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AUTOMATED BODY CONDITION SCORING: PROGRESSION ACROSS LACTATION AND ITS ASSOCIATION WITH DISEASE AND REPRODUCTION IN DAIRY CATTLE

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THESIS

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By

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ABSTRACT OF THESIS

AUTOMATED BODY CONDITION SCORING: PROGRESSION ACROSS LACTATION AND ITS ASSOCIATION WITH DISEASE AND REPRODUCTION IN DAIRY CATTLE

Body condition scoring is a technique used to noninvasively assess fat reserves. It provides an objective estimate to describe the current and past nutritional status of the dairy cow and has been associated with increased disease risk and breeding success. Traditionally body condition scores are taken manually by visual appraisal on a 1 to 5 scale, in one-quarter increments. However, recent studies have shown the potential of automating the body condition scoring of cows using images. The first objective was to estimate the likelihood of disease development and breeding success, using odds ratios, associated with body condition score scored automatically at various points in lactation. The second objective of our research was to use a commercially available automated body condition scoring camera system to monitor body condition across the lactation period to evaluate differences between stratified parameters and to develop an equation to predict the dynamics of the body condition score. We found that poor body condition score at different times during the transition period are associated with increased disease occurrence and lower reproductive success. Automated body condition scoring (ABCS) curve during lactation was influenced by many factors, such as parity, ABCS at time of calving, disease occurrence, and milk production.

KEYWORDS: BCS, imaging, dairy cattle management, precision dairy farming

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AUTOMATED BODY CONDITION SCORING: PROGRESSION ACROSS LACTATION AND ITS ASSOCIATION WITH DISEASE AND REPRODUCTION IN DAIRY CATTLE

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I was struggling with where to begin in this section but then I remembered reading the beginning of my grandfather's recent autobiography where he quoted a passage from the Bible (Ecclesiastes 3:1), "To everything there is a season, and a time to every purpose under the heaven." As I read this scripture I know I can forgive myself for the extra months I have spent to finish my Master's program, the guilt is lifted and all I feel is appreciation for the time I have had here. It also makes me thankful for the support I have had along the way and the patience accredited to me. I am grateful of the opportunities and experiences I have been able to earn here at this University throughout my time in the dairy program. I commend Dr. Costa for being willing to take over as my major professor during unforeseen events. Although undesirable, I have learned many lessons from the unfortunate circumstances that occurred. With that, I thank everyone who has treated me and others respectfully, equally, truthfully, and ethically; you are the change in the world.

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and Grandpa Truman, I have appreciated your constant support and always smiled at your holiday cards (I had kept everyone until now having to downsize my possessions to fit into one vehicle). My parents, thank you for always being there whenever I have needed anything. I would be living in a box with no car if I did not have your assistance along the way. I am extremely lucky to have such amazing parents. Even though, Mom, you gave me my annoying perfectionism and Dad, my aggressiveness, these qualities have (usually) benefited and helped lead me to my success. My brother, you have always been my best friend. Although we are exactly alike, you've always been the rebellious and brave one. I went to college and you went to serve our country. You make it possible for me to have the ability to attend college as a woman, earn an education, and to study a major of my choosing. I thank you for all the joy and encouragement you've given me in my life and the sacrifices you've made for my opportunities. You are capable of anything you want to do. Thank you to everyone who has made this possible for me and supported me along the way.

I am blessed.

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FREQUENTLY USED ABBREVIATIONS

305ME = 305-day mature-equivalent milk yield

ABCS = Automated body condition score

BCS = Body condition score

concCHANGE = Conception automated body condition – calving automated body condition

d = Day

DIM = Days in milk

DMI = Dry matter intake

Dry7CHANGE = Day 7 automated body condition – dry automated body condition

dryCHANGE = Calving automated body condition – dry automated body condition

h = Hour

NEB = Negative energy balance

PMR = Partial mixed ration

TMR = Total mixed ration

wk = Week

OUTLINE OF THESIS

The following thesis manuscript provides information and studies relating to the use of automated body condition scoring in dairy cows. The first chapter seeks to introduce the topic, and to state the purpose, objectives and the hypotheses of the studies presented in this thesis in the following chapters. The second chapter is a review of the literature review of the use of body condition scoring for dairy cattle. The aim of the literature review is to detail and critically analyze the background knowledge about body condition scoring of dairy cattle. The third chapter is an original research study on the relationship of automated body condition scoring with disease and reproduction, in the order of introduction, material and methods, results, discussion, and conclusion. Chapter four is the second original research project, progression of automated body condition score across lactation. The fourth chapter follows the same format of the previous chapter. Lastly, chapter five summarizes the conclusions from the original research projects and finishes with future research suggestions.

CHAPTER ONE

Introduction of Thesis:

Automated body condition scoring: progression across lactation and its association with disease and reproduction in dairy cows

JUSTIFICATION

Body condition scoring is a nutritional tool for producers to evaluate the stores of fat. By visually assessing the cows' rear exterior a score from 1 to 5 (in 0.25 increments) or 1 to 10 in other parts of the world, can be determined. Highly under- or over-conditioned cows are indicative of an improper nutrition program or other deviations, such as disease. Naturally, body condition follows a curve across lactation, yet major deviations, resulting from suboptimal environmental conditions, leads to disease and reproductive repercussions. Although generations of research have supported this claim, over half of producers include no body condition scoring on farm. Low adoption rates of this practice can be attributed to labor, time, and training required. Lastly, the actions to take following data collection may be unclear or difficult to implement.

These previously described limiting factors are largely offset when considering a newly released commercial automated body condition scoring camera. This system is mounted and automatically scores and reports body condition of cows passing underneath. An automated system largely diminishes the need for labor, time, and training. Additionally, the system allows for easily generated reports to help incorporate the practice into management decisions. Although the system has been previously validated, additional research is needed to ensure that published relationships of manual body condition scoring is still evident in this automated system. This thesis aims to investigate those relationships and to determine factors affecting future automated body condition.

OBJECTIVES

The following lists the objectives for original research described in the thesis.

Objective 3.1

To identify the effect of predisposed automated body condition on the prevalence of subclinical ketosis and milk fever, determined from blood measures.

Objective 3.2

To investigate the effect of predisposed automated body condition on the incidence of metritis, retained placenta, milk fever, ketosis, and milk fever in the transition period.

Objective 3.3

To examine the effects of prior automated body condition on reproductive success, measured as pregnancy loss incidence, time to conception, and survival of pregnancy.

Objective 4.1

To describe observations of factors related to the progression of automated body condition score across lactation.

Objective 4.2

To develop an equation to assist in the prediction of automated body condition score from calving to sample mean nadir, 71 days.

CHAPTER TWO

Review of Literature:

Management and latest development around body condition scoring of dairy cattle

INTRODUCTION

Body condition scoring (**BCS**) is one of the most efficient tools to monitor the nutritional status of dairy cows, assessing the cows' fat reserves and energy contents (Garnsworthy, 1988, NRC, 2001). The advantage of BCS is that it is not altered by other elements which may influence body weight, such as gut or udder fill, and pregnancy stage (Roy et al., 2011). Routine observation and maintenance of BCS is an important tool to guide decisions regarding the herd's nutritional status. The BCS of dairy cows can affect feed intake, health, and reproduction throughout lactation. At calving, cows in poor body condition have increased risk for metabolic disease. Negative impacts ensue to breeding, with cows in poor BCS being less likely to have a successful pregnancy. Despite decades of literature presence, BCS has been an underutilized practice in farm management (Caraviello et al., 2006). The aims of this review are to 1) describe methods to monitor body condition, 2) discuss implantation management strategies for body condition, 3) examine factors affecting body condition, and 4) evaluate the impacts of body condition.

OPTIONS FOR BODY CONDITION SCORING

Manual Body Condition Scoring

Body condition score (**BCS**) was developed to attain a visual appraisal of fat deposits present on the cow. Body condition scoring is indicative of fatness of the cows and less affected by gut fill or empty BW (ARC, 1980; Broster and Broster, 1998). Edmonson et al. (1989) developed and evaluated a chart to assess eight locations on the cow to determine BCS and showed small interobserver and intraobserver effects. Visually scoring involves assessing 8 regions of the rear half of the cow within the areas of the loin, pelvis, and tail head and providing a score of 1 to 5, in quarter increments (Edmonson et al., 1989). The

9^{th} to 11^{th} rib tissue, a measure of subcutaneous fat, is correlated with BCS (Otto et al., 1991). As well, BCS has been found to be as accurate as ultra-sounding for fat contents (Domecq et al., 1995). When evaluating the factors causing variation in BCS, Evans (1978) and Nicoll (1981) found 60 to 70% was due to animal variation, 5% because of evaluator variation, and 10% because of animal-evaluator variation. Although BW has been found to be highly correlated with BCS for primiparous cows (r = 0.74 to 0.76, $P < 0.01$) (Meikle et al., 2004), Andrew et al. (1994) reported cows of similar BW having variations up to 40% in body reserves. However, Wildman et al.(1982) found no correlation for BCS and BW and findings by West et al. (1990) indicated that body weight change may not be indicative of fat stores (West et al., 1990).

Shemeis et al. (1994) found the partitioning of fat was affected by BCS. In sheep of different BCS, differences were found in subcutaneous fat and intermuscular fat (Caldeira and Portugal, 2007). Likewise, Shemeis et al. (1994) found that heavier conditioned dairy cows had higher abdominal fat (kidney knob and channel fat, omental fat and mesenteric fat) and lower other offal proportions. Kidney and intestinal fat was proportionally greater for heavier conditioned cows (Shemeis et al., 1994). In a study on sheep, scored on a scale 0 to 5, ewes with BCS 1 and 2 had high intermuscular fat and ewes BCS 3 and 4 had high subcutaneous fat (Caldeira and Portugal, 2007). Caldeira and Portugal (2007) concluded that the milking breed ewes put on fat intermuscularly first, followed by omental and mesenteric fat, subcutaneous fat, and lastly kidney knob and channel fat.

Although the method previously described by Edmonson et al. (1989) is the most used method and scale in the United States, other countries may use other techniques, such as palpation, and various scales for scoring dairy cattle body condition (Roche et al., 2004).

