenges or a report of audit conformances and non-conformances. Each of the criteria will be listed with the evidence supporting the findings.

There are a number of programs available. I will list the most common third-party verification programs available. These programs all have policies which allow retail products to be marked with logos assuring the public the raw product was produced under humane animal care guidelines. There are other state, regional, and cooperative-led programs that have guidelines for animal care.

Validus Services “Animal Welfare Review – Dairy™”

<http://www.validusservices.com/>

Validus Services is a privately owned company based in Des Moines, Iowa. The company has years of experience assisting producers in complying with environmental rules and various quality assurance issues nationwide. They have performed over 11,000 Audits, Assessments and Management Plans.

Program Standard

The AWR-D Standards were developed by a panel of dairy experts with extensive producer input. Like most of the programs, the standards are based on Best Management Practices used on the farm to assure adequate animal care. Their audit process allows for continual improvement year to year. Auditors in each of their specific animal programs are trained and experienced in that program. The program has the highest number of observations based on statistical sample based on herd and group sizes, including high risk groups.

Oversight

The AWR-D program is structured under ISO 9001 guideline for training and oversight of quality management. All auditors are trained to ISO standards. Procedures, forms, and performances are reviewed under the USDA Process Verified program of the Agricultural Marketing Service. Training, standards, and re-certification of auditors are verified by the Professional Animal Auditor Certification Organization (PAACO) and by Dr. Temple Grandin (CSU). Additionally, they have certifications in progress to assure production and processing food safety under a Safe Quality Food (SQF) to ensure that products comply with rigorous food safety standards.

The expert committee thoroughly reviews program standards and current issues annually. Occasionally, issues will be reviewed with the committee as they arise.

Cost

The annual certification audit of AWR-D clients cost them \$1795 per day based on the time required for the audit.

American Humane Association “American Humane Certified™”

<http://www.thehumanetouch.org>

The American Humane Association has been around since 1877 when they first worked on care of animals during transportation. This Washington DC-based organization started their “Free Farmed” program a decade ago and changed the name in 2007. They are not affiliated with the Humane Society of United States (HSUS).

Standard

Like many groups involved in certifying animal care, their standards are based on the five freedoms as defined by the Royal Society for the Prevention of Cruelty to Animals (RSPCA) of Europe. A producer downloads the standards and adapts his or her farm to meet the standards. The checklist has some very specific questions which may need interpretation. When the management feels they are ready, they request an inspection from the Association. Any deficiencies are noted and a plan for improvement must be submitted. The changes must be reported with evidence of compliance within 90 days of the initial inspection. Each year the farm will be reviewed.

Oversight

A scientific committee developed and guides the program standards for each species. The Association uses ISO-certified auditors trained by Validus Services.

Cost

The annual audit costs a producer \$1,795 and a royalty fee based on amount of milk packaged with the certification logo mark.

Farmers Assuring Responsible Management (FARM)

<http://www.nationaldairyfarm.com>

The National Dairy FARM Program™ is a nation-wide, verifiable program that certifies animal care and condition. Third-party verification ensures the validity and the integrity of the program to consumers. The program was developed and is operated by National Milk Producers Federation in Washington DC.

Standard

The FARM Standards came from the National Dairy Animal Well-Being Initiative, a set of guidelines developed independently for the nation’s dairy producers. Like the other standards, these guidelines are based on the five freedoms and focus on current issues, such as lameness. The program requires farm evaluation every three years by field personnel, sanitarians, veterinarians, or Extension personnel who are re-certified each year.

Oversight

Program oversight is provided by Validus Services. They train and re-certify evaluators, as well as provide random third-party verification of participating farms.

Cost

A producer must commit to three years in the program and pay 15 cents per adult cow per year. Cooperatives pay based on hundred weights of milk produced. The second-party evaluation is a contract between the producer and the certified evaluator so costs can vary. The third-party verification cost is covered by the program, if the farm is selected.

Humane Farm Animal Care
<http://www.certifiedhumane.org/>

This program describes itself as “A national non-profit 501(c)3 organization created to improve the lives of farm animals by setting rigorous standards, conducting annual inspections, and certifying their humane treatment.” They are based in Herndon, VA and use the slogan “Remember, there are 10 billion animals in the U.S. that need our help.”

Standard

The HFAC standards for animal are based on the RSPCA standards also. Their standards have several prohibitions: no rBST use, and no ionophores, coccidiostats, etc. to boost growth, feed efficiency or milk production. Also tie stalls and stanchion barns are not acceptable cow housing. Participating farms are reviewed annually.

Oversight

The program reports endorsement by RSPCA, ASPCA, and HSUS, plus 41 other organizations. However, there is no oversight by PAACO or other livestock-related certifying groups. They have a scientific committee that reviews the standards.

Cost

The website shows participants pay an application fee of \$75 and a \$600 per day inspection fee. In addition, if the product is labeled “certified humane” the producer pays a certification fee of \$0.015 per hundredweight per month.

General Issues

Each program observes a sample of the cows for lameness, body condition, leg and hock lesions, and hygiene. These are called critical control points that indicate something may be wrong when the sampled animals exceed an acceptable limit. Following is a comparison of the limits for each program:

Critical Control point	AHA	Validus	FARM	HFAC
Lameness	95% score 1, 2	<5% score ≥ 3	90% score ≤ 2	<5% score 3, 4, 5
BCS	98% score >2, <4.5	<3% score <2 <10% score >4	90% score >2, <4.5 $\leq 5\%$ score <2	Differs by production cycle (2.5 to 3.75); <2 may not leave farm
Leg lesions	80% score 0, 1	<2% score 3	90% score 1 99% score ≤ 2	?
Hygiene	90% score 1, 2	<10% score >2	90% score <3	<5% have soil on bellies or udder

There are certain core issues in each of the programs. Evidence to support compliance may vary by program, but each is a “must” for assuring good animal care.

- 1) **A valid veterinarian-client-patient relationship.** The veterinarian overseeing health care for the animals must know procedures and challenges the farm deals with daily. They must be involved in the development of a herd health plan and be part of the periodic review of the plan. Ideally, they should be closely involved in developing the treatment and care protocols and in training employees to those protocols.
- 2) **Employee training.** There should be evidence of new employee training to the tasks they are assigned and general training in animal handling and farm policies. There should be evidence of continued training and a source of reference materials for each employee, such as posted protocols.
- 3) **Use of animal pain management.** Protocols and the herd health plan should include appropriate use of analgesics and anesthetics as prescribed by the herd veterinarian. Employees should know the timing, dose, and route of administration. There should be evidence of the appropriate administration equipment and drugs on the farm. Training should include safety with such drugs for the animal and the employee.
- 4) **Confined animals must have access to food & water.** In general, animals should always have feed and water. In some cases that is not possible. There should be evidence that those periods are as short as possible, depending on ambient conditions.
- 6) **Non-ambulatory animal management.** This is one that gets into every animal abuse video. The goal should be to move the non-ambulatory animal without harm. Legs and head hanging out of a

small bucket loader is not adequate. An adequate sized sled on the ground is the safest way to move an animal to a separate care area. Non-ambulatory animals must be able to reach feed and water. They should have shade and be protected from other animals.

7) Proper euthanasia. The farm should practice on-farm techniques approved by the American Veterinary Medical Association. There should be evidence of equipment used in good working condition and training of employees who can physically & emotionally carryout this procedure on cows/calves. The euthanasia protocol and practice should include timing of the decision based on the condition and prognosis of the animal. It should also include a practice for confirming death.

Most well-managed dairies can already comply with the standards used by any of these audit firms, but there is always room for improvement. Consider what this can do for the professional atmosphere of your farm and the overall image of the dairy producer. Remember, doing nothing hasn't worked.

Notes:

Integrating New Techniques for an Improved Reproduction Program

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Introduction

Currently, reproductive failure is the first reason for involuntary culling, which stresses the economic importance of improving fertility. Estrous synchronization programs have been researched extensively since the mid 1990's (Pursley et al. 1995; Moreira et al., 2001; Dewey et al., 2010) with the main objective of improving artificial insemination (AI) submission rate, decrease intervals between AI, reduce days open and improve overall reproductive performance. One major impediment to adequate reproductive performance is the reduced estrus detection rate, also known as AI submission rate. However, many dairies utilize estrus detection within a timed AI (TAI) protocol in order to reduce costs and possibly improve fertility. Until recently, research focused on evaluating fertility to TAI without considering the effects on estrus detection and overall fertility (i.e. both fertility of estrus detected and TAI cows) to the entire reproductive program. This may lead to false conclusions and recommendations since fertility may be drastically changed due to whether a dairy is utilizing estrus detection. In research studies in which cows are allowed to be inseminated in estrus during the ovulation synchronization protocol, rarely was fertility of cows inseminated in estrus reported and included in the overall reproductive performance of the programs being tested. In addition, initiation of resynchronization programs occurs at or before non-pregnancy diagnosis which can have implications on number of cows detected in estrus depending on how early non-pregnancy diagnosis occurs. Of recent, activity monitors have grown in popularity as a tool to improve estrus detection and questions have been raised to whether these are an additional tool or a replacement for synchronization programs.

Although the aim of reproductive programs is to increase AI submission rate and ultimately percentage of cows that become pregnant, often the use of timed AI protocols results in smaller pregnancy per AI (P/AI) compared with insemination in estrus. In addition, synchronization protocols continue to become more complicated due to the need to fit the biology of the cow and not the schedule of the farm for improved fertility. However, sometimes this is at the expense of what is realistically achievable and applicable on modern-dairy operations. Furthermore, 100% TAI might not be the best solution for improving fertility for dairies that achieve acceptable conception rates to the cows detected in estrus. Understanding how the type of presynchronization strategy used, timing

of non-pregnancy diagnosis, estrus distribution post TAI, and technologies to improve estrus detection will be important considerations for improved fertility to a complete reproductive program.

Presynchronization Programs

The timing of initiation of ovulation synchronization protocols is fundamental because it will determine the likelihood of ovulation to the first GnRH injection, timing of luteolysis during the protocol, length of dominance of the ovulatory follicle, and ultimately synchrony of the estrous cycle. Vasconcelos et al. (1999) observed that when beginning the synchronization protocol between d 5 to 9 of the estrous cycle, significant improvement occurred for the percentage of cows that ovulate to the first GnRH (> 90%) injection of an Ovsynch protocol. In addition, a new follicular wave is recruited within 40-48 h after the GnRH, a CL is present at the time of the prostaglandin (PG) F_{2α} injection (7 d later) resulting in synchronized luteolysis, and synchronized ovulation is induced with the second GnRH given on d 9.5 (Vasconcelos et al., 1999). Therefore, when implementing ovulation synchronization protocols the estrous cycle should be presynchronized to assure that a large percentage of cows start such protocols between d 5 and 9 of the estrous cycle.

Therefore, it becomes evident that methods to presynchronize the Ovsynch protocol have to be developed and implemented to increase P/AI without offsetting any economic gain due to higher fertility with increased inter AI breeding interval. Below we discuss a few new methods of presynchronizing an Ovsynch protocol.

Presynchronization for first postpartum AI

During the first postpartum synchronization and timed AI, much flexibility is allowed in timing of injections and type of injections (i.e. PG) used in order to achieve acceptable pregnancy rates to a timed AI program. The most commonly known and implemented presynchronization protocol is the Presynch, which is composed of two injections of PG given 14 d apart with the second PG given between 10 - 12 d before the start of the Ovsynch (Moreira et al., 2001; Galvão et al., 2007). This results in good synchrony of the estrous cycle after the second PG injection of the Presynch, with approximately 85% of cycling cows displaying estrus within 2 to 7 d. Consequently, by starting the Ovsynch approximately 10 - 12 d after the second PG of the Presynch the majority of cyclic cows would be between d 5 and 10 of the estrous cycle ultimately improving timed AI fertility. In addition, many producers inseminate cows based off estrus detection after the second PG injection of Presynch. This has two major advantages: 1) a producer can inseminate cows on estrus after the second PG injection, thereby reducing the number of cows that enter the timed AI program and significantly reducing costs; 2) by using Presynch, the cows that were not detected in estrus may be at the correct stage of their estrous cycle (i.e. d 5 – 9) to achieve the highest fertility to the timed AI program.

The Double-Ovsynch protocol which submits cows to a ‘presynchronizing Ovsynch’ followed 7 d later by the ‘breeding Ovsynch’. The protocol would be: GnRH d -17, PG d -10, GnRH d -7, GnRH d 0, PG d 7, GnRH d 9.5, and timed AI d 10 which is basically the Ovsynch twice and breeding off the second Ovsynch. As such, it is expected that approximately 40-50% of cows would ovulate to the first GnRH given on d -17 and a significantly larger proportion would ovulate to the GnRH given on d -7. This would cause the recruitment of a new follicular wave approximately 40-48 h later,

which would result in a large percentage of cows starting the ‘breeding Ovsynch’ in early diestrus and a large percentage of cows ovulating in response to the GnRH given on d 0 (Souza et al., 2008).

The G6G protocol utilizes an initial injection of PG d -8 to regress the CL and an injection of GnRH on d -6 to ovulate the dominant follicle (Bello et al., 2006). On d 0 the Ovsynch would begin same as described previously. This would promote cows to be approximately d 5 of the estrous cycle which is within the optimal range for beginning the Ovsynch protocol. Within this study, ovulation to the first GnRH of Ovsynch was 85% and cows synchronized to Ovsynch were approximately 96%.

For both the Double-Ovsynch and G6G protocols, the presynchronization protocol involves GnRH injection(s) instead of PG injections as in the Presynch-Ovsynch protocol. This can have dramatic effects on the number of cows that display estrous. For example, GnRH when injected will cause one of two physiological responses or both: 1) ovulation of a follicle greater than 10 mm, and (or) 2) follicular turnover and induction of a new follicular wave. If GnRH is injected and cows do not have a follicle large enough to produce sufficient estrogen then the cow will not show an estrous. However, alternatively PG promotes estrous expression by inducing CL regression and allowing the dominant follicle to grow, produce estrogen for estrous expression and ovulate. If GnRH based presynchronization protocols are utilized compared with PG based protocols, it’s likely that less cows will be detected in estrous and inseminated but will be synchronized and timed AI. This may not be the most profitable decision if the dairy can achieve acceptable conception rates to estrous detected cows.

Synchronization Protocols for First Breeding Evaluated With Estrus Detection

Recently our group evaluated the effect of adding a GnRH or PG between the Presynch and Ovsynch program for first AI in lactating dairy cows (Bruno et al., 2013). The objective was to evaluate effects of 3 reproductive programs for first AI on fertility in lactating dairy cows while taking into account estrus detected cows as well. Lactating cows (n=1521) from a dairy in TX were presynchronized with 2 injections of PG given at 36 and 50±3 DIM. At 50±3 DIM, 915 multiparous and 606 primiparous cows were assigned to 1 of 3 programs (Figure 1): OVS (n=552) which initiated the Ovsynch protocol 14 d after presynchronization, GGPG (n=402) in which a GnRH injection was given 7 d after presynchronization followed by the Ovsynch protocol 7 d later and P7GPG (n=567) in which a PG injection was given 7 d after presynchronization followed by the Ovsynch protocol 7 d later (Figure 1). Cows were AI based on signs of estrus beginning after the presynchronization and, if AI, cows were removed from subsequent injections. Pregnancy per AI (P/AI) was diagnosed at 66 d after AI. Overall 52.3% of cows were AI based on estrus detection with the GGPG program having the least (P<0.01) number of cows being identified in estrus (GGPG=46.8 vs. OVS=50.7 and P7GPG=57.7%). This illustrates how use of GnRH versus PG can reduce estrus detection which will increase the number of cows receiving more injections from the Ovsynch protocol and being TAI. Reproductive program did not affect (P>0.33) overall P/AI at 66 d after AI (OVS=32.3, P7GPG=31.9 and GGPG=28.1%) or pregnancy loss (P=0.68) between 36 and 66 d after AI. Cows AI upon estrus detection had higher P/AI than TAI (estrus detection = 37.9 vs. TAI = 28.8%, P<0.01). However, treatment did not affect (P>0.61) P/AI for cows AI upon estrus detection or TAI (OVS=32.3, P7GPG=31.9 and GGPG=28.1%). Interestingly, reproductive program affected (P<0.01) the median DIM at first service (P7GPG=59 vs. OVS=68 and GGPG=68 d: Figure 3). As shown in figure 2, since GnRH reduced estrus and sent more cows on to receive the Ovsynch

program, DIM at first breeding was increased without an increase in fertility. Conversely, if they received a PG injection more cows were AI off estrus and DIM was reduced.

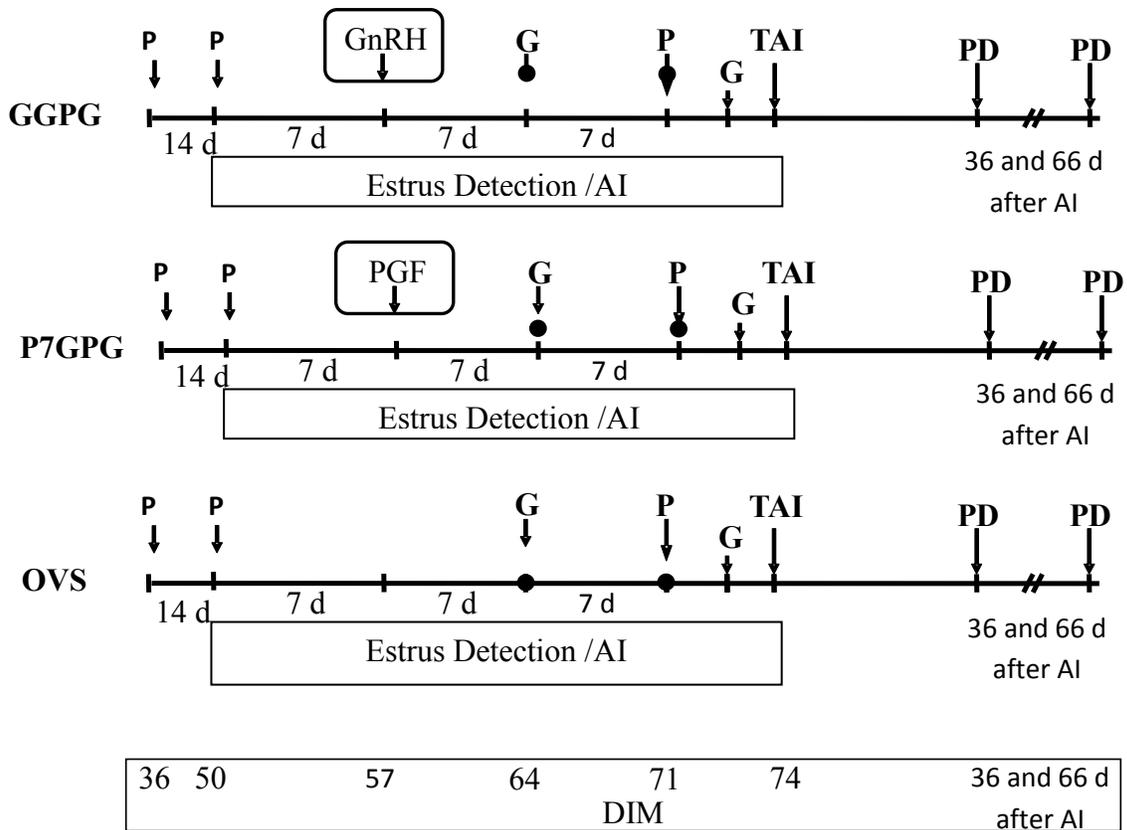


Figure 1. Diagram of experimental activities - Experiment 1. GGPG = GnRH based synchronization program, P7GPG = prostaglandin F2 α based synchronization program, OVS = Presynch-Ovsynch synchronization program. P or PGF = 25 mg of prostaglandin F2 α (dinoprost tromethamine; Lutalyse® 5 mg/mL, Pfizer Animal Health, Madison, NJ); G or GnRH = 86 μ g of GnRH (gonadorelin sterile solution; Fertagyl® 43 μ g/mL, Intervet/Merck Animal Health, NJ). TAI = timed AI, PD = Pregnancy diagnosis, DIM = days in milk, and = blood sample and ultrasound scan.

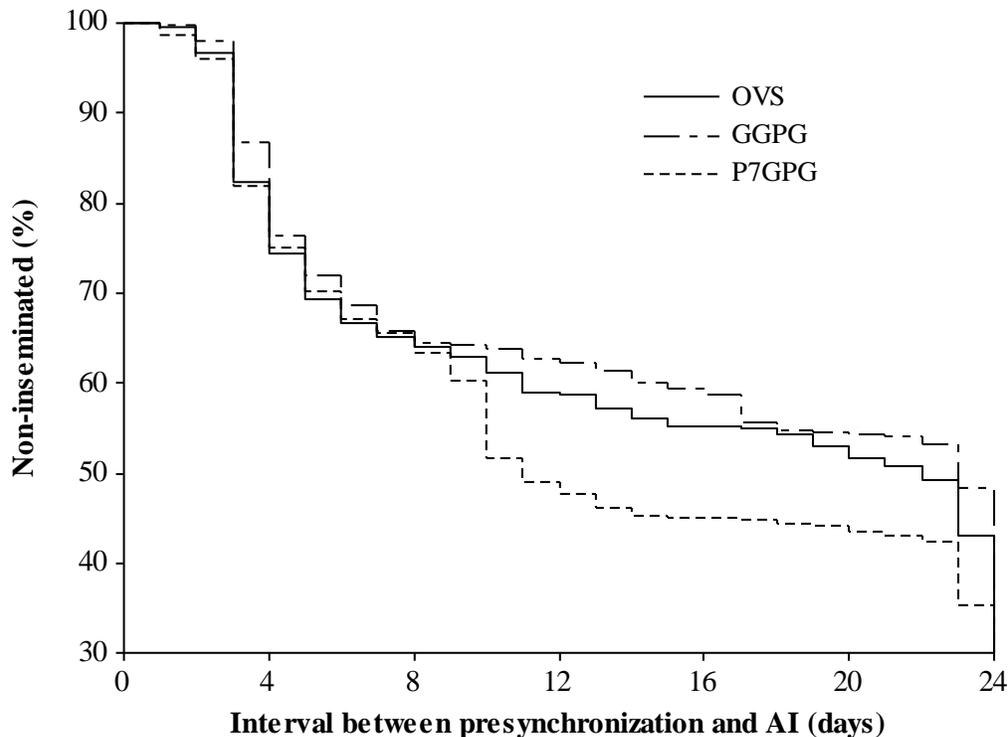


Figure 2. Kaplan-Meier survival analysis illustrating the effect of synchronization programs (Experiment 1) on interval between voluntary waiting period (VWP) and AI for 1,521 cows enrolled in three synchronization programs for first AI. There was a difference in median days between VWP and first AI (OVS = 22, GGPG = 23 and P7GPG = 11 days, $P < 0.001$).

