Genetically Modified Plants as Animal Feed

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Abstract

As a result of the ever increasing global population, the demands for food, fuel, feedstuffs, land, water, and global consequences of climate change bring a significant challenge to agriculture and its ability to produce products to meet these needs in a sustainable way. Livestock and poultry producers and farmers are continuing to look for ways to improve their farm enterprise's output, efficiency, and economic viability in an environmentally friendly manner. Producers must have feed ingredients and products available to them in sufficient quantities and quality at affordable prices. Biotechnology is the most promising tool available today to help meet these demands. The growing of biotech crops containing insect resistance and/or herbicide tolerance traits globally have already resulted in billions of dollars of benefits to farmers through increased yields and decreased costs of production. The environmental benefits include more efficient use of land for food and feed purposes, reduction in the volume of pesticides used, and reduction of carbon dioxide emission from reduced fuel use and soil carbon sequestration which is equivalent to removing millions of cars from the roads. Quality of feed ingredients will continue to improve with enhanced nutritional traits, reduced mycotoxins, and reduced anti-nutritional traits. A rigorous regulatory system is in place to assure that all commercial biotech products are as safe and wholesome as their conventional counterparts. In the future, plants will be genetically modified to be tolerant to drought and cold stress, saline conditions, resistance to a broader range of economic important insects and viruses, more efficient users of nitrogen, and contain enhanced traits such as lower lignin, altered amino acids/protein, altered fat and fatty acids, altered carbohydrates, increased levels of vitamins and minerals, and others including enzymes. In general, use of biotechnology in agriculture will be crucial in meeting global food and feed needs with increased yields, less inputs, improved efficiencies, and mitigation of negative environmental effects while providing significant economic benefits to the producer.

Introduction

With the world population likely to increase from 6.7 to 9.2 billion by 2050 (UN, 2007), the demand for food, fuel, feedstuffs, land, and water will present many challenges to agriculture. By 2020, the global meat demand is expected to increase by 58%; meat consumption is expected to increase from 233 million tons in 2000 to 300 million tons, milk consumption will increase from 568 to 700 million tons; egg production will increase by 30%; and poultry, beef and pig meat demand will increase by 85, 80, and 45%, respectively, from 1995 levels (FAO, 2004). The majority of the increase in demand will be in the developing countries. As a result of this increasing need for animal protein, the global demand for feedstuffs will be significant. The livestock, poultry and aquaculture industries will be faced with the challenge of meeting

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this demand for animal protein in a cost-effective, sustainable, and environmentally friendly way. During this time, the producer will need to overcome many challenges, including weather (climate change), water and land availability, labor, transportation, trade restrictions, politics, environmental issues (i.e., greenhouse gas emissions, waste disposal, nitrogen and phosphorus excretion, pesticide and herbicide use, carbon sequestration, and fossil fuel use), competition for resources (i.e., biofuels), animal health and diseases, food safety, and others. Much progress has been made in the past, but utilization of existing tools alone will not be adequate to meet the future demands. Smart and wise use of existing technologies, along with the creation and development of new ones, will need to occur in order to grow sufficient quantities and quality of grain, oilseeds, forages, and other food and feed products. Biotechnology is the most promising technology today to meet these needs.

What are Genetically Modified (GM) Plants

Plants can be modified by a variety of means. Traditional plant breeding modifies plants by selecting parental lines for a desired trait and cross-fertilizing them to produce offspring with the more desirable agronomic and/or nutritional value. Marker-assisted breeding is a relatively new technology for improving the rate of gain for yield and associated traits. Marker-assisted selection **(MAS)** is the most promising marker-assisted breeding tool. The MAS uses DNA markers that are tightly-linked to target loci (position of a gene on a chromosome) as a substitute for or to assist phenotypic screening. By determining the allele (one of several possible mutational forms of a gene at a given genetic locus) of a DNA marker, plants that possess particular genes or quantitative trait loci **(QTL)** may be identified based on their genotype rather than their phenotype. The fundamental advantages of MAS compared to conventional phenotypic selection include: 1) simpler compared to phenotypic screening; 2) selection may be carried out at seedling stage; and 3) single plants may be selected with high reliability (http://www.knowledgebank.irri.org/ricebreedingcourse/Marker_assisted_breeding.htm).

Biotechnology can be used as a more predictable, precise, and faster way to select specific native plant or exogenous genes that provide the plant with new genetic capabilities to tolerate herbicides, protect against insects and viruses, and enhance nutritional and health components. Biotechnology is defined as the application of (i) in vitro nucleic acid techniques, including recombinant deoxyribonucleic acid **(DNA)** and direct injection of nucleic acid into cells or organelles, or (ii) fusion of cells beyond the taxonomic family, that overcome natural physiological reproductive or recombination barriers and that are not techniques used in traditional breeding and selection. Genetically modified plants as used in this paper is defined as those plants derived from the use of biotechnology. Corn is a nice example of the progress in enhancing yield using various technologies. Little progress was made in the enhancement of corn yield using open pollination in the United States until about 1929 when double crossing was adopted. There were steady increases in corn yield to 1959 when it was further increased as a result of the adoption of single crossing. The advances up to this point in time were primarily due to traditional breeding. The rate of yield gain was then accelerated in 1996 with the adoption of genetically modified **(GM)** corn (Troyer, 2006). These significant step changes in yield will need to continue not only for corn but for other feed grains, oilseeds, and forages, as well utilizing a combination of technologies such as traditional breeding, marker-assisted breeding, biotechnology, no-till, and other agronomic practices.

Current GM Plant Biotech Traits in the United States

With a global market share of 50%, the United States is the largest producer of biotech crops in the world (James, 2008). In 2008, 154.4 million acres of biotech corn, soybeans, cotton, canola, sugar beet, alfalfa, papaya, and squash were grown in the US. The increase in biotech acres of 11.9 million between 2007 and 2008 was the largest among the 25 countries growing biotech crops. The US again demonstrated its leadership by being the first country to commercialize biotech sugar beets in 2008 on approximately 0.6 million acres.

In the United States, commercialized biotech crops include: herbicide-tolerant and/or insect-protected corn, cotton (87% of the upland cotton acreage), and potato; herbicide-tolerant soybeans (>90% of the acreage) , canola (> 90% of the acreage), alfalfa (~5% of the acreage) and sugar beet (~59% of the acreage); and virus-resistant squash and papaya (James, 2008). In 2008, Roundup Ready® sugar beets were first introduced into the US with a rapid adoption rate of an estimated 59%. Biotech crops are being offered with multiple traits to cover the tolerance to various herbicides and key economically significant insect pests. These traits include herbicide tolerance and various insect tolerance based on the insect of interest (European corn borer, ear worm, corn rootworm, etc.). Farmers have readily adopted the biotech crops with the stacked traits. As compared to 2007, in 2008 single traits in corn decreased from 37 to 22%, double traits decreased from 35 to 30%, and triple traits increased from 28 to 48% of the biotech corn acres. In cotton, 75% of the cotton biotech acres were planted in the stacked herbicide-tolerant and Bt (insect-protected) trait, 23% in the herbicide-tolerant trait, and 2% in the single Bt trait (James, 2008).

For a current listing of commercialized agricultural biotech products, the Biotechnology Industry Organization website should be viewed (http://www.biotradestatus.com/). This site allows a search for all commercialized products by crop, event name, trait provider (company), and country. Once the event is known, the specific gene that was inserted in the crop can be identified at the Biosafety Clearin-House link (http://bch.cbd.int/database/organisms/uniqueidentifiers/) or at the GM crop database at Agbios (http://www.agbios.com/dbase.php?action=ShowForm). The GM crop database at Agbios allows one to search by event name, crop plant, trait, inserted gene, type of approval, country, original developer, and any combination thereof. This site provides more detailed information on the summary of regulatory approvals, general description, introduced genetic elements, the donor organism, genetic modification method, characteristics of the genetic modification method used, environmental safety considerations, food and/or feed safety considerations, links to further information , and references. For example, Monsanto's triple stacked corn product contains the following events MON 810, MON 863, and NK603. Event MON 810 contains the *cry1Ab* gene from *Bacillus thuringiensis* subsp. *kurstaki* HD-1. The genetic modification affords resistance to attack by the European corn borer **(ECB)**, *Ostrinia nubilalis*. Event MON 863 confers resistance to corn root worm produced by inserting the *cry3Bb1* gene from *Bacillus thuringiensis* subsp. *kumamotoensis*. The neomycin phosphotransferase II (*npt II*) gene confers resistance to the antibiotic kanamycin. Event NK603 confers tolerance to the herbicide glyphosate, produced through introduction of (*cp4 epsps*) gene from *Agrobacterium tumefaciens* encoding 5-enolpyruvyl shikimate-3-phosphate synthase **(EPSPS)** from an enzyme involved in the shikimate biochemical pathway for the production of the aromatic amino acids.

Future GM Plant Biotech Traits

Meeting the demands for high auality animal feed

An increase in the demand for safe high quality feed ingredients will require more efficient use of the current agricultural land base, as well as utilizing marginal land in the future. Plant biotechnology has been successfully utilized in developing herbicide-tolerant traits, resulting in increased crop yields and reduced chemical weed control. The technology provided for the adoption of reduced/no tillage systems, resulting in decreased soil erosion and fossil -fuel use and reduction in greenhouse gases helping to mitigate climate change. Insect-protection traits have also been successfully developed, resulting in increased crop yields, reduced insecticide use and exposure to people and the environment, and higher quality crop product with reduced mycotoxins. Mycotoxins can have a significant negative effect on human and animal health as well as the economic implications in terms of both domestic markets and international trade (Wu, 2006). New traits, such as resistance to specific plant viruses, improved nitrogen utilization, and improved phosphorus utilization, will continue to increase yields and efficiencies while reducing the need for fertilizer and fossil fuel. Traits such as drought and salt tolerance will open up new land or enhance yields from marginal land, thereby helping to keep wetlands and forests from food production.

Improving plant products for animals is in progress with biotechnology being used to improve composition of plant carbohydrates, protein (amino acids), improve phosphorus availability, increase available energy through reduced oligosaccharides and /or lignin modification, increasing energy density, improving composition of lipid and fatty acids, minerals, vitamins and antioxidants, produce cost effective sources of enzymes such as phytase, and decrease anti-nutrients. For example, corn has been genetically modified to produce enhanced levels of free lysine (Lucas et al., 2007; Ufaz and Galili, 2008); lupin seeds were genetically modified to produce enhanced levels of sunflower 2S sulfur-rich albumins and thus methionine and cysteine (Ravindran et al., 2002; Ufaz and Galili, 2008); alfalfa was genetically modified to produce enhanced levels of methionine and cysteine (Avraham et al., 2005); and soybeans were genetically modified to produce enhanced levels of free tryptophan (Ufaz and Galili, 2008). Hancock and Viola (2005) discussed the possibilities of improving the nutritional value of crops through enhancement of L-ascorbic acid (Vitamin C). Using plant genetic modification techniques, soybeans could be developed that could improve animal growth efficiency, reduce phosphorus and nitrogen release into the environment to less than half of its present level, alleviate high levels of zinc and copper excretion, and allow removal of antibiotics from animal diets (Kerley and Allee, 2003). Digestible and metabolizable energy value of soybean meal could be improved up to 12% for monogastrics by removing oligosaccharides such as raffinose and stachyose (Graham et al., 2002). Plant biotechnology could also be used in developing products that benefit animal health and reproduction. For example, Humphrey et al. (2002) produced rice that was genetically modified to express human lactoferrin or lysozyme. Feeding a combination of lactoferrin and lysoyme to broiler chicks resulted in an antibiotic effect with improved feed efficiency and gut health.

Corn silage and alfalfa are the main forages fed in some countries, whereas, grasses are the main forages fed to ruminants in many world areas. Animal consumption of forages is a major contributor to green house gas production in agriculture. Therefore, targeting a more efficient digestion of the forage where less methane is produced would be a significant benefit. Biotech tools are available to up-regulate, down-regulate, or knock-out certain key enzymes in a metabolic pathway, insert new pathways, etc. through genetic manipulation. However, every metabolic alteration has consequences that need to be understood. If carbon is diverted towards the production of more starch, then there is less carbon for oil and protein production (e.g. corn plant). An understanding of the key metabolic pathways in plants and the genetic components that control and influence them will be crucial in developing improved forages. Using the tools of biotechnology, it may be possible to reduce or alter lignin for enhanced fiber digestibility; alter carbohydrates for improved microbial efficiency in the rumen and reduce its impact on fiber digestibility and ruminal pH; increase protein content, quality and amino acid balance; enhance digestible biomass; incorporate rate limiting digestive enzymes in the plant; and produce fermentation adjuvants in the plant that aid fermentation in the silo as well as in the rumen. The key is to identify those targets that will have the biggest economic impact to the livestock enterprise without sacrificing any of the key agronomic traits (Hartnell et al., 2005).

Meeting the demands for value-enhanced animal products

Providing a nutritional and healthful animal product to the consumer is the goal of the livestock, poultry, and aquaculture industries. Through plant biotechnology, feed ingredients may be enhanced such that a more nutritional and healthy animal product is achieved. Examples include: 1) altering the fatty acid composition of plant oils such that when consumed by animals the fatty acid composition of the animal is changed to a more nutritionally healthy profile (i.e., omega 3 fatty acids); and 2) enhancing the antioxidant capacity of meat enabling a longer shelf-life (e.g., Vitamin E) while providing anticancer attributes. Other potential targets include reducing human pathogen loads in animal-produced food products and creating foods for human consumption that promote weight loss, cardiovascular health, cancer prevention, and immune function (Kerley and Allee, 2003).

Safety of GM Plants

Government and international scientific organizations, including the Food and Agricultural Organization/World Health Organization of United Nations (FAO/WHO, 1991), Food and Drug Administration (FDA, 1992), Organization for Economic Co-operation Development (OECD, 1993), French Academy of Science (ADSF, 2002), and Society of Toxicology (SOT, 2003), have concluded that plant biotechnology does not pose any unique risk compared with other production methods. As with human food safety assessment, the safety assessment of livestock feed derived from a GM crop looks at the compositional, toxicological, and nutritional characteristics of the biotech feed in comparison with its conventional counterpart. This assessment includes the source of the gene, molecular characterization of the inserted DNA; history and safe use of the expressed protein, as well as its function, concentration, toxicology and mode of action; crop agronomic characteristics; and composition. For example, insect-protected proteins isolated from *Bacillus thuringiensis* (Bt) have been registered for use as microbial insecticides since 1961. The microbial Bt formulations contain Cry proteins (Cry is an acronym for crystalline protein inclusions) that have an exemplary safety record following 40 years of use in agriculture (Betz et al., 2000). There were at least 180 registered microbial Bt products in the U.S. (EPA, 1998).

All commercially approved GM products containing insect protection or herbicide tolerance traits are substantially equivalent to their conventional counterparts. In addition, no difference in animal performance, health, or animal product (meat, milk, or eggs) composition were observed in numerous livestock feeding studies conducted globally (Flachowsky et al., 2005, 2007). There are over 180 references in the literature reporting results and/or reviewing studies covering the feeding of crops containing insect-protected and/or herbicide-tolerant traits to animals (poultry, swine, beef cattle, dairy cattle, sheep, water buffalo, fish, and rabbits), all concluding nutritional wholesomeness (see http://www.fass.org/page.asp?pageID=43).