Bewley and Schutz (2008) reviewed international BCS systems where United States and Ireland/United Kingdom systems both scored on a 1 to 5 scale, but differed in their increments, 0.25 and 0.50 intervals, respectively. Australian and New Zealand systems both score BCS in increments of 0.5 but on scales of 1 to 8 and 1 to 10, respectively. Roche et al. (2004) reported the conversions for international BCS systems from New Zealand (**NZ**) BCS as USA = 1.5 + 0.32 NZ; Ireland = 0.81 + 0.4 NZ, and Australia = 2.2 + 0.54 NZ. Manual BCS scoring is the most prevalent way of BCS scoring across farms. However, all systems are incremental and shown to be related with the fat reserve of the animal.

Using the average BCS for different feeding groups of cows at key stages in the lactation cycle, may be one way to evaluate the effectiveness of the herds' nutrition (Grummer et al., 2004). Late lactation is a critical time to prevent over-conditioned cows entering the dry period, it is recommended if over 10% of these cows are fat then managerial change may be needed (Varga, 2007). Agreement on optimal BCS at dry-off and calving has yet to be reached, although it is accepted that cows should maintain a constant condition during dry-off. Recommendations for BCS at dry-off have been for 3.50 to 3.75 while others recommend targeting as low as 3.00 (Contreras et al., 2004). Butler (2014) recommends a 3.00 to 3.25 calving BCS and no higher than 0.5 BCS loss during the dry period. This recommendation is supported with evidence of disease risk reduction while having sufficient fat stores to support high milk production. Evaluating BCS should be done on a routine schedule to fully benefit but the scoring schedule may vary among farms depending on economics, time, and the herds BCS status. Important time points to consider assessing are dry-off, calving, breeding, 150 DIM, 200 DIM, and 250 DIM (Mulligan et al., 2006). If fully automated scoring is practiced the opportunity to monitor the herds' BCS more frequently is easily available. The need of regularity in evaluating automated BCS is dependent on the strategies and application of the scores on that farm.

Automated Body Condition Scoring

A more recent opportunity for BCS is scoring using automated technologies. The concept has been proven for the possibility to incorporate technology into BCS management. Some have used a black background to be able to distinguish the animal from the surrounds (Wang et al., 2008). However, commercial conditions can limit the ability of an algorithm developed in non-commercial settings to perform accurately (Van Hertem et al., 2013). Others have required ≥1 manual labeling procedure (Bewley et al., 2008; Halachmi et al., 2008; Azzaro et al., 2011) or selection of best image (Halachmi et al., 2008). Krukowski (2009) found 100% of predicted BCS to be ≤ 0.5 from the manual BCS using a training data set but when using the validation data set only 46% fell within the range. One automated scoring option currently available offers multiple options for scoring techniques, one option as a hand-held phone mounted scoring device and a moveable mounted device (Ingenera SA, Cureglia, Switzerland). The handheld device captures the score of the cow and requires the producer to manually record the result. Both systems require transfer of the data to a software system manually.

Other studies have investigated using cameras to automatically monitor BCS, although completely automated systems up until recently been unestablished. This has been developed into a commercial option, which is a fixed mounted system that automatically scores the cows and delivers the scores to the farm management software (DeLaval International AB, Tumba, Sweden). This system is fully automated and only requires the cow to walk beneath a video camera, resulting in daily BCS scores being available. As cows walk underneath the camera a 3-D video is taken. From the video a single best image is selected by the system and a proprietary algorithm determines the automated BCS. Scores are taken with each pass under the camera and RFID tags allow for automatic delivery of data recording (Hallén-Sandgren and Emanuelson, 2016). Mullins et al. (2018) investigated the precision of the automated system and found it to be equivalent to manual BCS. The authors also found that the extreme scores, high or low BCS, were less reliably evaluated by the automated camera system. As with Mullins et al. (2018), Krukowski (2009) reported their algorithm of automated BCS determination, least square solution, resulted in a bias for the mean manual score, 3.3 BCS. This process results in over estimated BCS for thin cows and under prediction of fat cows. Krukowski (2009) hypothesized that increasing the extreme condition scores in the training set would be able to improve the accuracy of the system.

IMPLEMENTATION STRATEGIES

Body condition score is linked with many important factors affecting cows and economics on dairies, such as disease, reproduction, and feeding (Roche et al., 2009). Yet the use of BCS on commercial farms is low. Time cost, training, and strategy of implementing BCS all limit its practice (Hallén Sandgren and Emanuelson, 2016). In a survey study, 33% of the participants indicated BCS was important in making decisions regarding the interval of the voluntary waiting period, although there was not much information given on the routine for scoring cows (Caraviello et al., 2006). While most producers value the information routine BCS of the whole herd may provide, many farms do not incorporate routine BCS in their management strategy of their animals. One study in Europe found that 36.4 % of producers scored cows (Heuwiser et al., 2010) and another found that 42.6% of the high producing herds surveyed in the United Statesutilized BCS (Kellogg et al., 2001). However, in the survey by Kellogg et al. (2001), producers that evaluated BCS did so at different time periods; calving (17.4%), peak milk (17.4%), mid-lactation (19.8%), , dry-off (25.6%), or at other times (19.8%), respectively. Although, Heuwieser et al. (2010) found that only 18.5 % of producers recorded their findings from examinations, limiting the potential of use. Although farmers may score their herd themselves, if a producer does not feel confident in scoring, lacks the time, or expertise, veterinarians and nutritionists are routinely on farm and equipped to condition score. This allows the producer to discuss proper goals for scores and ways to improve them. On the other hand, using an automated scoring system can lessen the time cost, diminish training, eliminate manual recording, and allow for easier implementation and use after adoption.

Kenyon et al. (2014) suggested that if producers were properly trained to use BCS that the adoption rates could increase. A study evaluating management factors associated with horse BCS found that the owners experience and involvement in a horse organization were predictive of BCS. These results may be because of education provided by increased experience or an organization, as well outside activity in a membership shows interest (Christie et al., 2006). Implementing a BCS strategy into a farm plan can be challenging. Use of the scores is highly dependent on the farm BCS status and scoring schedule. A farm with a more frequent scoring schedule has a larger application for the scores. Likewise, poor BCS may be more prevalent at different times in lactation for various farms, altering the way the farm may implement management for proper BCS. Body condition scores every 30 days can be frequent enough to offer valuable insight (Hady et al., 1994). Producer surveys have indicated the need for systems to be versatile and offer farm specific detection systems that fit their situation (Mollenhorst et al., 2012). Hady et al. (1994) recommended a higher proportion of the herd to be scored when cows were more distributed in BCS. Weigh scales or automated walk-over weigh scales can be used to evaluate weight changes and require less labor than BCS (Roche et al., 2007; Dickinson et al., 2013). However, Dickinson et al. (2013) determined that an automated weigh scale was unable to distinguish minor weight changes within cow. In addition, weight may not be an actual reflection of body fat stores as water, feed, and milk content can easily vary affecting live weight. Calculating the average per pen or proportion that are over or under conditioned is an effective strategy to monitor group rations and nutrition (Mulligan et al., 2006).

Grouping

Feed efficiency is evaluated by milk yield vs. dry matter consumption (VandeHaar et al., 2012). Grouping cows post-calving to feed properly could limit the effects of excessive and rapid BCS loss (Lopez-Gatius et al., 2001). While the ability to group may be limited by herd size, it can provide benefits if applicable based on farm limitations. Offering one feed ration does not allow for proper feed efficiency by all cows. Cows may be underfed or overfed dependent on their nutritional needs, resulting in poorer milk performance and adverse effects on disease and reproduction (VandeHaar et al., 2012).

Grouping within the herd may be affected by many factors such as group space, reproductive status, milk production, and BCS. Depending on herd size and the number of feeding groups, after freshening the cow will progress to a high production group. Reduction in milk production and increased BCS gain are key indicators to move the cow to a low production group to prevent over-conditioning. Cows that are already gaining weightor decreasing milk production will be allocating excess energy gained from greater feed intake towards fat stores (Linn, 2013). Reduced variability in BCS between cows would be the best economic strategy as a diet formulated to meet the needs of the average cow results in underfed and overfed cows, while formatting for the maximum production cow leads to overfeeding many cows (Kohn, 2007). Underfed cows will decrease their DIM and decrease BCS, typically higher milk production cows are the ones not provided enough energy in the ration and are underfed. The opposite occurs for overfed animals which will increase their BCS. Kenyon et al. (2014) recommends for sheep producers to keep all ewes above the target minimum BCS because setting a goal for an average BCS still allows for ewes to be below BCS by feeding for the average ewe. Although feeding to maintain this goal will allow some to acquire a much higher BCS, reducing efficiency. Throughout lactation and the dry period cows' nutritional needs vary. Not monitoring all individual cows would result in cows with a need of improved nutritional management being unnoticed (Kenyon et al., 2014). Evaluating individual cows each month is recommended (Garnsworthy, 2006) and a automated system allows for easy reports to target potential cows in need of attention. The energy allocation for milk production and fetal growth change, requiring a different ration need at different points in lactation. Over-conditioned cows in late lactation that progress into the dry period maintains their fat levels. Over-conditioned dry cows are therefore predisposed to greater transition period issues, as a decreasing feed intake greater than their healthy counterparts pre- and post- calving, resulting in higher prevalence of metabolic disease in these cows (Putnam et al., 1997; Putnam et al., 1999; Waltner et al., 1993). Altering condition in the dry period is difficult; therefore the optimum time to modify problem cows is 60 to 45 days pre-dry off.

Automated Milking Systems

Feeding dairy rations as a total mixed ration (**TMR**) is commonly adopted in the United States (NAHMS, 2014). Alternatively, cows being milked in an automated milking system (**AMS**) generally receive their ration split between a partial mixed ration (**PMR**) at the feed bunk and a ration allotment in the AMS. Offering a ration portion in an AMS can result in negative effects if not precisely balanced, such as improper rumen fermentation, altered feeding behavior, or decreasing milking performance. Yet, having the capacity for individual feeding allows for greater accuracy for specific cows' nutrient needs. Precision feeding through utilization of an AMS ration may allow for improved feed allocation, as with other individual feeding systems, by allowing the amount of feed and composition of the feed to be altered according to each cows' particular needs (Bach and Cabrera, 2017).