We concluded that reproductive programs for first AI must be selected by evaluating overall fertility outcomes which includes both cows detected in estrus and TAI cows if the dairy is utilizing estrus detection as part of their reproductive program. When a GnRH or PG injection was added in between the Presynch and Ovsynch program for first AI, P/AI was not altered but resulted in increased number of cows being AI upon estrus detection when PG injection was added or increased number of cows completing the TAI protocol when a GnRH injection was added 7 d after presynchronization. Dairy farms with good estrus detection and conception rates to those found in estrus, should take advantage of PG based synchronization programs since a higher percentage of cows would be AI upon estrus detection decreasing the cost and labor associated with TAI protocols.

Resynchronization Protocols Evaluated Without Estrus Detection

Resynchronization of non-pregnant cows continues to be a challenge for reproductive performance of dairy cows. According to published studies and on-farm data, P/AI of cows diagnosed not pregnant and resynchronized with the Ovsynch protocol is usually ($< 30\%$). Many synchronization and resynchronization programs have been published over the past 15 years. However, until recently, almost all of these programs only evaluated TAI fertility and either did not do estrus detection or choose to ignore the cows the came into estrus. Below are a few of those studies.

Silva et al. (2007) evaluated a PG-based presynchronization protocol before the start of the resynchronization. Therefore, cows were examined for pregnancy at 32 d after AI. Half of the cows diagnosed not pregnant were submitted to the Ovsynch protocol starting at 33 d after AI and were re-inseminated at 43 d after AI, whereas the other half of the cows were presynchronized with an injection of PG at 34 d after AI, were submitted to the Ovsynch at 46 d after AI and were re-inseminated at 56 d after AI. The hypothesis was that by giving PG at 34 d after AI a large percentage of cows would start a new estrus cycle between 36 and 41 d after AI and consequently start the Ovsynch between d 5 and 10 of the estrous cycle. Pregnancy per AI (P/AI) was increased by presynchronizing cows with PG (35.2 vs. 25.6%). Interestingly, the percentage of cows that ovulated to the first GnRH injection of the Ovsynch was not different (53.9 vs. 49.3%) and, therefore, it was suggested that increases in P/AI may have been the result of improved uterine health because of the additional PG injection and the extra time between inseminations.

Giordano et al. (2012) compared the reproductive performance of cows resynchronized with the Ovsynch or Double-Ovsynch. Cows resynchronized with the Ovsynch received the first GnRH at 32 d after AI and, if diagnosed not pregnant at 39 d after AI, they received the PG at 39 d after AI, the second GnRH at 41 d and timed AI at 42 d. Cows resynchronized with the Double-Ovsynch received a GnRH at 22 d after AI, and if diagnosed not pregnant at 29 d after AI they received a PG, at d 32, at d 39 a GnRH, at d 46 a PG, at d 48 a GnRH, and at d 49 the timed AI. Cows resynchronized with the Double-Ovsynch were more likely to ovulate to the first GnRH (85.4 vs. 68.9%) and had greater P/AI (38.5 vs. 30.0%).

A critical issue with both of these protocols is that the interval between AI was increased by 7 d in both protocols, despite the fact that cows in the Double-Ovsynch treatment (Giordano et al., 2012) were examined for pregnancy by ultrasound 10 d earlier. One possible alternative to reduce the interval between AI when presynchronizing with a PG injection is to inseminate cows that display estrus during the 12 d before the start of the Ovsynch protocol.

A good alternative to presynchronize the estrous cycle of cows of unknown pregnancy status is to treat them with GnRH injection similar to the study mentioned previously for first postpartum TAI. Considering that cows with follicles > 10 mm in diameter are likely to ovulate to a GnRH injection, it is expected that GnRH given at random would result in ovulation in approximately > 40% of lactating dairy cows. Another alternative is to treat cows with a CIDR device during the resynchronization protocol because treatment with a CIDR device during a timed AI protocol results in improved synchronization of the estrous cycle. These alternatives were evaluated in a recent study conducted in AZ and CA (Dewey et al., 2010).

In this study, cows in the GGPG treatment were presynchronized with an injection of GnRH given at 32 d after AI and if diagnosed not pregnant on d 39 after AI they were submitted to the Cosynch72 (d 0 GnRH, d 7 PG, and d 10 GnRH+ timed AI). Cows in the CIDR treatment diagnosed not pregnant on d 39 after AI received the Cosynch72 with the addition of a CIDR device between the GnRH and the PG, given on d 0 and 7, respectively. The control treatment was the Cosynch72 protocol that started on d 39 after AI if cows were diagnosed not pregnant. The end result was greater P/AI for GGPG cows (31.2%) than control cows (22.1%). Further, CIDR cows (29.5%) had P/AI similar to that of GGPG cows and greater than control cows. The authors concluded that presynchronizing cows with a GnRH 7 d before the start of the resynchronization or treating cows

with a CIDR device during the resynchronization protocol increased P/AI in nearly 8 percentage points without extending the interval between AI.

An interesting finding of this study is the small percentage (~ 25%) of cows that had luteolysis between the first GnRH injection (d 0) and the PG injection (d 7) of the Cosynch. The days when these injections were given would correspond, in cows with estrous cycle length of 22 d, to the beginning of the proestrus of the estrous cycle immediately after AI and early metestrus of the second estrous cycle after AI, respectively. This demonstrates that a large percentage of cows do not have the expected 22 d interval to return to estrus after a previous AI.

Resynchronization Protocols Evaluated With Estrus Detection

Although constantly new timed AI protocols are developed and evaluated, the importance of inseminating cows based on signs of estrus continues to be significant. Many dairies today utilize estrus detection as part of their reproductive program. Recently our group has evaluated the effects on fertility of integrating different resynchronization protocols into a reproductive program that utilizes estrus detection.

The first study evaluated the effects of 2 resynchronization timed AI protocols beginning at different intervals after AI on fertility in dairy cows (Bruno et al., 2013). Lactating cows from 2 dairies located in TX (n = 2233) and MN (n = 3077) were assigned to 1 of 4 timed AI protocols 17 ± 3 d after AI. Cows assigned to Early Resynch or Resynch received the OvSynch56 starting 24 or 31 d after AI, respectively. Cows assigned to Early GGPG or GGPG received a presynchronizing GnRH 17 or 24 d after AI, respectively, 7 d before the start of OvSynch56. Any cow observed in estrus was timed AI on the same day. Fewer Early GGPG ($P<0.01$) and more Resynch ($P<0.01$) cows were re-inseminated in estrus (Early GGPG=23.7, GGPG=49.0, Early Resynch=41.6 and Resynch=57.6%). However, treatment did not affect ($P=0.22$) P/AI 66 d after re-insemination (Early Resynch=26.1, Early GGPG=29.4, GGPG=30.5, Resynch=30.4%). Cows re-inseminated in estrus, however, had greater P/AI at 66 d (36.0 vs. 23.9%) than cows that received timed AI. We concluded that early start of resynchronization and presynchronization with GnRH reduced number of cows re-inseminated in estrus and neither the timing nor the resynchronization protocol affected overall P/AI.

Since GnRH reduced the number of cows in estrus and increased the number of cows that entered the TAI program, which yielded a lower P/AI, then possibly utilizing a PG injection for presynchronization with estrus detection will improve fertility. A second study was conducted to determine the speed at which cows non-pregnant to a previous AI and that had their estrous cycle presynchronized with a GnRH or PG injection are re-inseminated and become pregnant (Chebel et al., 2012). Jersey (site A, MN) and Holstein (site B, WI) cows, 32 ± 4 d after AI, were assigned to one of two presynchronization treatments: GGPG (n = 452) – GnRH injection at enrollment (d 0), 7 d before the start of the timed AI protocol; and, P11GPG (n = 466) – PG injection on d 3, 11 d before the start of the timed AI protocol. Cows observed in estrus at any interval after enrollment were re-inseminated on the same day. Timed AI protocols were the Ovsynch56 in site A and the Cosynch48 in site B. Cows in herd A were examined by ultrasound 32 ± 4 d after AI and those diagnosed non-pregnant continued in the experiment (n = 611), whereas cows (n = 875) in herd B had blood samples collected on the day of enrollment (32 ± 4 d after AI) and analyzed for concentration of pregnancy specific protein-B (PSPB; Biopryn). PSPB results were received 2.5 d after enrollment, thus cows in herd B enrolled in the GGPG treatment received the presynchronizing

GnRH injection at enrollment without previous knowledge of pregnancy status. However, cows in herd B enrolled in the P11GPG treatment only received PG if diagnosed non-pregnant, 2.5 d after enrollment. Cows in the P11GPG treatment had faster re-insemination rate (Figure 3) and were less likely to be submitted to the timed AI protocol (40.3 vs 89.8%) and to be re-inseminated at fixed time (38.6 vs 83.9%) as shown in table 1. Consequently, the interval from enrollment to re-insemination was shorter for P11GPG cows than GGPG cows (Table 1 and Figure 3). Percentages of cows pregnant at 67 ± 4 d after re-insemination were not affected by resynchronization protocol; however, pregnancy rate from d 0 to 7 and from d 8 to 14 was greater for P11GPG cows (Table 1). The increased pregnancy rate illustrates the expedited re-insemination rate and establishment of pregnancy for cows injected with PG. Authors concluded that fertility of non-pregnant cows that had their estrous cycle presynchronized with GnRH or PG was not different, but in herds with adequate estrous detection efficiency and accuracy, presynchronization with PG is likely to reduce the interval to establishment of pregnancy and to reduce the cost of resynchronization protocols.

It is important to note that, according to data from herd A, P/AI 32 ± 4 d after re-insemination tended to be ($P = 0.10$) affected by the interaction between presynchronization treatment and presence of CL on the day of enrollment. Cows in the GGPG treatment with a CL on the day of enrollment (CL+) had similar P/AI compared with P11GPG/CL+ cows (34.1 vs 32.7%, respectively). On the other hand, GGPG cows without a CL on the day of enrollment (CL-) had greater P/AI than P11GPG/CL- cows (44.4 vs 25%). This numerical difference was carried out to 67 ± 4 d after re-insemination (GGPG/CL+ = 30.8%, P11GPG/CL+ = 29.9%, GGPG/CL- = 37.7%, P11GPG/CL- = 22%), but there was no statistical significance ($P = 0.22$). This illustrates a possible advantage of ultrasound exam for diagnosis of non-pregnancy and ovarian structures, which would allow a more judicious decision regarding the resynchronization protocol for specific cows. Samples submitted for PSPB analysis, however, could also had been analyzed for progesterone (P4) concentration determining the best resynchronization protocol on presence ($P4 \geq 1$ ng/mL) or absence ($P4 < 1$ ng/mL) of a viable CL. An obvious disadvantage of the PSPB test is the fact that results are not known up to 48 to 72 h after sample collection, which may extend the interval between inseminations.

Table 1. Effect of GGPG or P11GPG on pattern of re-insemination, pregnancy per AI (P/AI) after re-insemination, and pregnancy rates.

	GGPG	P11GPG	<i>P</i> – value
Insemination rate, AHR (95% CI)*	Referent	1.24 (1.07, 1.45)	< 0.01
Cows submitted to the timed AI protocol, %	89.8	40.3	< 0.01
Cows inseminated at fixed time, %	83.9	38.6	< 0.01
Enrollment to re-insemination interval, days (\pm SEM)	15.0 ± 0.2	13.0 ± 0.4	< 0.01
P/AI 32 ± 4 d after re-insemination, %	42.3	39.3	0.43
P/AI 67 ± 4 d after re-insemination, %	37.0	35.4	0.70
Pregnancy loss from 32 to 67 ± 4 d after re-insemination, %	11.4	6.4	0.11
Pregnancy rate from 0 to 7 d after enrollment, %	3.6	17.7	< 0.01
Pregnancy rate from 8 to 14 d after enrollment, %	1.6	5.7	< 0.01

* AHR = Adjusted hazard ratio; 95% CI = 95% confidence interval

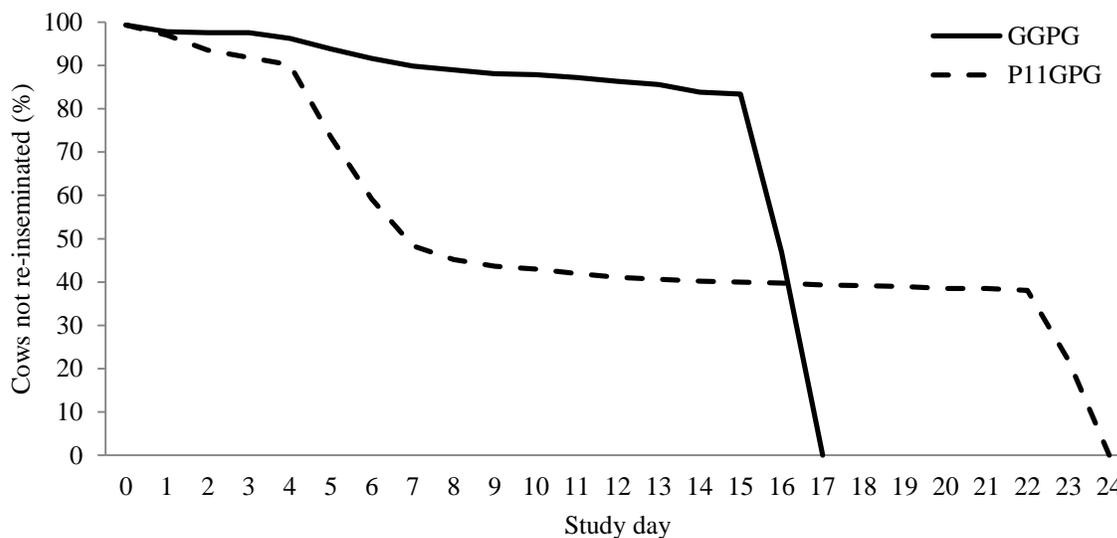


Figure 3. Survival analysis of interval from enrollment to re-insemination according to presynchronization treatment (Wilcoxon test of equality – $P < 0.01$).

Lastly, an experiment was conducted to evaluate the use of PG at different intervals prior to resynchronization programs on fertility in lactating dairy cows (Bruno et al., 2013). Cows ($n = 2,327$) were assigned to 1 of 3 resynchronization protocols 7 d prior to non-pregnancy diagnosis which is also experimental d 0: GGPG ($n = 458$), received a GnRH at enrollment (d 0) and OVS (GnRH 7 d later PG, 56 hrs GnRH, and 16 hrs later TAI) at non-pregnancy diagnosis 7 d later; P7GPG ($n = 940$) received a PG at non-pregnancy diagnosis and OVS 7 d later; and P11GPG ($n = 929$) received a PG 3 d after non-pregnancy diagnosis and OVS 11 d later. The GGPG protocol reduced estrus detection and treatment did not affect overall P/AI at 66 d after AI or pregnancy loss (Table 2). Cows AI upon estrus detection had greater P/AI than cows TAI (estrus detection = 32.3, TAI = 25.1%). However, treatment did not affect P/AI for cows AI upon estrus detection 66 d after AI or TAI (Table 2). Median days between non-pregnancy diagnosis and AI was affected by treatment (GGPG = 10 vs. P7GPG = 4 and P11GPG = 7 d; Figure 4). This reinforces the fact that PG based programs increased estrus detection and reduced interval to first AI and between AI while GnRH based programs increased the proportion of cows TAI. Also, cows AI upon estrus detection had increased P/AI than cows TAI. Interestingly, shortening the interval from PG to the initiation of resynchronization did not negatively affect fertility at TAI and reduced interval to AI. However, caution should be taken when utilizing PG 7 d prior to resynchronization if estrus detection is NOT used as the majority of the cows would be at the incorrect stage of the estrous cycle when beginning resynchronization.

Table 2. Effect of different presynchronization treatments and intervals on reproductive outcomes

Item, % (n/n)	GGPG	P7GPG	P11GPG	P - value
Enrollment, n	458	940	929	
Non-Pregnant 7 d after enrollment	42.0 (192/458)	40.6 (382/940)	37.5 (348/929)	
Estrus Detected (% , n/n)	21.9 (42/192) ^b	75.9 (290/382) ^a	78.2 (272/348) ^a	<0.01
Timed AI (% , n/n)	78.1 (150/192) ^a	24.1 (92/382) ^b	21.8 (76/348) ^b	<0.01
<i>P/AI, 66 d (% , n/n)</i>				
From 0 to 7 d	44.4 (8/18)	31.6 (24/79)	23.1 (14/65)	0.14
From 8 to 14 d	12.5 (3/24) ^b	26.7 (52/195) ^a	38.3 (57/149) ^a	< 0.01
From 15 to 21 d	25.7 (38/148)	40.0 (6/15)	37.5 (18/48)	0.19
From 22 to 28 d	-	20.1 (19/91)	22.2 (2/9)	0.36
From 29 to 35 d	-	-	18.4 (14/76)	-
Overall for Estrus Detected (%)	26.2 (11/42) ^b	28.4 (82/289) ^a	33.6 (91/271) ^a	0.31
Overall for Timed AI (%)	25.7 (38/148)	20.1 (19/91)	18.4 (14/76)	0.41
Overall (%)	25.7 (49/190)	26.6 (101/380)	30.3 (105/347)	0.38
Pregnancy loss (% , n/n)	7.1 (4/56) [*]	6.5 (7/108)	5.4 (6/111)	0.71
<i>Pregnancy rate, 66 d (% , n/n)</i>				
From 0 to 7 d	4.2 (8/190) ^b	6.3 (24/380) ^a	4.3 (14/347) ^b	< 0.01
From 8 to 14 d	1.7 (3/172) ^b	17.3 (52/301) ^a	20.2 (57/282) ^a	< 0.01
From 15 to 21 d	25.7 (38/148) ^a	5.6 (6/106) ^c	13.5 (18/133) ^b	< 0.01
From 22 to 28 d	-	20.9 (19/91) ^a	2.4 (2/85) ^b	< 0.01
From 29 to 35 d	-	-	18.4 (14/76)	-
Overall for Estrus Detected (%)	5.7 (11/190) ^b	21.6 (82/380) ^a	26.2 (91/347) ^a	< 0.01
Overall for Timed AI (%)	25.7 (38/147)	20.9 (19/91)	18.4 (14/76)	0.40
Overall (%)	25.7 (49/190)	26.6 (101/380)	30.3 (105/347)	0.38

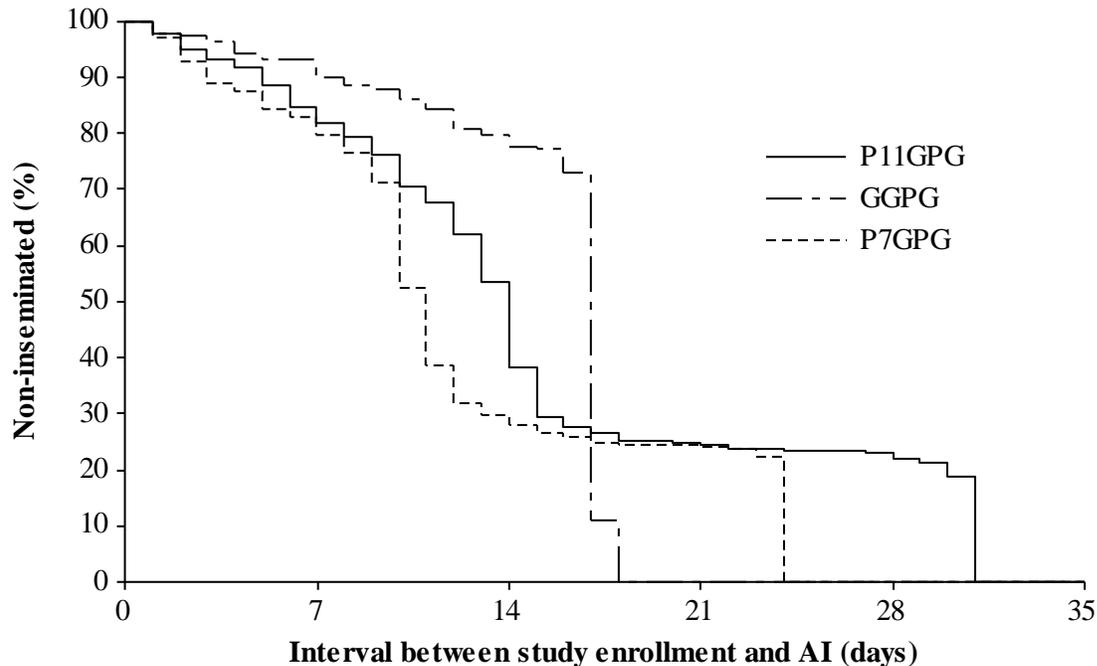


Figure 4. Kaplan-Meier survival analysis illustrating the effect of resynchronization programs on interval between study enrollment and subsequent AI for 3 resynchronization programs.

These studies illustrate how the number of cows detected in estrus is affected by timing of GnRH or PG injections and that caution should be exercised when recommending synchronization programs based on GnRH particularly to herds with good AI submission rates and good P/AI to cows inseminated in estrus. Furthermore, if no benefits to overall reproductive performance are achieved by implementing protocols that reduce estrous expression, a significant increase in cost of reproductive programs will be observed because greater percentage of cows have to be enrolled in fixed time AI protocols. Therefore, it may be advantageous for farms with acceptable estrus detection and conception rates to utilize synchronization programs that are PG based (i.e. P7GPG, P11GPG) compared with GnRH based protocols (i.e. GGPG, G6G or Double-Ovsynch) due to the effects that these protocols have on reducing estrus. For example, in the study by Bruno et al. (2012, 2013) cows re-inseminated in estrus had P/AI 12 and 7 percentage units greater than cows that were re-inseminated at fixed time, respectively. Some of this reduction is possibly due to a less fertile population of cows entering the synchronization protocol due to the more fertile cows displaying estrus and removed from the synchronization protocol.

Insemination based on signs of estrus during synchronization protocols

Although constantly new timed AI protocols are developed and evaluated, the importance of inseminating cows based on signs of estrus continues to be significant. In some situations the dairy may have facility limitations, not enough personnel, poor estrous expression, poor conception rates to cows detected in estrous or simple preference to not allow for daily observation of estrus and insemination so 100% timed AI protocols may be necessary. In herds with adequate estrus-detection

accuracy it is expected that P/AI of cows inseminated in estrus to be similar or greater than that of cows inseminated at fixed time.

In a recent study with 3,248 lactating dairy cows conducted in 7 large dairy herds across the US, cows were presynchronized with two injections of PG and those observed in estrus were inseminated (Chebel et al., 2010a; Figure 5). Cows not observed in estrus were submitted to a timed AI protocol (i.e. Ovsynch or Cosynch72). These herds were a mix of dry-lot (AZ and CA1) and free-stall (remaining herds). The average days in milk at first AI were 58.3 ± 0.2 and 73.3 ± 0.2 for cows inseminated in estrus and those inseminated at fixed timed AI, respectively. Cows inseminated in estrus after the second injection of PG of the Presynch protocol had P/AI that ranged from 25.3 to 41.2% and in only 2 of the 7 herds P/AI of cows inseminated in estrus was smaller than that of cows inseminated at fixed time (range – 22.4 to 46.9%).