Consumer groups have asked whether direct human consumption of the DNA or protein in plant biotech products impacts human health and whether human consumption of animal products (e.g.

meat, milk or eggs) from farm animals fed the biotech crops are safe. The United Nations FAO and WHO (1991), US FDA (1992) and EPA (US EPA, 2000) have each stated very clearly that the consumption of DNA from all sources (including plants improved through biotechnology) is safe, given the long history of safe consumption of DNA. Beever and Kemp (2000), Beever and Phipps (2001), and Jonas et al. (2001) have discussed the *in vivo* fate of DNA and concluded that there is a growing body of scientifically valid information available indicating no significant risk associated with the consumption of DNA or expressed proteins associated with GM crops. Even though DNA (plant, animal, microbial, etc.) has been consumed from the beginning of mankind without any adverse consequences, studies were conducted in an attempt to detect fragments of the transgenic DNA in milk, meat and eggs from animals that had been fed GM crops. Also, measurement of transgenic protein was attempted in these same tissues in spite of data showing the rapid digestion of these proteins in simulated gastric conditions. To date, all studies have shown that transgenic proteins and DNA have not been detected in meat, milk or eggs from animals fed GM crops (CAST, 2006). Over, 13 years of feeding transgenic crops to livestock in the US has further confirmed the safety of these products with no adverse effects having been documented. Recently the Council for Agricultural Science and Technology commissioned a task force to examine the safety of meat, milk and eggs from animals fed crops derived from plant biotechnology (CAST, 2006). The task force concluded "*The regulatory processes in place to assess the safety of biotechnology-derived crops have been effective in safeguarding public health. To date, there has been no authenticated case of an adverse health-related incident associated with the consumption of food or feed derived from modern biotechnology. The review of the currently available data concludes that meat, milk, and eggs produced by farm animals fed biotechnology-derived crops are as wholesome, safe, and nutritious as similar products derived from animals fed conventional crops.*"

Global Status of GM Crops

According to James (2008), the 2008 global area of GM crops continued to grow at the rate 15% per year for trait hectares (one hectare equals 2.47 acres) and 9.4% per year for actual hectare. In 2008, 309 million acres were planted by 13.3 million farmers (over 90% being small poor-resource farmers from developing countries) in 25 countries, 26 million acres more than in 2007. This rapid adoption since 1996 makes biotech crops the fastest adopted crop technology. In addition, another 30 countries have approved import of biotech products for food and feed for a total of 55 approving countries. Last year alone, five new countries (Egypt, Burkino Faso, Boliva, Brazil, and Australia) have introduced biotech crops for planting that have been approved in other countries. Even though the political hurdles in the European Union **(EU)** are high for biotech products, all seven EU countries planting Bt corn increased their acreage in 2008 with an overall increase of 21% which illustrates the positive benefits that are seen by the farmer. The global value of the biotech crop market in 2008 reached US$7.5 billion, representing 14% of the US$52.72 billion global crop protection market in 2008 and 22% of ~US$34 billion global commercial seed market (James, 2008).

Socio-Economic Benefits of Biotechnology

The rapid adoption of biotech crops is a result of the benefits realized by the producer. These include increased yields, improved crop quality, convenience, improved integrated pest management, reduced insecticide use and exposure, reduced chemical weed control, reduced mycotoxins in corn, providing for the adoption of reduced/no tillage systems resulting in decreased soil erosion and fossil -fuel use, reduction in greenhouse gases helping to mitigate climate change, and a significant impact on farm income (Brookes and Barfoot, 2008). In 2006, the increase in farm income was US$6.9 billion (herbicide-tolerant soybeans, US$3.08 billion; herbicide-tolerant corn, US$0.30 billion; herbicide-tolerant cotton, US$0.02 billion; herbicide-tolerant canola, US$0.23 billion; insect-protected corn, US$1.13 billion; insect-protected cotton, US$2.15 billion; other, US$0.03 billion), and for the period of 1996 through 2006, the increase in farm income totaled US$33.8 billion. The benefits seen with soybeans and canola were primarily from cost savings; whereas, a combination of higher yields and lower costs were seen with corn and cotton. Developing countries had farm income benefits in 2006 totaling US$3.7 billion, as compared to US$3.2 billion in developed countries. The total cost of the technology to all farmers in 2006 was US$2.69 billion with an income gained of US$6.92 billion, resulting in a total benefit of the technology to farmers and the seed supply chain of US$9.60 billion (Brookes and Barfoot, 2008).

Environmental Benefits of Biotechnology

There have been significant environmental benefits with the adoption of biotechnology (Brookes and Barfoot, 2008; James, 2008). There has been a 15.4% overall net reduction in the environmental impact on the cropping area devoted to GM crops since 1996 associated with herbicide and insecticide use of which a 7.9% reduction was due to decreased use of active pesticide ingredient. Herbicide-tolerant soybeans contributed the most to the reduction based on the large area of land in which the technology is utilized. The volume of herbicides used in GM soybean crops decreased by 62.4 million kg (137 million lb) over the 1996 to 2006 time period, resulting in a 20.4% overall environmental impact reduction. Indirect benefits included switching away from conventional tillage to reduced- or no-tillage systems resulting in decreased greenhouse gases, reduced soil erosion, decreased fossil fuel usage, and increased carbon sequestration. Adoption of insect-protected cotton also contributed significantly to the environmental impact. Since 1996, farmers have reduced their insecticide use by 22.9% [128.4 million kg (282.5 million lb)] or a 24.6% reduction in the environmental impact factor. Likewise, adoption of GM corn and GM canola have also resulted in a 9.9 and 24.2%, reduction, respectively, in the environmental impact associated with herbicide and insecticide use.

Adoption of GM crops significantly impacted greenhouse gas emissions between 1996 and 2006 (Brookes and Barfoot, 2008; James, 2008). In 2006, the permanent carbon dioxide savings arising from reduced fuel use was 1.2 million kg (2.64 million lb) equating to removing 540,185 cars from the road each year. The additional carbon sequestration gained from reduced tillage resulted in a reduction of 13.5 million kg (29.7 million lb) of carbon dioxide emissions per year or the removal of 6,021,604 cars from the road yearly.

Conclusion

The adoption of biotech crops has proven to be effective in deriving socio-economic and environmental benefits to the producer and consumer. Now and in the future, the use of biotechnology in agriculture will be crucial in meeting global food and feed demands with increased yields, less inputs, improved efficiencies, and mitigation of negative environmental effects while providing significant economic benefits to the producer and consumer.

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Potential of Using New Technology for Estimating Body Condition Scores

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Abstract

Although the benefits of body condition scoring **(BCS)** are intuitive to most dairy industry professionals, relatively few dairy farms have incorporated it as part of their routine management strategy. The lack of adoption of this technique is largely attributable to subjectivity and time requirements. An automated BCS system would be less demanding of time by trained personnel, less stressful to cattle, more objective and consistent, and possibly more cost effective. The technical feasibility of utilizing digital images (IceScore, Ice Robotics Ltd., Midlothian, UK) to determine BCS was assessed for lactating dairy cows at the Scottish Agricultural College **(SAC)** Crichton Royal Farm. Up to 23 anatomical points were manually identified on dorsal images (N = 3332) captured automatically from above as cows passed through a weigh station. All identifiable points were utilized to define and formulate measures describing the cow's contour. Hook angle and posterior hook angle were significant predictors of BCS ($P < 0.05$), and 100% of predicted BCS were within 0.50 points of actual BCS and 93% were within 0.25 points. The economic feasibility of investment in an automated BCS system was also explored using a dynamic, stochastic simulation dairy model designed to examine investments in dairy intervention technologies. The model was created in Microsoft Excel using the @Risk add-in to consider the stochastic nature of key variables with Monte Carlo simulation. Benefits of the BCS system were considered by estimating potential improvements resulting from technology adoption through reduced disease incidence, reduced days open, and increased energy efficiency. The simulation resulted in a series of net present values used to identify the probability of observing a positive net present value. Future efforts should explore ways to facilitate extraction of information from images automatically using a larger number of animals to accurately predict scores of cows across all levels of BCS. With further development and refinement, automated BCS may become an integral part of decision making on modern dairy farms with applications in nutrition, genetics, and animal well-being.

Introduction

Although the benefits of regular BCS are intuitive to most dairy producers, nutritionists, and consultants, relatively few dairy farms have incorporated it as part of their dairy management strategy (Hady et al., 1994). There are many reasons for the lack of adoption of this system, mostly related to its subjectivity and the time commitment required. These concerns have led to a search for alternative means of assessing body energy reserves in cattle. Coffey et al. (2003) proposed that automatic recording of BCS would increase its usefulness for dairy herd management and conjectured that BCS obtained from images could be at least as good, if not better than, traditional BCS at assessing body lipid content.

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Despite success with other species, few research groups have approached the idea of automatic body condition scoring in dairy cattle (Coffey et al., 2003; Leroy et al., 2005; Pompe et al., 2005). An automated BCS system would be preferred to observational scoring because it would require less time, be less stressful on the animal, be more objective and consistent, and possibly more cost effective (Leroy et al., 2005). Thus, we set out to explore the technical and economic feasibility of automation of BCS using digital images.

Materials and Methods

Digital imaging

Data for this study were collected at the Scottish Agricultural College Crichton Royal Farm in Dumfries, Scotland, UK from September to November 2006 (Bewley et al., 2008). Scores were obtained weekly using 2 different BCS systems which are the primary systems utilized within the United Kingdom (Lowman et al., 1976; Mulvany, 1977) and the United States (Edmonson et al., 1989; Ferguson et al., 1994). The Lowman/Mulvany **(UKBCS)** system involves palpation of specific body parts using a 0 to 5 scale with 0.25 intervals. The Edmonson/Ferguson **(USBCS)** system is based entirely upon visual assessment using a 1 to 5 scale with 0.25 intervals. The UKBCS were assessed by 2 experienced employees of the farm in a permanent weigh station as cows left the milking parlor following the a.m. milking. The USBCS were assessed by a visiting scientist from the United States trained in BCS using the flowcharts developed by Ferguson et al. (1994). Within-cow outliers were removed for both systems by comparing BCS obtained during the successive week. After these edits, means were 2.12 (± 0.35) and 2.89 (± 0.40), modes were 2.25 and 2.75, and ranges were 1.0 to 3.5 and 1.5 to 4.5 for the UKBCS (n = 2346) and USBCS (n = 2571), respectively.

Black and white images were collected using a digital camera placed above the permanent weigh station. The camera pointed downward toward and approximately 60 to 70 cm above the cows' backs. The camera was stationary and remained at the same height throughout the duration of the project. The weigh station was located in an exit alley from the parlor within an enclosed barn with minimal artificial lighting. When the rear gates of the weigh station closed after cow entry, the camera was triggered to capture an image from the cow in the station. Relative to collection of subjective BCS on the day of the week where scores were collected, image collection occurred simultaneously with UKBCS and prior to USBCS. Images were identified with a timestamp and stored for subsequent analysis. Image timestamps were matched with weigh station timestamps to identify the cows being photographed. Although the herd was milked 3 times per day, images were generally only available for the early p.m. milking because of lighting limitations at the a.m. and late p.m. milkings.

Twenty-three anatomical points, corresponding to identifiable features, were classified for potential influence on BCS (Figures 1 and 2). A computer program was created to identify these points on the collected images. With this program, image files are loaded, and points are identified manually and visually with the click of a computer mouse. When the point has been identified, an x/y coordinate corresponding to this point is recorded in a separate text file. If a point is not discernible on a particular image, that point is set to missing. Any image where both hooks were not clearly visible was considered to be of insufficient quality and no points were recorded. Points were selected moving clockwise around the cow, starting with the left forerib (facing the cow) and ending with the right forerib. An edit was performed on the data to remove any points that did not follow this pattern. When all 23 points were identified, the x/y coordinates created an outline of the cow (Figure 2). Distances between points on opposite sides of the cow were calculated (e.g. right hook to left hook) as measures of width at various points. These points were also used to calculate angles reflecting the shape of the contour of the cow. Fifteen angles around the hooks, pins, and tailhead were calculated when points were available in this manner (Figure 3).

For each image, 7 composite anatomical angles were calculated using the mean of opposing angles from the cow's left and right sides. For example, a composite hook angle was calculated as the average of left and right hook angles. Similarly, a coefficient of variation was calculated corresponding to each of the composite angles for each image. Cutoff values for outlier removal of these composite angles were created using the mean ± 3 standard deviations **(SD)** of these coefficients of variation across the entire data. When the coefficient of variation corresponding to an individual image composite angle was greater than or less than these cutoff values, the respective composite angle was removed. The objective of this edit was to remove angles where the left and right angles were considerably different, likely indicative of the cow standing diagonally within the weigh station, a poor quality image, or gross errors in point identification.

A weekly average of each composite angle, along with tailhead angle, was calculated for each cow/week combination. Weekly averages with less than 2 composite hook angles were removed from the data set prior to model creation. The MIXED procedure of SAS® (Cary, NC) was used to analyze models for prediction of BCS using the angles obtained from the images. These models were performed as a repeated measures analysis with variables repeated by week with cow as the random subject. All composite angles were considered in preliminary models, but only effects significant at $P < 0.05$ are included in the models reported here. The model included 834 and 767 observations for USBCS and UKBCS, respectively.

Economic analysis

A simulation model of a dairy enterprise was developed to evaluate the economics of investments in Precision Dairy Farming technologies by examining a series of random processes over a 10-year period. The model was designed to characterize the biological and economical complexities of a dairy system within a partial budgeting framework by examining the cost and benefit streams coinciding with investment in a Precision Dairy Farming technology. Although the model currently exists only in a research form, a secondary aim was to develop the model in a manner conducive to future utility as a flexible, farm-specific decision making tool. The basic model was constructed in Microsoft Excel 2007 (Microsoft, Seattle, WA). The @Risk 5.0 (Palisade Corporation, Ithaca, NY) add-in for Excel was utilized to account for the random nature of key variables in a Monte Carlo simulation. In Monte Carlo simulation, random drawings are extracted from distributions of multiple random variables over repeated iterations of a model to represent the impact of different combinations of these variables on financial or production metrics (Kristensen and Jorgensen, 1998). The basic structure of the model is depicted in Figure 4.

The underlying behavior of the dairy system was represented using current knowledge of herd and cow management with relationships defined from existing literature. Historical prices for critical sources of revenues and expenses within the system were also incorporated as model inputs. The flexibility of this model lies in the ability to change inputs describing the initial herd characteristics and the potential impact of the technology. Individual users may change these inputs to match the conditions observed on a specific farm.

After inputs are entered into the model, an extensive series of intermediate calculations are computed within 13 modules, each existing as a separate worksheet within the main Excel spreadsheet. Each module tracks changes over a 10-year period for its respective variables. Within these inter-connected modules (Figure 5), the impact of inputs, random variables, and technology-induced improvements are estimated over time using the underlying system behavior within the model. Results of calculations within one module often affect calculations in other modules with multiple feed-forward and feed-backward interdependencies. Each of these modules eventually results in a calculation that will influence the cost and revenue flows necessary for the partial budget analysis. Finally, the costs and revenues are utilized for the project analysis examining the net present value **(NPV)** and financial feasibility of the project along with associated sensitivity analyses.

Agricultural commodity markets are characterized by tremendous volatility, and in many countries, this volatility is increasing with reduced governmental price regulation. As a result, economic conditions and the profitability of investments can vary considerably, depending on the prices paid for inputs and the prices received for outputs. Producers are often critical of economic analyses that fail to account for this volatility by using a single value for critical prices, recognizing that the results of the analysis may be different with higher or lower milk prices, for example. In a simulation model, variability in prices can be accounted for by considering the random variation of these variables. In this model, historical U.S. prices from 1971 to 2006 for milk, replacement heifers, alfalfa, corn, and soybeans were collected from the "Understanding Dairy Markets" website (Gould, 2007). Historical cull cow prices were defined using the USDA-National Agricultural Statistics Service values for "beef cows and cull dairy cows sold for slaughter" (USDA-NASS, 2007). Base values for future prices (2007 to 2016) of milk, corn, soybeans, alfalfa, and cull cows were set using estimates from the Food and Agricultural Policy Research Institute's (FAPRI) U.S. and World Agricultural Outlook Report (FAPRI, 2007). Variation in prices was considered within the simulation based on historical variation. In this manner, the volatility in key prices can be considered within a profitability analysis.

Although there is probably no direct way to account for the many decisions that ultimately impact the actual profitability of an investment in a Precision Dairy Farming technology, this model includes a Best Management Practice Adherence Factor **(BMPAF)** to represent the potential for observing the maximum benefits from adopting a technology. The BMPAF is a crude scale from 1 to 100% designed, to represent the level of the farm management. At a value of 100%, the assumption is that the farm management is capable and likely to utilize the technology to its full potential. Consequently, they would observe the maximum benefit from the technology. On the other end of the spectrum, a value of 0% represents a scenario where farm management installs a technology without changing management to integrate the newly available data in efforts to improve herd performance. In this case, the farm would not recognize any of the benefits of the technology. Perhaps most importantly, sensitivity analyses allow the end user to evaluate the decision with knowledge of the role they play in its success.