While feeding dairy cattle using a TMR system has its benefits as a practice, it is unable to optimize efficiency and profitability in many cases, especially when feeding one ration. The ration is formulated to meet the needs of the highest producers or the mean animal of the group, allowing the lower producing cows to eat more than needed. As well, vitamins and minerals either must be fed to the entire group or to none, resulting in some cows risking either deficiency or many being fed an amount in excess of the daily intake recommendation or nutritional need (Vandehaar et al., 2016). There are various reasons a farm may choose not to group cows to maximize efficiency. Contreras-Govea et al. (2015) proposed that ensuring diets are properly formulated and developing a plan for moving cows between groups may deter some of the negative effects towards nutritional grouping. Determined from income over feed cost, three groups of lactating dairy cows are the ideal management scenario to ensure efficiency benefits, using BCS, parity, yield, and reproductive status as factors involving movement decisions (Contreras-Govea et al., 2015). Grouping into three groups does increase potential labor associated with formulating, preparing, and delivering more diets, yet increases economic potential of the cows. Most farmers avoid practicing > 1 diet to allow for simplicity and perceived negative milk yield impacts from group moves (Contreras-Govea et al., 2015). Installing concentrate feeders may be an alternative strategy to nutritional grouping, allowing higher producing cows to get the additional feed intake required and limiting the lower, later lactation cows feed costs (Cabrera et al., 2012).

Concentrate Feeders

As with grouping, concentrate feeders offer the opportunity to feed cows more closely to their individual nutrient needs. Grouping allows for cows in a similar situation to be fed according to those needs. Concentrate feeders offer more flexibility allowing for increased ration feeding options to individual cows. Concentrate feeders also reduce the limitations that grouping creates of group space and current farm set-up. Removing the movement while still receiving a more properly balanced ration provides additional benefits, but pen moves can also create addition stress from relocation and social changes (Nordlund et al., 2006).

Using concentrate feeders, limits can be placed on a cows' intake when their nutrient needs are lower, to reduce over-conditioning. Likewise, if a cow appears to be gaining condition, a restriction can be placed on her concentrate intake to prevent further improper gain. During the post-freshening period the demands for cows will change more rapidly, requiring more adjustments in the feeding system, while later in lactation fewer alterations will need to be made to adhere to the cows' nutrient requirements (Table 2.1).

The feed at the bunk can be balanced for all cows to consume by meeting the needs for the low production cows then supplementing the additional needs for higher producing animals in the feeder. This allows for higher production animals to consume feed to sustain their milk production without losing condition and lower production cows to not overeat resulting in over-conditioning (Grant and Bodman, 1995). Implementing ABCS into a concentrate system can allow for automatic concentrate allowance when ABCS may be decreased or increased beyond a threshold, to alleviate negative ABCS.

PROJECTION OF BODY CONDITION CHANGE

Factors Affecting Body Condition Change

Breed, feeding, time of BCS, and phase of lactation at scoring can all affect BCS (Mao et al., 2004). Friggens et al. (2004) defined genetically driven BCS change as, “that which would occur in cows kept in an environment that was in no way constraining.” Environmentally driven BCS change is from the environment the animal is performing in. For example, if feed is limited, the mobilization of condition will increase more than if genetically driven. High conditioned cows suffer greater losses of BCS post-calving due to decreased DMI (Roche et al., 2007). Others have also hypothesized that increased fat stores decrease the rumen area, that which results in the decreased DMI (Grovum and Chapman, 1988; McCann et al., 1992; Caldeira and Portugal, 2007). Figure 2.1 show a reconstructed flow-chart of factors affecting intake ability. Cows that have been forced off their trajectory by nutritional challenged respond with compensatory changes in body fatness in early lactation (Garnsworthy and Topps, 1982; Broster and Broster, 1998). The accumulation of condition in late lactation seems unrelated to energy content in the diet and lowering it results in lower milk production (Friggens et al., 1998).

The maintenance portion of the diet is the energy needed to function, without gaining or losing tissue (NRC, 2001). Although it has been suggested that despite efforts to prevent negative energy balance, BCS will still be lost (i.e. maintenance will not be kept) due to predetermined genetics. A cow's needed intake is based on its requirements at a given phase of lactation (Roche et al., 2013). Additionally, suggested energy requirements can vary, potentially from the various methods of determination (ARC, 1980). Energy efficiency can be affected by the feed in the diet (ARC, 1980). Lower BCS cows require a higher energy diet (Garnsworthy and Jones, 1987). As well, maintenance efficiency is increased if the energy in the ration is higher, requiring less feed intake and less muscle exertion and heat production (Reynolds et al., 1991). The energy cost of gaining BCS is higher with greater original BCS (ARC, 1980). During the first 30 DIM, 30% of milk yield is supplied from body condition (Mishra et al., 2016). Williams et al. (1989) hypothesized that, "body tissue mobilized during early lactation has a higher energy density than tissue gained under normal growth conditions". Energy requirements increase during pregnancy to account for maintenance and growth of the fetus (Gibb et al., 1992) and can be affected by the day of gestation and calf weight (Bell et al. 1995). Gibb et al., (1992) found that at week 29% , 0.0029 of the total body energy is used for pregnancy, which increases with increasing days in gestation. Gibb et al. (1992) observed cow gains, after 8 weeks in milk, even after removal of gains from fetal and uterine tissue. Goats also change their preference of delegation at the end of their lactation period from milk production to gaining BCS (Kharrat and Bocquier, 2010).

Although growing cows gain mainly protein tissue, mature cows will focus on fat gain (Holmes et al., 2002). Energy needed to synthesize tissue is dependent on whether the tissue is fat or protein and the metabolizable energy used for growth (Geenty and Rattray, 1987). Whether energy efficiency is different for fat or protein gain has not been resolved (ARC 1980; CSIRO, 2007; Mandok, 2013;). Other factors, such as absorption type and stage of lactation, do affect the efficiency of use of the energy for gains (ARC, 1980; CSIRO, 2007).

Predicting Body Condition Change Across Lactation

Koenen and Veerkamp (2001) found cows supplemented excessive energy devoted it towards milk production rather than reduction in mobilization of fat. Commonly, energy requirement predictions do not incorporate genetically mobilized BCS in addition to lactation and maintenance (Friggens, 2003). An important consideration is that while changing a certain aspect of genetics, such as increased milk production, it is also important to consider the other traits affected by this selection (Veerkamp, 1998).

Puillet and Martin (2017) used machine learning techniques to predict future BW loss or gain to be used in herd management. Predicting BCS change may be useful to mitigate the negative effects seen in cows deviating from their genetic pathway. For example, excessive BCS change becomes an issue when BCS is lost faster than predetermined from genetics, due to poor environment (Friggens et al., 2010). Being able to predict the future loss may allow for group managerial changes if groups are affected or individual cow attention, allowing for earlier detection systems (Friggens and Lovendahl, 2008). Body measured parameters to determine energy balance are more precise compared to milk measured parameters (Lovendahl et al., 2010). Although milk parameters may be less precise, they are advantageous because they can be automated and easily integrated (Lovendahl et al., 2010). An automated BCS system would therefore add this benefit to body measures as well and increase its applicability on farm. An issue with evaluating the use of BCS as a parameter to detect disease is the lack of high BCS cows to determine a threshold (Ruegg and Milton, 1995; Heuer et al., 1999). Although suggested for the automated function of the BCS system, having under- or over-conditioned cows sent to a second level inspection may be a useful strategy (Vieira et al., 2015).

Most studies have recommended a target BCS for various stages of lactation or acceptable losses between periods of time (Garnsworthy, 2006). Although this method has been long accepted and is easily understandable, recommending the same BCS for all production systems may not be suitable. European systems may offer pasture access, increasing feed variability, whereas that is not typical of a U.S. system (Sato et al., 2005). Stockdale (2001) proposed that goal BCS at calving can be affected by genetics, feeding, and breeds. Additionally, since BCS is genetically and environmentally driven, and both vary extensively farm to farm, proper management can be used to alleviate negative effects. The utilization of an automated BCS system would play an important complementary role to an already set management strategy and allow for increased accuracy in targeting specific cows for condition adjustment within individual herds.

IMPACTS OF BODY CONDITION

Dry matter intake starts to be reduced and cows start to enter negative energy balance pre-calving. This reduction is affected by lactation number, BCS, and macronutrient intake. Hayirli et al. (2002) witnessed a 32.2% reduction in DMI 3 weeks prior to calving, with 88.9% of the reduction in the last week before freshening. Negative energy balance is a result of milk production and maintenance needs exceeding the level of energy intake. If a cow's negative energy balance is too excessive or decreased for too long, negative effects can ensue (Roche et al., 2009).

Subclinical Disease

Milk fever. Subclinical milk fever is heavily prevalent in dairy herds and largely undiagnosed. Approximately 25 to 54 % of dairy cows have been found to develop subclinical milk fever, dependent on lactation number (Reinhardt et al., 2011). Venjakob et al. (2017) found 47.6 % of cows diagnosed with subclinical milk fever. It is usually diagnosed as calcium concentrations < 8.6 mg/dL (< 2.15 mmol/L) and evaluated close to calving (Goff, 2013). Martinez et al. (2012) found no association between calcium and BCS, although cows with subclinical milk fever did later lose more BCS. Ribeiro et al. (2013) also saw more loss in BCS for cows with subclinical milk fever. Additionally, cows with subclinical milk fever had significantly lower BCS across DIM (Ribeiro et al. 2013).

Ketosis. High concentrations of beta-hydroxybutyrate (**BHB**) are typically a sign of subclinical ketosis occurrence. Levels of BHB for the threshold indicative of subclinical ketosis vary, typically ≥ 1.2 mmol/L. Mobilization of fat stores increases the levels of ketones circulating in the bloodstream. Because higher conditioned cows mobilize more stores, BHB levels and subclinical ketosis is found increased in these animals. Meikle et al. (2004) found BHB concentrations decreased as BCS decreased post-calving. Additionally, cows with ≥ 3.75 BCS at dry-off had an increased risk of developing subclinical ketosis (OR 5.25) (Garro et al., 2014). Likewise, Bernabucci et al. (2005) reported cows with BCS > 3 had higher BHBA and NEFA levels compared to cows with ≤ 3 BCS.