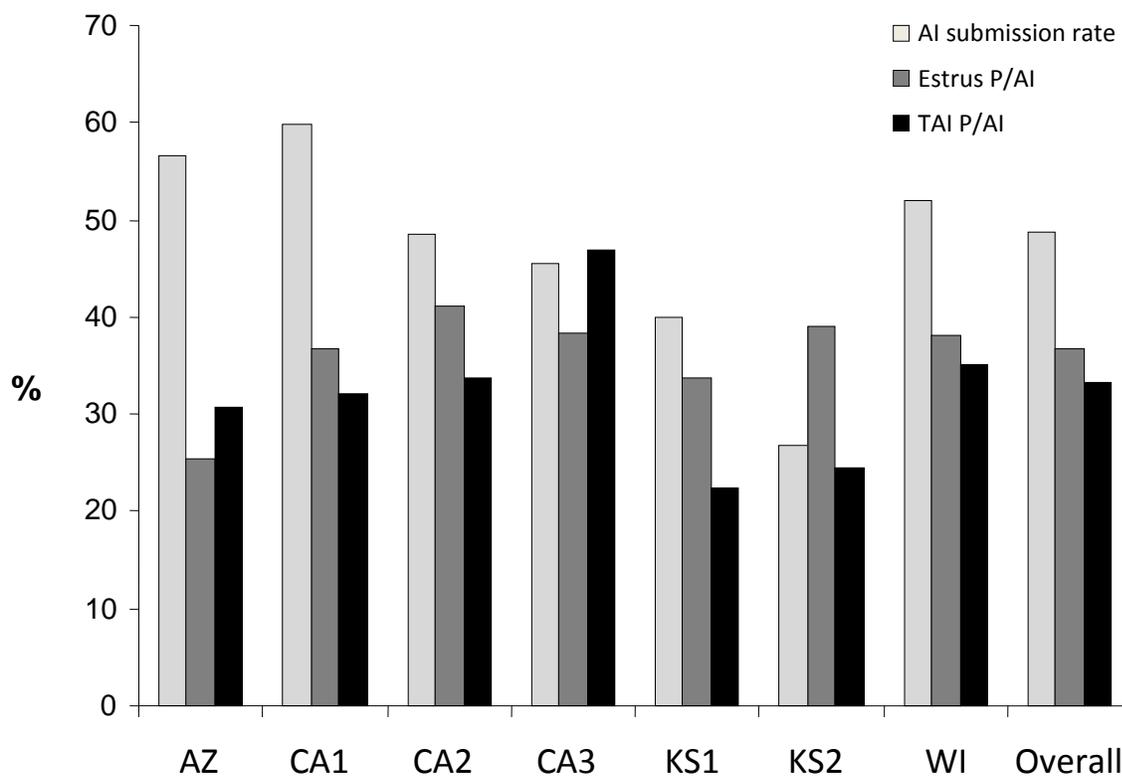


Figure 5. AI submission rate and pregnancy per AI (P/AI) of cows inseminated on estrus (Estrus) or timed AI (TAI). All cows were presynchronized with the Presynch protocol and those not observed in estrus within 12-14 d after the last PG injection of the Presynch were enrolled in a timed AI protocol (Chebel et al., 2010a).

In another study, Chebel et al. (2010b) evaluated the reproductive and economic performances of cows submitted to the Presynch-Ovsynch with or without ‘cherry-picking’ (insemination of cows that displayed estrus between the second PG of the Presynch and beginning of the Ovsynch). In this study, P/AI after first AI was not different between cows in the ‘cherry-picking’ and ‘100% timed AI’ protocols (Table 3).

Table 3. Effect of inseminating cows in estrus following a presynchronization protocol on reproductive and economic performance of lactating Holstein cows.

Items	Treatments		P – value
	Cherry-picking	100% timed AI	
Number	321	318	
Percentage inseminated on estrus at first AI, %	58.9	0.0	< 0.01
Days in milk at first AI (\pm SEM)	64.7 \pm 0.4	74.2 \pm 0.5	< 0.01
P/AI at 32 d after first AI, %	33.0	39.6	0.14
P/AI at 60 d after first AI, %	25.3	31.1	0.20
Pregnancy loss from 32 to 60 d after first AI, %	22.9	21.4	0.97
Cost of synchronization for first AI	19.1 \pm 0.02	21.0 0.02	< 0.01
Balance ¹ after 305 DIM	447.6 \pm 28.7	400.0 \pm 28.7	0.21

¹Balance was calculated based on cost of synchronization for first AI, reproductive status at the end of 305 DIM, cost of replacement and salvage value, and income over feed cost.

Furthermore, when the rate at which cows became pregnant was evaluated (Figure 6), it was evident that inseminating 100% of cows at fixed time did not improve reproductive efficiency significantly to pay for the additional cost of first AI synchronization protocols.

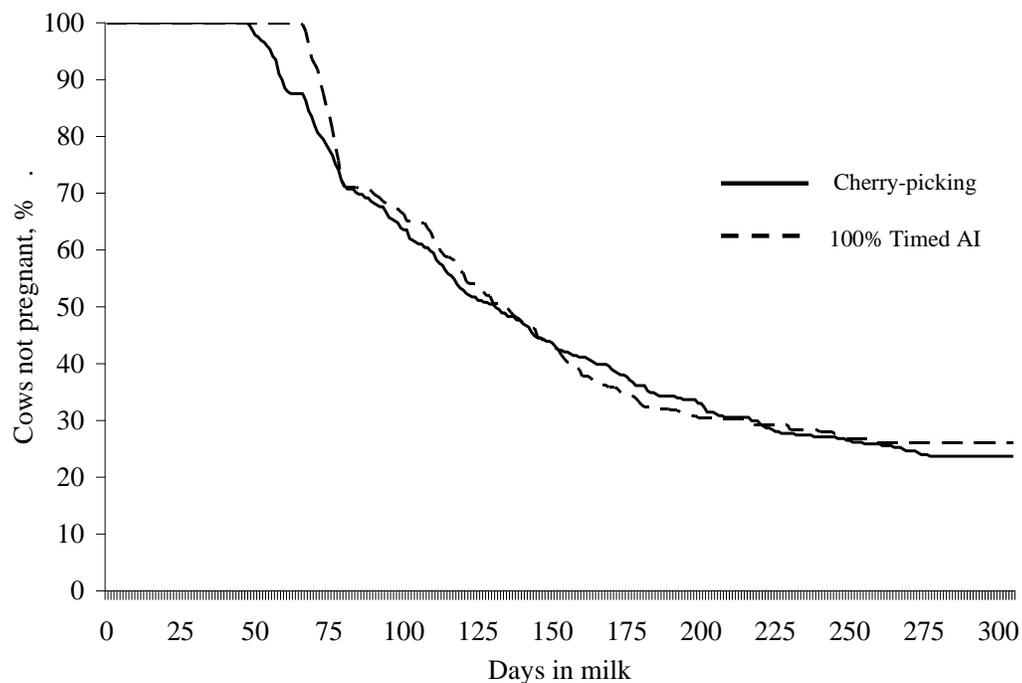


Figure 6. Effect of ‘cherry-picking’ after the Presynch on interval from parturition to pregnancy ($P = 0.22$). Mean (\pm SEM) and median interval from parturition to establishment of a new pregnancy: ‘Cherry-picking’ = 154.0 \pm 4.7 and 125 and ‘100% Timed AI’ = 153.4 \pm 4.2 and 134.5.

When data from 5 different studies conducted in 4 different farms in CA were combined, the P/AI of cows inseminated at estrus after the presynchronization protocol (i.e two injections of PG 14 d apart) was approximately 2.5% units greater than those inseminated at fixed timed AI (34.9 vs. 32.5%; Santos et al., 2007). Other studies have demonstrated a slight increase in P/AI of cows inseminated at fixed timed AI compared with those inseminated at estrus (28.3 vs. 31.5%; Stevenson and Phatak, 2005).

The importance of inseminating cows in estrus becomes even more important when dealing with re-insemination. In the study by Dewey et al. (2010), cows that displayed estrus from 32 to 46 d after previous AI and were re-inseminated had P/AI = 37.1%, whereas cows re-inseminated at fixed time (on d 49 after previous AI) had P/AI = 28.4%. The findings of the study by Dewey et al. (2010) are reinforced by on-farm data. Below (Table 4) is the P/AI of cows re-inseminated based on signs of estrus or at fixed time in 4 herds across the US (data extracted from Dairy Comp 305).

Table 4. Pregnancy per AI (P/AI) of cows re-inseminated based on signs of estrus or at fixed time

Herd	Lactating dairy cows, no.	3.5% Fat corrected milk (lb/d)	P/AI, %	
			Estrus	Timed AI
A	537	80	37	27
B	1,016	90	29	22
C	3,379	82	20	12
D	5,778	70	38	28

Timing of pregnancy diagnosis when initiating resynchronization

Another consideration for when and what synchronization program to utilize is the timing of pregnancy diagnosis. Research continues to explore ways to reduce the interval between inseminations to increase the number of cows pregnant and reduce the number of days open. Several alternatives for pregnancy diagnosis are currently available such as utilizing blood pregnancy tests as early as d 28 post AI. Also, ultrasonography can be utilized at approximately 27 d post AI and transrectal palpation is normally recommended at 32 d post AI or greater depending on technician skill level.

Most dairies initiate their resynchronization program either prior to or at non-pregnancy diagnosis. The time at which pregnancy diagnosis occurs and subsequently initiation of the synchronization program may reduce estrus expression depending on the timing and type of hormonal injection utilized as shown above. For example, in the (Bruno et al. 2011) study, if the first GnRH of GGPG began at 17 d after TAI versus waiting until 24 d after TAI, estrus detection was reduced by 25 percentage units (24 % vs. 49%). Previous research has shown that >50% of the animals show estrus after day 21 with the greatest amount occurring before d 25 (Chebel et al., 2006). Also, if GnRH is utilized as a presynchronization tool instead of PG, number of cows detected in estrus can be reduced from 78% to 24% after injection. In turn more cows would enter the synchronization program and receive timed AI. This may reduce fertility and increase drug costs if your estrus detected cows can achieve conception rates similar to or greater than timed AI. If synchronization protocols are implemented based on when non-pregnancy diagnosis occurs caution should be given

to the type of protocol utilized and timing of pregnancy diagnosis to maximize fertility and profitability.

Activity Monitors and Synchronization

Recently studies were conducted to determine whether activity monitors could eliminate the need for time AI protocols completely. Two recent experiments, however, indicated that activity monitors are not able to achieve AI submission rates of > 85% as some companies were claiming for the simple fact that some cows will not display estrus. Valenza et al. (2012) fitted 42 cows with an activity monitor system (collar) and a mounting detection system (Kamar). The cows were synchronized and allowed to come in estrus. Cows were then examined by ultrasound to determine ovarian activity and occurrence of ovulation. In this small experiment, according to activity monitor and mounting detector 67 and 62%, respectively, of cows were observed in heat and ovulated; 7 and 12%, respectively, of cows were not observed in heat and ovulated; 5% of cows were observed in heat and did not ovulate; and, 21% of cows were not observed in heat and did not ovulate. Therefore, based on an activity monitor system and a mounting detection system 28 to 33%, respectively, of cows were not observed in estrus. Furthermore, considering ovulation as the 'gold standard', cows that ovulated and were in estrus were +/+, cows that did not ovulate and were in estrus were -/+, cows that ovulated and were not in estrus were +/-, and cows that did not ovulate and were not in estrus were -/-. Thus, the activity monitor system and the heat detection system resulted in sensitivity of 91 and 84%, respectively, specificity of 81%, positive predictive value of 93%, and negative predictive value of 75 and 64%, respectively. Therefore, based on this small experiment the activity monitor and mounting detection system had similar performance.

In a study presented at the 2012 American Dairy Science Association, researchers evaluated the insemination pattern and P/AI of cows that were fitted with activity monitors and were submitted to the Ovsynch protocol with estrus detection, to the Presynch/Ovsynch with estrus detection, and to the Presynch/Ovsynch protocol without estrus detection (100% TAI; Fricke et al., 2012). In this study, 70% of cows that received the two PG presynchronizing injections were observed in estrus, whereas approximately 57% of cows that were not presynchronized with PG were observed in estrus. The P/AI of cows inseminated in estrus was 30% and the P/AI of cows inseminated at fixed time was 36%. These numbers are very similar to those reported by Chebel et al. (2006, 2010b) and Lima et al. (2009). In these studies the percentage of cows that were inseminated in estrus after two presynchronizing injections of PG ranged from 50 to 62%. On the other hand, P/AI of cows inseminated in estrus ranged from 27 to 44% and P/AI of cows inseminated at fixed time ranged from 21 to 41%. The results from these studies suggest that activity monitors may perform just as well as detection of estrus based on tail paint removal and that P/AI of cows inseminated in estrus based on activity or tail paint removal may be similar, these being extremely dependent on farm and personnel.

Field observations of two herds that adopted the activity monitor systems for estrus detection and abolished the use of fixed time AI for first postpartum AI demonstrate that there is a significant risk of increasing significantly the variability in interval to first AI, increasing interval to first postpartum AI, and reducing AI submission rate and pregnancy rate. Although this was not data from controlled studies, it was possible to observe that once timed AI protocols stopped being used in the herds that adopted the activity monitoring system their pattern of first postpartum AI started to resemble the pattern of first postpartum AI before timed AI protocols were widely adopted.

Conclusion

Strides continue to be made in improving fertility to synchronization programs. Using presynchronization protocols before the start of a synchronization program improves fertility compared with cows initiating the synchronization program at random stages of their estrous cycle. Presynchronization with a GnRH injection will reduce the number of cows displaying estrus and increase the number of cows which receive TAI. However, the opposite will occur when utilizing a PG injection which is an important consideration if a dairy farm is utilizing estrus detection. Timing of GnRH injections prior to resynchronization can greatly reduce number of cows detected in estrus if given before d 25. Activity monitors are an additional tool which can aid in improving estrus detection; however, it does not observe 100% of the cows in estrus so a robust synchronization program is still important to use as an insurance tool to insure that all cows receive TAI by a certain DIM. Future studies should continue to focus on improving TAI fertility without negatively affecting the number of cows displaying estrus.

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Notes:

New Technologies to Improve Dairy Cattle Reproduction

Panel moderator: Paul M. Fricke, Ph.D.
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Synergies between new reproductive management technologies hold the key to maximizing reproductive efficiency on dairy farms; however, reproductive management protocols that allow for synchronization of ovulation and subsequent identification and resynchronization of nonpregnant cows must be practical to implement within the day to day operation of a dairy farm or the protocol will fail due to lack of compliance (Fricke et al., 2003). This is especially true for larger farms that must schedule and administer artificial inseminations, hormone injections, and pregnancy tests for a large number of animals on a daily or weekly basis.

New technologies to improve reproduction discussed in this panel include: 1) use of pregnancy-associated glycoprotein (PAG) tests to determine pregnancy status; 2) use of progesterone testing to assess and manage reproduction; and 3) use of accelerometer systems to detect estrus. This panel will feature three individuals who have extensive practical experience using each of the technologies discussed. Contact information and a biography of each panelist appear before a brief synopsis of each technology and a summary of recent research in each area presented in each section.

Panel Member: Dr. Robert Vlietstra, DVM. Contact: robvliet@gmail.com.

Biography: Robert Vlietstra taught Geology, Biology and Math in Midland, Michigan after graduation from Calvin College in 1974. He completed an additional B.S. degree in Animal Science (1978) at MSU and the D.V.M. degree (1982) from the College of Veterinary Medicine at Michigan State University. Bob worked as a resident farm veterinarian in Lexington, Kentucky after completing the DVM curriculum. He was an associate veterinarian in LaGrange, Indiana, as he worked his way back to Michigan. In August of 1983, he began an eleven year stint as a solo practitioner in the Zeeland, Michigan area. Dr. Bob merged his solo practice with a neighboring established practice that began West Michigan Veterinary Service. His professional interest is dairy production medicine with a concentration in theriogenology and nutrition. He serves WMVS as the director of its Reproduction Consulting Service and Laboratory, featuring the Bio-PRYN test.

Use of Pregnancy-Associated Glycoprotein (PAG) tests to assess pregnancy status

Early identification of nonpregnant dairy cows post breeding can improve reproductive efficiency and pregnancy rate by decreasing the interval between AI services and increasing AI service rate. Thus, new technologies to identify nonpregnant dairy cows early after artificial insemination (AI) may play a key role in systematic management strategies to improve reproductive efficiency and profitability on commercial dairy farms. Transrectal palpation is the oldest and most widely used

method for early nonpregnancy diagnosis in dairy cattle (Cowie, 1948); however, a newer technology may emerge to replace transrectal palpation as the method of choice for nonpregnancy diagnosis in the dairy industry. One such technology is the development of commercially available tests to detect pregnancy-associated glycoproteins (PAGs) in maternal serum; however, this new technology must be practically integrated into a systematic on-farm reproductive management strategy for it to succeed. Research reviewed in this paper support use of PAGs as a method for early nonpregnancy diagnosis in dairy cattle; however, there are some caveats and limitations with regard to their incorporation into a systematic reproductive management program that must be considered to determine the appropriate timing of nonpregnancy diagnosis.

Pregnancy-associated glycoproteins constitute a family of inactive aspartic proteinases (Xie et al., 1991) comprising 22 genes located on chromosome 29 in the bovine (Telugu et al., 2009) with different patterns of expression throughout pregnancy and produced mainly by the binucleate cells of the placenta (Xie et al., 1991; Green et al., 2000; Patel et al., 2004) but also by the trophoblast (Xie et al., 1991). Placentation in ruminants is noninvasive and is classified as synepitheliochorial cotyledonary, which describes the fetal-maternal syncytium formed by the fusion of trophoblast binucleate cells and uterine epithelial cells (Wooding, 1992). The giant binucleate cells are large cells containing two nuclei and are the invasive component of the trophoblast representing 15 to 20 % of the total cellular population within the mature placenta. Mature chorionic binucleate cells at all stages of bovine pregnancy migrate into the uterine epithelium and release the contents of cytosolic granules containing PAG's through exocytosis where they enter the maternal circulation (Wooding and Whates, 1980; Wooding, 1983; Zoli et al., 1992).

Identification of nonpregnant cows early post breeding can only improve reproductive efficiency when coupled with a management strategy to rapidly submit nonpregnant cows for a subsequent AI service. Thus, any method for early nonpregnancy diagnosis must be integrated as a component of the overall reproductive management strategy in place on the farm.

Currently, three non-pregnancy tests based on detection of PAGs in maternal serum are commercially available for use by dairy farmers:

- 1) BioPRYN
BioTracking, LLC, Moscow, ID
<http://www.biotracking.com/>
- 2) DG29
Conception Animal Reproduction Technologies, Beaumont, QC
http://www.conception-animal.com/test_an.html
- 3) IDEXX Bovine Pregnancy Test
IDEXX Laboratories, Inc., Westbrook, ME,
http://www.idexx.com/view/xhtml/en_us/livestock-poultry/ruminant/lpd-bovine-pregnancy-test.jsf

None of these tests are cow-side or on-farm, so blood samples must be collected by farm personnel and sent by courier to a local or regional laboratory that runs the assay. Results are then returned to the farm via email, usually within 24 to 72 h.

Recently, IDEXX Laboratories has developed a PAG test for milk samples that is marketed through regional DHIA testing centers throughout the United States. Cows must be ≥ 35 days post-insemination and must be a minimum of 60 days post-calving for accurate results. This milk-based PAG test is currently being marketed as a pregnancy recheck for cows initially diagnosed pregnant by a veterinarian.

Data from a field trial conducted in Wisconsin (Silva et al., 2007b) supported that use of a commercial PAG assay for detecting non-pregnant cows 27 d after AI yielded acceptable sensitivity and specificity, had a high negative predictive value indicating that few cows would be subjected to iatrogenic pregnancy loss during a resynchronization protocol, and had a similar accuracy when compared to transrectal ultrasonography. Furthermore, commercial PAG tests may more reliably detect cows undergoing pregnancy loss compared to use of transrectal ultrasonography when the non-pregnancy test is conducted before 30 d after AI (Giordano et al., 2012). Data from a second field trial in Wisconsin (Silva et al., 2009) showed that initiation of resynchronization 25 d after an initial TAI resulted in similar fertility to initiation of resynchronization 32 d after TAI in lactating Holstein cows thereby decreasing DIM at TAI and total days open after the initial TAI. Based on our results (Giordano et al., 2012), it is important to follow the manufacturer's instructions when using these commercial tests so that cows are not subjected to non-pregnancy testing too early postpartum to avoid false positive results and that cows are not tested too early post-insemination to avoid poor sensitivity, specificity, and accuracy of the test.

Panel Member: Dr. Neil Michael, DVM, MBA. Contact: nmichael@vitaplus.com.

Biography: Dr. Michael is Director of Dairy Initiatives at Vita Plus in Madison, WI. In this newly created position, Michael works with the entire dairy team to implement targeted initiatives in dairy nutrition and management. His activities range from consulting on individual dairies to development and implementation of support tools for Vita Plus staff. He serves as a resource for dairy customers and staff on dairy records, nutrition, management and reproductive strategies. Michael graduated with a Bachelor of Science degree from Purdue University. He continued his education at Purdue, earning veterinary certification in 1982 and a Masters of Business Administration in 2006. He practiced veterinary medicine, primarily in Wisconsin, from 1982 to 1997 before working in sales and technical services with Monsanto Dairy Business. For the past 10 years, Michael worked in technical services at ABS Global, Inc. in Deforest, Wis., most recently as Director of Global Technical Services. He is a member of the American Veterinary Medical Association, American Association of Bovine Practitioners, American Dairy Science Association and Wisconsin Veterinary Medical Association.

Progesterone Testing to Manage and Assess Dairy Cattle Reproduction

Progesterone is a female steroid hormone produced by dairy cattle post puberty during specific stages of each estrous cycle and is required for maintenance of pregnancy. Progesterone is produced by the corpus luteum that develops on an ovary after ovulation and is secreted into the blood and subsequently into milk. At the time of estrus, progesterone levels are low in both blood and milk after which levels increase until Day 17 to 18 of the estrous cycle when they decrease again (unless the animal is pregnant) to low levels as the next follicle and estrus approach. As a result of their relationship with estrus and cyclicity, measurement of progesterone in blood or milk can be used as a tool for reproductive management on commercial dairies.

Progesterone can be measured quantitatively in laboratories using an expensive radioimmunoassay (RIA) procedure. A RIA is performed on whole blood or serum samples and is considered the gold standard for P4 measurement. Additionally, ELISA technology can be used to measure progesterone levels quantitatively or qualitatively in milk and blood and is available in both laboratories and cow-side applications.