Investment analysis of automated body condition scoring

The model was used for an investment analysis of the proposed system for automatically monitoring BCS on dairy farms. The primary objective of this effort was to identify the factors that influence the potential profitability of investing in an automated BCS system. An expert opinion survey was conducted to provide estimates for potential improvements associated with technology adoption. Benefits of technology adoption were estimated through assessment of the impact of BCS on the incidence of ketosis, milk fever, metritis, conception rate at first service, and energy efficiency.

For this research example, industry averages for production and financial parameters, selected to represent conditions for a U.S. dairy farm milking 1000 cows in 2007 were used.

The NPV was the metric used to assess the profitability of the investment. The default discount rate of 8% was adjusted to 10% because this technology has not been marketed commercially, thus the risk for early adopters of the technology is higher. The discount rate partially accounts for this increased risk by requiring higher returns from the investment. The general rule of thumb is that a decision with a NPV greater than 0 is a "go" decision and a worthwhile investment for the business. The investment at the beginning of the project includes the purchase costs of the equipment needed to run the system in addition to purchasing any other setup costs or purchases required to start the system. Recognizing that a simpler model ignores the uncertainty inherent in a dairy system, Monte Carlo simulation was conducted using the @Risk add-in. This type of simulation provides infinite opportunities for sensitivity analyses. Simulations were run using 1000 iterations in each simulation. Simulations were run using estimates provided by experts for scenarios with little to no improvement in the distribution of BCS and with definite improvement.

Results and Discussion

Digital imaging

Because of problems with lighting or setup limitations with the experimental equipment, usable images were available only for 46 of 61 possible days. The average number of usable images per day was 72.44 with a SD of 42.91 and a range of 6 to 149. Usable images were available for 242 different cows. On average, there were 13.77 images per cow with a SD of 8.59 and a range of 1 to 38. The primary reason for deeming an image as non-usable was lighting because there was simply not enough contrast between the background and the cow's body to identify anatomical landmarks. This issue was more prominent for cows that were predominantly black; predominantly white cows were much easier to identify. There were also issues with regard to cow position beneath the camera. In some cases, an image was taken of either the front or rear quarter of the cow, preventing assessment of the anatomical points of interest. Cows standing at an angle within the weigh station were also a problem. Tails moving within images and dirt also prevented some images from being used.

Correlations were calculated between USBCS and UKBCS and weekly composite angles. All correlations of composite angles with USBCS were significantly different from zero ($P < 0.01$). Correlations with UKBCS were significantly different from zero ($P < 0.02$) for all composite angles except tail angle. The hook posterior angle ($r = 0.5239$), hook angle ($r = 0.4834$), and tailhead depression ($r = 0.3104$) had the strongest correlations with USBCS. The hook posterior angle ($r = 0.4601$), hook angle ($r = 0.3301$), hook anterior curvature ($r = 0.1984$), and tailhead depression ($r = 0.1856$) had the strongest correlations with UKBCS. Although the correlations of USBCS and UKBCS with the hook anterior angle were moderate ($r = 0.2459$ and 0.1416, respectively), they were not nearly as strong as with hook posterior angle. This demonstrates that the cow is more likely to deposit fat in the area between the hooks and thurls than around the short ribs.

For each angle, a trend of increasing angle size with increasing BCS was observed for both systems. In other words, as BCS increases, the angle flattens toward a straight line (180°). For hook angle and hook posterior angle, this indicates that the hooks are less sharp or prominent with increasing BCS. In fact, this is similar to the descriptions that Ferguson et al. (1994) use within their flowchart distinguishing between round or angular hooks. For the tailhead depression, this indicates that the angle reflecting the depression around the tailhead changes as this region fills with body reserves. This corresponds to the use of the coccygeal (tailhead) ligament within the Ferguson et al. (1994) flowchart. Another way of describing these changes is that the degree of "boniness" changes as the level of fat varies (Coffey et al., 2003). These results support our hypothesis that BCS is reflected in angles around the hooks and rump as measured using digital images.

The primary objective of this work was to develop models to describe BCS using this information obtained from the collected digital images. For the USBCS model, 100% of predicted BCS were within 0.50 points of actual BCS and 92.79% were within 0.25 points. For the UKBCS model, 99.87% of predicted BCS were within 0.50 points of actual BCS and 89.95% were within 0.25 points. These results were similar to those of Leroy et al. (2005) who found, on a series of 32 test images, the deviation between the calculated score and a BCS assessed by an expert was 0.27. In lactating buffalo, Negretti et al. (2008) reported differences of 0.21, 0.26, and 0.27 units between subjectively evaluated BCS using a 1 to 9 scale and calculated BCS using 3 different equations. However, the range of scores of animals in this study was fairly narrow (5 to 8). Ferguson et al. (1994) found that human observers agreed with a modal BCS of 4 observers 58.1% of the time and varied by only 0.25 units 32.6% of the time. Thus, BCS changes of 0.25 cannot realistically be detected, even with trained observers. In our data set, the agreement between subjective BCS and BCS as predicted by image analysis was similar to the expected difference between 2 different subjective BCS observers.

Examples of images from a thin and a fat cow (Figure 6) demonstrate visually the difference in the contours of animals of varying BCS. The thin cow's hooks are much more prominent and pronounced than those of the fat cow, and this is reflected in the difference in the angles measured from these images. Further, the depression around the tailhead is more pronounced. Predicted scores from these models against actual scores for both systems are depicted in Figure 7. In models predicting both USBCS and UKBCS, the residuals increase in magnitude with increasing BCS. In effect, these models over-predict the BCS of thin cows and under-predict the BCS of fat cows. This result should not be surprising given that in a well-managed herd, such as the one used in this study, few cows score at either extreme of the BCS scale. Thus, this result is likely reflective of inadequate data from cows with particularly low or high BCS to properly predict their BCS using images.

Future efforts in this area should strive to work in large herds where, even in a normal distribution, more cows in extreme categories will exist or in herds with an unusual number of thin and fat cows. The ability to identify thin and fat cows is imperative for successful on-farm adoption of automated BCS as this is where the real value of BCS lies. The largest benefits in body condition scoring result from using information about why cows are outside of the optimal BCS range for their respective parity and stage of lactation to improve herd nutritional management strategies.

Limitations and future considerations

If images were consistently available on a daily basis for all cows, models could be improved through the use of more stringent outlier removal strategies. With 7 images in a week, an image with angles that clearly deviated from the other images during that week could be removed prior to assignment of a predicted BCS. Unfortunately, using such strict rules in this small data set would have removed too many images, resulting in only a small pool of images for model development. Future research efforts should focus on ways of obtaining images more frequently using a larger number of animals across a wider range of scores to improve upon the relationships demonstrated here. Because of the short duration of this project, we were unable to determine if the measured angles changed within cows, reflecting the changes expected in a cow's BCS during a lactation. Before technology adoption, it is essential to establish that this important pattern is reflected using images from cows followed through complete lactations.

Another limitation to consider is potential error in identifying the anatomical points of interest. The human eye and hand are subject to some degree of error. Furthermore, the anatomical points chosen do not necessarily all correspond to an obvious visual clue. Similarly, the USBCS were provided by one evaluator and the UKBCS by 2 evaluators. Consequently, subjectivity and human error limit the value of collected BCS as predictors in the developed models.

An automated method of point extraction may prove superior to this manual extraction technique. While previous work has focused primarily on images of the rear of the cow (Coffey, 2003; Leroy et al., 2005, Pompe et al., 2005), this research focused on a top-down view of the cow. To gain a better perspective of the cow's anatomy, it may be necessary to combine these 2 approaches, possibly aiming for a 3-dimensional view of the animal.

In the models presented here, the number of angles (2 to 3) used in prediction equations is relatively limited. Edmonson et al. (1989) stated that a score from a single area is a good indication of overall BCS. However, observational BCS involves assimilation of information about multiple visual cues of the cow by the human brain. Whether 2 to 3 points will provide a sufficient representation of overall energy reserves remains to be determined. Perhaps, more accurate algorithms could be developed, compiling information from additional geometrical calculations. Although not possible with the images in this data set, it would be beneficial if adjustment could be made for differences in cow size and posture (Leroy et al., 2005).

While the results of this study demonstrate a clear relationship between angles calculated using digital images and BCS, this relationship may or may not imply a relationship with actual body fat content. Estimates as to the degree with which BCS represents actual body fat have varied considerably with correlation coefficients of 0.57 to 0.90 (Wright and Russel, 1984; Otto et al., 1991; Waltner et al., 1994). Although BCS is used as the "gold standard" for assessing body energy reserves, it is not a perfect measure of energy reserves and is limited by its subjectivity. Future efforts should attempt to define how BCS obtained from image analysis reflects actual body fat in addition to subjective BCS. Initially, this may be accomplished using a more objective measurement of energy reserves, such as ultrasound. However, with a goal of determining the amount of fat within an animal's body, the highest degree of accuracy can be obtained only in a post-slaughter chemical analysis of the entire body with contents of the digestive and urinary tracts removed (Otto, 1990). It may also be useful to measure the angles around the hooks and pins used in this study on live animals to compare with angles calculated using image analysis.

Profitability analysis

In a simulation with a small likelihood of improvement in BCS distribution, 12.6% of simulation iterations resulted in a positive NPV, whereas this same number was 86.6% for the scenario with a definite improvement in BCS distribution. In other words, using the model assumptions for an average 1000-cow U.S. dairy in 2007, investing in an automated BCS system was the right decision 12.6 or 86.6% of the time, depending on the assumption of what would happen with BCS distribution after technology adoption. The individual decision maker's level of risk aversion would then determine whether they should make the investment. Although this serves as an example of how this model could be used for an individual decision maker, this profitability analysis should not be taken literally. In reality, an individual dairy producer would need to look at this decision using herd-specific variables to assess the investment potential of the technology. The main take home message from these simulations was that because results from the investment analysis were highly variable, this technology is certainly not a “one size fits all” technology that would prove beneficial for all dairy producers.

Sensitivity analyses

The primary objective of this research was to gain a better understanding of the factors that would influence the profitability of investing in an automated BCS system through sensitivity analysis. Sensitivity analysis, designed to evaluate the range of potential responses, provides further insight into an investment analysis (van Asseldonk et al., 1999). In sensitivity analyses, tornado diagrams visually portray the effect of either inputs or random variables on an output of interest. In a tornado diagram, the lengths of the bars are representative of the sensitivity of the output to each input. The tornado diagram is arranged with the most sensitive input at the top, progressing toward the least sensitive input at the bottom. In this manner, it is easy to visualize and compare the relative importance of inputs to the final results of the model. Improvements in reproductive performance had the largest influence on revenues, followed by energy efficiency and then by disease reduction. Random variables that had the most influence on NPV were as follows: variable cost increases after technology adoption; the odds ratios for ketosis and milk fever incidence and conception rates at first service associated with varying BCS ranges; uncertainty of the impact of ketosis, milk fever, and metritis on days open, unrealized milk, veterinary costs, labor, and discarded milk; and the change in the percent of cows with BCS at calving d” 3.25 before and after technology adoption. Scatter plots of the most sensitive random variables plotted against NPV, along with correlation coefficients, demonstrate how random variables impact profitability. In both simulations, the random variable that had the strongest relationship with NPV was the variable cost increase. Not surprisingly, as the variable costs per cow increased; the NPV decreased in both simulations (Figure 8). Thus, the value of an automated BCS system was highly dependent on the costs incurred to utilize the information provided by the system to alter nutritional management for improved BCS profiles.

Finally, the results of any simulation model are highly dependent on the assumptions within the model. A one-way sensitivity analysis tornado diagram compares multiple variables on the same graph. Essentially, each input is varied (1 at a time) between feasible high and low values, and the model is evaluated for the output at those levels, holding all other inputs at their default levels. On the tornado diagram, for each input, the lower value is plotted at the left end of the bar and the higher value at the right end of the bar (Clemen, 1996). Simulations were run for high and low feasible values for 6 key inputs that may affect NPV. The tornado diagram for the 95th percentile NPV from the simulation with a small likelihood of improvement in BCS distribution is presented in Figure 9. Herd size had the most influence on NPV. The NPV was higher for the larger herd because the investment costs and benefits were spread among more cows.

The next most important variable was the BMPAF. Again, this result was not surprising and reiterates that one of the most important determinants of project success was what the producer actually does to manage the information provided by the technology. There are many nutritional, health, reproductive, and environmental decisions made by the dairy producer that have a major impact on changes in body reserves for both individual cows and groups of cows. Management level plays a critical role in determining returns from investing in a Precision Dairy Farming technology. The level of management in day-to-day handling of individual cows may also influence the impact of Precision Dairy Farming technologies. Van Asseldonk (1999) defined management capacity as "having the appropriate personal characteristics and skills to deal with the right problems and opportunities in the right moment and in the right way." Effective use of an information system requires an investment in human capital in addition to investment in the technology (Streeter and Hornbaker, 1993). Then, the level of milk production was the next most sensitive input. As the level of milk production increased, the benefits of reducing disease incidence and calving intervals increased. As would be expected, the NPV increased with an increased base incidence of ketosis because the effects of BCS on ketosis would be exaggerated. The purchase price of the technology had a relatively small impact on the NPV, as did the base culling rate.

Conclusion

The potential applications for automated body condition scoring are immense. This research builds upon the work of Coffey (2003), demonstrating the potential for the use of digital images in assessing BCS of dairy cattle. In our work, there appears to be a strong relationship between the angles measured and BCS as determined by trained evaluators. Clearly, the manual identification of points is not feasible beyond labor-intensive research studies. Although the tailhead information did not add much value to predictive models in this study, the potential for using this information to supplement hook descriptions should be explored further in future work. Finally, future studies should place strong emphasis on selecting herds with ample numbers of cows with low and high BCS to ensure that automated scoring systems accurately detect these critically important animals.

Because of limitations related to lighting and separation of the cow image from the background of the image, standard digital photography may not function well in an automated system. Rather, other technologies, such as thermal imaging, should be explored to facilitate automatical extraction of information from images. Arias et al. (2004) successfully demonstrated how digital image processing and neural networks could be used for automatic extraction of morphological descriptions of a cow's body using differences in color within an image. As these imaging technologies are applied to other industries, costs of these technologies will continue to decrease. Similarly, computer storage limitations are no longer a major concern. Once the aforementioned technical difficulties are overcome, automated BCS may become an integral part of decision making on modern dairy farms.

Precision Dairy Farming technologies provide tremendous opportunities for improvements in individual animal management on dairy farms. Formal investment analyses can help producers in deciding which technologies should be purchased. Dairy producers and consultants are accustomed to seeing results from more simple economic analyses that present investment decisions as "black and white" or "good or bad" scenarios. In reality, very few economic decisions for dairy farms are that clear-cut. Examining decisions with a simulation model accounts for more of the risk and uncertainty characteristic of the dairy system. Given this risk and uncertainty, a random investment analysis will represent that there is uncertainty in the profitability of some projects. Ultimately, the dairy manager's level of risk aversion will determine whether or not he or she invests in a technology using the results from this type of analysis. Perhaps the most interesting conclusion from this research was that the factors that had the most influence on the profitability investment in an automated BCS system were those related to what happens with the technology after it has been purchased, as indicated by the increase in variable costs needed for management changes and the management capacity of the farm. Decision support tools, such as this one, that are designed to investigate dairy herd decisions at a systems level may help dairy producers make better decisions.

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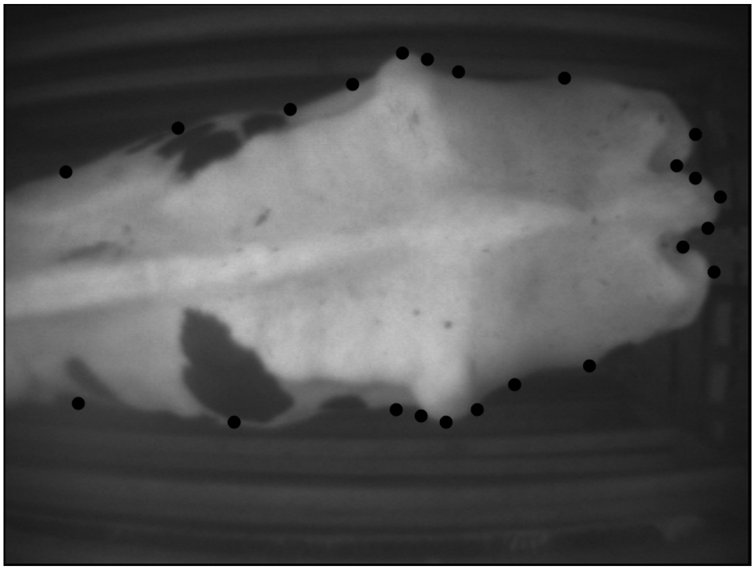

Figure 1. Twenty-three key anatomical points identified (where possible) for each image (Bewley et al., 2008).