Clinical Disease

As the fetus begins to develop in the late dry period and then followed by milk production prior to calving, the nutrient demands of cows are higher than can be obtained in the diet (Bell, 1995; Chilliard, 1999). Higher BCS decreases the DMI, resulting in increased mobilization of body reserves which can negatively impact liver functions (Garro et al., 2014). Lack of carbohydrates increases NEFAs and ketones in the liver and circulating blood (Herdt, 2000). Increased BCS mobilization increases liver NEFA uptake and higher levels of fatty acids are accumulated than are broken down (Friggens et al., 2010). Fatty liver results in reduced metabolism and immune functions (Zerbe et al., 2000). Ketone levels are raised when the livers typical functions are impaired (Friggens et al., 2010). In lipid mobilization, fat stores release NEFAs, which are then used for milk or energy. Ketones are increased in greater negative energy balance (**NEB**) resulting from the increased uptake of NEFA (Bell, 1995). Cows in negative energy balance have increased inflammatory activity (Wathes et al., 2009). Around calving, levels of immunoglobulin and white blood cells are altered (Rinaldi et al., 2008; Herr et al., 2011). Limiting BCS loss post-calving by monitoring and adjusting management for proper condition at dry-off and maintenance of that condition until calving can help reduce risk of disease (Roche, 2006).

Retained placenta. Waltner et al. (1993) found no relationship with retained placenta incidence and BCS. Gearhart et al. (1990) also reported no effect of BCS on retained placenta, although noted that this could have been caused by a small sample size. Additionally, Ruegg and Milton (1995) found no association between calving BCS and retained placenta occurrence. Markusfeld et al. (1997) noted a non-significant relationship between calving BCS and retained placenta in primiparous cows, although the relationship was significant ($P < 0.05$) in multiparous cows. Multiparous cows with higher calving BCS had lower odds compared to cows with one unit lower BCS, of retained placenta. No relationship was found between dry-off BCS or dry-off to calving BCS loss with retained placenta occurrence (Markusfeld et al., 1997).

Milk fever. Contreras et al. (2004) reported cows with BCS at dry-off ≤ 3.00 had a lower incidence of milk fever than those ≥ 3.25, 2.7 and 4.5 %, respectively, although the total number of cows developing milk fever was low (n = 10). Chapinal et al. (2012) found no relationship between dry BCS ≥ 3.75 and milk fever outcome. Cows that lost 1.0 to 1.5 BCS from the dry period to calving have been found to have a higher incidence of milk fever (Kim and Suh, 2003). Roche and Berry (2006) found significant odds ratios of milk fever development of 1.13, 0.56, 1.00, 0.96, and 1.31 for calving BCS of ≤ 2.50, 2.75, 3.00, 3.25, and ≥ 3.50, respectively. The development of milk fever in over-conditioned cows may be due to the decrease in DMI, but also decreasing calcium intake, which is at increased demand immediately post-calving (Rukkwamsuk et al., 1999). Heuer et al. (1999) also found 3.3 times higher risk for cows ≥ 4 BCS at calving.

Metritis. Metritis can decrease DMI and affect metabolic disease occurrence (Garro et al., 2014). It has been previously reported that cows that lost 1.0 to 1.5 BCS from dry-off to calving had higher incidence of metritis (Kim and Suh, 2003). Although, Waltner et al. (1993) found no relationship with metritis incidence and BCS. Gearhart et al. (1990) found higher metritis when cows were ≥ 4.0 BCS at 30 DIM, yet their sample size of over-conditioned cows was small. Metritis in multiparous cows was significantly (P < 0.05) related to calving BCS, with 30% lower odds for the higher adjacent BCS unit, although primiparous cows were non-significant (Markusfeld et al., 1997). Additionally, markusfeld et al. (1997) also found 2.2 odds ratio for higher BCS losses in multiparous cows from dry-off to calving but did not find a relationship with dry-off BCS.

Ketosis. Ferguson (2002) reported greater odds of ketosis with increased dry BCS and Gillund et al. (2001) observed the same relationship with calving BCS. Body condition scores of ≤ 2.75, 3.00 to 3.25, 3.50 to 3.75, and ≥ 4.00 had odds ratios of 1.0, 1.0, 2.4, 2.3, and 2.4, respectively. Body condition score recorded between calving and 8 DIM was significantly associated with ketosis outcome in a study by (Seifi et al., 2011). Cows that were ≤ 3.00, 3.25 to 3.50, and ≥ 3.75 BCS had odds ratios of 7.09, 3.43, and 1.00, respectively, although the overall incidence of ketosis was low in the study (3.65 %). Higher BCS at calving until 2 weeks in milk for cows diagnosed with ketosis is reported to be a significant ($P < 0.001$) relationship (Shin et al., 2015). Cows with ketosis have been reported to lose more BCS by 30 DIM post-calving, yet it was not a statistically significant finding (Gearhart et al., 1990).

Displaced abomasum. In a study by Contreras et al. (2004), the incidence of displaced abomasum was higher in cows ≤ 3.00 BCS at calving then their heavier counterparts, 2.2 and 1.8 %, respectively. In a Brazilian study done on 7 herds, BCS at displaced abomasum diagnosis (mean DIM ± SD; 33.60 ± 46.27) was significantly lower (2.32 v. 3.11; $P < 0.001$) compared to cows without a positive case (Cardoso et al., 2008). As Gearhart et al. (1990) found with ketosis, cows with displaced abomasum lost more condition from calving to 30 DIM, although this difference was not statistically significant. Moreover, it has been reported thatcows that lose > 0.25 BCS by 4 weeks in milk post-calving had significantly greater displaced abomasum incidence (Hoedemaker et al., 2009). Additionally, they found that cows losing no BCS, compared to 0.25 and > 0.25 BCS loss, during the same time frame had lower odds, 0.09 and 0.07 respectively, of developing a displaced abomasum. Body condition score taken the last 5 weeks pre-calving was significantly associated with increased risk (RR: 2.4) of displaced abomasum in higher conditioned cows (Cameron et al., 1998).

Effects on Reproduction

Reports of condition on reproductive aspects are contradicting. Wildman et al. (1982) found higher condition to be related to improved reproduction, yet others have found no effect (Bourchier et al. 1987). Many have hypothesized that the genetic aspect of BCS is related to presumption of reproduction and its maintenance (Friggens, 2003; Roche et al., 2007). Friggens (2003) hypothesizes that cows in lower BCS have less condition and are at increased risk, therefore less likely to have a successful pregnancy. In an Italian study cows that lost ≥ 20% BCS 10 d pre-calving to 30 d post-calving suffered the greatest reproductively, compared to those who lost less BCS (Prandi et al., 1999). Jílek et al. (2008) found that cows with > 3.5 BCS one-month post-calving had the shortest calving to first service interval, indicative of resumption of cyclitic membranes and ability to demonstrate estrus behavior. Although BHB is typically associated with metabolic disease monitoring, Walsh et al. (2007) found higher concentrations to be associated with lower probability of pregnancy at first service. Successful reproductive programs have high levels of cows eligible for breeding and a high conception at breeding (Roche, 2006).

Heat detection. The number eligible for breeding is affected by both the cows' resumption of ovulation and ability to demonstrate estrus behavior (Roche, 2006). Disease occurrence increases the days to observing first estrus post-calving (Roche, 2006). Additionally, Markusfeld et al. (1995) found higher calving BCS to improve estrus expression. Likewise, Pryce et al. (2001) found a relationship with calving BCS and days to first heat. Although some have found relationships with days to first heat, others have found non-significant relationships with its association with calving BCS (Garnsworthy and Jones, 1987; Ruegg and Milton, 1995). Many have reported the optimum BCS loss in early lactation of ≤ 0.5 for improved reproduction (Overton and Waldron, 2004, Mulligan et al., 2006; Roche, 2006,), likely preventing under-conditioned cows at breeding.

Conception rate. It is argued that lower condition at breeding reduces chances of conception because of the decreased likelihood of cow's survivability and pregnancy survivability. In addition, parity, disease, and season also affect ovulation occurrence (Beam and Butler, 1997; Opsomer et al., 2000; Wathes et al., 2007). Opsomer et al. (2000) found increased time to ovulation for cows that lost more condition. Yamada and others (2003) found that cows with high BCS mobilization (1.00 to 1.50 BCS) from 10 DIM to 30 DIM had a higher conception rate than those with low BCS mobilization (0.25 to 0.75 BCS). Although, when increasing the time frame of BCS change from 10 DIM to breeding, the low BCS mobilizing cows had higher conception rates. The likelihood of conception at first service was increased with higher nadir BCS and decreased with increased BCS loss (Roche et al., 2007). Cows that were 2.75 BCS or higher at 30 DIM, 40 DIM, and breeding had increased conception rates (Yamada et al., 2003).

Survival of pregnancy. Loss of pregnancy typically occurs in the early embryo stage (Diskin et al., 2006; Diskin and Morris, 2008). The quality of oocytes produced can be reduced when cows are in negative energy balance (Leroy et al., 2005, Roche, 2006), resulting in embryo loss (Sartori et al., 2004, Roche, 2006). Additionally, cows with high DMI (typically lower conditioned cows) have lower progesterone concentrations, as well increasing embryo loss risks (Sangsritavong et al., 2002). Silke et al. (2002) reported significantly more embryo loss for cows that lost condition, opposed to those who maintained or gained, within 4 to 8 weeks post-conception. Although Moreira, et al. (1999), found 27 to 48 d past breeding embryo losses were unrelated to low BCS.