Strategic progesterone testing can help you evaluate heat detection accuracy (Rivera et al., 2004), cyclicity status (Silva et al., 2007a), and synchronization efficiency. Additional applications for blood progesterone evaluation include training and certification of AI technicians as well as setup of new activity system installations.

Blood samples can be obtained from the caudal tail vein in restrained cattle. Either whole blood or serum is acceptable, and samples should be refrigerated before submission to a laboratory for testing.

- *Accuracy*: for chalk or visual detection methods, collect a minimum of 15 samples from animals detected in estrus and inseminated within the last 24 hrs. Samples can be refrigerated until the necessary number of samples is collected for submission to the laboratory. Note that samples should be unannounced to prevent biased sampling.
- *Synchronization Efficiency (SE)*: collect a minimum of 15 samples from animals enrolled within a TAI program on the day of insemination. Additional sample sets may be required to investigate particular bias' such as DIM, parity, or times bred.
- *Cyclicity*: collect a second sample on the SAME animals sampled for Synchronization Efficiency above at 7 to 14 days after insemination. The SE samples should be held until cyclicity samples are taken and the duplicate sets submitted to the lab at the same time.

The accepted cutoff for blood progesterone (P4) levels evaluated by RIA methods is 1 ng/ml. Levels below the cutoff are considered to be indicative of animals near estrus or animals without ovarian activity (non-cyclic) while levels above 1ng/ml are indicative of animals with a source of progesterone production (ie. a corpus luteum). Note that high levels of blood progesterone by themselves should not be considered confirmation of pregnancy status. Using the above methods, interpretation and goals are as follows:

- Accuracy of detection is calculated as the percent of samples collected from cows detected to be in estrus that are low P4 with a goal of greater than 85%.
- Synchronization efficiency is reported as the percent of cycling animals with low P4 divided by the number of cycling animals evaluated with a goal of greater than 95% at time of TAI.
- Cyclicity is calculated as the percent of total sample pairs where P4 levels go from low to high (or high to low) during the 7-14 day sampling interval. Goal for cyclicity is greater than 95% of animals that are submitted to a TAI program although this will differ dependent upon DIM at evaluation.

Panel Member: Peter Dueppengiesser, Perry, NY. Contact: dueppdairy@frontiernet.net.

Biography: A 1986 graduate of Cornell University, Peter earned his B.S. in Animal Science. He is a partner in Dueppengiesser Dairy Company in Perry, New York with his brother Mike. They milk 1200 cows and raise 1000 head of young stock. R.H.A. 27,370 3.8 1036 3.0 816. They crop 800 acres of corn, 100 acres of wheat, and 900 acres of alfalfa. The dairy has been using the Semex AI

24 Heat Detection System since June 2010 along with various pre-synch, ov-synch strategies. They are very active in showing and marketing registered Holsteins under the Ransom Rail Farm prefix. Peter served as a past chairman of the Northeast Dairy Producers Association (NEDPA). He volunteers as a leader for his local 4-H program, as an advisor for the junior Holstein club, and serves on the parish council in his local church. Married to his wife Roxanne for 21 years, the couple has two sons, Jacob, a freshman at Cornell University, and Jared, a junior in high school.

Use of Accelerometer Systems for Detection of Estrus

Despite the widespread adoption of hormonal synchronization protocols that allow for timed artificial insemination (TAI), detection of behavioral estrus continues to play an important role in the overall reproductive management program on most dairies in the U.S. (Caraviello et al., 2006; Miller et al., 2007). Several challenges for estrus detection on farms include attenuation of the duration of estrous behavior associated with increased milk production near the time of estrus resulting in shorter periods of time in which to visually detect estrous behavior (Lopez et al., 2004), low number of cows expressing standing estrus (Lyimo et al., 2000; Roelofs et al., 2005; Palmer et al., 2010), silent ovulations (Thatcher and Wilcox, 1973; Palmer et al., 2010; Ranasinghe et al., 2010), and reduced expression of estrous behavior due to confinement (Palmer et al., 2010). Whatever the cause, the low efficiency of estrus detection not only increases time from calving to first AI but increases the average interval between AI services (Stevenson and Call, 1983), thereby limiting the rate at which cows become pregnant.

Because of the impact of AI service rate on reproductive performance and the problems associated with visual estrus detection on farms, many technologies have been developed to enhance estrus detection by providing continuous surveillance of behavior including rump-mounted devices and androgenized females (Gwazdauskas et al., 1990), pedometry (Peralta et al., 2005; Roelofs et al., 2005), and radiotelemetry (Walker et al., 1996; Dransfield et al., 1998; Xu et al., 1998). New electronic systems that incorporate accelerometers as a means to associate increased physical activity with estrous behavior in cattle (Holman et al., 2011; Jónsson et al., 2011) have been developed and marketed to the dairy industry. Whereas a large body of literature exists on the accuracy and efficacy of using various technologies to predict ovulation and timing of AI in relation to ovulation in lactating dairy cows, no other studies have investigated accelerometers for such purposes.

Recent data from the University of Wisconsin-Madison that evaluated an accelerometer system (Valenza et al., 2012) showed that only two thirds of the cows that were considered properly synchronized to come into estrus would have been inseminated based on the accelerometer system and would go on to ovulate after AI. The remaining cows either would not be inseminated because they were not detected in estrus or would not have a chance to conceive to AI because they would fail to ovulate after estrus. These data underscore the importance of implementing a comprehensive reproductive management program for identification and treatment of cows that would otherwise not be inseminated and to identify those cows failing to ovulate when cycling spontaneously. Based on data from this experiment using this accelerometer system (Valenza et al., 2012), the mean time of AI in relation to ovulation was acceptable for most of the cows detected in estrus; however, variability in the duration of estrus and timing of AI in relation to ovulation could lead to poor fertility in some cows.

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Controlling Feed Costs: Focusing on Margins Instead of Ratios

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Feed costs are overwhelmingly the largest expense for dairy producers. Feed costs were typically 50% of total costs in years past, but now are 60+%. With these escalating costs, producers and nutritionists are closely evaluating the feeding program to identify opportunities to improve efficiencies. There are many places to look, and many measures and metrics are available.

What is the best measure of feeding economics? Is a ratio or a margin more appropriate? There are a variety of ratios used in the dairy industry to evaluate feeding economics, and they are misleading or inaccurate if used inappropriately. Examples include milk price to feed price (USDA Milk:Feed ratio), dry matter intake to milk production (milk:feed), and feed cost per cwt. Income Over Feed Cost (IOFC) is the most common margin used to measure feeding economics. While margins are nearly always preferred over ratios, both can be misinterpreted. Understanding how they are calculated and interpreted helps avoid misuse and mistakes.

Milk-Feed Ratio

The Milk-Feed ratio is simply the pounds of 16% total ration equal to 1 lb of milk, or the ratio of milk price to feed price. Feed price is determined using market values for a ration containing 51% corn, 8% soybeans, and 41% alfalfa hay. For example, if milk price was \$0.20/lb and the 16% ration was \$0.10/lb, the ratio would be 2.0. Table 1 illustrates several examples in various market conditions, with each successive row in the table escalating to higher feed and milk prices. In this example, when both milk and feed prices rise, the ratio declines but the margin improves. A higher margin means more profit, so in this case the ratio is misleading. The Milk-Feed ratio is a poor measure of feeding economy, and has little to no utility.

Feed Cost/cwt the Right Way

Calculated the correct way on financial statements (accrual usage of feed consumed by milking and dry cows divided by cwts milk shipped), feed cost/cwt provides a long term picture of how good of a job the dairy did in converting feed dollars to saleable hundredweights of milk. It does not include heifers, but is impacted by many factors including price paid for feed, shrink, refusals, hospital, efficiency of converting feed into milk, dry cow numbers, and dry period lengths. Management

factors such as reproduction, milk per cow, days in milk, facility design, cow comfort, milking frequency, etc impact as well. If feed cost per cwt on the financial statement is too high, there are many places to look for improvement.

The biggest weakness of this number is that it ignores the value of milk. It typically costs more feed to produce higher value milk (higher components or lower SCC). Thus, it is inappropriate to compare feed cost per hundredweight for herds with different component levels or milk quality.

It is important that accrual usage of feed is used to calculate feed cost/cwt. Accrual usage requires measuring delivery (and by proxy consumption) of feed over the period of time the financial statement is constructed. Feeding programs along with monthly inventory adjustments are ideal tools to measure accrual usage of feed. If accrual usage is not used, feed cost/cwt is difficult to measure as the feed consumed may not correspond to the milk shipped, making the calculation irrelevant.

Feed Cost/cwt the Wrong Way

Feed cost per cwt can also be calculated on a cow by cow basis (feed costs per day divided by milk per cow/100). This number has no useful purpose for a dairy. By accident it may lead to correct decisions; just as often it will lead to incorrect decisions.

Income Over Feed Cost

Income over feed cost (IOFC) is a margin that is calculated as (milk revenue per cow per day) minus (feed costs per cow per day). Any management or feeding change that increases IOFC is likely good provided it does not impact cow health. The IOFC is driven by several factors. Obvious are feed price and milk price. Others include feed conversions, milk per cow, and the value of milk (i.e. components and premiums). Day to day feeding and management decisions should be evaluated using income over feed costs. Items like shrink, refusals, hospital, and dry cows are not generally considered by IOFC.

Example: Consider a dairy with the following numbers for the month of January:

- Milking and dry cows consumed \$108,000 in feed
- The dairy shipped 10,100 cwts
- Milk cow feed costs were \$6.80 per day
- Tank average was 75 lbs
- Milk price was \$18/cwt

Measures of Feeding Economics

- **Feed Cost/cwt** (the correct way that appears on financial statements)
 - $108,000/10,100 = 10.80/\text{cwt}$
- **Feed Cost/cwt** (the wrong way; often mistakenly used to make decisions)

- $\$6.80 / (75/100) = \$9.07/\text{cwt}$
- ***Income over Feed Cost***
 - $(75 * 0.18) - 6.80 = \$6.70/\text{day}$

Why not use Feed Cost/cwt the wrong way?

Suppose the dairy above changed the ration to get more milk. Suppose the ration costs increased from \$6.80/day to \$7.05/day, and milk increased from 75 to 77 lbs.

- Feed cost/cwt (the wrong way) would now be $\$7.05 / (77/100) = \$9.16/\text{cwt}$.
- Income Over Feed Cost would now be $(77 * 0.18) - 7.05 = \$6.81/\text{day}$

Was this a good change for the dairy? Feed Cost per cwt increased 9 cents/cwt but IOFC increased 11 cent per day. Feed cost/cwt suggests it was a poor decision because feed costs increased. The IOFC suggests it was a good decision because the dairy increased profit. Which is correct? Mathematically both are correct, but feed cost per cwt gave the wrong answer. Of course the dairy should take the profit, provided cow health was not impacted.

Should Market Costs for Home-Grown Feeds be Used?

Many dairies have a farming enterprise that produces some or all of the forages and grains for the dairy. If the success of the dairy is hinged on the farm providing feed below market value, it is an unhealthy business model. If feed markets drop, and the advantage of cheap feed is gone, the dairy will lose its competitive advantage and may be at risk. A healthy dairy business should be able to survive and profit long term using market values for feeds. A farming enterprise is a great business for a dairy to engage in, but should not subsidize the dairy business.

Is IOFC the best measure?

Even though income over feed cost is an ideal tool to measure the impact of management and feeding decisions, it has several potential shortcomings:

- Component changes are often not factored into the equation. In the above examples, fat and protein were not considered, and they have a large economic impact.
- It is not useful to monitor change over time. If IOFC improves, does it mean that the herd improved, or simply that milk price was higher or feed costs were lower? It is impossible to differentiate, so IOFC is a poor barometer of herd performance.

Components Must Be Considered

Milk premiums in most markets are offered for high quality milk (low bacteria and somatic cell counts). In component markets butterfat, protein, and other solids directly impact milk price. Shipping higher value milk is an opportunity for many dairies.

Given how most dairies are paid for their milk, it doesn't make sense to use milk/cow as a measure of performance. For instance, most would agree that a 60 lb cow with 4.8% fat and 3.6% protein is better than a 65 lb cow with a 3.5% fat and 2.8% protein. This seems obvious by looking at the raw numbers and knowing what components are worth. But what about a 71 lb herd with 3.95% fat and 3.26% protein, compared to an 80 lb herd with 3.40% fat and 2.90% protein? Which is better? This comparison is not so simple.

To make comparisons more equitable, we have traditionally used Fat Corrected Milk (FCM) or Energy Corrected Milk (ECM). Both FCM and ECM are designed to relate the energy content of milk. They are strictly based on biology, and have no economic basis. The formulas work the same when protein is \$1.00 per pound or \$4.00 per pound.

A new measure called Money Corrected Milk™ (MCM) is a milk-check based measure of cow productivity. It considers the economic value of milk components, and the impact of milk check assessments. Similar to ECM or FCM, it is expressed as pounds of milk per cow per day. Instead of relating to the energy contained in the milk, MCM relates to the income derived from the milk produced. In the examples in Tables 2 and 3, MCM is calculated using a 3.5% fat, 3.0% protein, 5.70% other solids basis. The inputs needed include all items that impact the milk check, such as value of fat and protein, quality premiums, hauling, and other assessments.

So which is better, the 71 lb cow with high components, or the 80 lb cow with low components as displayed in Table 3? If tank average is the measure, as it normally is, the 80 lb herd is obviously better. It is also better if FCM or ECM is the measure. If the measure is MCM, the 71 lb herd and the 80 lbs herd are exactly the same. They are both 77.8 lbs of MCM. The MCM is directly related to income per cow per day.

Table 3 also contains a Holstein-Jersey example. The MCM concept is ideally suited to compare economic performance of different breeds. In the example in Table 3, a 78 lb Holstein has the same MCM as a 54 lb Jersey.

Money Corrected Milk™ IOFC uses the MCM concept to provide the best measure of dairy feeding economics. The difference from traditional IOFC is twofold:

- The milk check based approach of Money Corrected Milk™ is used to determine income
- Economic factors (feed price, component prices, and milk check assessment values) are fixed over time.

In Table 3, MCM IOFC is calculated for the Holstein-Jersey comparison. In this example, the Jerseys are generating more milk income after feed costs are covered. That means more revenue to cover other expenses.

By using the Money Corrected Milk™ concept, components and all milk check factors are considered. By fixing prices, any change in Money Corrected Milk™ IOFC is due to changes in cow performance.

Summary

There are many measures of feeding economics used in the dairy industry. In general, margins matter and ratios don't when it comes to feeding economics.

Table 1. Milk:Feed ratio and margin/cwt

Milk, \$/lb	16% Dairy	Feed \$/cwt ¹	Milk-Feed	Margin ² , \$/cwt
\$0.15	\$0.054	\$3.86	2.78	\$11.14
\$0.18	\$0.09	\$6.44	2.00	\$11.56
\$0.21	\$0.11	\$7.87	1.91	\$13.13
\$0.24	\$0.13	\$9.30	1.85	\$14.72
\$0.25	\$0.14	\$10.02	1.79	\$14.99

Table 2. Inputs for Money Corrected Milk™ calculation

Item	Value
Butterfat, \$/lb	\$2.50
Protein, \$/lb	\$3.00
Other solids, \$/lb	\$0.15
Fluid Adjustment, \$/cwt	\$0.00
Quality Bonus, \$/cwt	\$0.50
Hauling, \$/cwt	\$1.00
Advertising and Promotion, \$/cwt	-\$0.15
Basis, \$/cwt	\$2.00

Table 3. Herd Comparisons

	Holstein A	Holstein B	Holstein	Jersey
Tank Average	71.0	80.0	78.4	54.1
Fat%	3.95	3.40	3.00	5.00
Protein%	3.26	2.90	2.70	3.70
Other Solids%	5.70	5.70	5.70	5.70
FCM	75.4	78.9	73.0	65.4
ECM	75.4	77.3	70.6	66.4
MCM™	77.8	77.8	70.0	70.0
Income/day	\$15.52	\$15.52	\$13.96	\$13.96
DMI			51.5	49.5
MCM™ IOFC ¹			\$6.23	\$6.53

¹ \$0.15/lb DM TMR cost

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Getting the Most from Your Bunker/Pile Silo

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Dry Matter Losses

Exposure to oxygen is a major cause of dry matter loss and silage deterioration. The oxygen supports aerobic organisms that use readily available carbohydrates in forage as an energy source, thus depleting the silage of the energy cows use to produce milk. Table 1 summarizes estimates of losses that occur in the process of harvesting, storing and feeding out hay and whole plant corn used for silage. With appropriate management, forage producers can preserve most (85-90%) of the dry matter made into silage. However, those who fail to apply excellent management may only recover 60-85% of the dry matter they have harvested.

Table 1. Dry Matter Loss for Forage Harvest, Ensiling and Feedout

	Dry Matter Loss	
	Range (%)	Normal (%)
Mowing/Conditioning Haylage*	1-4	2
Respiration Haylage*	1-7	4
Rain (Haylage only)*	0-50	varies
Raking Haylage*	1-20	5
Merging Haylage*	1-3	1
Chopping Haylage*	1-8	3
Chopping Whole Plant Corn***	0-1	0.5
Storage Filling**	2-6	
Ensiling, Storage & Feedout (bunker)*	10-16	12
Haylage Total	17-64 ⁺	
Whole Plant Corn Total	12-23	

* Rotz and Muck, 1994

** Forage: the Science of Grassland Agriculture, 4th Edition, quoted in Bickert, W. G. et al, 2000

*** Personal communication with Dr. Kevin Shinnars, Biological Systems Engineering Department, UW Madison.

⁺ Rain Loss not included

Table 2 can be used to estimate the value of feed lost based on quantity placed into storage, the estimated dry matter lost and forage worth \$100/T DM. If forage is worth more than \$100/T DM

multiply the table value by a proportionally higher value. For example when feed is worth \$300/T DM, multiply the table value by 3. If 5,000 tons of dry matter were stored, forage was worth \$300/T DM and estimated loss was 20%, the expected value lost would be \$300,000 [(5,000 T DM/1,000 T DM) x (\$300/T DM/\$100/T DM) x \$20,000].

Table 2. Value of Dry Matter Loss

Feed Placed into Storage (T DM)	100	200	300	400	500	1,000
Dry Matter Loss (%)	Value of Feed Lost (\$)					
10	1,000	2,000	3,000	4,000	5,000	10,000
15	1,500	3,000	4,500	6,000	7,500	15,000
20	2,000	4,000	6,000	8,000	10,000	20,000
25	2,500	5,000	7,500	10,000	12,500	25,000

Size Silo Properly

Bunker silos and silage piles should be sized so as to remove silage at a high rate. This helps to keep ahead of the spoilage rate. This will be discussed in more detail later. Size the silo to achieve at least a 12” per day removal rate. Thus if a silo must store feed for a 365 day feeding period, it must have an average length of at least 365 ft. Stack silage so it is no higher than the unloading equipment can reach (no overhangs to avoid avalanches). With these two constraints and an assumption about silage density, one can calculate a face cross section based on volume removed each day. An example may be helpful. Assume a 1,000 cow herd is being fed 15 lbs of forage dry matter per cow per day from a particular storage. The storage has a silage dry matter density of 17 lbs DM/ft³, a 1 ft/day removal rate and is limited to 16 ft height by the reach of the unloading equipment. The volume removed from storage is 882 ft³/day (1,000 cows x 15 lbs DM/cow/day/17 lbs DM/ft³). The face cross section area of the volume removed is 882 ft² (882 ft³/day/1 ft/day). The average width then becomes 55 ft (882 ft²/16 ft).

Prepare the Bunker Silo

Concrete is pervious to oxygen penetration. Cracks and holes in bunker silo walls allow a much higher rate of oxygen penetration than does solid concrete. Seal wall cracks and holes with spray/trowel on concrete, epoxy or grout. Plastic film is used to enhance the oxygen retarding features of walls. Select a plastic sheet so it is at least as wide as the wall is tall plus an additional eight feet. Line the wall with the plastic sheet extending about two feet onto the bunker floor. Use forage to hold the plastic on the bunker floor. Extend the extra plastic over the top of the bunker wall. Care should be taken to avoid the plastic being punctured by the wall top. Placing gravel filled bags between the concrete wall and the plastic can help. Some have used a split drain tile fitted on top of the concrete wall to provide a rounded top surface. When the bunker is full, the wall plastic is extended over the forage surface before the cover plastic is applied. The wall plastic helps to provide a good air and water seal at the wall edge. Water draining from the cover plastic is diverted away from the silage and down the wall. The edge seal goes a long way toward eliminating the “shoulder spoilage” commonly seen in bunker silos.

Harvest at Correct Moisture and Maturity

High levels of readily available carbohydrate (sugars) are needed to ferment into acids. Mowing alfalfa in the early to mid bloom stage optimizes plant sugars and protein content. The crop should then be dried to the 35-40% dry matter range to optimize fermentation and to limit porosity in storage. Porosity is a measure of space between forage particles (see Porosity discussion below). The rate of drying and the rate of chopping needs to be matched to avoid large variation in crop moisture content as it is placed into the storage. Data and experience shows the variation in moisture content at harvest is much higher in hay silage than in whole plant corn silage. Comparing the dry matter values in Tables 3 and 4 confirm this. Jones et. al., 2004, point out the wide variation in results of fermentation as seen in Tables 3 and 4. The preferred pH of alfalfa silage should be in the range of 4.0-5.5. The data of Table 3 suggest that has been generally achieved over the range of dry matter contents. Lactic acid is the preferred acid with 60% of total acids being desired. In the case of alfalfa silage, the trend is for lactic acid concentration to increase slightly with increasing dry matter content while the other acids decline in concentration with increasing dry matter content. Butyric acid is an indication that a clostridial fermentation has occurred. Clostridial fermentation tends to predominate at lower dry matter contents and in alfalfa which has a higher buffering capacity than whole plant corn. Lower initial levels of sugar can limit lactic acid and acetic acid production, thus limiting the rate of pH drop. This can also enhance a clostridial fermentation.

Harvest whole plant corn at 1/3 – 1/2 half milk line for optimum moisture and to have sufficient sugars for good fermentation. Be sure to test the plant moisture content as this stage of maturity is approached. For good fermentation of corn silage, the recommended dry matter content is 30-35%. The preferred pH of whole plant corn silage should be in the range of 3.5-4.5. The data of Table 4 suggest that has been generally achieved over the range of dry matter contents with a tendency for higher pH as dry matter increases. In the case of whole plant corn silage the trend is for Lactic acid concentration to decrease slightly with increasing dry matter content while the other acids decline in concentration with increasing dry matter content. The generally high level of sugars and low buffering capacity discourages clostridial fermentation with resultant butyric acid production. This is seen in Table 4.

Seepage of cell contents occurs when forage moisture content is above 70% and/or forage is driven over too much. Seepage contains about 5% dry matter and as the liquid leaves the storage dry matter is lost.