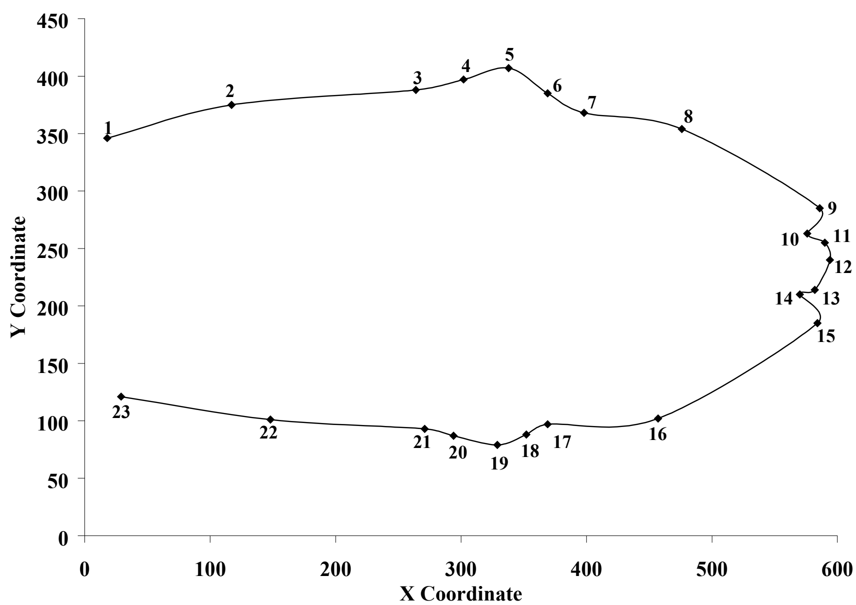

Figure 2. Sample cow outline using 23 key anatomical points [(1) Left Forerib, (2) Left Short Rib Start, (3) Left Hook Start, (4) Left Hook Anterior Midpoint, (5) Left Hook, (6) Left Hook Posterior Midpoint, (7) Left Hook End, (8) Left Thurl, (9) Left Pin, (10) Left Tailhead Nadir, (11) Left Tailhead Junction, (12) Tail, (13) Right Tailhead Junction, (14) Right Tailhead Nadir, (15) Right Pin, (16) Right Thurl, (17) Right Hook End, (18) Right Hook Posterior Midpoint, (19) Right Hook, (20) Right Hook Anterior Midpoint, (21) Right Hook Start, (22) Right Short Rib Start, and (23) Right Forerib] (Bewley et al., 2008).

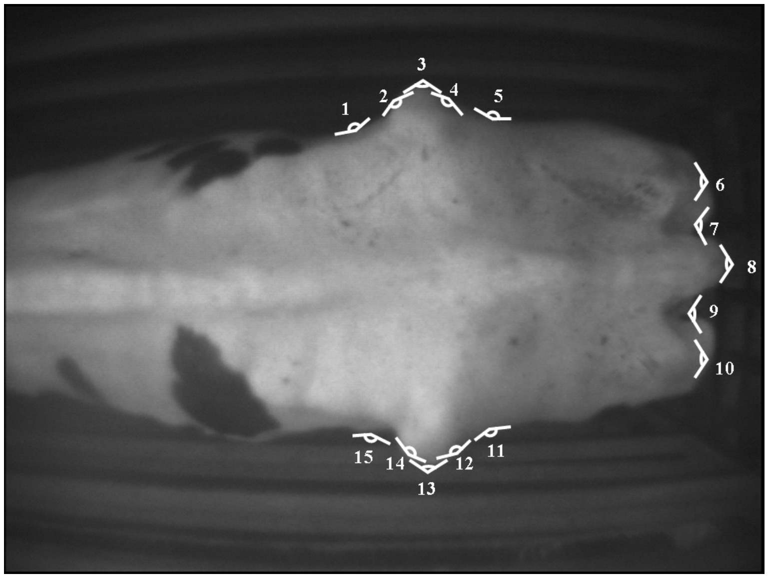

Figure 3. Angles calculated using the key anatomical points: [(1) Left Hook Anterior Angle, (2) Left Hook Anterior Curvature, (3) Left Hook Angle, (4) Left Hook Posterior Angle, (5) Left Hook Posterior Curvature, (6) Left, Thurl to Pin Angle, (7) Left Tailhead Depression, (8) Tailhead Angle, (9) Right Tailhead Depression, (10) Right Thurl to Pin Angle, (11) Right Hook Posterior Angle, (12) Right Hook Posterior Curvature, (13) Right Hook Angle, (14) Right Hook Anterior Curvature, and (15) Right Hook Anterior Angle] (Bewley et al., 2008).

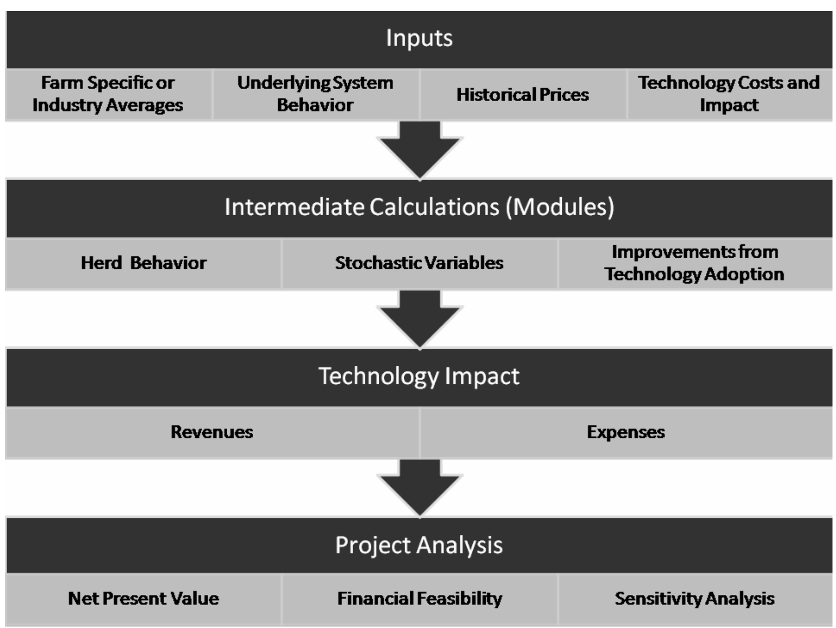

Figure 4. Diagram depicting general flow of information within the Precision Dairy Farming investment model.

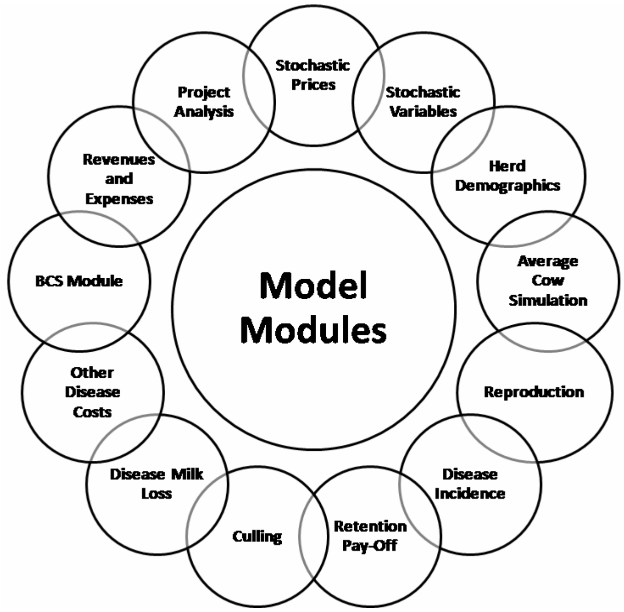

Figure 5. Diagram of Precision Dairy Farming investment model modules.

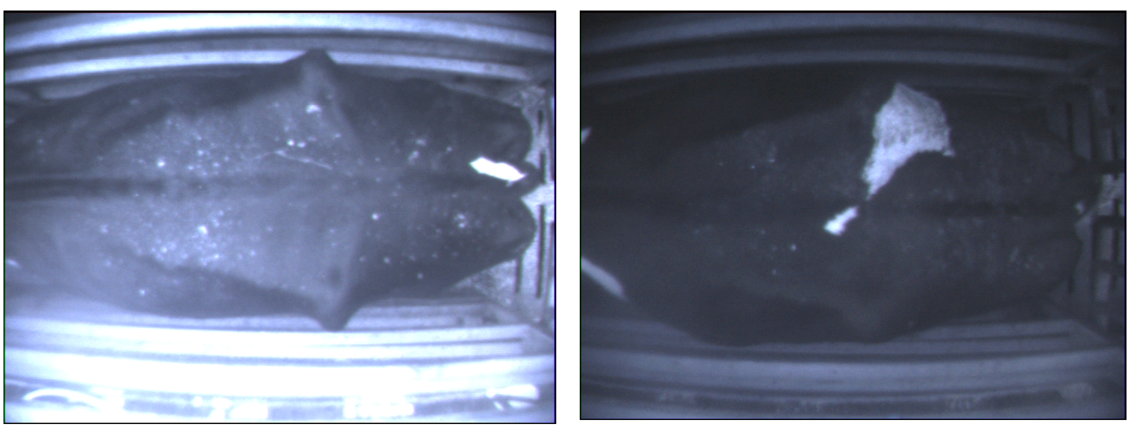

Figure 6. Examples of predicted USBCS of a thin[1] and fat[2] cow (Bewley et al., 2008).

[1 (Left)] USBCS = 2.50, Predicted USBCS = 2.63, Average Posterior Hook Angle = 149.99°, and Average Hook Angle = 116.62°

[2 (Right)] USBCS = 3.50, Predicted USBCS = 3.62, Average Posterior Hook Angle = 172.14°, and Average Hook Angle = 153.47°.

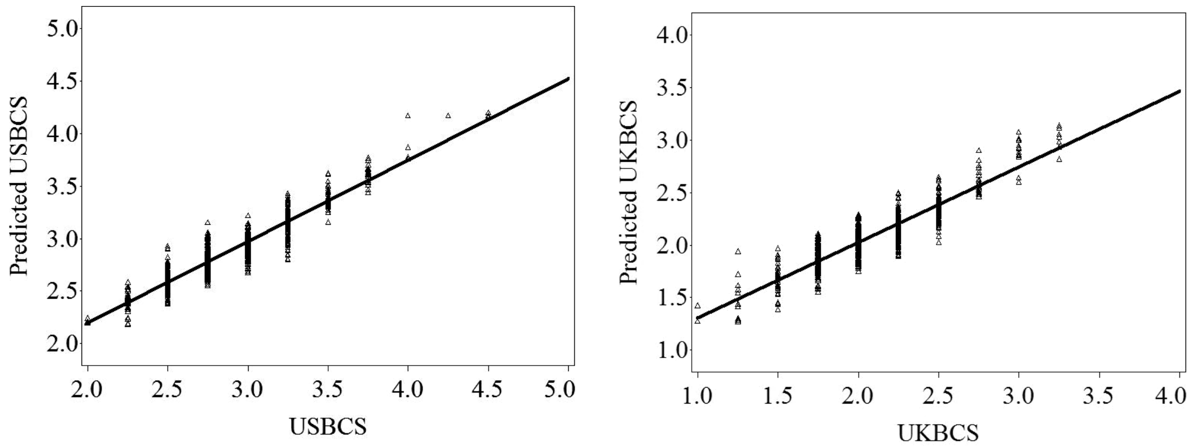

Figure 7. Predicted versus actual USBCS and UKBCS (Bewley et al., 2008).

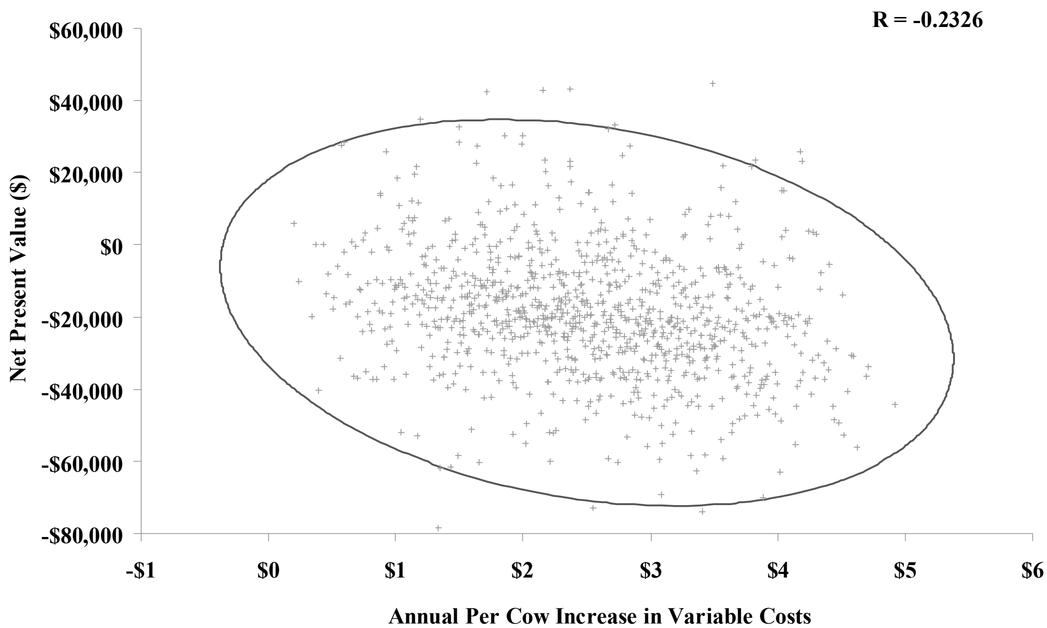

Figure 8. Scatter plot of Net Present Value versus annual percentage increase in variable costs (for simulation using all expert opinions provided).

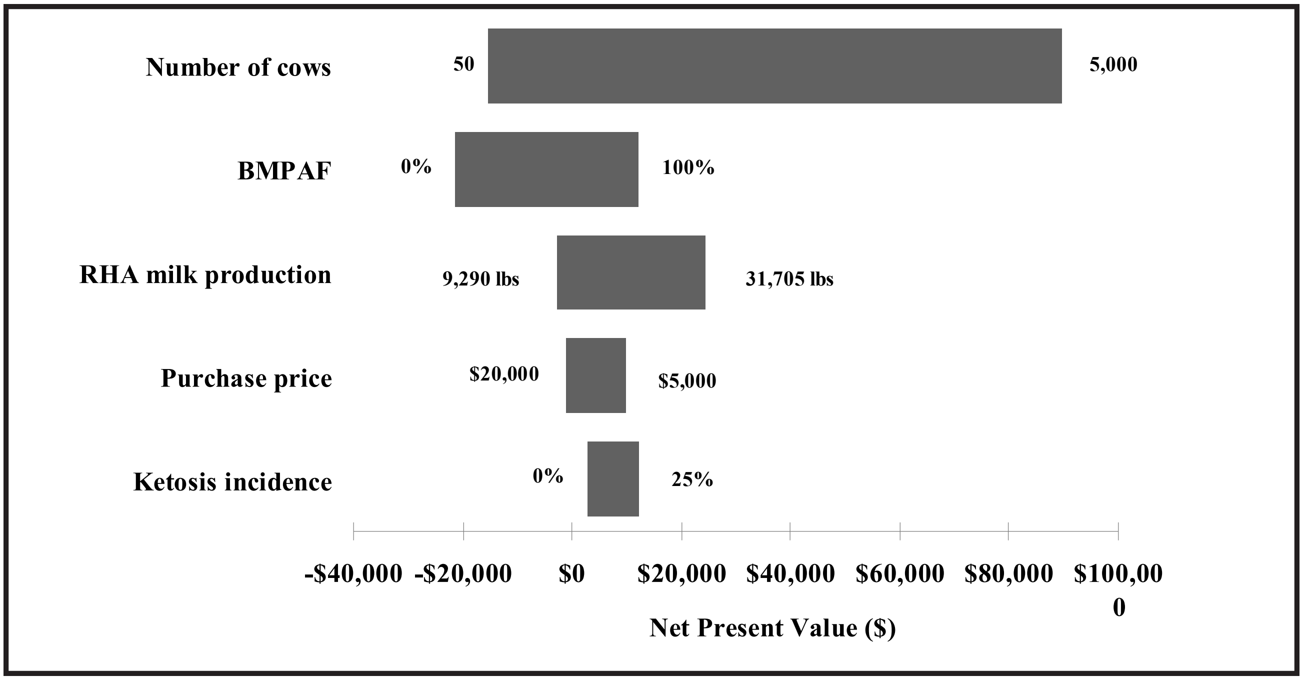

Figure 9. Tornado diagrams for inputs affecting 95th percentile of Net Present Value for simulations using the estimates of all survey respondents[1].