Other Factors Related to BCS change

Welfare. Across species BCS is considered an effective indicator of criterion relating to welfare level. Species such as mice (Ullman-Culleré and Foltz, 1999), beef (Ndou et al., 2011), dogs (Yam et al., 2016), buffalo (de Rosa et al., 2005), and horses (Pritchard et al., 2005) use BCS as a characteristic of welfare level in evaluations. The principle of good feeding and criterion of absence of prolonged hunger has as an important indicator the BCS of the animals, being a major component of good health (Welfare Quality, 2009). Body condition can be used as an indicator for more than just good feeding criterion but also absence of disease (Battini et al., 2014). With cattle it has already been shown that poor BCS increases disease risk and downer cows, known to be an issue with the public view of animal welfare (Stull et al., 2007). In goats, correlations between cold weather and mortality of under-conditioned individual goats (McGregor and Butler, 2008). Lameness, also an indicator for other criterion, is shown to increase with low BCS and BCS loss (Walker et al., 2008; Lim et al., 2015). BCS is highly correlated with digital cushion thickness, higher BCS having greater thickness (Bicahlo, 2009). While there are resources to aid in accuracy of scoring, both within and between scorers there is still error involved. It can help with subjective data obtained (Banhazi et al., 2012). When trained welfare assessors were asked to score the importance of the welfare indicators BCS was within the top four (de Graaf et al., 2017).

In the United States, 98% of the United States milk supply in 2016 received audits from a benchmarking program mandated by most cooperatives (National FARM Program, 2016). This audit requires 99% of all cattle on the farm to score a BCS 2 or higher (National FARM Program, 2016). The accuracy of scoring is necessary when using BCS in welfare assessments (Vasseur et al., 2013). Validation of technologies used in welfare assessments and assuring their purpose of inclusion is important so that technology use improves producers' life and advance producers' knowledge of the animal to improve its welfare. Automated BCS systems can keep constant recording of animals' condition and can allow for a timelier notice of potentially negative welfare situations (Sassi et al., 2016).

Genetics. Reducing costs associated with feed, a major proportion of total costs, is important to increasing efficiency and profitability. There are genetic differences among cows in their ability to reduce feed intake while maintaining milk production (Connor, 2015). Dry matter intake is difficult to measure individually, especially on a large scale. Using traits that are easier to measure and correlated with DMI to help predict feed efficiency is an effective strategy (Manzanilla-Pech et al., 2016). Body weight is difficult to select for because the separation between cow sizes and BW cannot be made without BCS (Köck et al., 2018). Body condition is a conformation trait that has been proved predictive of DMI and useful in calculating feed efficiency (Kennedy et al., 1999; Manzanilla-Pech et al., 2016). Studies have estimated BCS and BCS change heritability's at 0.27 to 0.37 and 0.01 to 0.10, respectively (Pryce et al., 2001; Dechow et al., 200;Berry et al., 2003,). Although, heritability's vary at different points in lactation, with dry-off having estimates of 0.07 to 0.09 (Dechow et al., 2002). Early lactation BCS is negatively correlated with BCS change (Heuer et al., 1999; Dechow et al., 2002; Berry et al., 2003,).

However, BCS change and not the static BCS may be a more important characteristic. Hurley et al. (2016) found that 25% of variation when estimating energy conversion efficiency, or energy requirements over energy intake was caused from BCS loss. It is likely necessary to ensure the inclusion of BCS loss in efficiency calculations to account for early BCS loss (Vallimont et al., 2011). Negative genetic correlations indicated loss of BCS increases efficiency (Hurley et al., 2016). Moe et al. (1981) also concluded that BCS loss followed by later regain was an efficient means of energy use. Although, feed efficiency may have the potential to be selected for by using BCS in mid- to late- lactation, while keeping the genetic correlations to energy balance and not reducing energy balance in early lactation (Spurlock et al., 2012). Non-diseased cows have higher feed intakes during early lactation than their diseased counterparts (Mulligan et al., 2006). Others report that over-conditioned cows genetically lose more BCS in early lactation and regain condition in mid- to late- lactation, although the genetic relationship of BCS change to BCS in mid- to late- lactation is minor (Berry et al., 2003; Hurley et al., 2016). The stage in production is important to include in genetic predictions, BCS heritability's range at different stages in production (Spurlock et al., 2012). Higher BCS loss from day 5 to day 60 is mostly impacted by an increased BCS at calving; therefore reducing BCS at calving would also reduce the early lactation BCS loss (Berry et al., 2003). As well, it is suspected that when estimating the genetic variances and heritability, some potential is lost being that they are measured in quarter points, therefore there is potential for the automation system to be used in making genetic predictions more precise (Berry et al., 2002).

ECONOMICS OF MEASURING BODY CONDITION SCORE

When economically modeled, reproductive advancements from improved BCS had the greatest financial effect (Bewley et al., 2010). European farms have increasingly crossbred with beef bulls to allow for increased cull cow prices or breeding within beef herds (Berry et al., 2006). Some have found that calves and culls result in 10 to 20 % of income (van der Werf et al., 1998). Carcass value decreases with improper BCS at culling (Apple, 1999; Smith et al., 1994; Loeber et al., 2001). Apple (1999) recommended culling beef cows at intermediate BCS because higher or lower BCS decreases the economic value of the cow. As well, once negative energy balance is decreased too far, resulting in a low BCS, cows catabolize muscle to meet physiological needs (Smith et al., 1994). The economics of the system investment also depends on action being taken from the provided data (Van De Gucht et al., 2017).

A key point in technology investment is the difference between potential improvements from implementation and actual realizations. Using the data provided and applying it into practical, useable management decisions must be done to utilize all advantages (van Asseldonk et al., 1999). DeLorenzo and Thomas (1995) notes, “experience, knowledge, and constraints,” are difficult to estimate in economic models. In a survey of dairy producers, 63.9% indicated that the cost benefit ratio was important when considering a technology purchase. As well, 40.4% indicated that the technology must be simple and easy to use (Borchers et al., 2015). Determining the economic effects of welfare improvement is difficult to measure and therefore automation economics may underestimate the full financial benefits (Van de Gucht et al., 2018). Decisions to invest in technologies are affected by many factors, such as economics, finances, replacement owners, and farm size (Van Asseldonk et al., 1999; Aramyan et al., 2007). Bewley et al.

(2010) also concluded that the automated BCS system investment decision was herd-specific. Consider factors such as cows' status of concern and how that will continue and affect their management and profitability (Rutten et al., 2013). Using technology can help aid in this decision and streamline information that may have not be available without the investment (Groenendaal et al., 2004). Specifically, BCS automation investment depends on the current status of the herds BCS and their ability to implement changes with the use of BCS data (Bewley et al., 2010).

Using technology on dairy farms provides many useful opportunities for improved performance, although it is a change to current practice. Improvement in systems clarity and functionality after the data is received is needed. Most data, even if provided as an alert, may not be used if the action to respond is unclear (Barkema, et al., 2015). This can lead to improper or limited use of the data provided by the system (Jacobs and Siegford, 2012). A vital part of an effective change is having a support team, to educate and resolve issues that arise (Elrod and Tippett, 2002). Harvey (1990) discussed that with every change there is a loss associated with it. Technology replaces previous practices, yet information is lost from not visually observing the cow (Elrod and Tippett, 2002).

Ingvartsen and Andersen (2000) suggested that BCS could be useful in revealing cows with low intake and therefore metabolic stress. Decision trees or automated alerts for certain BCS criteria, such as cows that deviate from a certain static BCS or BCS change at a particular time, should be generated from the system to allow for greater functionality. Although an automated system has the potential to provide daily BCS, this may be unnecessary to evaluate daily to obtain benefits (Hady et al., 1994). For manual scoring Mulligan et al. (2006) recommends attaining scores at dry-off, calving, breeding, 150 DIM, 200 DIM, and 250 DIM. Average scores per group and the amount they vary should be evaluated to ensure proper DMI (Mulligan et al., 2006). Others have proposed potential criteria for goals for a cow to be bred and maximum loss of BCS in early lactation (Pryce et al., 2001; Buckley et al., 2003). Condition scores are indicative of nutrition and correlated with body fat and energy (NRC, 2001). Individual feeding, although ideal, is impractical on most farms and proper grouping, with low variation within group, supports improved feeding efficiency (McGilliard et el., 1983, Sniffen et al., 1993). Grouping cows into separate groups to allow for feeding more precisely improves the overall BCS distribution of the herd and is more economical than feeding one TMR for the herd (Cabrera and Kalantari, 2016; Kalantari et al., 2016,). The exact integration of a BCS protocol should be specific to the herd and developed with the producer to attain the largest benefit from the system (Hady et al., 1994).

Cost: benefit ratio was surveyed to be the most important investment decision by producers (Borchers and Bewley, 2015). Although the initial cost of the automated system may be large, the cost of a veterinarian, nutritionist, employee, or the producers time opportunity cost would be removed from scoring. In addition, utilizing the data provided to manage BCS can improve disease, reproduction, and feeding efficiency (Bewley et al., 2010). Other studies have demonstrated the ability to integrate other traits into automated BCS systems, potentially increasing the feasibility of the producers' investment (Van De Gucht et al., 2017; Hansen et al., 2018). Although welfare is difficult to account for in economic models, it is important to consider as a positive impact of investment in automated BCS systems. Farms are already being required to obtain certain levels of proper

BCS (National FARM Program, 2016) and Britt et al. (2018) predicts that welfare scrutiny will increase in the future.