Dry matter losses increase during storage and feedout if the forage is harvested too dry. Lower moisture content contributes to higher porosity which allows faster oxygen penetration into the silage when exposed to air. Lower moisture content can contribute to reduced acid production with resultant higher pH and faster aerobic microbial growth rates. The lower moisture content also reduces the thermal mass of the silage which contributes to more rapid heating for each molecule of sugar decomposed. Dry, poorly fermented silage can heat in the feed bunk contributing to dry matter loss during feeding. Corn silage is more susceptible to heating in the feed bunk because there are likely to be higher levels of readily available carbohydrates in corn silage than in legume silage.

Harvest at High Enough Rate to Fill the Silo Quickly and Continuously

While silos are being filled, forage is exposed to oxygen thus supporting microbial deterioration. Exposed forage is also susceptible to precipitation which can leach soluble carbohydrates. When forage is continuously being added to the storage surface, the rate of oxygen penetration is reduced. When the surface is exposed to the air for extended periods (overnight, precipitation

Table 3. Typical Fermentation Profile of Mixed Mostly Legume Silage at Various Dry Matter Contents. (Jones et al, 2004)

	< 30% Dry Matter		30-35% Dry Matter		>35% Dry Matter	
	n ¹	Range ²	n ¹	Range ²	n ¹	Range ²
Dry Matter, %	65	24.0-29.2	45	32.0-34.3	122	36.00-54.4
pH	65	4.0-5.8	41	4.2-4.9	99	4.2-5.4
Lactic,% of DM	47	0.3-6.8	29	3.0-7.6	46	1.6-5.5
Acetic, % of DM	47	1.6-5.1	29	0.9-3.3	46	0.4-2.6
Propionic, % DM	43	0.2-0.9	21	0.1-0.5	29	0.1-0.5
Iso-Butyric, % DM	30	0.1-0.5	13	0.1-0.6	18	0.1-0.6
Butyric, % DM	32	0.2-3.3	12	0.2-0.9	19	0.0-1.0
Ammonia, CP Equiv. % DM	47	0.4-5.3	29	0.6-1.8	46	0.5-2.1
NH ₃ -N, % DM	34	0.7-19.6	28	2.3-5.6	42	1.4-5.0

Source: Data provided by Cumberland Valley Analytical Services, Inc.

¹Number of samples

²Range was calculated by subtracting or adding one standard deviation to the average obtained for all samples

Table 4. Typical Fermentation Profile of Corn Silage at Various Dry Matter Contents. (Jones et al, 2004)

	< 30% Dry Matter		30-35% Dry Matter		>35% Dry Matter	
	n ¹	Range ²	n ¹	Range ²	n ¹	Range ²
Dry Matter, %	483	25.7-29.4	570	31.9-34.2	669	35.1-43.2
pH	477	3.5-4.4	551	3.5-4.5	603	3.7-4.8
Lactic,% of DM	383	2.9-8.0	351	2.7-7.0	314	2.1-5.9
Acetic, % of DM	386	1.6-6.0	351	0.9-4.1	315	0.4-2.9
Propionic, % DM	310	0.1-1.0	252	0.1-0.7	200	0.0-0.6
Iso-Butyric, % DM	127	0.0-1.3	116	0.1-0.9	112	0.2-0.7
Butyric, % DM	106	0.0-0.8	78	0.1-0.7	91	0.1-0.6
Ammonia, CP Equiv. % DM	386	0.0-1.6	352	0.0-1.8	315	0.0-1.8
NH ₃ -N, % DM	290	1.0-9.6	282	0.0-9.0	237	0.0-7.7

Source: Data provided by Cumberland Valley Analytical Services, Inc.

¹Number of samples

²Range was calculated by subtracting or adding one standard deviation to the average obtained for all samples

event), the forage at the surface undergoes extended aerobic deterioration. This is often seen as a discolored line across the feedout face. Significant heating and dry matter loss has occurred in this zone. Harvesting as continuously as possible and covering the surface with plastic during stoppage periods are ways to reduce this loss. Sizing smaller silos allows for each to be filled more quickly which allows for more frequent covering and sealing. Providing enough equipment and labor to harvest and transport forage quickly allows the storage to be filled quickly. However, increasing the harvest rate also requires an increased storage filling and packing capacity. This is discussed more fully later.

Set knives to obtain 3/8th inch TLC for hay and unprocessed whole plant corn and 1/2-3/4 inch TLC for processed whole plant corn. Shorter particles pack better and release more soluble carbohydrates which enhances fermentation.

Pack Forage to a High Bulk Density

Bulk density is a measure of the weight of forage particles and water within a given volume of silage. High bulk density (> 44 Lbs AF/ft³) has low porosity which limits the rate of oxygen transmission through silage. For the same packing effort, higher moisture forage will pack to a higher bulk density. To achieve high bulk density, harvest at the recommended moisture content, use heavy packing tractor(s), pack continuously, pack the whole surface (keep packing slope shallow) multiple times, and use multiple packing tractors if the harvest rate is high.

For many years, specialists have recommended filling the storage unit as quickly as possible to avoid the effects of precipitation, over drying of wilted forage, extended periods of crop respiration and exposure to aerobic decomposition during the filling process. Forage harvesting equipment has been increasing in capacity to meet this need. Self propelled forage harvester estimated capacity as a function of machine horse power is shown in Figure 1. Power requirements of 2.4 – 3.0 HP-hr/T were used to develop the upper and lower bounds for the harvest rate (Shinners, 2009). The horse power values used in developing the graph were obtained from web sites for the four major manufacturers of self-propelled forage harvesters (April 2009).

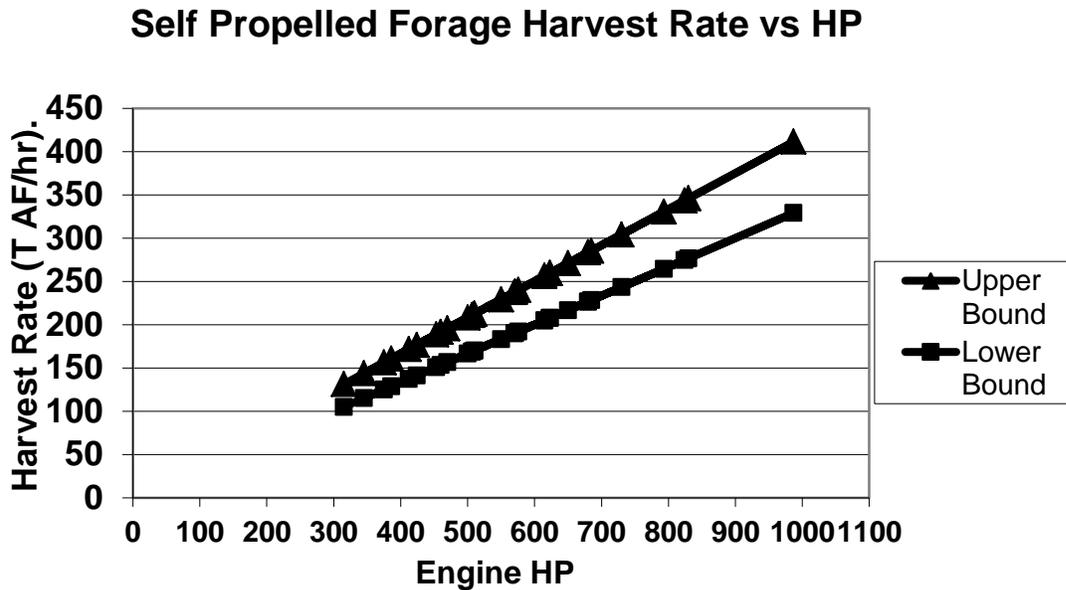


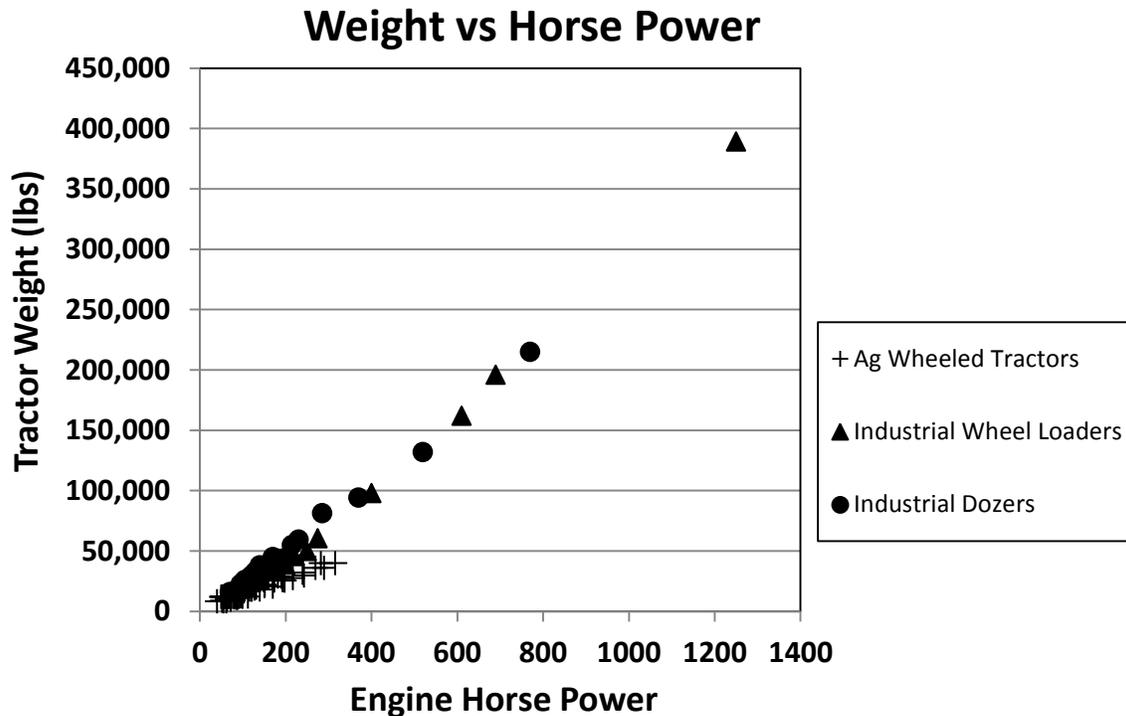
Figure 1. Maximum Estimated Harvest Rate for Self Propelled Forage Harvesters

The harvest rates are the maximum expected under ideal conditions. Factors that reduce actual capacity are: (1) forage available is limiting due to not bringing enough windrows together to satisfy the throughput capacity of the harvester; (2) transport vehicles limiting by vehicle exchange or not enough vehicles available to present to the harvester; (3) field capacity constraints presented by small fields, (4) reduced speed due to obstructions or ground surface conditions, or (5) service and maintenance etc. Even with these possible limitations to achieving full capacity, it is reasonable to assume forage could be arriving at the storage unit at 75% of these values under certain harvest conditions. As new harvesters with these high harvest rates are introduced, the harvest/storage team often is not prepared to deliver and pack the forage into the silo at these rates. Frequently, filling and packing machines for the bunker or pile are insufficient in numbers and weight to get the forage packed to the desired density. Using the “Bunker Silo Density Calculator” spreadsheet of Holmes and Muck, 2007, with the assumptions of 14-ft sidewall, 18 ft peak height, 35% dry matter forage, 6-inch packing layer thickness and a harvest rate of 60 T AF/ hr, a 32,000 lb tractor is needed to push and pack the forage to achieve about a 44 lbs AF/ ft³ density with a porosity of 0.40. The values in Table 5 were developed using the range of harvest rates reduced to 75% of the upper bound of Figure 1 and the “Bunker Silo Density Calculator” spreadsheet trying to achieve a similar 44 lbs AF/ft³ density and a porosity of 0.40. The values in Table 5 suggest current high capacity harvesting can be accommodated when enough tractors of sufficient weight are employed to pack in the bunker silo. The bunker silo must be of sufficient width to accommodate the numbers of tractors operating safely or more than one bunker must be filled simultaneously to allow the tractors to operate.

Table 5. Number of Packing Tractors Required in a Bunker Silo at Different Harvest Capacities

Harvest Capacity (T AF/hr)	Number of Tractors	Tractor Weight (lbs/tractor)
98	1	42,000
213	2	42000
248	3/2	38,000/47,000
308	3	42,000

The conventional pushing and packing tractor used in the United States is an agricultural tractor with four wheel drive or front wheel assist and weighted with one or more of; steel wheel weights, front end weights, 3-point hitch weight, liquid in tires weight. Fully weighted tractors are usually in the range of 40-50,000 lbs. Tractors often use dual wheel arrangements with well lugged tires for good traction. Pushing tractors use tall and wide blades. Some producers have experimented with alternative packing vehicles. Industrial wheel loaders are heavier than agricultural tractors on a per horse power basis, Figure 2. They are often used for silage feed out from the bunker/pile silo. This makes them prime candidates for alternative packing vehicles. The tires on industrial loaders are not as well lugged as farm tractors which allows them to slide more easily on wet sloped silage surfaces. This makes the operators much less comfortable about their safety while packing. Transmissions may be prone to overheating due to constant changes in direction. Tracked industrial dozers have been tried. Their naturally heavy weight and some vibration may contribute to good packing but research showing densification effectiveness of tracked industrial dozers is lacking. Tracked vehicles are likely more stable on wet sloped surfaces than wheel loaders. Some producers have used loaded dump trucks and concrete mixing trucks as packing vehicles. These vehicles may be loaded up to 80,000 lbs Gross Vehicle Weight (GVW) on many state highways but on farms they may be loaded up to 100,000 lbs GVW with sand, gravel, stone or concrete. With these kinds of loads, silage could be packed to very good densities. Some concerns about these vehicles are 1) the failure of bunker silo sidewalls due to loads imposed, 2) the likelihood of roll over due to high center of gravity and 3) lack of traction on sloped wet silage. Industrial rollers and sheeps foot rollers and rollers designed for packing silage receive strong producer testimonials, however, there is no research data to verify improved silage density with this equipment. There is currently a study being conducted by the University of Wisconsin and the US Dairy Forage Research Center comparing a conventional tractor to the same weight tractor towing a silage packing machine. Expect results in summer of 2013.



Silage piles should be built so the entire surface can be driven upon to obtain high-density forage throughout. The side slopes of the pile should be at a minimum of 3 units of run for each unit of rise (3:1) to obtain a surface which can be driven over with minimal risk of tractor roll over.

Muck and Holmes, 2000 reported dry matter densities were positively correlated with the height of silage above the core, indicating the effect of self-compaction in bunkers and the effect of previous compactions on the lower layers. Dry matter density was also positively correlated with average packing tractor weight, packing time, and dry matter content. Density was inversely correlated with the initial depth of the crop layer when spread in the silo. Use of rear duals or all duals on packing tractors had little effect on density. Other factors such as tire pressure, crop, and average particle size were not significantly correlated with density.

One practical issue is packing time relative to crop delivery rate. Assuming one packs continuously with one tractor throughout filling, packing time per ton (1 to 4 min/T AF) is high under low delivery rates (<30 T AF/h) and generally declines with increasing delivery rate. This result suggests farmers using high capacity harvesters need to pay particular attention to spreading the crop in a thin layer and would benefit from using several heavy packing tractors simultaneously. If a satisfactory bulk density is not being achieved, a producer can select one or more of the following options to increase bulk density:

- a. Reduce delivery rate of silage to the storage.
- b. Decrease dry matter content.
- c. Increase depth of silage in the bunker/pile silo.
- d. Increase average tractor weight by adding more weight to each tractor, or replace existing tractors with heavier tractors.
- e. Add more packing tractors. Use heavier rather than lighter tractors so the average weight is not reduced when adding a tractor.
- f. Spend more time packing per ton.

Items a. to c. are somewhat difficult to accomplish if the harvest rate and bunker silo capacity are currently being pushed to the limit. Few will be willing to slow the harvest rate so packing can be accomplished. Fermentation occurs best in the range of 30-40% dry matter. Decreasing dry matter content beyond 30% to improve bulk density is counterproductive for good preservation. If the bunker is full, adding silage depth above the full mark can be dangerous. Items d. to f. are more often within the control of the producer. Producers achieving high packing density have adopted the use of very heavy tractors and spend adequate time packing. When the delivery rate to the silo is quite high (as with self-propelled harvesters operating in corn silage), one or more additional packing tractors are needed. In a well-packed silo, all tractor tires pass over the entire packing layer surface at least once. More passes are beneficial. Because density near the wall of a bunker silo is frequently lower than toward the interior, packers should make more passes near the walls.

Recommendations for many years have included distributing forage in thin layers before packing. Preliminary research by Muck and Holmes, 2007 has not confirmed the value of thin layers when packing time per ton is kept constant. However, when a given weight of forage is distributed in thin layers, each pass of the packing tractor results in more packing time per ton when the layer is thin than when the layer is thicker.

Porosity

Porosity is a measure of the voids between the solid particles of a material. Pore space can be filled with fluids including gas and/or water in silage. The “air filled” porosity allows gases to move within the material. For gases to move throughout the material, the pores must be continuous. Closed pores do not contribute to gas flow. Figure 3 shows a graph of porosity as calculated using the equations of Richard et al, 2004. From Figure 3, porosity is most influenced by bulk density (as fed density) over the range of dry matter contents recommended (0.30-0.40) for ensiling. Figure 4 was developed using a modified version of the spreadsheet for calculating average density in a bunker silo by Holmes and Muck, 2007. From Figure 4, it is apparent porosity increases with harvest rate and increasing dry matter content. To keep porosity below 0.4, multiple heavy tractors and lower dry matter content are needed when the harvest rate is high. A minimum bulk density of 44 lbs AF/ft³ keeps porosity below 0.4 within the recommended range of DM content.

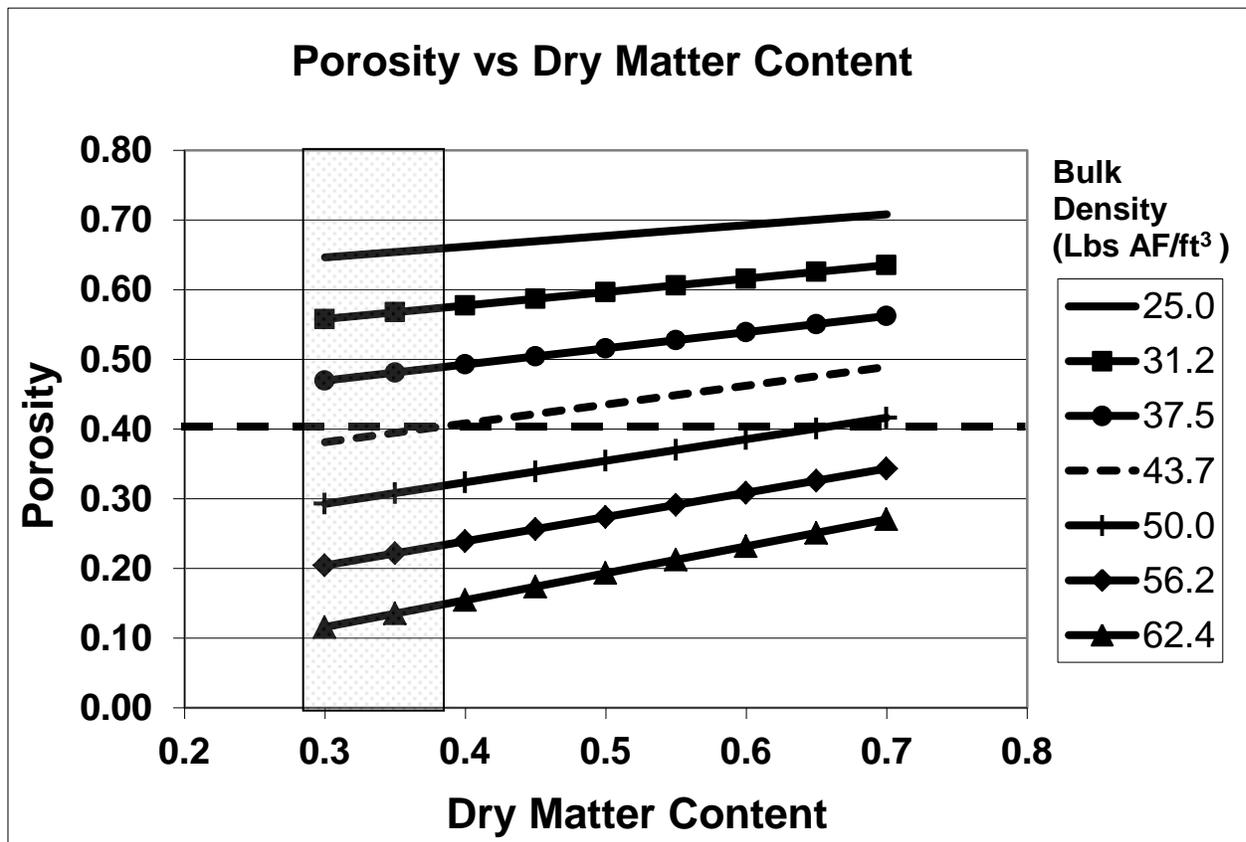


Figure 3. Graph of Porosity (decimal) vs. Dry Matter Content (decimal) for Various Bulk Densities

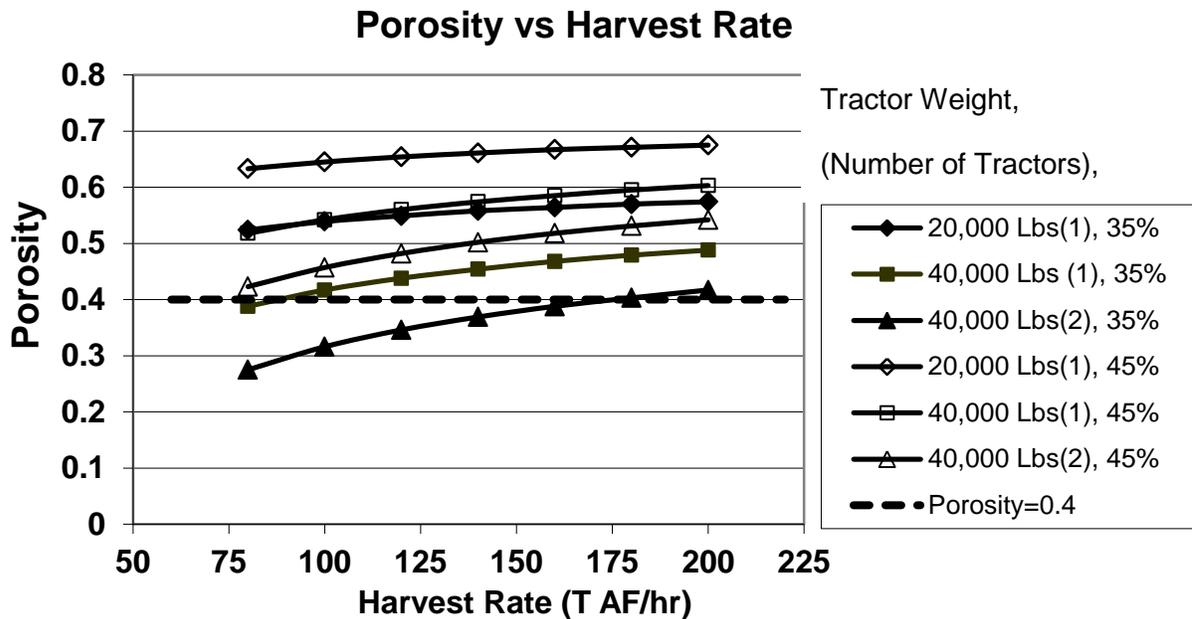


Figure 4. Porosity vs Harvest Rate for Different Combinations of Tractors and Dry Matter

If forage DM exceeds 40%, packing effort needs to be much higher to produce high bulk density and to keep porosity at or below 0.40. In recent years, there has been an increase in factors leading to lower bulk density and higher porosity. These factors include the increased harvest rates without increased packing effort mentioned above, as well as a trend for field-wilted forages to be harvested drier. Arguments for dryer forage at harvest include: desire to avoid a clostridial fermentation and desire to increase the DM content of the ration when other feed ingredients are high in moisture. When field mowing and raking rates exceed harvest rate, the drying occurs too fast (drying gets ahead of harvest rate). Drier forage also lowers bulk density. Whatever the reasons for ensiling forage too dry, the nutrient losses will increase but the recognition of those losses does not occur until sample analyses document the reduced feed quality.