[1]BMPAF = Best Management Practice Adherence Factor and RHA milk production rolling herd average milk production (lb).

Implications of Changes in Core Body Temperature

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Abstract

Dairy farmers and veterinarians have used body temperatures, most commonly rectal temperatures, to detect and manage febrile disease and changes in the state of cows (estrus and onset of calving) for many years. Mastitis, pneumonia, metritis, lameness, estrus, onset of parturition, heat stress, and subacute ruminal acidosis **(SARA)** are among the physiological conditions potentially correlated with body temperature that deviates from normal. Many new technologies have been introduced to measure body temperature of cattle at various locations, including rectum, ear (tympanic), vagina, reticulum-rumen, skin, and milk. While each location has its own advantages and disadvantages, temperature measurements at some of these locations can be automated for routine, frequent, and non-disruptive temperature recording. Systems for measurement of reticular temperature are available commercially. However, many factors other than the physiological conditions of interest affect reticular temperature. Among these are ambient temperature, food and water consumption, stage of lactation cycle, age, recumbency, activity level, stage of gestation, and of course, general health. The relationship between reticular and rectal temperatures appears to be relatively consistent, though the correlation is affected by time of season, housing system, and time of day. Reticular temperatures are affected by water intake, and substantially so for large volumes and extremely cold water; and dips in reticular temperature following water consumption must be considered when interpreting observations. Research is continuing to assess the ability of reticular temperature monitoring, perhaps in conjunction with other precision dairy farming tools, to allow earlier intervention with appropriate management. Success of early intervention will be the key to the ultimate success of any temperature monitoring technology.

Introduction

Dairy farmers and veterinarians have used body temperatures, most commonly rectal temperatures, in detection and management of febrile disease and changes in the state of cows (estrus, heat stress, and onset of calving) for many years. Nakamura et al. (1983) defined body temperature as the “single most useful measurable parameter and a sensitive indicator of the reactions of the animal to physico-environmental factors, disease processes, and physiologic functions such as nutrition, lactation, and reproduction.” Because restraining animals to collect rectal temperatures manually may cause stress that alters temperature, a reliable method with no human intervention is likely to provide a more accurate measure (Prendville et al., 2002).

While the number of proposed experimental techniques for non-disruptive temperature monitoring is large, the number of companies actually marketing telemetric equipment to the livestock industry is limited (Brown-Brandl et al., 2003). The CowTemp™ telemetric system (Innotek, Inc.,

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Garrett, IN) was designed to transmit body temperature at a pre-determined regular interval using a reticular bolus, a receiver, and a computer program to summarize the data. Limited research has been conducted with this product at Purdue University (McAfee et al., 1998; Nielsen et al., 2001). However, at the time of this publication, the CowTemp™ product was not being marketed commercially. The CorTemp™ (HQ Inc., Palmetto, FL) temperature/heart rate monitoring system, originally developed for work with humans, consists of ingestible body temperature sensor pills, optional heart monitors, radio frequency **(RF)** remote units, a long range central station, a series of shorter range substations, and a central information collection station (Hicks et al., 2001; Green et al., 2005). Thus far, high investment costs and limited battery life have prevented this product from being commercialized. The ETD Bolus™ system (CowTek Inc., Brule, NE) consists of a rumen bolus, a desktop or long range exciter, receivers (each monitor up to 300 feet away), and a PDA or PC for data collection and analysis and provides temperature readings as frequently as every 30 minutes. Dr. Roger Meads (Trace Technology, Inc. and Dairy Business Resource, Inc., Hortonville, WI) has also developed an automatic temperature recording system. Digital Angel Corp. (South St. Paul, MN) developed the Bio-Thermo™ technology for tracking temperature. However, due to slaughter recovery issues, Bio-Thermo is not currently being marketed for the cattle industry. The Bella Health System (**BHS**; Bella Health Systems, Greeley, CO), formerly marketed in an earlier version as MaGiiX™ Cattle Temperature Monitoring System (**CTMS**; MaGiiX Inc., Post Falls, ID) utilizes RF identification **(RFID)** technology within a rumen bolus, a panel reader placed at a parlor entrance or exit, and a software package to collect, analyze, and view data. The BHS is currently being used at several universities and on a few large dairy farms in the western United States. Rumen temperature monitors are also commercially available as Smartbolus (TenXsys Inc., Eagle, ID) and Kahne Rumen Sensor (Kahne Ltd., Auckland, New Zealand), which also combines rumen pressure sensing.

Measuring Temperature in Dairy Cows

Although valuable for monitoring animals, core body temperatures are inherently difficult to obtain. Normal temperature varies considerably among cows (Lefcourt et al., 1999). Daily temperature variation is somewhat random with a standard deviation around 0.6 (Fallon, 1959). Debate exists on how frequently temperature should be measured to detect differences in physiological responses (Lefcourt et al., 1999). Measuring temperatures continuously would be advantageous by demonstrating the dynamic changes in temperature throughout the day (Mitchell et al., 2001; Brown-Brandl et al., 2003; Green et al., 2005). Most research indicates that body temperatures of cattle follow a distinct circadian rhythm with a range of 0.2 to 0.9°C (Nakamura et al., 1983; Lefcourt et al., 1999; Al-Haidary et al., 2001; Piccione et al., 2003; Piccione and Refinetti, 2003).

Many factors influence body temperature, including overall health, environment, ambient temperature, activity level, estrus, pregnancy status, eating and drinking behavior, and excitement (Lefcourt et al., 1999). Temperatures are higher in lactating cows than in dry cows (Nakamura et al., 1983; Bennett and Holmes, 1987). Average body temperature varies by season, reflective of ambient temperatures, a phenomena termed "seasonal drift" by Fordham et al. (1988). Feeding may increase body temperatures (Bitman et al., 1984). Araki et al. (1984) found sharp decreases in temperature after cows went through the parlor. Metz et al. (1987) found that body temperature increased about 0.2°C while lactating cows were lying (and decreased after standing up) indoors; however, the same pattern was not observed for dry cows on pasture. This result may, at least in part, explain the findings that cow rumen temperatures are higher at night than during the day (Ipema et al., 2008).

Attempts to measure body temperature of cattle have been made at various locations, including rectum, ear (tympanic), vagina, reticulum-rumen, and milk. Firk et al. (2002) suggests that the value of a temperature monitor is highly dependent on its location. Tympanic temperature has been suggested to be a superior measure of deep-body temperature because of proximity to the hypothalamic thermosensitive site and reduced lag time (Seawright et al., 1983; Bergen and Kennedy, 2000). However, continuously monitoring tympanic temperature can prove challenging because temperature transmitters may create ear infections, leading to increased temperatures (Bergen and Kennedy, 2000). In a study by Bergen and Kennedy (2000), the correlation between tympanic and vaginal temperatures was 0.77, with vaginal temperatures averaging 0.35°C higher than tympanic temperatures. Rajamahendran et al. (1989) found rectal and vaginal temperatures to be highly correlated ($r = 0.95$).

Hahn et al. (1990) simultaneously measured temperature at four locations (tympanic, rectal, sub-dermal upper shoulder, and sub-dermal upper flank). Tympanic temperatures detected thermoregulatory responses that the rectal temperatures could not. The dermal upper shoulder and sub-dermal upper flank measurements were heavily influenced by environmental stimuli, such as changing air speeds or wetting of skin. Ultimately, the authors concluded that internal sites of temperature measurement are more useful indicators of core body temperature during changing conditions than external sites of temperature measurement (Hahn et al., 1990). The accuracy of rectal thermometers is limited to the competency of the operator using them (Aalseth, 2005).

Milk temperatures are highly correlated, but significantly lower, than body temperatures (Schlunsen et al., 1987; Fordham et al., 1988). Bitman et al. (1984) used thermistors to compare udder temperatures to core body temperatures (as measured in the peritoneal cavity) every 1.4 minutes. Udder temperatures ran about 1°C lower than peritoneal cavity temperatures, but they were highly correlated ($r = 0.98$ to 0.99). These researchers concluded that mammary gland temperature was not controlled by a different mechanism than core body temperature.

Rumen temperatures have been demonstrated to be effective measures of core body temperature (Hicks et al., 2001; Prendiville et al., 2002; Small et al., 2008). Because of the activity of heat-producing rumen microorganisms, ruminal temperatures are generally about 1°C higher than core body temperatures (Bitman et al., 1984). Ruminal or reticular temperatures typically run higher than rectal temperatures (Simmons et al., 1965). Prendiville et al. (2002) compared temperature readings from CowTemp™ rumen boluses, tympanic telemetry transmitters, and rectal temperatures taken hourly. The averages for the 5-day period studied were 39.0, 38.4, and 38.2°C for rumen, tympanic, and rectal temperatures, respectively. While there was no significant difference between tympanic and rectal temperatures ($P > 0.05$), rumen temperature was higher than rectal or tympanic temperature on 3 of the 5 days. Using the CorTemp sensor pill, Hicks et al. (2001) found sensor temperatures, as measured in the rumen, to be statistically the same as rectal temperatures. Dramatic decreases in ruminal temperature occur after the cow drinks water (Dracy et al., 1963; Simmons et al., 1965); and this has been further demonstrated in comparison of temperatures recorded at a stationary panel for heifers motivated by water versus activity (Small et al., 2008). It takes 60 to 90 minutes for temperatures to return back to their pre-drinking levels (Dracy et al., 1963; Cunningham et al., 1964). The level of temperature depression is related to the amount and temperature of water consumed (Cunningham et al., 1964).

Temperature and Health

Perhaps the largest potential benefit of employing an automatic temperature monitoring system on a dairy would be in early detection of cases of disease, illnesses, or disorders that plague the dairy industry (Maatje et al., 1987). For many diseases, an increase in temperature is an early physiological response. In recent years, intensive fresh cow management programs have been established based upon using electronic thermometers to detect fever (Aalseth, 2005). Many of these fresh cow management programs are based on identifying animals with temperatures outside of a pre-established range and treating outliers. Aalseth (2005) lists the primary benefits of an intensive fresh cow management program as: 1) reduced involuntary cow losses in the first 30 and 60 days post freshening, 2) decreased postpartum disease, 3) improved reproduction, and 4) increased milk production.

Attempts have been made to use milk temperature as a predictor of mastitis. Models that combine udder temperature obtained via infrared thermography with environmental temperature may be useful in future applications in predicting mastitis (Schutz et al., 2001; Berry et al., 2003; Hovinen et al., 2008). Udder temperatures are generally 3 to 5°C cooler than rectal temperatures (Berry et al., 2003). A large udder temperature rise (>1.0°C) is typically associated with clinical mastitis and may be observed even before clinical symptoms are evident, and as such, temperature increases arise from changes in vascularization (Hovinen et al., 2008) that may or may not be captured by milk temperature. Indeed, Hovinen et al. (2008) concluded that while infrared thermography may be useful to automate mastitis detection, increases in udder skin surface temperature actually lagged increased rectal temperature, possibly because acute response to infection leads to swelling that may reduce blood flow to the skin surface. This is consistent with earlier conclusions that infrared thermography may not advance the stage at which mastitis is observed relative to other measures, like visual observation and electrical conductivity (Schutz et al., 2001).

In a study of Holstein-Friesian cows in tie-stall barns, milk temperatures were monitored for a period of six years (Schlunsen et al., 1987). Temperature increases were caused by the following: estrus 26%, no disease 22%, medicinal treatment 16%, uteritis 15%, metabolic disorder 11%, mastitis 5%, and inflammation of claws and limbs 5%. Veterinary diagnosis suggested that changes in temperature were able to detect mastitis and uteritis, most effectively followed by metabolic disorder and inflammation of claws, with the least effectiveness in detecting estrus. Authors caution that because temperature is affected by so many variables, other physiological parameters are necessary for a complete diagnosis (Schlunsen et al., 1987). Maatje et al. (1987) found increases in temperature in 0 of 3 cases of retained placenta, 3 of 3 cases of retained placenta plus metritis, 1 of 1 case of metritis, 0 of 3 cases of milk fever, 4 of 5 cases of teat damage plus mastitis, 10 of 13 cases of mastitis, 3 of 4 cases of sole ulceration, and 0 of 6 cases of lameness. Utilizing an indwelling temperature and pH probe, AlZahal et al. (2008) found a convincing correlation between the nadir of rumen pH and time of peak temperature and determined that rumen temperatures could be useful in detecting SARA, given development of an effective rumen temperature monitoring system.

Temperature and Estrus

Detecting increases in temperature at estrus has been suggested as a strategy for estrus detection (Nakamura et al., 1983, Schlunsen et al., 1987; Fordham et al., 1988; Redden et al., 1993; Kyle et al., 1998; Piccione et al., 2003; Piccione and Refinetti, 2003). Debate exists in the literature with regard to whether or how much temperature increases during estrus (Fordham et al., 1988).

Wrenn et al. (1958) found a decrease in body temperature one to two days prior to estrus, a sharp increase in temperature on the day of estrus, and a gradual increase in temperature following estrus. Frequency of observation of temperatures may also determine the efficacy of temperature for predicting estrus (Gil et al., 1997; Schlunsen et al., 1987). It is not clear whether temperature increases during estrus for physiological reasons or simply as a consequence of increased activity levels during estrus (Kyle et al., 1998). Progesterone has been suggested as the substance responsible for cyclic temperature variation in cows (Wrenn et al., 1958).

As an example of several attempts to enhance estrus detection with temperature monitoring, McArthur et al. (1992) used an increase of 0.4°C above the average of the previous 3 days to identify a temperature increase and identified 2 estrus periods in 2 cows in a controlled experiment. With the same technology in a commercial study, these researchers also attempted to identify temperature increases with a threshold value from 38.8 to 39.2°C. The detection rate ranged from 24 to 71%, but the percentage of false positives was 90 to 95%. In the same data set, increases in temperature from 0.2 to 0.6°C above the previous 5-day average for the same milking identified 32 to 50% of estrus events, but the percentage of false positives was 65 to 86%. The duration of elevation in body temperature was 9 hours. The authors concluded that milk temperature alone is not a reliable predictor of estrus because the length of the temperature increase does not coincide with milking times for all cows and the amount of variation inherent in temperatures within and between cows.

The length of the increase in body temperature associated with estrus must be considered when evaluating the frequency of temperature readings. If the length of time between measurements is greater than the duration of an individual animal's temperature increase, the estrus event will not be detected by the temperature monitoring system (Gil et al., 1997; Schlunsen et al., 1987). Further, the inconsistency of temperature response to estrus may limit the value of temperature changes for estrus detection (Nakamura et al., 1983). Schlunsen et al. (1987) were only able to detect estrus in 42% of animals measuring milk temperatures at milking times. In a review of automation of estrus detection, Firk et al. (2002) concluded that body or milk temperatures are "not useful for practical application, because these traits are highly influenced by other factors."