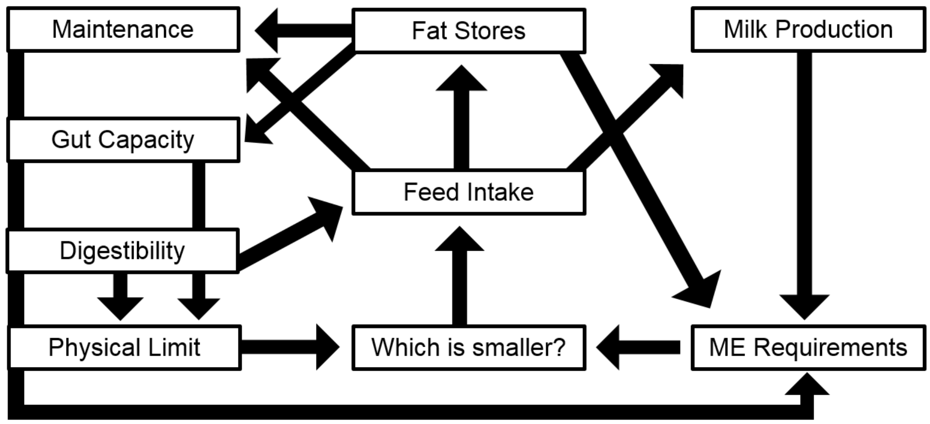
CONCLUSION

Body condition can provide insight into the cow's current health status and previous management efficiency. Changes in BCS are associated with several factors such as metabolic illness, or deficiency in feeding and other management practices in dairy cattle. Observation and implementation of intervention strategies can improve body condition and potentially reduce negative impacts. Use of body condition scores to evaluate current practices can also aid in prevention of improper condition at times when cows are most susceptible to BCS change. Establishing a routine BCS practice and application of the scores into farm management goals and decisions can improve herd reproduction, health, and welfare. Using automated body condition scoring systems can allow for a more uniform observation of changes in BCS across time. The objectives of this thesis were to 1) describe body condition score across lactation, using an automated BCS scoring system and 2) observe the effects of body condition on disease and reproduction, using an automated BCS scoring system.

Table 2.1. Suggested feeding alterations based on weeks in lactation

Week in Milk	Adjustment Frequency
≤ 6	2x/week
6 to 12	1x/week
≥ 12	Monthly

Figure 2.1. Representation re-illustrated from Forbes (1983) involving the ability of cows to maintain feed intake. Beginning at feed intake the factors it affects and what vice versa are shown.



CHAPTER THREE

Study One:

Automated body condition scoring: Evaluation of effects on disease and reproduction in a commercial dairy herd

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INTRODUCTION

Body condition scoring is a practical method to estimate energy balance by visually assessing the fat reserves present subcutaneously in the animal. Excess energy is deposited as reserves and in periods of negative energy balance (when needs overcome intake) fat is mobilized (Butler and Smith, 1989; Edmonson et al., 1989). Extreme body condition score has been linked to disease in many species, such as, humans, horses, cats, and dogs (Henneke et al., 1984; Scarlett and Donoghue, 1998). Both the static extremes and changes between body condition scores (BCS) at different time points can indicate important information regarding cows' health and reproduction. Cows that follow an ideal BCS curve throughout lactation, dry period and transition period are at a decreased risk for disease and lower reproductive success (Roche et al., 2009; Gomez et al., 2018).

The linkage of BCS change to disease occurrence has been described as a result of elevated proinflammatory cytokines, leading to decreased DMI, decreased nutrient uptake, and impaired adipose and liver activity (Ingvartsen and Andersen, 2000; Dandona et al., 2004; Hotamisligil, 2006; Odegaard and Chawla, 2013). Beta-hydroxybutyrate (BHB), an organic compound often measured as an indicator for subclinical ketosis (Mulligan et al., 2006), has been found in significantly higher concentrations in well-conditioned compared to under-conditioned cows at calving (Roche et al., 2015). Rathbun et al. (2017) also found that cows that were over conditioned at time of partum or showed a >1 BCS change of body condition during the transition period shown higher concentration of beta-hydroxybutyrate acid (**BHBA**). Additionally, calcium concentrations can be monitored as an indicator of subclinical milk fever (MF) when in reduced levels (Mulligan et al., 2006). However, calcium concentrations and milk fever do not have a clear relationship with BCS at calving. For instance, Martinez et al. (2012) reported no effect of calving BCS on subclinical milk fever and Chapinal et al. (2012) did not see an effect of precalving BCS ≥ 3.75 on milk fever. Ribeiro et al. (2013) described a positive correlation between calcium concentrations and BCS at 7 DIM, while Valldecabres et al. (2017) reported negative correlations with BCS at calving and low calcium concentrations. The current ambiguity on the relationship between BCS and calcium concentrations calls for additional research to investigate whether more accurate BCS scoring can be used as a precursor for hypocalcemia related disease.

Clinical disease incidence is known to be affected by extreme BCS and BCS change around calving (see review by Roche at el., 2009; Koeck et al. 2014; Gomez et al., 2018). The most recognized relationship with BCS and clinical disease is ketosis (Duffield, 2000; Gillund et al., 2001) as lost body condition during the dry period increases the risk for developing ketosis (Kim and Suh, 2003). It has previously been reported that cows with a BCS greater than 3.5 around calving are more susceptible to ketosis compared to cows with lower BCS (Gillund et al., 2001). The occurrence of milk fever also increases in cows with higher BCS, possibly due to decreased calcium intake (Heuer et al., 1999; Ostergaard et al., 2003). In addition, Roche and Berry (2006) found that cows with a BCS above 2.5 at calving had an increased risk of milk fever. Moreover, LeBlanc et al. (2005) found no relationship between prepartum BCS and displaced abomasum occurrence. Another study found that displaced abomasum incidence increased as BCS at calving was higher, although other disease occurrences were unaccounted for (Shaver, 1997). In agreement, others have also found that an increased BCS at calving increases displaced abomasum occurrence (Shirley, 1994; Cameron et al., 1998). Previous studies have shown that poor

BCS can increase metritis (Wathes et al., 2009), whereas others have found no relationship, potentially because of the actual negative energy balance experienced in the different studies or diagnosis of metritis (Kaneene and Miller, 1995; Huzzey et al., 2007). However, several studies have concluded that BCS does not have a relationship with the diagnosis of retained placenta (Waltner et al., 1993; Ruegg and Milton, 1995; Kim and Suh, 2003).

Along with disease, reproductive success of dairy cattle is also affected by low or high BCS. Chapinal et al. (2012) reported that cows that were thin and moderately conditioned prior to calving were less likely to conceive at breeding. Conception rates have been found to decline in cows with decreased BCS in early lactation (Domecq et al., 1997; Loeffler et al., 1999; Lopez-Gatius et al., 2002; Santos et al., 2009) and at 2 to 4 wks post-calving (Heuer et al., 1999) and for cows with low BCS at breeding (Moreira et al., 1999). Starbuck et al. (2004) found that over-conditioned cows had a higher proportion of unsuccessful conceptions compared to normal and under-conditioned cows at their first post-conception examination. However, a previous study reported no relationship between BCS at calving and conception at first service (Gillund et al., 2001). Differences in findings across studies can be possibly attributed to the differences in BCS proportions within the herds, especially the lack of heavily under- or over-conditioned cows, various times of BCS measurement, differences in BCS categories set by the researchers to evaluate, or lack of association.

Although the importance of proper BCS has been well documented in many studies as mentioned above, a survey by Caraviello et al. (2006) reported that over half of the participating producers never measure or record BCS routinely from cows in their herds. A German fresh cow management survey found similar results, where only 36% of the participants responded that they body conditioned scored their herds routinely (Heuwieser et al., 2010). Lack of adoption of routine BCS is in part because of the practicality of when to score cows on the farm, and how to address data management of the scores (Hady et al., 1994). An automated BCS system can provide daily scores and a data recording system to help the producer obtain qualitative data. Also, a user-friendly system for analyzing large BCS data sets which helps with identification of cows with BCS changes and management decisions. On-farm automation is increasing, and dairies will continue to adopt more technologies (Britt et al., 2018). However, in a recent survey, only 2.8% of producers recorded BCS using automated technology. This was attributed to the lack of commercially available options (Borchers and Bewley, 2015). Mazeris (2015) found an automated BCS system to be highly accurate in relation to a human scorer, with 98% of scores being within a quarter point. Additionally, data reported by Hallén Sandgren and Emanuelson, (2016) showed the repeatability of the automated BCS system to be high and increasing after 4 wks in milk. Anglart (2010) demonstrated a strong correlation between 3D image analysis and manual BCS scoring (r=0.84) with 69% of the scores registered within a quarter point of the manual scores. The commercially available system used in this experiment was included in a recent validation study, which demonstrated that the range of BCS was highly in agreement with manual scores (Mullins et al., 2018). Thus, the aim of this study was to evaluate the relationship between automated BCS recordings around parturition, and its change during the transition period, on metabolic disease and reproductive outcomes on a commercial dairy farm.

MATERIALS AND METHODS

This study was conducted at a commercial dairy farm in Indiana. The farm housed approximately 3,200 dry and lactating cows. Cows (n=3,243) used in this study were 2.1 ± 1.1 (mean ± SD) lactation number, 186.1 ± 111.1 DIM, 3.28 ± 0.25 BCS, and 29,432.5 ± 6,543.2 305-mature equivalent milk yield (**305ME**). Dairy cows were grouped according to parity, DIM, BCS, reproductive status, and milk yield Cows were milked three times daily and ABCS one time daily.

Body Condition Scoring

The study farm had an exit alleyway on both the north and south ends of the parlor. Two BCS cameras (BCS™, DeLaval International AB, Tumba, Sweden) were used andmounted on the sort-gate at each exit, where cows passed through daily post-milking. The system automatically records a 3-D video of cows passing under the mounted camera and selects the best image for analysis. An algorithm analyzes the image and determines an automated body condition score (**ABCS**) for the cow, which is presented in DelPro Farm Manager computer software. The system has been validated and shown accuracy in assessing proper BCS of dairy cows (Mullins et al., 2018). Scores from the system were reported in the tenth decimal and based on the BCS scoring system described by Edmonson et al. (1989). All ABCS data was retrieved from DelPro Farm Manager (DeLaval International AB, Tumba, Sweden).