Sloping the Top Surface

Sloping the top surface of the forage, while filling, allows for precipitation to be drained from the plastic cover. Slopes greater than 3 horizontal to 1 vertical (3:1) run the risk of tractor roll over. Many producers use steep sloped surfaces in an attempt to store more forage in a limited space. Steep slopes are usually not packed properly because the operator is fearful of driving on the sloped surface. Weighting materials used to hold the plastic close to the forage are less effective on slopes steeper than 3:1. Extra time is required to tie tire sidewalls so they don't slide down a steep sloped surface. Frequently, silage losses are higher on the steep sloped surface than they are on shallower slopes where the silage is packed well and the plastic is held close to the silage. These losses are visible as blackened silage which must be removed before feeding. So the extra costs associated with steep slopes include: added labor to secure the weighting material, higher dry matter losses and extra labor to pitch off the waste feed. Potential dangers include tractor roll over and falling from the feedout face while pitching waste feed.

Covering

Dry matter losses occur in storage due to exposure to oxygen and precipitation. This exposure can occur through any or all of: Holes/cracks in walls, No plastic cover, Plastic not applied immediately after filling, Plastic cover not weighted uniformly, Plastic edges not well sealed, Plastic sheet joints not sealed, Holes in plastic not sealed in a timely way. Polyethylene is the conventional material used to cover silage to exclude oxygen. It should be applied immediately after filling the storage. Weighting material should be uniformly applied to limit plastic billowing in the wind. Joints in the plastic and where the plastic joins the walls or ground should be sealed to limit oxygen from entering the silage at the joint. Perimeter edges of plastic should be sealed with windrows of soil or gravel filled bags touching each other. Overlap plastic at least 4 feet at joints with upslope plastic on top of the down slope plastic sheet. Weight joints with gravel filled bags or a double layer of tires. Place tires or tire sidewalls uniformly on plastic so tire edges touch to keep the plastic in intimate contact with the silage. In very windy sites, consider a double layer of tires/sidewalls to limit billowing and plastic blow off. Tarps are available to protect the plastic from ultraviolet light and punctures. Tarps can distribute weighting forces to keep the plastic in contact with the silage thus not requiring so many weighting objects. Rows of gravel filled bags should be applied at 10-20 foot intervals along the length of the storage top surface to hold the tarp down. Using tires and/or sidewalls to weight the plastic/tarp between the rows of bags can provide an added weighting to the plastic.

Other methods for uniformly weighting the plastic that have been tried include the application of; soil, wet straw, waste silage, wet sawdust etc. These materials can do an effective job of sealing the silage if enough material is applied. Problems with this technique include the difficulty of removing the weighting material and contamination of the silage with spilled weighting material. Snow and ice can complicate the use of these alternative weighting materials and the tarps.

Polyethylene is the most common plastic used to protect silage from oxygen and precipitation. It can be obtained in a variety of thicknesses from 4-9 mils (thousandths of an inch). The thicker the film, the higher its resistance to oxygen infiltration and the more resistant to tearing. Polyethylene comes in black on black and white on black colors. When using polyethylene with the white surface exposed to the atmosphere, the plastic reflects more of the solar radiation and does not become so hot as the black colored plastic. This helps to keep the silage in direct contact with the silage slightly cooler. The effect is however limited to the top inch of silage. Polyethylene exposed to the sun becomes brittle and deteriorates quickly. Manufacturers of polyethylene used for silage protection add ultraviolet (UV) radiation protectants to the plastic to give it a longer life when exposed to the sun. Select plastic with enough UV protection for the expected storage period. If the storage period could be up to 24 months, make sure the UV protection level is that long.

Polyethylene comes in a variety of sheet sizes and forms (folded bundles, rolls). Select sheet size so as to minimize the number of joints in the sheets but not so large the package cannot be handled by the application crew. In cases where very large sheets are applied, plan to use a tractor with a 3-point hitch dispenser to carry a roll of film across the silage surface. Workers report 8 mil polyethylene is easier to apply and walk on than is 4 mil plastic. The thicker plastic is less susceptible to wind blowing the plastic out of control. The 8 mil plastic is less likely to be torn during application.

Oxygen barrier film is a relatively new product for protecting forage from oxygen and precipitation. There are several types of these films available on the market. Some are single polymer films and

some are multiple layers of different polymers in one sheet. Some films are not manufactured with UV protection. Those films should be covered with a tarp or polyethylene film containing UV protection to help hold down the film and protect it from solar radiation. For a film to do its job, it must exclude oxygen and precipitation as continuously as possible. Research has shown oxygen barrier films can reduce dry matter loss and increase the concentration of fermentation byproducts in the silage below this plastic compared to polyethylene. However, research has also shown the oxygen barrier plastic must be used in such a way so as to limit oxygen penetration at laps and walls and to patch holes or the benefits will not be completely realized. Inspection and patching of holes in any plastic covering should be done on a weekly basis so oxygen is excluded from the aerobic organisms for as long as possible. Use a specially designed patching tape supplied by the plastic distributor when patching holes.

Studies comparing polyethylene and oxygen barrier films have frequently found very limited visible spoilage under oxygen barrier films and limited to some visible spoilage under polyethylene. Often times, when the plastic is properly applied, dry matter loss under each film is the same and quite low in the top six inches. Silage under oxygen barrier film usually has higher levels of fermentation products compared to a polyethylene cover. Where increased pH, dry matter loss, spoilage and reduced fermentation products are found in silage under either film, there is a high likelihood the film has not been sealed as well as it should have been. Research and experience shows improved silage quality when the plastic film is held closely to the silage.

Once the storage is opened for feeding, the edge of the cut plastic should also be sealed to limit oxygen penetration under the plastic. Gravel filled bags work well to seal the edge of plastic at the feedout face.

Feedout

During the feedout process, the feeding face is exposed to oxygen continuously. The higher the porosity and roughness of the feedout face the more quickly and deeply into the silage oxygen penetrates. Packing the forage to a high bulk density ($>44 \text{ lbs/ft}^3$) limits the porosity. Proper use of a front end loader bucket and/or a facer helps to achieve a smooth feedout face with limited porosity. The rate (inches/day) at which silage is removed from the feedout face determines how long silage (within 3 feet of the feedout face) is exposed to oxygen. At the rate of 12 inches per day, the silage is exposed for only 3 days while a feedout rate of 3 inches per day exposes the silage to oxygen for 12 days. Silage can heat and lose a high level of dry matter in 12 days of oxygen exposure. The key is to manage the storage so silage is removed at no less than 6 inches per day to limit the time silage is exposed to oxygen. This is done by limiting the feedout face cross section area by selecting silos that are long and narrow compared to short and wide. See the discussion about sizing bunker/pile silos “Size Silo Properly” above. In Figure 5, the dry matter loss is less than the goal of 3% when bulk density is greater than 40 lbs AF/ft^3 and the face removal rate is greater than 6 inches per day.

A ragged silage feedout face has larger surface area exposed to oxygen and fissures and cracks allow oxygen to penetrate deep into silage. The method for removing silage from the bunker/pile silo should leave a smooth tight feedout face. Methods that can be used to achieve a smooth feedout face include:

1. Scraping silage at feedout face in a downward motion with the loader bucket edge.
2. Scraping silage at feedout face with the loader bucket side while driving parallel to the face.
3. Use a rotating facer.
4. Use a silage rake. This method leaves a corrugated face which is not as smooth as the other methods.

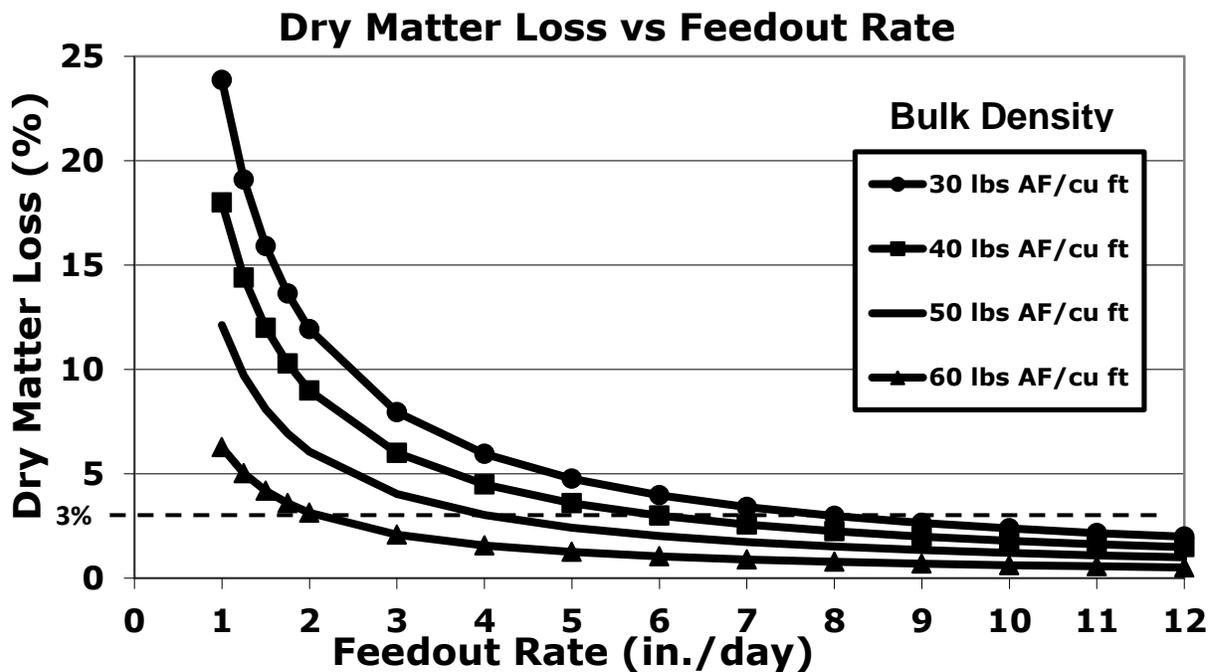


Figure 5. Dry Matter Loss vs Feedout Rate (Derived from Pitt and Muck, 1993)

Silage removed from the feedout face and residing on the storage floor has low density which allows oxygen to penetrate quickly and deeply. This can result in rapid silage heating with resultant dry matter loss. Remove only the amount of feed that will be used in one feeding so excess feed is not left on the floor for extended periods.

Practice Safety

Injury and death are expensive and personally devastating! It can happen to you. There should be protocols to reduce the likelihood of injury and death. Enforcement of the protocols is needed to ensure compliance. Some practices that limit injuries and deaths include but are not limited to:

- Four wheel drive packing tractor
- Roll over protection on tractor and **use** seatbelts
- Experienced packing tractor driver
- Keep pedestrians (especially children) away from work areas.
- Keep packing surfaces shallower than at 3:1 slope
- Don't fill higher than the unloader can reach (reduced overhangs)

Face wall side of silo when covering and weighting (don't back up to edge),
Consider guard rails at wall top.
Use trailer dump while parked only on solid surfaces
Avoid approaching the feedout face while on the ground (avalanches are real)
Avoid standing/walking on top of silo near the feedout face (avalanches are real)
Don't place forage on top of plastic cover when adding new feed (pull back the plastic first)

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Notes:

Feeding Low Crude Protein Diets to Improve Efficiency of Nitrogen Use

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The dairy industry is coming under increased pressure from federal and local governments and from public opinion to reduce its environmental impact. Among the pollutants, nitrogen (N) excretion is a major concern. Ammonia N released from manure during storage and land application combines with sulfur dioxide and nitrogen oxides in the air to form very small particles (less than 2.5 μ m). These particles cause haze and contribute to lung problems and asthma in humans. If manure is over-applied or applied to frozen or sloped land, N can migrate into surface waters and contribute to eutrophication, which can ultimately cause degradation of aquatic ecosystems and coastal hypoxia. Within the soil, manure N is converted to nitrate, nitrite, and nitrous oxide. The former 2 can migrate into aquifers causing blood oxygen exchange problems in infants (methemoglobinemia). Nitrous oxide can escape to the atmosphere contributing to decreased stratospheric ozone concentrations and greenhouse warming. In the latter case, it has greater than 300 times the greenhouse gas effect of carbon dioxide. Nitrogen oxide, nitrogen dioxide, and sulfur dioxide (derived from the sulfur containing amino acids in undigested protein) that escapes to the air creates acid when dissolved in raindrops causing acid rain, which increases the acidity of soil and surface water (Wolfe and Patz, 2002).

Protein, which is the source of the waste N and environmental pollution, is an expensive dietary nutrient (Table 1) representing approximately 42% of the cost of a lactating cow ration (St-Pierre, 2012). The reduction of dietary protein levels could potentially result in decreased demand for high protein ingredients, reduced price of those ingredients, and the diversion of acreage to higher yielding crops such as corn instead of growing oilseeds. This would result in increased corn supply, which would cause a reduction in the cost of low protein ingredients as well.

Table 1. Nutrient values based on central Ohio ingredient prices. From ST-Pierre and Knapp^a.

Nutrient	Sep., 2008	Aug., 2009	Oct., 2010	Sep., 2011	Sep., 2012	Nov., 2012
NE _L , \$/mcal	0.145	0.103	0.121	0.166	0.194	0.115
MP, \$/lb	0.292	0.466	0.277	0.280	0.498	0.636
neNDF, \$/lb	-0.195	-0.257	-0.072	-0.082	-0.121	-0.041
eNDF, \$/lb	-0.074	-0.045	-0.001	0.081	-0.011	0.059

^a www.dairy.osu.edu/bdnews; MP=metabolizable protein, neNDF=non-effective NDF; eNDF=effective NDF.

In a survey carried out on 103 large scale dairies across the country (613 ± 46 cows; 34.5 ± 0.3 kg of milk per cow per day), nutritionists reported feeding diets with 17.8 ± 0.1 % crude protein (**CP**) (Caraviello et al., 2006). A meta-analysis of 846 experimental diets found a similar mean CP content and conversion efficiencies for dietary and metabolizable N (based on NRC, 2001) to milk protein of 24.6 % and 42.6 %, respectively (Hristov et al., 2004). Assuming the same dietary conditions (22.1 kg/d DMI and 17.8 % CP) over a 10 month lactation, the national herd of 9 million dairy cattle (Livestock, Dairy, and Poultry Outlook: August 2012, LDPM-218, Dairy Economic Research Service, USDA) would excrete 1.3 million metric tons (**mmt**) of N per year. If a dietary protein conversion efficiency of 35% could be achieved with no change in milk protein output, excreted N would be reduced 39% to 0.51 mmt.

Dietary protein is used to support microbial growth in the rumen. The combination of microbial protein flow from the rumen and ruminally undegraded dietary protein (**RUP**), which represents the majority of the metabolizable protein (**MP**) supply to the animal, is used for maintenance and productive functions such as milk protein synthesis. Several models, such as the NRC Nutrient Requirement models (NRC, 1989; 2001), estimate ruminal and animal N requirements, supply of ruminally degradable protein (**RDP**) and RUP, and are used in ration balancing software. Because the NRC model is widely used, it is a primary determinant of protein use in dairy diets.

Provision of less RDP than required by the microbes or the animal will result in reduced milk protein yield although it will increase N efficiency. Increased N efficiency seems to be a positive effect. However, increased N efficiency will not necessarily result in efficiency gains at the national level. If one considers that a given amount of milk is required to meet consumer demand, a loss in production per cow will require that additional cows be milked. The maintenance costs of those extra animals will quickly negate the apparent gains in efficiency per animal.

Feeding protein in excess of requirements results in the use of the surplus protein for energy needs, increased N excretion, and decreased animal efficiency (Kalscheur et al., 2006). Thus, it is important that animals be fed precisely at their requirements if maximal efficiency is to be achieved. The benefits of improved efficiency to the industry are reduced production costs associated with purchasing less dietary protein. The benefit to society is the reduced environmental impact of generating food, e.g. milk.

Ruminally Degradable Protein Requirements

Ruminally degradable protein supply and requirement predictions by the NRC model (2001) represent our best estimates of current nutritional knowledge. The degradation of dietary CP in the rumen is important as it supports microbial growth. Inadequate RDP leads to reduced ruminal ammonia concentrations, which causes a depression in microbial growth and flow to the small intestine. It also causes a reduction in fiber degradation (Firkins et al., 1986) and reduced DMI (Allen, 2000). However, the reduction in microbial flow does not always lead to a reduction in metabolizable protein available to the animal, as reductions in microbial N flow can be offset by increases in RUP flow (Santos et al., 1998). If dietary protein is not degraded in the rumen, it is able to bypass microbial activity and flow into the small intestine. Therefore, the loss in fiber digestion and intake is of greater significance as there is no capacity for fiber digestion in the small intestine and very little capacity in the large intestine. If ruminal fiber digestion is inhibited or dry matter intake is reduced, the supply of energy to the animal will be reduced thereby reducing milk yield.

Evidence suggests that ruminants can remain productive at much lower N inputs than are currently recommended and used in practice (Christensen et al., 1994; Christensen et al., 1993). The RDP requirements for dairy cows generally range from 9.5 to 10.5% of dietary DM depending on diet, animal characteristics, and production level. Recommendations for RDP in the NRC (2001) were statistically derived from a large data set collected from literature. Although the resulting regression equation describes the data reasonably well ($r^2=0.52$), few of the experiments used in the evaluation utilized RDP levels that were well below the current recommendation. Thus, it is possible the current requirements are set too high because of inadequate range in the data used to derive them.

Results from research trials where the RDP: RUP ratio was changed while holding CP constant are difficult to interpret because the decreasing concentration of RDP is confounded with the increasing concentration of RUP. Gressley and Armentano (2007) observed no changes in milk production when 10.1% and 7.4% RDP diets were compared. Cyriac et al. (2008) observed no change in milk yield or DM intake when diets with 8.8% RDP were fed, but did observe a significant reduction in intake and a trend for a reduction in milk yield when RDP concentrations of 7.7% were fed (Table 2). In a subsequent study, using the 11.3 and 8.8% RDP diets of Cyriac et al. (2008) in an experimental design with more power, Li et al. (2009) did observe a significant reduction in DM intake and a strong trend for a reduction in milk yield for cows given the 8.8% RDP diet.

Table 2. Least squares means for intake, milk yield, and milk composition of dairy cows fed diets with constant RUP and varying RDP content. From Cyriac et al. (2008).

Item	RDP, % of diet DM				SEM	Contrasts ¹	
	11.3	10.1	8.8	7.6		L	Q
Intake, kg/d						(P <)	
DM	24.1 ^a	23.9 ^a	23.2 ^a	20.4 ^b	0.57	<0.0001	0.33
CP	4.44	4.02	3.52	2.79	0.09	<0.0001	0.10
Milk Production							
Milk yield, kg/d	41.2	42.1	40.3	36.6	1.95	0.09	0.26
Milk lactose, %	4.87	4.88	4.86	4.88	0.03	0.92	0.96
Milk CP, %	2.98	3.00	3.01	2.92	0.05	0.45	0.25
Milk fat, %	3.43	3.13	3.22	3.33	0.20	0.82	0.32
MUN, mg/dL	20.2	17.6	14.2	12.4	0.62	<0.0001	0.58

¹Contrasts: L = linear, Q = quadratic

^aMeans in a row without common superscript differ at P < 0.01. Pair-wise least square mean comparison (Tukey) was conducted only for DMI

Thus, it would appear that RDP requirements may be greater than necessary and dietary RDP could safely be reduced to 9% of DM or less under most conditions. However, there may be diversity among animals in their ability to tolerate lower RDP diets. Preliminary findings by Aguilar et al. (2011) showed that animals on a common diet and with similar milk yield vary in their transport of blood urea back into the rumen. Because this urea is an alternative source of ruminally degradable nitrogen, it is possible that animals with high transport activity may tolerate a lower dietary RDP content than those with low transport activity. However, this is preliminary work and needs to be extended before a final conclusion can be reached.

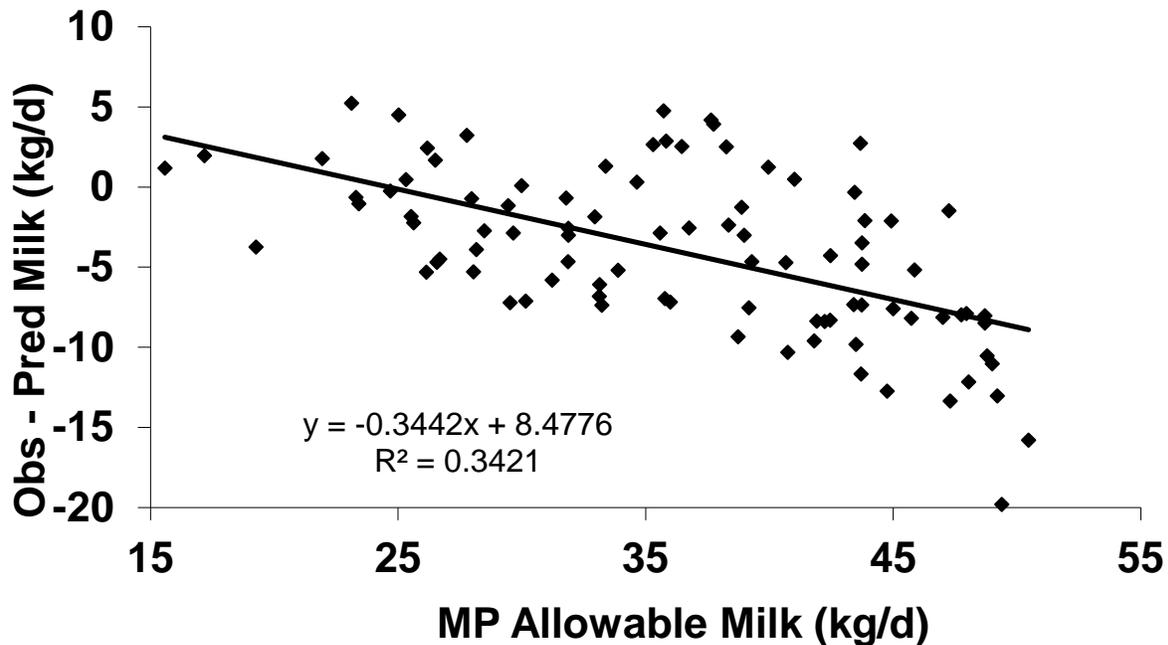
When deficiencies occur, they are almost universally associated with a drop in DM intake. Even though it is not currently clear what the diversity in cows may be, in terms of their tolerance for low RDP diets, some diversity among cows and thus among herds likely exists. If one wants to truly optimize the level of RDP feeding for each herd, then on-farm calibration should be adopted. Where multiple pens are fed a similar diet, one pen could be fed a lower RDP diet while the other pen is maintained at or above NRC requirements. If no change in DMI is observed after 10 days on the lower RDP diet, then one could adopt this as an estimate of the RDP requirements for that herd. Of course, given success with the first incremental reduction in RDP, additional reductions should be attempted assuming they make economic sense. Having established a herd specific requirement, this could be used for several years before requiring reassessment.