Temperature and Heat Stress

Telemetric temperature monitoring systems have been proposed as a tool to use in management of the negative effects of heat stress in cattle (Al-Haidary et al., 2001; Araki et al., 1984; Bennett and Holmes, 1987; Hicks et al., 2001; Lefcourt and Adams, 1996; Spiers et al., 2001). Peaks in core body temperature lag behind ambient temperature peaks by 1 to 5 hours and typically occur late in the evening (Al-Haidary et al., 2001; Hahn et al., 1990; Lefcourt and Adams, 1996; Spiers et al., 2001). Frequent or continuous monitoring of temperatures would be advantageous in understanding animal responses to heat stress (Lefcourt and Adams, 1996, 1998). Beginning at 25.6°C daily maximum ambient temperature, maximum daily body temperatures increases linearly at a rate of 0.42°C per 5°C (Lefcourt and Adams, 1996). Temperature monitoring is more challenging in the summer because of these rises in temperature and the effects of cooling strategies (Maatje et al., 1987). Peaks in body temperature are difficult to identify when environmental temperatures decrease below -7.5°C (Lefcourt and Adams, 1998). During winter, body temperatures are not significantly affected by ambient temperatures; however, the occurrence of circadian rhythms during colder weather suggests that thermoregulation is related to other influencers, like day length and daily heat load in addition to temperature (Lefcourt and Adams, 1998). A better understanding of the patterns of body temperature under varying scenarios may be useful in determining management strategies during heat stress (Al-Haidary et al., 2001). In one study, a vaginal telemetry temperature recording device identified a 1.5°C decrease in temperature following a cooling strategy (Nakamura et al., 1983). Data from telemetric temperature monitors could be fed into an immediate biological feedback loop designed to keep an animal in its thermoneutral zone (Lacey et al., 2000).

Continuous measurements of temperature could prove useful in evaluation of cooling and heat abatement strategies by providing a more accurate indication of cow response. Variation among cows may determine criteria for genetic selection of animals more tolerant of elevated temperatures. Nakamura et al. (1983) suggest that low early morning temperatures may be indicative of a cow's ability to dissipate heat.

Temperature and Calving

Automatic temperature monitoring systems for cattle have been proposed for use in identifying the onset of calving. The mechanism for this relationship is undetermined (Aoki et al., 2005), but it is common across species. The ability to predict calving time would be useful in assisting difficult births. Consequently, calf mortality rates may decrease and reproductive function of the dam could improve. Body temperature has been demonstrated to drop between 8 to 48 hours before calving. Temperatures increase 3 to 5 days before calving and begin dropping about 2 days before parturition (Metz et al., 1987). Temperatures may drop 1.0 to 1.6°C 1 to 2 days prior to calving (Wrenn et al., 1958). A research project using the CowTemp™ product demonstrated the ability to identify 9 cows soon to calve within 9 to 23 hours of parturition by identifying temperatures significantly lower than a rolling average of previous temperatures (Nielsen et al., 2001). Aoki et al. (2005) examined the ability of continuous vaginal temperatures to predict calving time in Japanese Black × Holstein-Friesian crossbred beef cattle. After identifying vaginal temperatures at a particular time in the day that were at least 0.3 or 0.5°C higher than temperatures at the same time on the preceding day for at least 3 consecutive hours, all cows in this study calved within 60 hours. When only maximum and minimum temperatures for the day were considered, the predictive ability decreased, likely because insufficient data were available to predict time of parturition.

The remainder of this report will provide a summary of research we have conducted with automatic temperature monitoring of cows to determine relationships with rectal temperature and impact of water consumption on reticular temperature. Work on cost-benefit implications will be examined briefly. While no endorsement is implied, the CTMS system (MaGiiX Inc., Post Falls, ID) was selected for work in this report to provide an example of how to approach profitability analysis of intervention technologies. At the time of selection, it was the only system commercially available and with an established pricing schedule. Tools established for cost-benefit analysis could easily be applied to other systems.

Relationship with Rectal Temperature

The magnetized, biologically inert CTMS bolus resides in the cow's reticulum and is queried each time the cow passes a reader. The intent of this experiment was to evaluate the association between rectal and reticular temperatures, and the results have been reported (Bewley et al., 2008a). Each lactating cow at the Purdue University Dairy Research and Education Center was administered a reticular bolus. Temperatures were collected for all cows for 4 consecutive milkings each during 4 collection periods selected to represent varying environmental conditions. Cows were managed in 3 housing systems: a freestall barn with 128 stalls in 4 quadrants, a bedded-pack barn with an open grass lot, and a geothermally-modified barn with tiestalls for overflow and sick cows and box stalls for recently fresh cows.

The 4 collections were conducted on May 30 and 31, 2006 (spring), September 27 and 28, 2006 (fall), January 31 and February 1, 2007 (winter), and July 25 and 26, 2007 (summer). The numbers of cows sampled during each collection period were 185, 187, 180, and 182 for spring, fall, winter, and summer, respectively, and ambient maximum temperature-humidity index **(THI)** and average THI for the collection days during these time periods are in Figure 2. Because of herd turnover and dry periods, 280 total cows were utilized across the entire study period, but only around 190 cows had temperatures collected for any one time period. All temperatures were recorded immediately after milking. Milking times were from 5:00 a.m. to 9:30 a.m. and from 4:00 p.m. to 9:30 p.m. for the a.m. and p.m. milkings, respectively.

Rectal temperatures were recorded using a GLA M750 digital thermometer (GLA Agricultural Electronics, San Louis Obispo, CA) for each cow as she left the milking parlor, and reticular temperatures were recorded for cows as they passed the stationary reader panels positioned before and after the scale in which rectal temperatures were recorded (Figure 1). The first reader panel was located in a single-lane exit alley from the milking parlor. After cows passed the first reader panel, they were diverted into a stationary scale where rectal temperatures were collected. Following collection of a rectal temperature, cows passed a second reader panel located in a pathway leading to the freestall barn. This second panel was added only after the spring collection period (and thus available for the fall, winter, and summer collection periods) to increase the percentage of cows with a valid reticular temperature reading. Adding a second panel proved beneficial by increasing the likelihood that a cow's temperature was measured at 1 of the 2 panels. Both panels used the same technology to read boluses and were close in proximity; consequently, variation in temperatures between panels was not a concern.

Reticular and rectal temperatures were recorded simultaneously in the milking parlor's exit lane in 4 consecutive milkings in each of 4 seasons, totaling 16 measurements per cow. Data were edited to remove reticular temperatures likely to have been impacted by a recent drinking bout. For the 2042 observations used in analyses, means (± SD) were 39.28 (± 0.41), 38.83 (± 0.36), and 0.45 (± 0.33) for reticular temperature, rectal temperature, and difference between reticular and rectal temperatures, respectively. The reticular and rectal temperatures were modestly correlated ($r = 0.645$, $P < 0.0001$). Numbers of paired observations and Pearson coefficients of correlations of reticular temperature with rectal temperature for season, milking, and housing system are in Table 1. Corresponding least squares means for reticular and rectal temperatures are in Figure 3 for levels of these effects. Within categories, average differences between rectal and reticular temperatures were quite consistent.

Because dairy producers and veterinarians are accustomed to viewing rectal temperatures, equations to adjust reticular temperatures to a rectal-based scale may increase the utility and interpretability of rumen temperatures. The resulting conversion equations were obtained from this work:

AM Milking: RECT = 19.23 + 0.496 (RETT)
PM Milking: RECT = 15.88 + 0.587 (RETT),

where RECT is rectal temperature and RETT is the measured reticular temperature.

Effect of Water Intake

While automated reticular temperature recording may allow early detection of disease, estrus, heat stress, and the onset of calving, one potential limitation to collection of reticular temperatures is the impact of water temperature and consumption on recorded temperatures. Two replicated 3 x 3 Latin Square experiments were conducted at the Purdue Dairy Research and Education Center to assess the impact of water intake on reticular temperatures using the Cattle Temperature Monitoring System (Bewley et al., 2008b). Nine high-producing, mid-lactation, 2nd parity cows with low somatic cell counts (SCC) were selected. Prior to administering a water treatment, access to feed and water was restricted for at least 2 hours. Baseline reticular temperatures were established from measurements prior to water intake.

In the first experiment, treatments were 25.2 kg (55.4 lb) of hot water (34.3°C ± 1.0), warm water (18.2°C ± 0.4), or cold water (7.6°C ± 0.4). Most of the water was infused by oral gavage. However, the length of time allotted for measuring cows was limited to 3 hours because the cows were deprived of feed and water during that time and because the cows had to be herded past the stationary panel readers. As the cows tired, it became more and more difficult to encourage them to move past the panels. As expected, following an initial dramatic drop in reticular temperature, a gradual rise toward baseline occurred. Least squares means for maximum drop in temperature were 8.5 ± 0.5, 6.9 ± 0.5, and 2.2 ± 0.5°C for cold, warm, and hot water treatments, respectively. It was somewhat surprising that during the entire 3 hours after water "consumption", reticular temperatures did not return to baseline. Therefore, water volume was reduced and a control group of cows that did not consume any water was added for a second experiment.

In experiment 2, treatments were 18.9 kg (41.6 lb) of body temperature water (38.9°C ± 0.2), cold water (5.1°C ± 0.4), or control (no water). Following water intake, reticular temperatures were collected for 3 hours. In experiment 2, control cows remained within the 95% confidence interval of the baseline through the observation period, and cows receiving body temperature water experienced an initial drop in temperature 0.4 ± 0.2°C, with a return to within the baseline confidence interval within 15 minutes (Figure 4). Cows receiving cold water did not return to within the baseline confidence interval after a large drop of 9.2 ± 0.2°C during the 3 hour observational period. Moreover, a regression analysis of continued ascent in temperatures predicted that temperatures would return to baseline within 3.5 hours. The volume of water fed to cows in this study was substantial, making the cold water treatment almost a worst case scenario. However, these results demonstrate that when cows consume large quantities of cold water, the impact of water intake is sizable and sustained. The value of reticular temperatures for daily monitoring in a production setting hinges largely on the implications of this impact. Technologies that record temperatures at specific times, such as after milking, as in this study, or when moving between housing and feed (Small et al., 2008), may not be greatly affected because of the time lag following water (or feed) consumption. Technologies that may log frequent recordings of rumen temperature must employ algorithms to smooth temperatures over periods of sharply decreased temperatures resulting from drinking bouts.

Utility of Automated Temperature Monitoring

Perhaps the largest single factor that will determine the rate of adoption of automatic temperature technologies is how quickly the technologies can move from the present, largely experimental stage to a more reliable and commercially viable stage. Reliability implies that the equipment is failsafe and mass produced to decrease initial investment and per animal costs. There is interest in the use of body temperature to manage physiological and infectious conditions of dairy cattle. We conducted a survey of 19 industry experts in the field of health and dairy cattle management and asked what conditions the availability of regular temperature observations would be likely to impact. In order, the responses ranked heat stress, mastitis detection, and estrus detection as most important, followed by metritis, respiratory disease, animal well-being, and pregnancy diagnosis (Table 2).

Care must be taken in comparing the costs and expected benefits of investment in temperature monitoring technologies, as many determinations depend intrinsically on the assumptions about the value of resultant management practices. Using an early version of a cost-benefit model, similar to that reported by Bewley and Schutz in another paper within this Proceedings to assess investment in automatic body condition scoring, the feasibility that investment in a temperature monitoring system would be profitable depended largely on the herd's current estrus detection rate and on the assumed improvement in estrus detection. However, this result was largely predicated by the extent to which one assumes periodic temperature observation may enhance estrus detection. The effect of herd size on such investment may partially arise from initial fixed cost of the system but may be more related to reduction in costs of days open that may be magnified in larger herds. But most other factors considered at the time this model was developed were based on lacking or incomplete information about the extent to which additional knowledge about cow temperatures might impact herd management decisions and the success of those decisions. Our knowledge about those factors is growing, but remains, at best, incomplete. Research is continuing to assess the ability of reticular temperature monitoring, perhaps in conjunction with other precision dairy farming tools, to allow earlier intervention with appropriate management, and outcome of early intervention will be the key to the ultimate success or failure of any temperature monitoring technology.

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Table 1. Numbers of paired observations (n) and Pearson correlation coefficients (r) between reticular and rectal temperatures between paired observations across categories (Bewley et al., 2008a)[1].

	Season			
	Spring	Summer	Fall	Winter
r	0.715	0.580	0.726	0.565
n	330	584	573	555
	Milking			
	a.m.	p.m.		
r	0.547	0.729		
n	999	1043		
	Housing System[2]			
	FS	GM	BP	
r	0.646	0.758	0.576	
n	1539	210	293	

[1]$P < 0.005$ for H_0: $r \neq 0$ for all correlations

[2]FS = Freestall, GM = Tie-Stall with geothermal modified ambient temperatures, and BP = Bedded pack.

Table 2. Results of a survey of 19 industry professionals asked to rank 1 to 7 the potential for automatic temperature recording to impact management of 7 infectious or physiologic conditions.

	Frequency of ranking by experts (1 = highest, 7 = lowest)							
Temperature Application	1	2	3	4	5	6	7	Mean
Heat stress monitoring	5	5	2	4	0	1	2	3.00
Mastitis detection	4	3	6	2	4	2	0	3.24
Estrus detection	1	5	3	3	4	5	0	3.90
Metritis detection	1	3	3	2	5	3	1	4.11
Pneumonia/respiratory disease detection	3	1	2	5	2	4	2	4.16
Animal well-being	2	2	4	0	3	4	2	4.18
Pregnancy detection	4	0	1	1	0	2	13	5.43

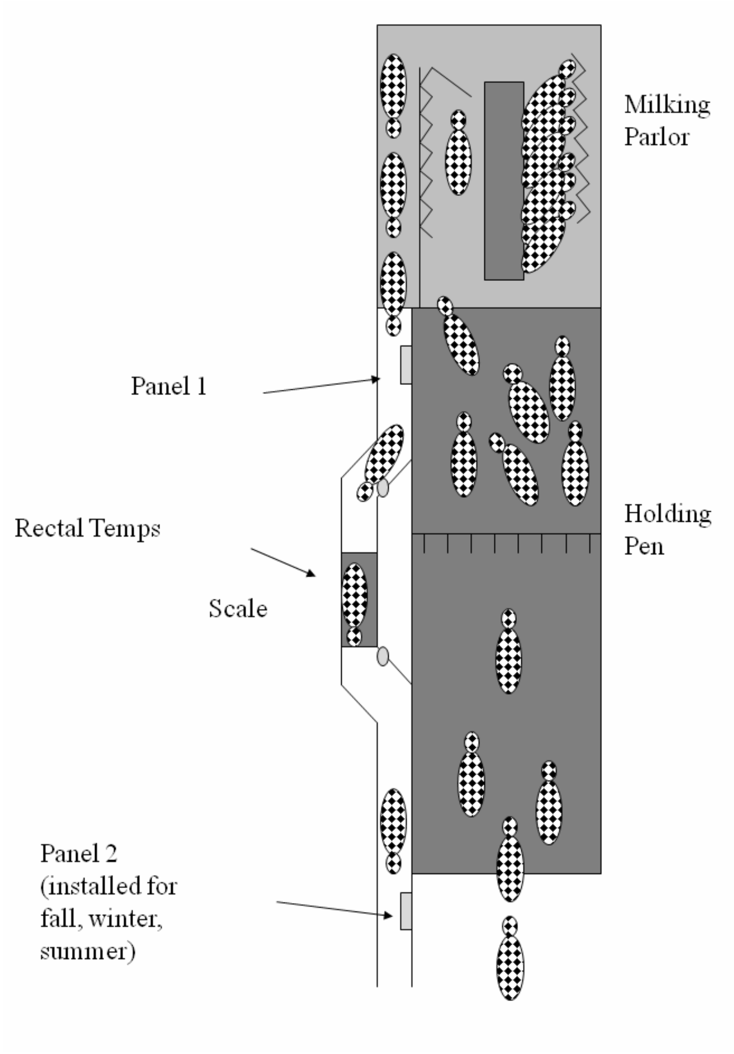

Figure 1. Schematic of layout of Cow Temperature Monitoring System as installed at Purdue University Dairy Research and Education Center.