Subclinical Disease Outcomes

Subclinical ketosis and milk fever were determined from blood samples evaluated for BHB and calcium, respectively. Samples were taken on the same day weekly from September 16, 2016 to September 14, 2017. Primiparous and multiparous cows were sorted to be sampled if they were ≤ 7 DIM at the day of sample. Samples for BHB and Ca2+ were taken in sodium heparin-coated blood tubes (BD Vacutainer, Becton, Dickinson and Co., Franklin Lakes, NJ). Whole blood BHB concentrations were determined using a hand-held ketone meter (PortaCheck, Moorestown, NJ, validated by Sailer et al., 2018) within 3 h post-sampling. After BHB testing the blood was centrifuged for 20 min (3,200 × *g*, 25°C). Following centrifugation, plasma was separated and stored at −20°C until shipment for analysis. Plasma calcium concentrations were determined from lab assay. After centrifugation at 3000 g for 20 min, the supernatant was used to measure serum Ca2+ levels using the AU Calcium oCPC reagent (Beckman Coulter, Krefeld, Germany). Briefly, Ca2+ ions were reacted with o-Cresolphthalein-compex one (oCPC) to form an intense purple colored Ca2+-oCPC complex, and the intensity was measured using a Beckman Coulter AU480 analyzer (Beckman Coulter, Krefeld, Germany) at the University of Illinois Veterinary Diagnostic Lab, Urbana, IL. Subclinical ketosis and milk fever were considered positive when concentrations of BHB and calcium were ≥ 1.2 mmol/L and < 8.6 mmol/L, respectively (McArt et al., 2012; Rodríguez et al., 2017).

Clinical Disease Outcomes

All clinical disease outcomes were diagnosed and recorded by herd personnel or the herd veterinarian into a herd management software (DairyComp 305, Valley Agricultural Software Inc., Tulare, CA). Data was automatically synced and retrieved electronically from a herd software integration program (BoviSync, Dairy LLC, Eden, WI) to include data from June 22, 2016 to December 13, 2017. The clinical diseases considered were ketosis, milk fever, displaced abomasum, retained placenta, and metritis. Cases of milk fever, retained placenta, and metritis were excluded if they occurred > 14 DIM.

Ketosis and displaced abomasum cases > 30 DIM were excluded. Clinical disease definitions used for diagnosis of the respective diseases considered are listed in Table 3.1.

Reproductive Outcomes

Reproductive records were retrieved in the same form as clinical disease data. Reproductive outcomes assessed included odds of abortion, time to conception following first service, and survival of pregnancy following conception.

Statistical Analysis

Statistical analyses were performed using SAS 9.3 (SAS Institute Inc., Cary, NC) and significance was declared at $P \leq 0.05$. All descriptive statistics were determined from PROC MEANS. The relationship between ABCS and positive subclinical disease outcome, as a binary response, were analyzed using PROC LOGISTIC and accounted for calving month, parity, DIM, and **305ME**. Automated body condition score (**ABCS**) at day of dry-off, calving, and ABCS change from dry-off to calving (**dryCHANGE**) were evaluated as predictors for positive subclinical ketosis and milk fever outcomes. Automated body condition scores effect on positive clinical disease outcome, as a binary response, were analyzed using PROC LOGISTIC and accounted for calving month, parity, and 305ME. The analysis for milk fever also accounted for a positive ketosis event. The analysis for retained placenta also accounted for a positive metritis event. The analysis for metritis also accounted for a positive retained placenta and ketosis event. The analysis for ketosis also accounted for a positive milk fever, and metritis event within cow. The analysis for displaced abomasum also accounted for a positive metritis and ketosis event. Static ABCS at day of dry-off, calving, 7 DIM, and 14 DIM were evaluated as predictors to all included positive clinical disease outcomes. Score changes of dryCHANGE and change from dry-off to 7 DIM (**dry7CHANGE**) were also evaluated. Odds ratios (**OR**), with significant *P*-values, reported < 1.00, 1.00, and > 1.00 represent decreased odds, no difference, and increased odds of the outcome, respectively. All subclinical and clinical data was analyzed with ABCS as a continuous predictor. Therefore, odds ratios were as a reported as a one-unit change, as done in previous studies (Nash et al., 2000; García-Ispierto et al., 2006; Roche et al., 2007;), to prevent bias involved in selecting the predictor variables, ABCS, thresholds for categorical analysis (Altman and Royston, 2006; Royston et al., 2006; Dawson and Weiss, 2012). For example, if the OR of calving ABCS on an investigated outcome is 1.25, the interpretation would be the odds of the outcome are 1.25 higher for a one-unit (0.1) increase in ABCS. Extra consideration should be given when evaluating odds ratio regarding changes in ABCS, which are sensitive to misinterpretation (Gearhart et al., 1990). For instance, if the OR of dryCHANGE on an investigated outcome is 1.25, the interpretation would be the odds of the outcome are 1.25 higher for a one-unit (0.1) increase in dryCHANGE. In other words, a loss of 0.3 ABCS, compared to 0.2 ABS, from dry-off to calving increases the odds of the outcome. Conversely, if the OR was 0.75, the scenario would be interpreted as a loss of 0.3 ABCS, compared to 0.2 ABS, from dry-off to calving decreases the odds of the outcome.

Automated body condition score's effect on abortion occurrence, as a binary response, was analyzed using PROC LOGISTIC and controlled for calving month, parity, disease occurrence, and 305ME. Static ABCS at day of dry-off, calving, 45 DIM, conception, and 60 d pregnant were evaluated as predictors. Score changes of dryCHANGE, dry7change, and calving to conception (**concCHANGE**) were also considered.

The effects of ABCS on time to conception and survival of pregnancy were evaluated separately using a Cox proportional hazard regression model (PROC PHREG). Both models accounted for conception month, lactation number, disease occurrence, and ME305. Cows were only included in the analysis for one lactation. When modeling time to conception, cows entered the model if they received a first breeding (n = 2306) and outcomes were conception, no conception by 200 DIM, or loss to follow-up. Cows were considered a loss to follow-up and censored if at the end of the study period they were ≥ 100 d pregnant and had not yet conceived at the end of the study period, removed from the herd because of culling or death, and recorded do not breed by the farm. Cows were removed from the model if they were < 100 DIM at the end of the study period or suffered an abortion from the conception considered. Total cows included for the time to conception analysis were 599, 1,404, 1,472, and 1,527, for dry-off, calving, 7 DIM, and 45 DIM ABCS, respectively. Within the included cows, censored cows accounted for 21.37, 16.74, 17.60, and 18.86%, respectively, with the remaining cows being followed until conception. For the survival of pregnancy, cows entered the model if they conceived and outcomes were abortion occurrence, calving, or loss to follow-up. Cows were censored if at the end of the study period they were ≥ 100 d pregnant and had not aborted or calved following the conception. Cows were removed from the model if they were < 100 d pregnant at the end of the study period. Total cows included in the survival of pregnancy analysis were 1140, 1,797, 1,843, 2,177, and 2,123, for dry-off, calving, 7 DIM, conception, and 60 d pregnant ABCS, respectively. Within the included cows, censored cows accounted for 79.04, 82.74, 81.88, 81.86, and 83.94%, respectively, with the remaining cows being followed until conception. Kaplan-Meier survival curves were plotted using PROC LIFETEST for both time to conception and time to pregnancy loss associated with BCS at dry-off, calving, 7 DIM, 45 DIM, conception, and 60 d pregnant. Because the evaluations were continuous the upper 25%, middle 50%, and lower 25% ABCS were plotted.

RESULTS

The mean ABCS of cows throughout the study was 3.30 ± 0.25 (Mean ± SD). The descriptive data of ABCS at the time points and changes of interest is listed in Table 3.2. Scores for dry-off did not include the dry period prior to 1st lactation cows.

Subclinical Disease Outcomes

Mean BHBA and calcium of cows was 0.78 ± 0.25 and 8.61 ± 1.22 (Mean ± SD), respectively. Prevalence of subclinical ketosis and milk fever was 7.90% and 36.65%, respectively. There was no observed relationship between ABCS at calving or dryCHANGE and subclinical ketosis cases ($P > 0.05$; Table 3.3). Dry ABCS and calving ABCS were not associated with subclinical milk fever cases ($P > 0.05$, Table 3.3). Although, an increased positive change from dryCHANGE increased subclinical milk fever ($P = 0.05$, Table 3.3). Dry ABCS was significantly associated with subclinical ketosis ($P = 0.04$, Table 3.3). For a one-unit, or 0.1 increase in ABCS from dry-off to calving, there is a 23% increase in the odds of developing subclinical ketosis ($P < 0.001$, Table 3.4).

Clinical Disease Outcomes

Within the time evaluated, 23.7% of cows developed ≥ 1 of the five diseases of interest. Incidence of MF, RP, metritis, ketosis, and DA were 2.39%, 5.83%, 14.31%, 11.49%, and 3.32%, respectively. Increased ABCS at dry-off (Table 3.4) was associated with decreased odds of milk fever (OR = 0.83; 95% CI: 0.72 to 0.95) and metritis (OR =

0.82; 95% CI: 0.73 to 0.92), and increased odds of ketosis (OR = 1.19; 95% CI: 1.09 to 1.29). Automated BCS at calving and 7 DIM was associated with milk fever and metritis, respectively, both having decreased odds with higher calving ABCS. Ketosis odds were lower for cows with more positive change from dry-off to calving (OR = 0.88; 95% CI: 0.81 to 0.94) and dry7CHANGE (OR = 0.79; 95% CI: 0.72 to 0.88) and was the only outcome significant for ABCS changes. Automated BCS was not a significant predictor for retained placenta or DA occurrence at any of the evaluated times or changes (Table 3.4).

Reproductive Outcomes

When evaluating the ABCS at dry-off, calving, 7 DIM, dryCHANGE, and dry7CHANGE relationships with abortion occurrence using logistic regression, none were significant predictors for abortion (Table 3.5). The other factors assessed for abortion were conception ABCS, 60 d pregnant ABCS, and concCHANGE, all significant predictors. Odds for abortion were estimated for a higher ABCS at conception (OR = 0.92; 95% CI: 0.86 to 0.99) and 60 d pregnant (OR = 0.91; 95% CI: 0.85 to 0.98). Further, greater positive concCHANGE decreased the odds (OR = 0.90; 95% CI: 0.83 to 0.97). For time to conception, no effect was found between any BCS time considered, dry-off, calving, 7 DIM, or 45 DIM ABCS ($P > 0.05$, Table 3.6). On the plotted time to conception figures (Figure 3.1), time to conception varies based on the ABCS quartile for that ABCS time considered, yet this plot does not consider the other related factors affecting the outcome. When considering survival of pregnancy, Figure 3.2 shows all the ABCS time points considered and the time to pregnancy loss for each previously described quartile. The incidence of pregnancy loss in the studied data was 18.70%, similar to the herd level of

18.18%. Multiparous cows had higher pregnancy loss by 7.11% (21.36% v. 14.25 %). Only 60 d pregnant ABCS was significantly associated with the time to pregnancy loss (P-value = 0.03; Table 3.6).