Metabolizable Protein Requirements

Although we commonly state animal N requirements in terms of MP, the true requirements are for the specific amino acids (AA) resident in that protein. Because there is diversity of AA composition in the absorbed protein, stating the requirements in MP units inherently forces a certain level of over-prediction of requirements to compensate for variation in AA composition of that protein. This is perhaps most apparent when feeding diets constructed largely from corn products which are inherently low in lysine. Such a diet could be created to meet MP requirements, but animals may still respond to the addition of a protected lysine source or more protein that also provides lysine to the ration. When these types of data are mixed with all other experiments in the literature and subjected to statistical analyses to derive MP requirements, the loss in production associated with a specific amino acid deficiency forces the statistical algorithm to solve to a higher MP requirement than would be necessary if the diet contained a perfect mix of amino acids. For example, pigs can achieve efficiencies of absorbed protein deposition in muscle protein of 85% when fed a diet perfectly matched to their AA requirements (Baker, 1996) as compared to 42.6% efficiency of conversion of MP to milk protein in lactating cows (Hristov et al., 2004). So, it is a given that MP requirements are greater than needed to compensate for variable AA supply. Thus, animals could successfully be fed a lower MP diet if the AA composition of that diet was better matched to AA requirements as demonstrated by Haque et al. (2012) using diets with less than 13% CP. As the cost of RUP is 3-fold greater than the cost of RDP (Knapp, 2009), being able to reduce dietary RUP is of great economic interest.

Aside from the question of balancing for AA to achieve greater efficiency, there are additional problems with the NRC (2001) MP requirement equations. Obviously, one would expect the model to predict requirements at all levels of production with the same precision. For example, if the precision of the system at 60 lbs of milk/d is plus or minus 15%, then one should expect similar precision at 80 and 90 lbs of milk. Unfortunately this is not the case. As demonstrated in Figure 4, the model over-predicts (predicted – observed; Should be 0 if all predictions were perfect) the amount of MP allowable milk at high levels of production and under-predicts at lower levels. Thus, when using the model, one may need to balance for slightly greater amounts of MP in the diet if working with high producing cows and the reverse when working with lower producing cows. As the MP supply predictions have been well validated, the problem appears to reside in the requirement equations.

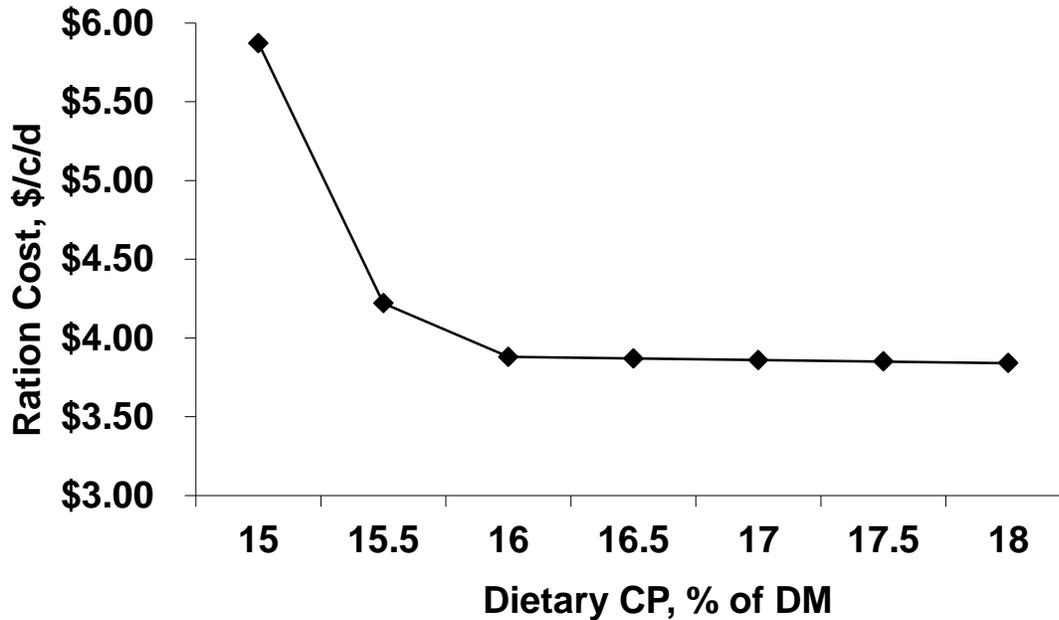
Figure 4. Residual errors (Obs – Pred) associated with predictions of metabolizable protein (MP) allowable milk yields by the NRC (2001) model. Adapted from NRC (2001).



The problem with predicting MP requirements is at least partially driven by the model assumption that the conversion of MP to milk protein, after subtraction of maintenance use, is a constant 65%. In a summary of literature data, Lapierre et al. (2007) found that the highest efficiency was 43% and it declined from there as milk protein output (and MP supply) increased. Hanigan et al. (1998) summarized publications reporting responses to post-rationally infused casein and found a similar maximal efficiency of conversion of about 45% with an average conversion efficiency of 22%. The reduction in efficiency at higher levels of production would seem to explain the over-predictions of allowable MP at those increased levels of milk yield. This problem is well recognized by our group, as well as others, and we are working to fix this problem. Such a fix will undoubtedly be in the next release of the NRC which is likely to occur in the next 4 to 5 years. However, in the mean time, one should be aware of the problem.

When using the NRC model to balance a given ration at differing levels of dietary protein, one can assess the potential for saving money by removing all constraints from CP and relying on the model to solve for rations that meet RDP and MP requirements. Such an exercise is demonstrated in **Error! Not a valid bookmark self-reference.** with Eastern US ingredients at prevailing prices in 2011. From that work, it is apparent that diets can be formulated to meet NRC requirements down to at least 16% CP, although the cheapest ration was at the highest level of protein. As protein costs increase relative to dietary energy costs, such low protein rations could become cost beneficial. Thus, it is important to allow the models to work without placing arbitrary limits on dietary protein content. Least cost rations, containing 16% CP that still meet NRC requirements, can only be achieved if arbitrary minimums are not placed on dietary CP content.

Figure 5. The cost of diets formulated to varying protein levels using the NRC (2001) model and a least cost algorithm. Adapted from Stewart et al. (2012).



If one assumes the RDP requirement is over-predicted by 0.5% unit, then the above analyses (When using the NRC model to balance a given ration at differing levels of dietary protein, one can assess the potential for saving money by removing all constraints from CP and relying on the model to solve for rations that meet RDP and MP requirements. Such an exercise is demonstrated in **Error! Not a valid bookmark self-reference.** with Eastern US ingredients at prevailing prices in 2011. From that work, it is apparent that diets can be formulated to meet NRC requirements down to at least 16% CP, although the cheapest ration was at the highest level of protein. As protein costs increase relative to dietary energy costs, such low protein rations could become cost beneficial. Thus, it is important to allow the models to work without placing arbitrary limits on dietary protein content. Least cost rations, containing 16% CP that still meet NRC requirements, can only be achieved if arbitrary minimums are not placed on dietary CP content.

Figure 5) would likely shift downward by a 0.5% unit. Instead of a minimum effective dietary CP content of 16%, one should be able to work down to a 15.5% dietary protein range. If the same or even greater is true for RUP given a proper mix of AA, it should be possible to balance rations for less than 14.5% protein for high producing cows. Such a level of intake would achieve an efficiency of 30% which is half way to our goal of 35% efficiency. Achieving 35% efficiency (11.5% CP diets) likely requires much more precise AA supply and requirement prediction equations so that diets can be formulated for AA as well as MP.

Amino Acid Requirements

The challenge of predicting AA supply and requirements for ruminants is much greater than for monogastric species. Flow of AA from the rumen is a function of the AA content of undigested feed protein, microbial protein, and sloughed digestive tract cells and secretions (NRC, 2001). The difficulty of predicting each of these entities has greatly hampered our ability to derive AA requirements based on performance data as is done with swine and poultry. Most of the progress that has been made in ruminants has occurred through the use of catheterized and cannulated animals, allowing the provision of AA post-ruinally (for example Haque et al., 2012). However, this is very intensive and expensive work. To date we have amassed the most information on methionine and lysine with histidine results appearing more recently (Korhonen et al., 2000; Noftsger and St-Pierre, 2003; Rulquin et al., 1993). We are far from the level of understanding that the swine and poultry people have of the remaining essential AA requirements and likely not to achieve that level of understanding any time in the near future.

As AA requirements are expressed as a percentage of MP supply, the problem with variable efficiency of MP use and over-predicting the marginal responses of milk protein to changing MP supply is partially propagated in existing AA requirement equations and likely contributing to the lack of accuracy and precision in those equations (NRC, 2001). Work at the tissue level, using multi-catheterized animals, has clearly shown that the liver and gut tissues remove a constant fraction of AA from blood presented in each pass by that tissue. Because mammary tissue does not generally remove more than half of the AA presented to it, there is significant recycling to the gut and liver resulting in additional removal. This is magnified as AA supply increases relative to energy supply, as the mammary tissue has the ability to change its removal of AA to meet its needs (Bequette et al., 2000). So if mammary tissue is presented with a good energy supply, it will be capable to produce milk near its maximum potential and will increase its AA extraction efficiency to achieve this. The same will happen if energy is held constant and AA supply is reduced. Conversely if the mammary tissue is presented with inadequate energy, it will reduce its use of AA and reduce extraction from blood. In the former case, less AA are recycled to the liver and gut, less are catabolized, and AA extraction efficiency is increased. In the latter case, more AA are recycled, catabolism increases, and AA extraction efficiency decreases. So, assuming a constant efficiency of post-absorptive AA use for milk protein synthesis is clearly wrong.

The above interactions between energy and AA supplies to the mammary tissue are mediated by intracellular signaling that integrates information regarding the intracellular supply of several key AA (Appuhamy et al., 2012; Appuhamy et al., 2011), the supply of energy in the cell (Appuhamy et al., 2009), and hormonal signals indicating overall animal status, i.e. insulin (Appuhamy et al., 2011) and probably IGF-1. Because these 3 entities all interact to set the overall rate of milk protein synthesis, and because the tissue can adapt its AA extraction capacity to meet intracellular AA demand, the concept of a single limiting AA or even a nutrient is wrong.

The first limiting nutrient and AA concept is based on the hypothesis commonly called the Law of the Minimum, which Sprengel (1828) formulated based on plant growth responses to soil minerals. The original hypothesis stated that a nutrient can limit plant growth, and when limiting, growth will be proportional to supply. Von Liebig (see Paris, 1992 for a translation) subsequently restated the hypothesis in stronger terms indicating that if a nutrient was limiting for growth, responses to other nutrients could not occur (von Liebig, 1862). Mitchell and Block (1946) used von Liebig's extension of Sprengel's hypothesis to develop the concept of the order of limiting AA which is commonly described using the analogy of a water barrel with broken staves. Based on this

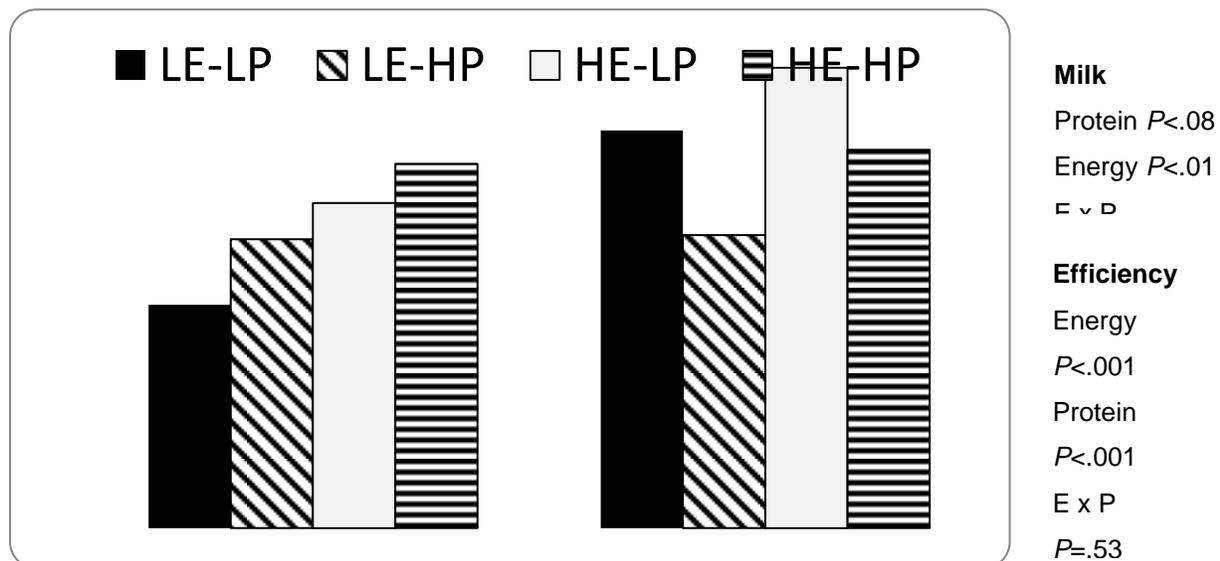
formulation, if any nutrient is limiting milk production, then only the addition of that nutrient to the diet will result in a positive milk yield response, e.g. the single limiting nutrient paradigm.

In order to determine which nutrient is most limiting, one must be able to calculate the allowable milk yield from that nutrient. That calculation is quite simple if one assumes a constant transfer efficiency, as is the case in the NRC model. However, as discussed above, transfer efficiency of AA is not fixed. Because AA removal from blood is regulated in concert with needs for milk protein synthesis (Bequette et al., 2000), the efficiency of AA transfer from the gut to milk protein is variable thus violating one of von Liebig's assumptions.

Integration of signals arising from several AA, energy supply in the mammary cells, and hormonal signals to set rates of milk protein synthesis also violates the assumption that only one nutrient can be limiting production. If more of one nutrient or hormone can offset less of another, there are almost an infinite number of combinations of AA, energy substrates, and hormonal concentrations that will result in the very same amount of milk. This concept is demonstrated *in vivo* by the work of Rius et al. (2010a) in Figure 6. More of any one AA, while all others are held constant, will push milk protein synthesis higher regardless of which is perceived to be "first limiting" (Clark et al., 1978; Hanigan et al., 2000). Therefore, current protein and AA requirement models for lactation inappropriately represent the underlying biology, which leads to large prediction errors.

The take home message from this discussion is that rations can be balanced at levels well below 15% CP, probably even below 13%, if we are able to reliably match AA supply with true animal needs. But current models of AA requirements used in field application programs appear to be incompatible with making such predictions. We are in the process of devising a new prediction scheme that will be a better representation of the biology, and thus should provide much greater accuracy allowing us to achieve N efficiencies of 35% in lactating cattle.

Figure 6. Milk yield and metabolizable protein efficiency of conversion to milk protein in response to varying energy and ruminally undegraded protein supply. From Rius et al. (2010). HEHP = 1.54 MCal/kg; 11.8% MP; HELP = 1.54 MCal/kg, 9.5% MP; LEHP = 1.45 MCal/kg, 11.8% MP; LELP = 1.45 MCal/kg, 9.5% MP.



Milk Urea Nitrogen as a Tool to Monitor Feeding Programs

Synthesized urea is released into blood and equilibrates with body fluids including milk (Broderick and Clayton, 1997) resulting in high correlations among blood urea N, milk urea N (MUN), dietary N, and N balance in the cow (Preston et al., 1965). If protein in the diet is deficient relative to cow requirements, AA catabolism will be minimized resulting in low urea synthesis and concentrations of urea in blood and milk. Conversely if dietary protein is in excess, AA catabolism will increase resulting in greater urea synthesis and concentrations of urea in blood and milk. Thus, protein feeding can be adjusted based on MUN concentrations to achieve maximal efficiency without compromising milk production. Because kidney urea clearance is concentration dependent, there is also a high correlation between MUN and urinary N excretion (Jonker et al., 1998). Milk urea N is also a good indicator of ammonia emissions from dairy manure (Burgos et al., 2007). These relationships and routine measurement of MUN by milk processors and DHIA testing laboratories provides a useful tool for monitoring feeding programs and feed management practices to achieve maximum N efficiency and minimum environmental loading (NRCS, 2011).

Although MUN concentration is clearly related to protein sufficiency, there are several factors that can cause deviations from expected values. These include time of sampling, season of the year, body weight, breed, and nutritional factors (Broderick and Clayton, 1997; DePeters and Cant, 1992; Kauffman and St-Pierre, 2001). There are also significant cow effects (Wattiaux et al., 2005) that are at least partially explained by genetic variance (Miglior et al., 2007; Mitchell et al., 2005; Stoop et al., 2007; Wood et al., 2003). Given the genetic effects on MUN, it is possible that sire selection decisions within a herd may result in herd concentrations of MUN differing from the expected values based on feed management.

When the model of Kauffman and St-Pierre (2001) was used to predict MUN concentrations for individual cows in trials performed by Cyriac et al. (2008) and Rius et al. (2010), the variance in residual MUN associated with cow was 4.1 ± 1.1 mg/dl ($P < 0.001$), indicating that individual cows can deviate considerably from the expected MUN value given a defined diet (Aguilar et al., 2012). Aguilar et al. (2012) also observed highly significant cow effects and a strong trend for a herd effect ($P < 0.08$) when analyzing data from 6 herds in the state of Virginia after corrections for differences in dietary nutrients and level of production. Least squares means for MUN by herd ranged from a low of 13.6 mg/dl to a high of 17.3 mg/dl. Given that a percentage unit change in dietary CP, e.g. 17% to 16%, results in a 1.1 mg/dl change in MUN, the herd with the highest MUN would have had to reduce dietary CP to 12.8% to achieve the commonly accepted MUN target of 12 mg/dl, if all other factors are held constant. Thus, it is important to recognize that not all herds can be expected to achieve the same target MUN, and herd specific calibrated targets are required if maximal efficiency is to be achieved and maintained.

Herd calibration can be achieved through an assessment of the herds feeding program, taking into account all possible factors that may affect observed variation in MUN. If the herd is well managed, fed a balanced diet that does not exceed NRC (2001) requirements for protein, and the diet has adequate energy, the prevailing MUN could serve as a calibrated target value for that herd. If the herd is overfeeding protein relative to energy supply and milk production, the ration would have to be rebalanced and fed for a period of 2 or 3 weeks before reassessing MUN. The MUN value achieved after this period of feeding to requirements reflects the calibrated NRC reference target for

the herd. At this MUN level, a diet balanced properly for RDP and RUP should not precipitate a protein deficiency.

Given a reference MUN target for the herd, one can then determine if the herd will tolerate lower RDP and RUP feeding levels. Because RUP costs considerably more than RDP, it makes sense to start with RUP calibration first. After feeding the diet balanced to NRC requirements, reduce the RUP content of the diet by 0.25% or 0.5% units while holding energy and RDP content constant. Feed the diet for a period of 2 weeks and determine if any loss in milk production or DM intake has occurred while also recording MUN content. If there is no loss in production or intake, try removing another 0.25% units from RUP and again assess production, intake, and MUN after another 2 weeks. Any loss in production will be much less than that predicted by the NRC model because it over-predicts responses. Once a loss is experienced, add back the last reduction in RUP and store this value as your target RUP content and MUN target level for that herd.

Having established a herd specific RUP feeding level, you can try reducing RDP content if economically favorable. Remove 0.25% or 0.5% units of RDP from the diet while holding energy content constant and RUP at the newly established level. Again feed the diet for 2 weeks and monitor DM intake, production, and MUN. Note that DM intake will generally change before milk production. If no loss in production or intake, remove another 0.25% units of RDP and repeat the process. Once a loss of DM intake or production occurs, add back the last increment of RDP and store this value as your target RDP content for that herd. Also store the new MUN value as your target MUN for the herd.

This herd specific MUN target can be used to monitor your feeding program. If MUN drops below the target value, it is highly likely that a loss in production will follow soon and corrective action should be taken immediately. Note that a drop in MUN does not provide any information regarding whether the problem is with RDP or RUP. It simply tells you the animal is short on N relative to its current level of production. You will have to determine whether it is a problem with RDP, RUP, other dietary factors such as energy and fiber, or animal health. It also important to recognize that the amount of salt in the ration will affect MUN (Spek et al., 2012), so make sure salt inclusion remains constant and similar to the level used when determining the target MUN values.

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Notes:

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Abstract

Diet-induced milk fat depression (MFD) continues to have major economic impact in the dairy industry. Finding solutions to this problem remains a priority. Current thinking links MFD with certain types of conjugated linoleic acid (CLA) produced from lipid metabolism in the rumen by the mixed microbial population. This paper will discuss a systematic approach to understanding and addressing the nutritional interactions that cause MFD.

Introduction

Sustained drops in milk fat yield translate into significant economic loss on a dairy because milk pricing is based on components in most Federal Orders. Fortunately, many producers experience few problems with MFD because their nutritionists have developed and maintain a consistent, well formulated feeding program. Even the best nutritionist, however, can fall victim to MFD after responding to changes in feed prices, limited availability of some feed ingredients, or unexpected changes in nutrient composition of feed ingredients. Apparently logical changes in the feeding program can drop milk fat several fractions of a percentage point to more than a full percentage point in a short period of time. It can take several weeks to months to identify the nutritional cause and return milk fat to normal.

CLA - bioactive lipids made by microorganisms in the rumen from unsaturated fatty acids in the feed.