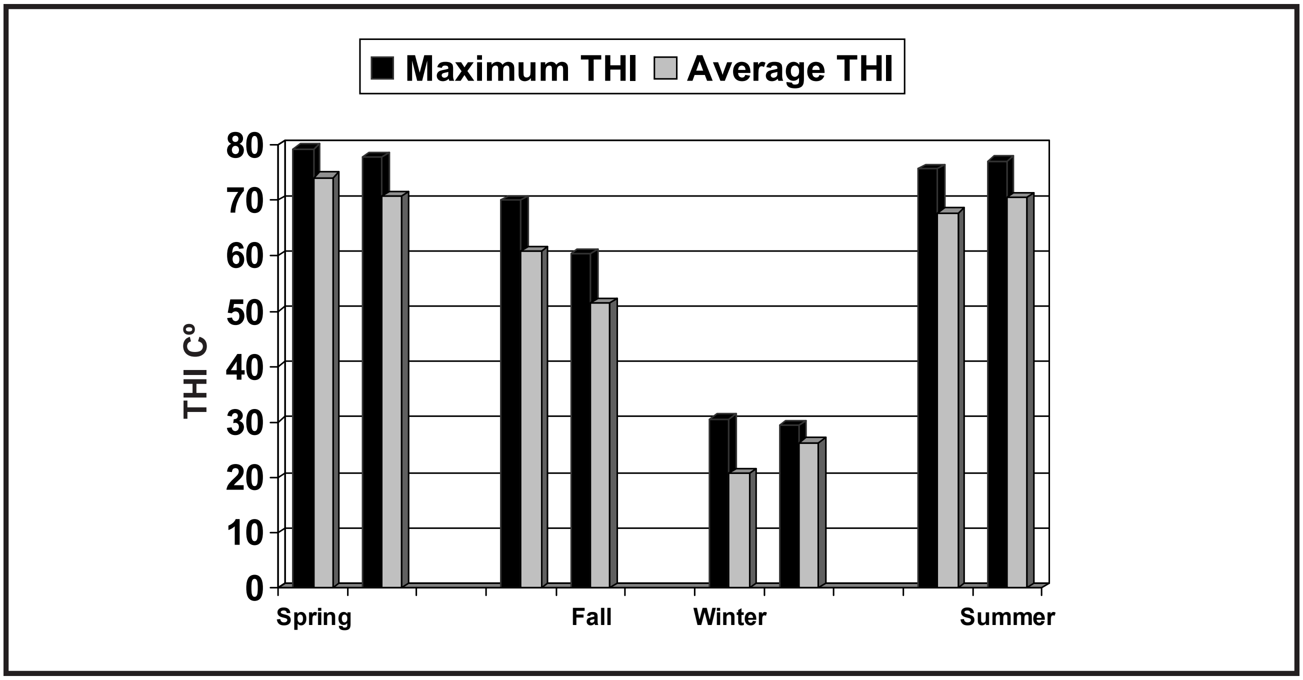

Figure 2. Maximum and average values for Temperature Humidity Index (THI) for the 2 days within each of the 4 collection periods.

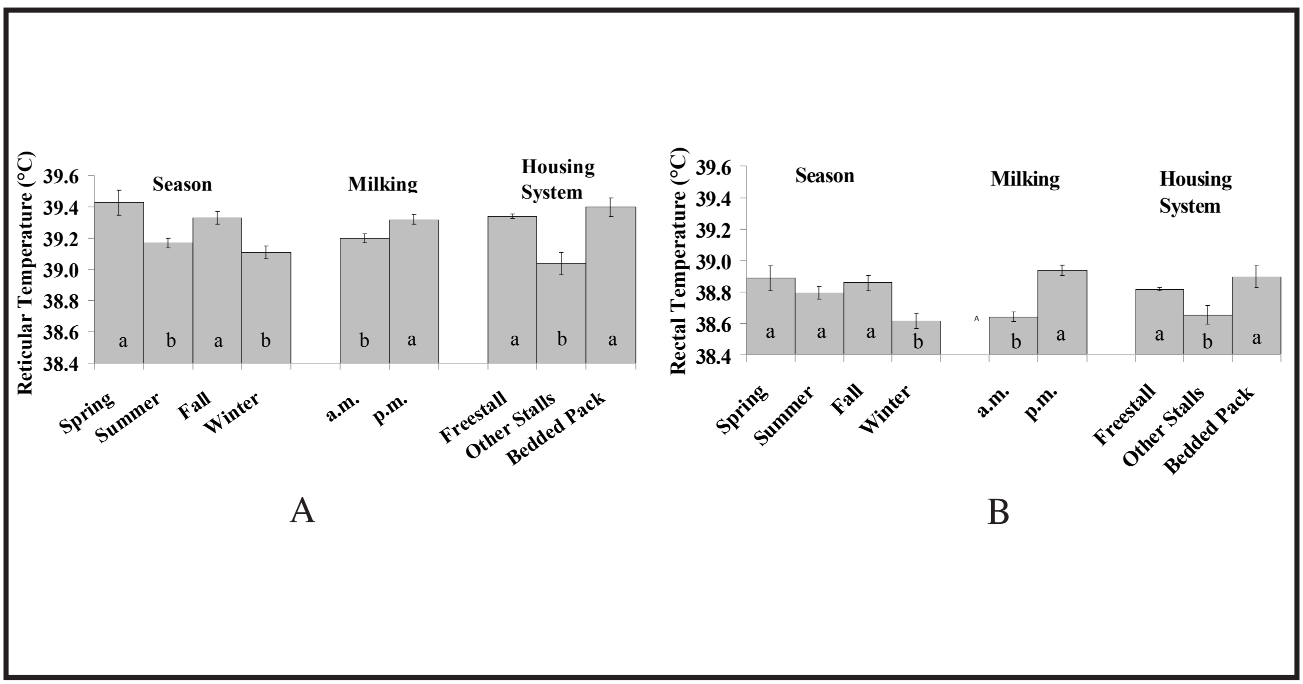

Figure 3. Least squares means for significant fixed effects in mixed models for reticular (Panel A) and rectal (Panel B) temperatures. Means within category with different letters were significantly different (P < 0.05) using Tukey's adjustment for comparison of means. For housing system, FS = Freestall, GM = Tie-Stall with geothermal modified ambient temperatures, and BP = Bedded pack.

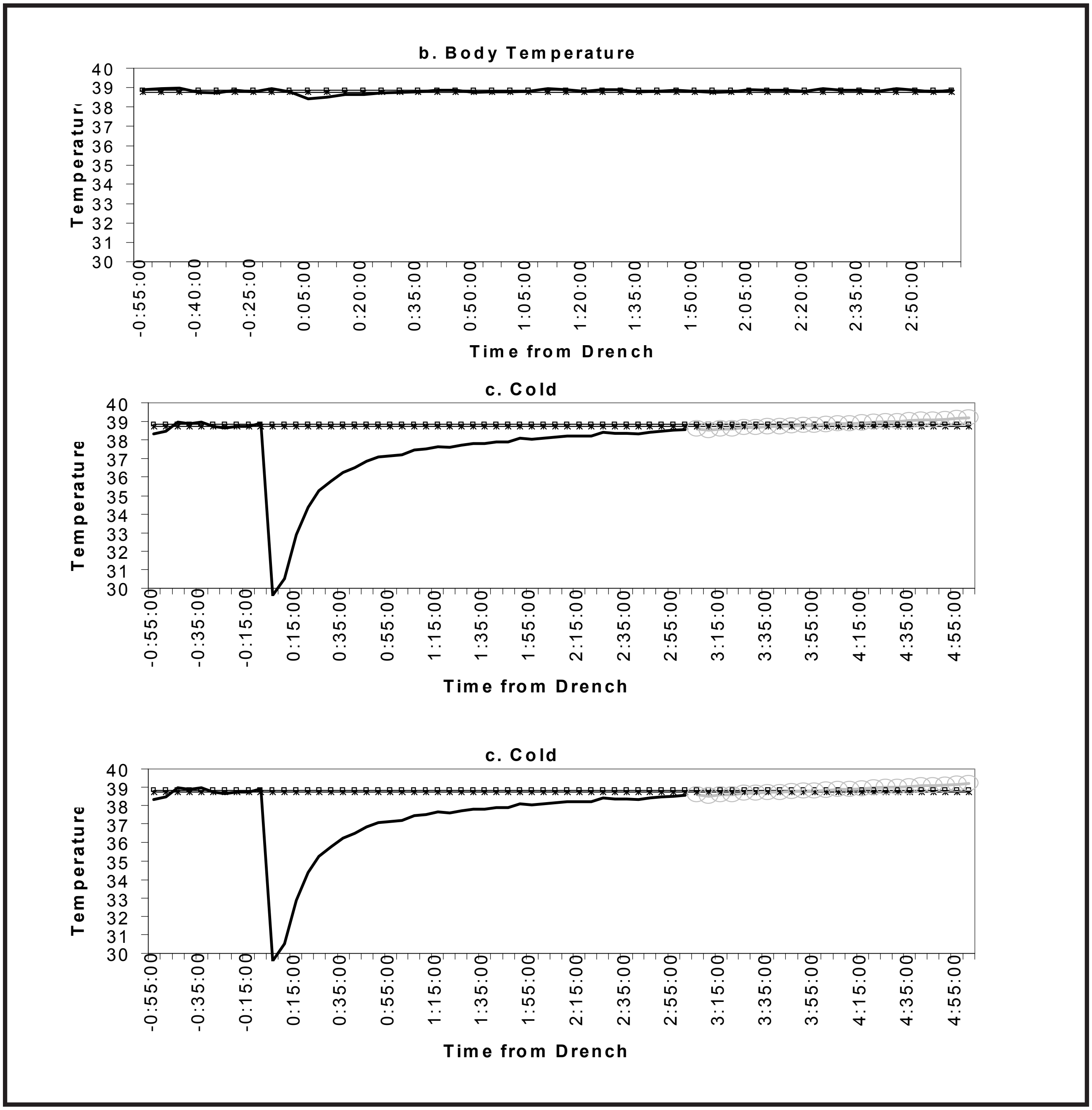

Figure 4. Reticular temperature response patterns for treatments involving consumption of no water (control) (a), body temperature water (b), and cold water (c) (Bewley et al., 2008b).

Impact of Heat Stress on Production and Fertility of Dairy Cattle

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Abstract

Summer heat stress depresses both milk production and reproductive performance of dairy cows. The use of efficient cooling systems is required because high milk-producing cows are not capable of maintaining normothermia in the summer. Cooling, if efficient enough, is capable of narrowing the gap between winter and summer milk production; however, its positive effect on fertility is limited. Fertility surveys show that, unlike milk yield, the improvement of conception rate by cooling is small. Therefore, additional hormonal treatments are required. Various hormonal approaches have been examined: addition of exogenous progesterone, injection of gonadotrophin releasing hormone **(GnRH)** at onset of estrus, the timed artificial insemination **(AI)** (Ovsynch) protocol, embryo transfer, and induction of follicular waves by GnRH and prostaglandin $F_{2á}$ **($PGF_{2á}$)**; their potential for improving summer fertility is presented.

Introduction

Heat stress is a worldwide problem. About two thirds of the world's cattle population is located in hot zones. Summer heat stress is a major factor contributing to low milk production and low fertility in lactating dairy cows. The problem is multifactorial in nature, because various tissues are being affected and their function is disrupted under heat stress conditions (Wolfenson et al., 2000). High milk production is associated with high metabolic heat production. As a result, cows have to dissipate large amounts of heat in order to maintain normothermia. At air temperatures around 27ºC (80°F), under humid climates, the body temperature of lactating cows rises above normothermic values, and severe hyperthermia develops as air temperature rises above 86 to 90ºF and above. In several middle-eastern states in the USA, the ambient temperatures rise to values that induce hyperthermia in lactating cows during the summer.

During the 1980's we developed in Israel an efficient cooling system that is based on direct cooling by evaporation of water from the skin (Flamenbaum et al., 1986). Since the sweating rate in cattle is relatively low, it became necessary to wet the skin and saturate the coats of cattle with water. Short-term water sprinkling followed by ventilation facilitates water evaporation and the rate of cooling. The sprinkling (or misting) and ventilation cooling system is widely used in several hot countries, including southern states in the USA (Berman and Wolfenson, 1992).

Effect of Cooling on Milk Yield and Fertility

The effect of cooling on milk production and reproductive performance differs substantially, in the sense that summer cooling is capable of markedly improving summer milk yield, whereas summer fertility is only slightly improved. The following large survey, conducted in Israel over a 4-year period, is a typical example illustrating the

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effect of summer cooling on milk production and reproductive performance (Flamenbaum and Ezra, 2003). Farms were classified into 3 different groups according to the intensity of cooling in summer. Farms that used intensive cooling, cooled cows in both the holding and feeding areas for a total of 10 cooling periods and 7.5 cumulative hours per day. Each cooling period combined cycles of sprinkling (30 seconds) and ventilation (4.5 minutes). Farms that used moderate cooling, cooled cows in the holding area only for a total of 6 cooling periods and 4.5 cumulative hours per day. Farms that used minimal cooling, cooled cows 3 times before milking in the holding area. Milk production for summer and winter included 125,000 milk records and 17,000 inseminations. The average high temperature in summer was 31.8°C (89°F). The ratios between summer and winter milk production for multiparous cows in farms using intensive, moderate, or minimal cooling regimes were 98.5%, 96.1%, and 90.7%, respectively. Conception rates for multiparous cows were 46.6%, 45.8%, and 43.5% in winter, and 33.8%, 34.5%, and 16.7% in summer for farms using intensive, moderate, or minimal cooling regimes, respectively. The results clearly show that intensive cooling is capable of minimizing, but not completely eliminating, the drop of milk yield in summer, compared with that in winter. Improvement of milk yield by cooling is due, partly, to an increase of food intake. Lower food intake during heat stress is known to be a major cause of low milk production during the summer. However, studies show a direct disruptive effect of heat stress on milk synthesis and on alterations in the secretion of hormones and metabolites involved in milk production, which are not related to low food intake. In contrast to milk yield, the slightly improved conception rates by cooling still remained much lower in summer than in winter.

Low fertility in summer was recorded in several US states. Conception rates drop from about 30% in winter to about 12% in the humid summer in Florida. In the dry climate of Arizona, conception rates drop from about 40% to around 20%. In the Midwest, summer conception drops as well. For example, conception rates of about 12,000 cows in three farms in Missouri dropped from 30.2% in the winter to 21% in the summer and 24.5% in the cool months of the fall (S. Poock, College of Veterinary Medicine, University of Missouri, personal communication, 2008).

The main conclusion of the above are as follows: (1) Improving milk production can be accomplished by means of efficient cooling, and that summer milk yield may reach a production level that is lower by only 2 to 4% of that in the winter, and (2) in contrast, fertility in summer cannot approach winter conception rates. This is because several components of the reproductive system are susceptible to thermal stress, and disruption of any single one may terminate pregnancy. Therefore, an efficient cooling system is a prerequisite for improving summer fertility; however, additional hormonal treatments are required in order to improve summer fertility of dairy cows.

Hormonal Strategies Aimed at Improving Summer Fertility

Evaporative cooling improves summer fertility to some extent; however, there is a compelling need to find additional ways to further improve fertility during the hot season. Five approaches to improve summer fertility of lactating cows are presented below. In all, efficient cooling is required to lower body temperature as much as possible to a level that enables embryonic survival.

First approach: exogenous progesterone

Dairy cows during the summer exhibited low concentrations of plasma progesterone. Supplementing exogenous progesterone post AI in summer was equivocal in term of its effect on conception. The variability among studies in thermal stress severity, and whether or not efficient cooling was applied, contributed to the variable effect of exogenous progesterone on summer fertility. We examined the effect of supplementing exogenous progesterone post-AI on conception rates during the summer and autumn for lactating cows that were efficiently cooled during the hot season (Wolfenson et al., 2009). Treated cows received an intravaginal device containing progesterone (Controlled Intravaginal Drug Release; **CIDR**) on day 5 after AI for 12 days. A total of 377 cows were included in the study. The CIDR increased progesterone concentrations by about 2 ng/ml. Overall, CIDR treatment increased (not significantly) conception rates by 6% compared with controls (33 vs. 39%). However, the CIDR treatment significantly increased (+23%, $P < 0.05$) the conception rates of cows with low body condition scores at peak lactation. Similarly, CIDR significantly increased (+22%, $P < 0.05$) the conception rate of cows that exhibited uterine disorder at parturition. The CIDR treatment increased numerically, but not statistically significant, the conception rate in the fall (+13%) and less so in the summer, and in mature cows (+8%) and less so in first-calf heifers. Results indicated that exogenous progesterone post AI increased the conception of cows that were efficiently cooled during the hot summer. The most beneficial effect of CIDR was documented in cows diagnosed as having uterine disease postpartum and in cows exhibiting low body condition score at peak lactation.

Second approach: GnRH at onset of estrus

The concentration of the preovulatory luteinizing hormone **(LH)** surge in the summer is lower than that in the winter. It has been shown that low LH surge can be associated with delayed ovulation, and with the formation of a suboptimal corpus luteum and the secretion of low progesterone levels (Bloch et al., 2006). A study was carried out during the summer and winter on 363 primiparous and multiparous cows (Kaim et al., 2003). Cows were synchronized and watched continuously for manifestation of estrus. A single dose of GnRH analogue was injected right after onset of estrus. In the summer, but not in the winter, GnRH treatment increased conception rates from 35.1 to 51.6%. In both seasons, GnRH increased the conception rates of cows with a low body condition score at AI and that of primiparous cows more than that of multiparous cows. It can be concluded that GnRH administered at estrus onset increases the preovulatory LH surge, prevents possible delays in ovulation, and is likely to increase the post-ovulation progesterone concentration. The GnRH administered at estrus onset was found more effective in primiparous cows and during the summer in increasing conception rate in cows with low body condition scores at AI.

Third approach: Timed AI

During the summer, the intensity and duration of estrous behavior are lower than that in the winter. As a result, the percentage of inseminated cows is lower in the summer. A possible treatment is to use the Ovsynch protocol for summer breeding. A study conducted in Florida (de la Sota et al., 1998) showed that the overall pregnancy rate by 120 days postpartum was higher for treated cows than for untreated control cows (27.0 vs. 16.5; $P < 0.05$). The number of days open for cows conceiving by 120 days postpartum was less for time-inseminated, Ovsynch-treated cows (77.6 ± 3.8 vs. 90.0 ± 4.2 days; $P < 0.05$), as was the interval to first service (58.7 ± 2.1 vs. 91.0 ± 1.9 days; $P < 0.01$). The authors concluded that the timed program did improve group reproductive performance. The timed program will not protect the embryo from temperature-induced embryonic mortality, but management limitations induced by heat stress on estrus detection are eliminated.

Fourth approach: Embryo transfer

It has been shown that the embryo at the very early stages of its development, during days 1 to 3 of pregnancy, is highly susceptible to hyperthermia, and that later during days 5 to 8 of pregnancy the embryo becomes more resistant to high temperatures. Therefore, performing embryo transfer of high-quality embryos on days 7 to 8 after estrus may improve conception rates. A study in Florida (Hansen and Aréchiga, 1999) showed that transfer of fresh embryos markedly improved pregnancy rates, whereas use of frozen embryos that had been thawed did not improve pregnancy rates above those obtained by using AI.

Fifth approach: induction of follicular waves

We showed in previous studies that the ovarian follicles and the enclosed oocytes are susceptible to thermal stress (Roth et al., 2001). We examined the possibility that induction of consecutive follicular waves by administration of GnRH + $PGF_{2á}$ with the aim to enhance the removal of damaged follicles and to enhance the emergence of healthier ones will improve fertility (Roth et al., 2009). Three consecutive 9-day follicular cycles were induced with GnRH and $PGF_{2á}$ 7 days later. Control cows were untreated. Cows were AI at estrus. Overall, the GnRH-$PGF_{2á}$ treatment resulted in a slight non-significant increase in conception rates compared with controls (27 and 32%). The treatment significantly increased conception rates of first-calf heifers (37 vs. 53%, $P < 0.05$), but not those of multiparous cows. The treatment increased numerically, but not statistically significant, compared with untreated controls the conception rates in cows with a milk yield lower than 40 kg/day (888 lb/day; +15%), cows with high BCS at parturition (+ 15%), and in cows with a low somatic cell count (+ 10%). Taken together, hormonal treatment inducing follicular turnover, combined with efficient cooling, appears to improve summer and autumn fertility, mainly in first-calf heifers.

Conclusion

Milk production and reproductive performance are being depressed during summer heat stress. Efficient cooling is capable of substantially improving milk yield to levels close to those of winter milk production. However, summer conception improved slightly with cooling, and additional hormonal treatments are required to further raise summer fertility. Five hormonal approaches aimed at improving the fertility of cooled cows in the summer were examined. Exogenous progesterone post AI improved conception mainly of cows with low body conditions and those with uterine disease post-partum. Injection of GnRH at onset of estrus has the potential to increase summer fertility, but it is not feasible to use at this time. The Ovsynch protocol is capable of increasing pregnancy rates, and it decreases the days open. Use of embryo transfer improved summer fertility, but its use is limited at present, compared with the conventional AI. Enhanced removal of heat-induced impaired follicles from the ovaries improved fertility, mainly of first-calf heifers. The use of a combination of two treatments could be beneficial and warrants examination.

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Grouping to Increase Milk Yield and Decrease Feed Costs

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Abstract

There are many advantages of grouping cows to optimize their rations as their response in energy intake and partitioning to diets change throughout lactation. The primary advantage is that grouping cows allows management of body condition while maximizing milk yield. Rations that limit over-conditioned cows in late-lactation do not allow cows to reach their potential milk yield at peak lactation, reducing annual milk production. Grouping also allows optimal forage allocation, can reduce feed costs, increase efficiency of nutrient utilization, and reduce nitrogen excretion. These benefits outweigh the benefits of feeding a single ration to all lactating cows for larger herds and for many smaller herds as well.

Introduction

Many producers have abandoned feeding multiple totally mixed rations **(TMR)** to milking cows after they leave the fresh group (or after calving), despite great differences in nutrient requirements and animal physiology between cows in early and late lactation. This has happened at an accelerated rate over the last 10 years for various reasons, including convenience and labor savings and the availability of recombinant bovine somatotropin **(rbST)** to help prevent over-conditioned cows. Recent limitations on use of rbST, as well as recent changes in the long term forecast for cost of feeds, and the growing importance of reducing nitrogen excretion are reasons to reevaluate this management strategy. The purpose of this article is to identify and discuss factors that should be considered when evaluating grouping strategies on individual farms.

Manage Body Condition

The most important reason to consider feeding more than one ration to lactating cows is to manage body condition without limiting milk yield. Over-conditioned cows are at high-risk for culling during the next lactation because of metabolic disorders, poor health, and reproductive failure. When only one lactation-ration is fed, it must be formulated to limit over-conditioning in late lactation. However, diets that prevent excessive body condition in late lactation, also limit milk yield of high-producing cows. <u>Feeding one ration to all cows is always a compromise between achieving higher peak milk yield and managing body condition.</u>

Much of the success of the single TMR strategy is because of the use of rbST. As lactation proceeds, milk yield declines and energy is increasingly partitioned to body stores to restore condition. With a single TMR formulated for the higher yielding cows, other lower yielding cows gain condition more rapidly and become over-conditioned. Use of rbST limits over-conditioned cows by partitioning more energy to milk and away from body condition. Because many herds have abandoned use of rbST, managing body condition

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will be more challenging when a single TMR is fed. To effectively manage body condition of later lactation cows with a single TMR, the diet typically must be less fermentable and more filling, limiting milk yield of high-producing cows.

Benefits of Grouping

Potential effects of grouping on profitability increase with higher feed and milk prices. While milk price has been highly variable recently, feed prices are likely to remain high for the foreseeable future because of increased export of crops and use of crops for biofuel production. Grouping cows by their physiological responses to diets can increase profitability by improving milk yield, increasing efficiency of milk production, and reducing culling of over-conditioned cows. Nutrient utilization increases as nutrients required for maintenance are diluted across more milk production. Less nitrogen will be excreted as waste when lower producing cows are offered rations with a lower crude protein **(CP)** concentration that more closely matches their requirements. Decreasing CP concentration by 2 percentage units for 120 days per lactation (last trimester) will result in about 20 lb less N excreted/cow/year.

Effects on Milk Production

The limitation on milk yield from a single TMR system varies from farm to farm and is dependent primarily upon variation in milk yield among cows. This is because response to diet change varies greatly among cows varying in milk yield. We found that individual cows ranging from about 50 to 120 lb/day of 3.5% fat-corrected milk responded very differently to a reduction in ration forage content from 67 to 44% of ration DM. Milk yield was not affected by change to the lower forage ration for cows producing less than about 90 lb/day, but milk yield was limited by the higher forage ration for cows producing more than 90 lb/day. For cows with milk yield above 90 lb/day, the high forage diet limited milk yield to an increasingly greater extent with greater milk yield, with up to 20 lb/day lower 3.5% fat-corrected milk for the highest producing cows. Dry matter **(DM)** intake was greater for cows fed the low-forage diet, so income over feed costs decreased for cows producing less than 90 lb/day, but improved greatly for cows producing over 90 lb/day of milk.

Milking cows vary in nutrient requirements according to milk yield and growth, but factors affecting feed intake and partitioning of energy also change as lactation proceeds. Because of this, quite different diets are required to optimize production for high producing cows in early lactation compared to cows in late lactation. High producing cows have a great drive to eat and feed intake is limited primarily by gut fill. Because lactose, which is produced from glucose in the mammary gland, drives milk yield, high-producing cows require greater glucose production by the liver. The liver can produce much more glucose as the starch content of diets increase (primarily from cereal grains), and high-producing cows thrive on highly fermentable diets. In high-producing cows, little energy is partitioned to body condition and most is used for milk production because both insulin concentration in the blood and insulin sensitivity of tissues are low.

In contrast, highly fermentable diets can depress feed intake, cause excessive weight and condition gain, and result in milk fat depression for lower producing cows. As production declines throughout lactation, gut fill becomes less of a limitation on feed intake and cows can be fed higher forage rations without limiting milk yield. Feed intake becomes increasingly limited by the fermentability of the diet; highly fermentable diets that are necessary to attain high milk yield can depress feed intake as milk yield declines. Glucose demand declines because less is needed to produce milk lactose, and blood glucose concentration increases, stimulating greater secretion of insulin. Insulin signals body tissues to produce fat, partitioning energy to body condition at the expense of milk yield. Tissue sensitivity to insulin increases as growth hormone (and consequently milk yield) declines throughout lactation. Because insulin concentration and insulin sensitivity increase as lactation progresses, more energy is partitioned to body tissues at the expense of milk. Highly fermentable diets increase plasma glucose and insulin to a greater extent as milk production declines. Therefore, while highly fermentable diets are necessary to achieve high milk yield in early lactation, they depress milk yield and result in more rapid fattening in late lactation.

Lower producing cows also are more prone to milk fat depression when fed highly fermentable diets. We evaluated production response to a change in diet fermentability by comparing highly fermentable high moisture corn and less fermentable dry corn and found that effect of diet on milk fat response was opposite for high-producing and low-producing cows. When ration fermentability was increased, milk fat concentration decreased up to 1 percentage unit for the lower producing cows but increased up to 1 percentage unit for the higher producing cows. Milk fat depression can result in more rapid gain in body condition as energy spared by reduced milk fat production is available to body tissues.

Optimal Forage

The filling effect of diets is determined almost entirely by the concentration and digestion characteristics of forage fiber. Other diet ingredients (e.g. grains, protein and fat supplements, and high fiber byproduct feeds) digest and pass from the rumen much more quickly than forage fiber. It is important to note that it is the concentration of forage fiber in the ration, not the fiber concentration of the forage, that is important because high-fiber forages can be supplemented with more concentrate. While forage fiber is very filling compared to other components of rations, the filling effect of forage fiber varies greatly because of great differences in digestion characteristics among sources. Across many experiments, a one-unit increase in digestibility of forage fiber (measured in vitro or in situ) corresponded to an increase of 0.55 lb of 3.5% fat-corrected milk yield within forage family. However, feed intake and milk yield response to enhanced fiber digestibility benefits higher yielding cows to a greater extent than low producing cows. We found that fat-corrected milk yield response varied from 0 to nearly 2 lb/day for each percentage increase in forage in vitro fiber digestibility as milk yield of cows increased from 70 to 120 lb/day. In addition, fiber from a perennial grass, such as orchardgrass, is much more filling than fiber from an annual grass, such as corn silage, or a legume such as alfalfa, despite its greater digestibility because of its slower passage rate from the rumen. Because of this, perennial grasses and mixed legume-grass forages should be limited in rations of high producing cows with intake limited by gut fill. Forages containing significant concentrations of perennial grass would be better targeted to lower producing cows whose feed intake is less limited by gut fill.

Feed Cost

Ration cost might be greater when a single TMR is fed to all cows because more expensive ingredients that benefit high producing cows are fed for the entire lactation. While forages now cost more to grow than in the recent past because of higher input costs (e.g., fuel and fertilizer), even when purchased, they cost less than most other ration ingredients averaging $0.05 to 0.07/lb of DM. Corn grain at $5.00 a bushel equates to $0.10/lb of DM, soybean meal at $340/ton is almost twice as much at $0.19/lb of DM, and bypass protein sources and most fat sources are more expensive yet. Some fat sources now cost more than $0.60/lb of DM! In addition, expensive feed additives that may enhance production in early lactation might be less effective in later lactation. Because energy and protein requirements decline with milk yield and feed intake is less limited by gut fill, lower cost forages and other feeds can be fed to lower producing cows if at least 2 TMR are fed to lactating cows, decreasing feed costs for up to one-third of each lactation.

Benefits of a Single TMR

Feeding a single TMR to all milking cows allows grouping by reproductive status (requiring self-locking stanchions in fewer pens), one (or more) less ration to be formulated, possible labor savings, and elimination of cows getting fed the wrong diet. Labor savings depend upon how mixer capacity is matched to pen and (or) herd size. In some situations, there will be little or no savings in labor for 1 versus 2 TMR because the same number of batches must be mixed per day. However, when partial capacity mixes must be made to feed more than one TMR, labor will be saved with a single TMR. Additionally, topping off feed bunks might require more labor if partial batches must be mixed. Milk yield and health might be compromised for cows inadvertently, ending up in the wrong pen when more than 1 TMR is fed requiring additional management for prevention. Another perceived benefit of a single TMR is eliminating the drop in milk yield when cows change diets. However, proper ration formulation can minimize the reduction or even increase production after switching rations as discussed below.

Decreased Milk Yield When Changing Groups

Movement to a different group might decrease milk yield because of social adjustment and (or) diet change. Movement according to reproductive status with a single TMR system can result in a temporary decrease in milk yield until cows are socially adjusted, which is normally of short duration, lasting only a day or two. However, many producers recall more sustained reductions in milk yield following a group change because of the diet, and this is one of the main reasons they prefer a single TMR system. Although the diet might be formulated to provide adequate energy, protein, minerals, and vitamins according to recommendations, ration formulation programs do not account for <u>effects of feeds on energy intake and partitioning</u>. If the diet is too fermentable, feed intake and milk fat production might be depressed and insulin will increase partitioning more energy to body condition at the expense of milk yield. Careful consideration of diet ingredients is necessary to prevent decreased milk yield following a ration change. Increasing energy intake with highly digestible fiber from grass or low-lignin corn silage (e.g., brown midrib; **BMR**) and more slowly fermented starch (dry ground corn) will allow more energy to be partitioned to milk rather than body condition, allowing higher energy diets while limiting over-conditioned cows.

How Many Groups and When to Switch?

Our understanding of how cows vary in their response to diet changes is just beginning, and more information will be available to help devise grouping strategies as time progresses. However, for 2 different lactation groups, body condition score should be used to prevent "train wrecks" from over-conditioned cows in the early part of the next lactation. Post-fresh cows should be fed a low-fill, highly fermentable diet until they reach a body condition score of 3 to 3.25. This will allow for a slight further increase in body condition in late lactation. Cows with signs of low ruminal pH (e.g., low milk fat and very lose manure) should be switched sooner to improve ruminal and total tract digestibilities by increasing ruminal pH. The later lactation diet should be formulated to maintain body condition while maximizing milk yield using highly digestible fiber from forage and byproduct feeds and more slowly fermenting grain sources (e.g. dry corn with vitreous endosperm).

Other Considerations

Several factors must be considered when determining the optimal grouping strategy on your farm. The extent of compromise between milk yield and management of body condition when feeding a single TMR depends primarily on variation of milk yield within the group but also upon age of cows. The extent of variation is dependent upon reproductive success because milk yield generally will be lower for cows with extended lactations. Because peak milk yield increases and persistency of milk yield declines with increased parity, there is greater variation in milk yield among older cows. Herds using a single TMR that will benefit the most from adding one or more groups are those that don't use rbST, have a wide range in milk yield and (or) age among cows, and those with mixer capacity matched to group size.

Conclusions

- Potential profits from increased milk yield, production efficiency, and nutrient utilization as well as decreased feed costs and culling can be realized by adding another ration to a single TMR system.

- Some of the real and perceived benefits of feeding a single TMR are relatively minor compared to the lost opportunity of not grouping cows according to their production response to diets.

- Increased feed cost and lack of rbST merits careful consideration of the benefits and costs of grouping systems now.