MFD is caused by nutrition-driven changes in the rumen. Lipids in feed are metabolized by the rumen microbial population, which leads to the formation of bioactive lipids. “Bioactive” means the lipids affect living cells and tissue. These bioactive lipids are

CLA_{MFI} – the three CLA produced in the rumen that are milk fat inhibitors and cause MFD.

referred to as conjugated linoleic acid or CLA. Microorganisms in the rumen produce more than twenty types of known CLA but three have been shown to cause MFD. This discussion will refer to these three as CLA_{MFI}, because these CLA act as milk fat inhibitors (MFI). The CLA_{MFI} produced in the rumen travel via the blood to the mammary gland, where they inhibit the synthesis of milk fat by impairing the production of several enzymes essential for fat synthesis in the mammary gland. CLA_{MFI} are also present in cows that produce acceptable milk fat levels, but at concentrations too low to cause MFD.

The bottom line is that the type of feed the cow consumes affects rumen conditions, which in turn affects the amount and type of CLA produced. Since CLA_{MFI} overproduction in the rumen leads to MFD, excess CLA_{MFI} and therefore MFD can be controlled by paying close attention to several key nutritional risks. This paper outlines these risks and thus grants the nutritionist control of milk fat synthesis.

What Nutritionists Worry About in Trying to Prevent or Overcome MFD

Do I Have a Case of MFD That Can Be Controlled Nutritionally?

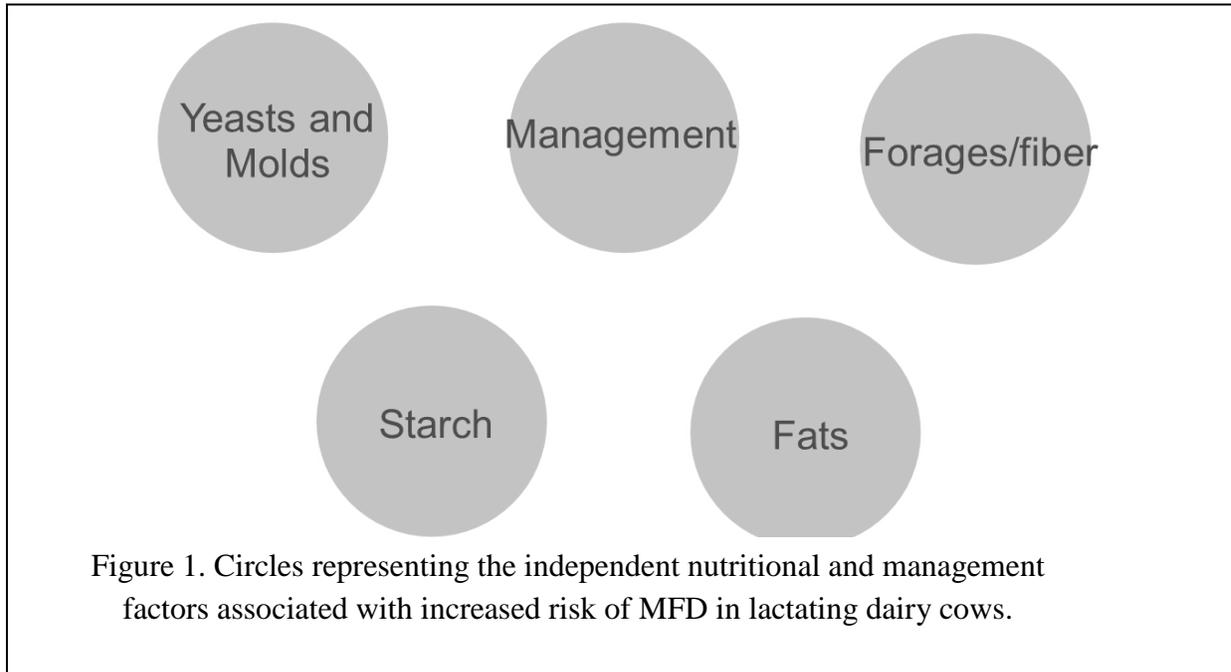
When considering the milk fat status at any given time for a given herd, there are a few basic questions that nutritionists will ponder before diving into aggressive dietary changes that may or may not improve milk components. A few of these include:

- Am I satisfied with the herd’s milk fat production and should I take the risk of messing up a good thing?
- I’ve seen a drop in milk fat percentage but is the drop in lbs of fat really large enough to affect my milk check?
- I’ve seen a drop in milk fat recently but is it a sustained trend or just part of the normal variability in fat tests?
- Is the drop in fat test I’ve seen a nutritional problem or could it be regular seasonal changes in lactation that occur each year?

What are the Nutritional Factors That Can Cause MFD?

Five independent nutritional factors are currently targeted for influencing rumen production of CLA_{MFI} and development of MFD (represented in Figure 1). Each will be discussed. More is known about the influence of forages, starch, and fat in the diet. These factors will receive more detailed

consideration in this paper than yeast and management influences, which have been less tested and documented.



Too much fat in the diet of dairy cows is a classic cause of MFD. Nutritionists are keenly aware that fat must be limited to lower levels than protein or carbohydrate to avoid impaired rumen fermentation, reductions in feed intake, and MFD. It is tempting to push the limit on feeding fat when prices are favorable for high-fat byproducts, when grain prices reach record levels making commercial fats more competitive, or when the farm has access to (perceptually inexpensive) high-fat waste products from a nearby food processing plant. The key to preventing MFD from these high-fat ingredients is to fully understand the nutritional and chemical impact these ingredients have on both the rumen microbes and the cow, and to choose a feeding rate that will provide the most benefit with the least risk of detriment to the production of milk and components.

Fat supplements pose different degrees of MFD risk. Low-risk fats are those that cause little disruption of the microbial population in the rumen and thus maintain normal fermentation and limited production of CLA_{MFI}. Low-risk fats are generally characterized by high saturated fatty acids

or calcium salts of fatty acids. Most commercial bypass fats are based on one or both of these characteristics, so the risk of MFD is low. Bypass fat feeding rate is usually limited by cost and availability. In addition, bypass fats are dry solid products, rather than liquid fats, and therefore easier to package, transport, and mix on the farm without specialized equipment. Bypass fats are also called rumen-inert fats to emphasize their lower risk to disrupt the rumen.

High-risk fat supplements contain more unsaturated fatty acids (Table 1) that are typically found in forages, cereal grains, and oilseeds (cottonseed, soybeans, canola, sunflower, etc). A high concentration of unsaturated fatty acids in the rumen from one or more of these sources can inhibit some microbial species in the rumen. This change can favor species that produce CLA_{MFI}, the

Table 1. Individual and total unsaturated fatty acid (UFA) values for fat sources used as energy supplements in cattle rations.

Fat	Oleic	Linoleic	Linolenic	Total UFA
	----- % of total-----			
Tallow	42	3		45
Animal-vegetable	34	16	2	52
Palm	43	10		53
Poultry fat	41	19	1	61
Restaurant grease	48	20	3	71
Cottonseed	19	53		72
Soybean	25	53	7	85
Corn	29	55	1	85
Canola	60	20	10	90

accumulation of which can lead to MFD. These unsaturated high-risk fat supplements are referred to as rumen-active fats to emphasize their tendency to disrupt rumen conditions.

A convenient tool to monitor risky unsaturated fatty acid intake is called RUFAL or Rumen Unsaturated Fatty Acid Load. RUFAL reflects the total unsaturated fatty acid supply entering the rumen each day from feed. RUFAL accounts for unsaturated fatty acids from all feed ingredients rather than fatty acids only from fat supplements. RUFAL may better indicate potential rumen fermentation disruption than simply calculating the percentage of fat added to the diet. Studies show that increasing RUFAL causes fermentation disruption, which can hurt animal performance. Excessive RUFAL can lead to MFD. Although a single RUFAL cutoff to prevent MFD has not been established, values below 500 g/day are viewed as low fat intakes while those above 500 g/day indicate fatty acid intakes that may be at risk of being too high. It should be noted that herds with milk fat above 3.8% have fed RUFAL in excess of 1,000 g/day, so the tool only suggests a guideline for identifying diets low or high in fat.

Of the many strategies to feeding fat to dairy cows, perhaps the most important, yet most elusive, is the proper amount to feed. A proper feeding rate can usually prevent MFD associated with fat supplements. To effectively use the vast array of fat products available, practical guidelines must be developed that match sources of fat with proper supplementation. Many recommendations to limit rumen-active fats suggest a single feeding rate for added fat in dairy rations. These single numbers are easy to remember and calculate, but don't account for fatty acid contributions from the basal diet or adjust fat feeding rates in relation to fat supplement composition. An alternative approach includes the following two calculations:

1. Limit the total fat consumed from all sources (basal ingredients plus fat supplements) so that

$$\text{lbs total fatty acid intake} = \text{lbs milk fat produced}$$

2. Limit rumen-active fats so that

$$\text{lbs. rumen-active fatty acids} = \frac{4 * \text{NDF} * \text{DMI}}{\text{UFA} * 100}$$

Where,

NDF is % of the dairy TMR

DMI is dry matter intake of cows in lbs/day

UFA is % unsaturated fatty acids in the rumen-active fat supplement

Detailed instructions on using these calculations including examples can be seen at <http://virtusnutrition.com/>. Click on the window labeled “**What’s Your Fat Feeding Strategy?**”



High grain diets are also known to cause MFD. Rapid fermentation of starch can cause acid accumulation and lower pH in the rumen. Factors that can result in marked changes in rumen pH through any 24-h period include: dietary carbohydrate profile and rates of degradation of the carbohydrate fractions as affected by source, processing, and moisture; physically effective NDF (peNDF) supply as affected by source and particle size; and production of salivary buffers as a function of peNDF supply and source. Despite our general understanding of these factors, the degree and duration of low rumen pH

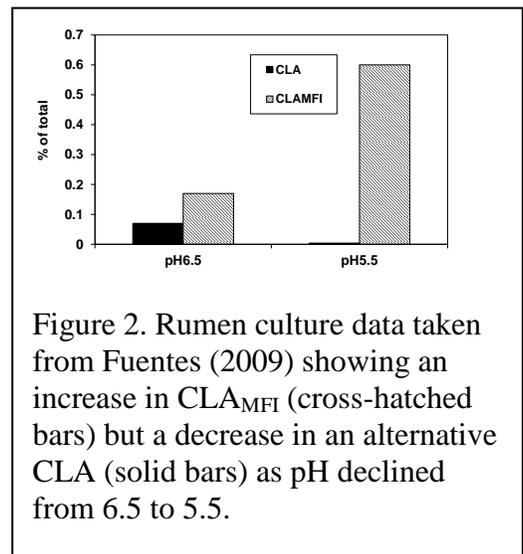


Figure 2. Rumen culture data taken from Fuentes (2009) showing an increase in CLA_{MFI} (cross-hatched bars) but a decrease in an alternative CLA (solid bars) as pH declined from 6.5 to 5.5.

required for accumulation of CLA_{MFI} in the rumen is not known. Although data are limited, rumen pH changes are most likely associated with MFD because they alter bacterial populations by favoring those that have alternative pathways of biohydrogenation.

Studies show that low pH alters the microbial population in the rumen and causes accumulation of CLA_{MFI}. In a study by Fuentes et al. (2009), the pH of rumen cultures was lowered from 6.5 to 5.5, causing a shift in CLA production that included increased CLA_{MFI} (Figure 2). Although milk fat percentages often decline as rumen pH values decrease, there is still a lot of variation seen as scatter around the line in Figure 3. This indicates that rumen pH is not the only factor controlling CLA_{MFI} and milk fat percentage. Therefore, rumen acidosis should not be viewed as a prerequisite for MFD.

The rate of degradability of the starch fraction in grains also determines risk for MFD. Field observations and inferences from studies indicate that rapid rates of starch fermentability are linked to a greater risk of MFD. Fermented feeds with high grain content such as corn silage and high moisture corn carry the highest risk. Differences in corn varieties, silo storage time, and climate conditions for plant growth can all lead to rapid rates of starch degradation in silage and high-moisture corn. Longer storage can lead to higher rates of starch degradability. A study by Newbold et al. (2006), using an in vitro test in rumen fluid over three hours, found a 30% increase in degradability in corn silage stored for 2 months vs. 10 months. If high rates of starch degradability in forages are suspected as a cause of MFD, usually there is little that can remedy the situation. One option is to dilute the forage with less degradable feed, but often that is not available. An alternative option is to focus on other risk factors (such as rumen pH and dietary fat) to minimize CLA_{MFI} production.

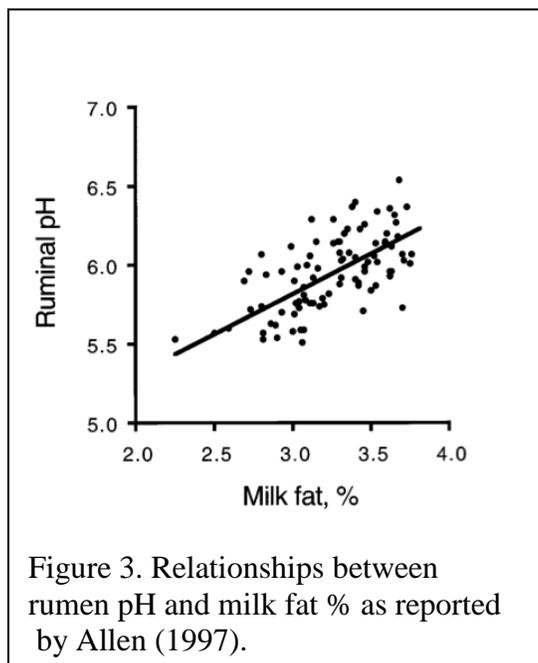


Figure 3. Relationships between rumen pH and milk fat % as reported by Allen (1997).



Maintaining adequate forage levels in dairy diets decreases the risk of MFD. As explained previously, forage can help maintain rumen pH and limit the synthesis of CLA_{MFI}. This approach emphasizes peNDF to sustain cud-chewing and production of salivary buffers. Nutritionists use specific forage guidelines tailored for specific dairies with individualized forage needs. Within those guidelines, however, maintaining a consistent forage program is the first line of defense against problems with MFD.

Again, the rate of starch degradability in forage also affects CLA_{MFI} production. High rates of starch degradability in silage has been associated with an increased risk of MFD, which means that silage NDF alone, as a proxy of forage level and assumed peNDF, is not enough to explain all occurrences of MFD.

A lesser known and often ignored attribute of forages related to MFD is their contribution to the cow's total fat intake. For example, fatty acids in corn silage typically average around 1.5 to 2.0% of DM, but can reach 3.5% or higher. It is important to remember that fatty acid content

Crude Fat

- estimated by extracting a ground feed sample with organic solvents
- low cost and AOAC DEFINE approved
- higher than fatty acid values because includes fatty acids plus other nonlipid contaminants such as pigments, carbohydrates, and some vitamins.

Total Fatty Acids

- isolates only the fatty acid fraction in feed lipids using gas chromatography
- higher cost and not AOAC approved
- lower values than a crude fat analysis because includes only fatty acids and no other contaminants.

Figure 5. Key differences between a lipid analysis of forages by crude fat vs. total fatty acids.

- High fat content with fatty acids 2.5% or more of plant DM.
- High free fatty acids reaching 50% or more of total fatty acids.
- High rates of starch degradability reaching 85% or more in a 7-hour in vitro test.
- High yeasts and molds. Alarms go off with yeast counts approaching 1 million cfu/g.

Figure 4. Characteristics of corn silage often associated with increased risk of MFD.

is not the same as crude fat content when requesting a forage analysis (Figure 5). Fat content has traditionally been determined as the ether-extractable component of the feed. In addition to extracting fat, ether also extracts some carbohydrate, vitamins, and pigments. Therefore, crude fat in cereal grains, forages, and the total mixed ration often contain less than 60% fatty acids. Forage containing 3.5% total fatty acids could contain 5 to 6% crude fat.

Given the large quantities of corn silage fed to cows in some operations, this amounts to significant fat intakes just from silages alone. High fatty acid intakes have also been reported in grazed forages, but again challenges face proper analysis. Ryegrass at Clemson University grazed by cows November through March 2009 had an initial fatty acid content of 6.8% of DM and fell to 4.7% by the end of grazing. Importantly, hay analysis does not represent grazing intakes.

Cutting and drying plant material during haymaking causes extensive loss of fatty acids and other nutrients because plant metabolism continues for a time after the grass is cut. To best represent what a cow consumes during actual grazing, ryegrass samples in the Clemson University grazing study were clipped and immediately immersed in liquid nitrogen to stop all plant metabolism. Then, samples were freeze-dried and kept frozen before analysis.



Yeasts/molds and management factors are both regarded as significant risk factors for MFD, but little is known about exactly how they affect rumen function and the accumulation of CLA_{MFI}. Speculative theories about molds and yeasts suggest they may produce antimicrobial substances as part of their metabolism, which in turn may negatively impact the rumen microbial population; however much remains to be proven in this regard. High yeast and mold counts in fermented feeds is undesirable, not only for risk of MFD, but also because it can reduce feed intake, negatively effect animal health, and decrease overall lactation performance, in addition to incurring additional feed losses through ‘shrink.’ In well-preserved silage, yeast counts below 10,000 CFU/g are common. Counts that effect animal health and performance poorly are not well defined and likely depend on the specific strain of yeast or mold infecting the plant. As a general rule, yeast counts at or above a million CFU/g should cause concern.

A number of management factors also have been connected with increased risk of MFD. Among these are bunk space, stocking density, and mixing of the TMR. These factors can all cause sorting and slug-feeding of grain resulting in low rumen pH and subsequent production of CLA_{MFI} in the rumen. In general, all attempts to maintain cow comfort and maintain good overall herd management will minimize the risk of MFD.

Why Do I Still Sometimes Have MFD Problems Even when I Follow All The Proper Guidelines?

The answer to this question is because the circles shown in Figure 1 are better depicted in Figure 6. Instead of being independent, the nutritional risks for MFD are interconnected. A subtle change in one nutritional parameter, even within accepted guidelines, can imbalance the whole rumen environment and cause accumulation of CLA_{MFI}. Thus, if you are within the proper guidelines, but still have MFD, then the overall balance of all parameters has been upset.

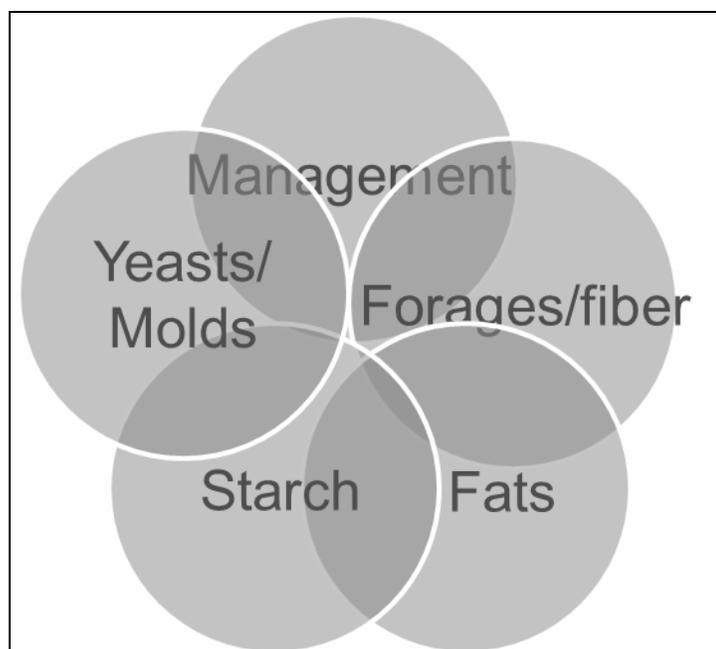


Figure 6. An alternative depiction of the interaction among individual factors associated with increased risk of MFD. Dark shaded areas of the circle represent interactions of one MFD risk factor with other MFD risk factors.

For example, cultures of rumen microorganisms were fed either a high corn or high barley diet along with the presence or absence of soybean oil (0 and 5%) and of the presence or absence of monensin (0 and 25 ppm). A lipid compound called *trans*-10 18:1 was monitored as a proxy for CLA_{MFI} (the production of the two are highly related and *trans*-10 was more reliably analyzed at the time of this study). The addition of soybean oil increased *trans*-10 18:1 concentrations in the cultures for both the corn and barley diets (Jenkins et al., 2003). To a lesser extent, monensin also increased *trans*-10 18:1 for both corn and barley. However, when monensin and soybean oil were both added to the diets the combination interacted. Adding monensin with soybean oil did not elevate *trans*-10 18:1 when the diet was corn-based. When the diet was barley-based, adding monensin with soybean oil elevated *trans*-10 18:1 more than either risk factor alone.

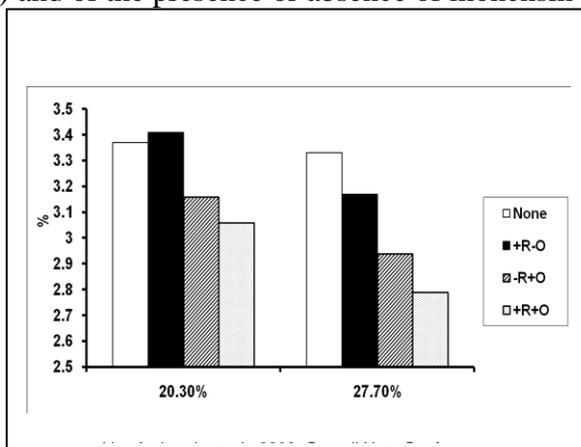


Figure 7. Milk fat percentages from cows fed low starch vs. high starch diets supplemented with monensin (R) or corn oil (O). From Van Amburgh et al. (2008).

A similar grain, monensin and fat interaction was examined in lactating dairy cows (Van Amburgh et al., 2008). Eighty Holstein cows were assigned either a high (27.7%) or low (20.3%) starch diet for 21 days, followed by the addition of monensin (13 ppm) or corn oil (1.25%) for an additional 21

day. Then, cows were switched to diets with opposite corn oil levels for a final 21 day period, providing eight treatments. Oil level was a higher risk factor for MFD compared to monensin: corn oil decreased milk fat from 3.32 to 2.99% versus 3.20% to 3.11% for monensin. Feeding high-starch diets had borderline effects on MFD: milk fat declined from 3.25 to 3.06%. Starch degradability may have contributed to MFD in this study because the diets contained steam-flaked corn, which has an inherently fast rate of rumen starch degradation. Therefore degradability, compounded by high dry matter intake, may be a more potent MFD risk factor than starch intake alone.

Take-Home Message

The breakthrough in MFD occurred with the discovery that it was linked to CLA production in the rumen. Feeding management controls MFD by limiting accumulation of CLA_{MFI} in the rumen. In general, no single dietary factor is responsible for MFD, and interactions among various dietary components can increase the rumen outflow of CLA_{MFI}. All risks have to be considered with regard to the combination of factors at play in a given ration formulation and with regard to the limitations of management and physical plant. Further research is required to better understand the rumen conditions that promote the formation of CLA_{MFI} that may trigger MFD. An improved understanding of these events will provide the critical framework with which to better troubleshoot MFD.

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Notes:

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