DISCUSSION

Many previous studies have evaluated the effects of BCS on disease and reproduction (Waltner et al., 1993; Morrison et al., 1999; Bedere et al., 2018; Roche et al., 2018). However, to date, to the authors' knowledge, no studies have utilized automated BCS technology in connection with the evaluated parameters in this study. The outcomes of this study for BCS and disease relationships were similar to other studies (see review by Roche et al., 2009), where extreme BCS and high degree of change in BCS were associated with a number of negative conditions. Briefly, we found that an increased positive change in BCS from the time of drying to calving increased subclinical milk fever and that an extreme ABCS at dry-off was significantly associated with subclinical ketosis, milk fever, metritis, and ketosis. Automated BCS at calving and at 7 DIM was also associated with milk fever and metritis, respectively, with decreased odds with higher calving ABCS.

In contrast, there have been many conflicting findings regarding specific aspects of disease (Roche et al., 2006). The present herd had an overall low prevalence of subclinical ketosis, which could have affected the outcomes of the analysis, although dry ABCS was still a significant predictor. Our study did not find a relationship between dry-off BCS, calving BCS, or dryCHANGE and reduced calcium concentrations or subclinical milk fever occurrence. This could be a result of only testing cows one time, resulting in a prevalence rather than incidence level, although prevalence levels were comparable to other findings (Suss et al., 2016; Tiberio et al., 2016). More specifically, Suss et al. (2016)

found a similar 10.4% prevalence of subclinical ketosis when testing once within 21 DIM and using the same threshold cut-off value. Tiberio et al. (2016) found higher prevalence levels, 19.7%, when examining incidence of subclinical ketosis, testing four times from 5 to 18 DIM. Cows with a dry BCS ≥ 4.0 had significantly higher maximum calcium concentrations compared to cows with a lower BCS. Additionally, subclinical ketosis occurrence was not related to calving BCS or dryCHANGE but was significantly affected by dry-off BCS. Cows with a dry BCS ≥ 4.0 had significantly higher maximum calcium concentrations compared to cows with lower BCS. Finally, Tiberio et al. (2016) reported that higher maximum calcium concentrations were found in cows that lost > 0.75 BCS post-calving compared to cows that had a stable BCS post-calving. Future research might benefit from increasing sampling times for subclinical ketosis and milk fever.

In this study, calving BCS was unrelated to retained placenta, which agrees with earlier work by Pedron et al. (1993) and Heuer et al. (1999) but disagrees with findings by Markusfeld et al. (1997) who found that under-conditioned cows were of higher risk of contracting retained placenta. Displaced abomasum was also not associated with BCS, a finding like Contreras et al. (2004) who did not detect any differences in the occurrence of displaced abomasum between cows with a BCS lower than 3.0 or higher than 3.25. This contrasted findings by (Dyk, 1995) who reported a higher risk of displaced abomasum for over-conditioned cows. Moreover, Heuer (1999) reported that half of all cows that are diagnosed with displaced abomasum, are found to be in negative energy balance, a state commonly associated with the transition period around calving (Butler and Smith, 1989; LeBlanc et al., 2005).

In our study, greater BCS dry-off, calving, and 7 DIM decreased the odds of milk fever, which contrasts with earlier studies where a high BCS increased the odds of milk fever (Heuer et al. 1999; Neave et al., 2018) and partially contrasts with findings in grazing systems where both over and underconditioned cows were at higher risk of MF (Roche and Berry, 2006). It has been shown that decreased DMI is present prior to diagnosis in cows with metritis (Huzzey et al., 2007). Although decreased DMI is typical of an over-conditioned cow, metritis had decreased odds of occurrence for heavier conditioned cows at dry-off and 7 DIM. Beta-hydroxybutyrate, markedly known in literature for increased risk in developing ketosis, did have greater odds in higher conditioned cows at dry-off. This agrees with many studies and warrants the results found from the subclinical ketosis data. As well, an increased positive change from dry to calving period decreased the odds of ketosis. Future research should attempt to incorporate ABCS into management for clinical diseases and work to use ABCS to reduce clinical disease.

This study did not find any relationship between BCS and conception rates. Previous studies have shown conflicting results regarding the relationship between BCS and conception rates. When considering conception, it's been found cows with > 3.5 BCS within 30 DIM had the shortest calving to first service interval (Jilek et al., 2008). However, the same study found that BCS prior to calving was not associated with time of calving to conception or first service to conception and number of services (Jílek et al., 2008). For instance, Domecq et al. (1997) found that a decrease in BCS during the first 4 wk post-calving significantly decreased conception rates while Buckley et al. (2003) saw the same relationship during the first 90 d post-calving. However, our results contrast with older studies by Garnsworthy and Jones (1987) and Jones and Garnsworthy (1988) as well as a study by Gillund et al. (2001) who did not find any differences between cows with different BCS at calving on the number of days to first estrus, number of days to conception, or the number of inseminations needed to conceive.

Reproductive success is affected by both the number of cows available to be inseminated and the number of cows observed in heat (Roche, 2006). Heavier cows have demonstrated lower heat intensities (Markusfeld et al., 1997) and longer time to begin ovulation and conception (Berry et al., 2003), although this aspect of reproduction was not considered in this study because of a timed artificial insemination program. The increased positive change in BCS from calving to conception was related to lower odds of pregnancy loss, suggesting that cows gaining condition during this time were more able to maintain a conception. Lopez-Gatius et al. (2002) had similar findings within the change for dry-off to 30 DIM, as pregnancy loss increased (OR 2.4; $P < 0.05$) with a 1 unit decreased change in BCS. Body condition scoring immediately preceding the day of AI is considered a reliable predictor of pregnancy at day 39 post-AI (Gomez et al., 2018). Gomez et al. (2018) showed that body condition change from −10 d to AI did not predict the likelihood of a cow being pregnant day 39 post-AI and previous studies have shown that greater BCS loss in early lactation resulted in lower reproductive success (Domecq et al., 1997, Pryce et al., 2000). Ruegg and Milton (1995) reported that calving BCS and BCS loss from calving to first breeding was unrelated to any reproductive measures. This study did however find a relationship with BCS and reproductive outcomes. Time to pregnancy loss was affected by the BCS at 60 d pregnant, with lower conditioned cows having a lower proportion of cows maintain pregnancy.

One potential reason for the inconsistencies found in linking BCS to diseases or reproduction is that previous work has used grouping factors of BCS when evaluating the effects, such as ≤ 3.00, 3.25 to 3.50, and ≥ 3.75. Hossein-Zadeh and Akbarian (2015) hypothesized that the various findings of the effects of BCS on reproduction may be due to the different stages in and the diverse reproductive parameters used when BCS was evaluated. The authors have chosen to evaluate BCS as a continuous variable because of the increased sensitivity of the camera evaluation and to avoid bias when setting thresholds.

The newly commercially available technology allows for an increased number of cows to be scored in a short period of time and scoring days due to automation. Additionally, reducing the amount of labor needed to evaluate cows BCS. In addition to an increased number of continuous BCS records available in this study, the technology also allows for increased precision of BCS points appointed. The BCS technology is based off the 1 to 5 scale, with 0.25 increments the system reports the scores with 0.1 values, which allows for increased precision when evaluating the data but makes it difficult to compare data to other studies evaluating BCS effects. For example, an automated BCS of 3.10 is challenging to determine if it is relatable to a manual 3.00 or 3.25. This alone may be the cause of some inconsistences seen in this study as with previous literature. In a study on sheep, Kenyon et al. (2014) hypothesizes that an optimal BCS to recommend to producers is improper because of the large amount of variability between herds. Variability is allotted to similar commonly considered aspects within dairy cattle, in addition to production system and level and quality of feed. Regular surveying of parameters is needed to identify issues and distinguish abnormalities early. Body condition score, traditionally taken manually, may be more limited on its applications on farm, depending on the frequency of scoring. The biological benefit to the cow from improved or proper condition has been demonstrated in countless studies yet the integration of routine BCS on farm is low. Automated BCS warrants increased utilization of BCS in management (Hansen et al., 2018). Despite poor BCS being indicative of increased disease occurrence and lower reproductive success, it is not itself prognostic of a certain illness or outcome. Therefore, developing a strategy to utilize BCS data remains difficult and can be more complex than other technology data to incorporate. As with rumination monitoring, incorporating BCS into standard protocols of disease detection may improve the current detection alerts (Beauchemin, 2018). Yet, the potential to use the ABCS for indication of future disease or poor reproductive metrics was demonstrated and shows use for future research.

Although the study found significant results, various factors could have been changed to improve the study. Subclinical evaluations could have been taken various times throughout the first 2 weeks of lactation to receive incidence levels and more accurate measures of subclinical status within cow and across the herd. Clinical diseases were evaluated using farm recorded data as well as the ABCS values. While the performed statistical analyses captured all available aspects of this data, statistically evaluating the data in different ways may have allowed for more results. In the future, studies may look at other ABCS collection time periods and factors, such as feed rations or treatment decisions, not included in this study.

CONCLUSIONS

Body condition scores can provide useful information about individual cows, groups, and herd nutritional status. Body condition score as a routine practice is underutilized and should be evaluated and managed on dairy herds and can now be done automatically with a commercially available 3D camera. We found that poor body condition score at different times during the transition period is associated with increased disease occurrence and lower reproductive success. Automated BCS allow for frequently recorded and accessible scores, easing the establishment of BCS into a herd protocol or herd management and can be a useful tool to monitor transition cows.

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Table 3.1. Farmer diagnosis definitions for clinical disease measures used in the study at a commercial dairy farm in Indiana, USA.

Clinical Disease	Definition
Retained placenta	Fetal membrane ≥ 12 h post-calving
Metritis	Fever and watery, foul smelling vaginal discharge
Milk fever	Weak, muscle tremors, down cows
Ketosis	Reduced feed intake and milk production, depression, urine ketones
Displaced abomasum	Reduced feed intake and milk production, “pinging”

Table 3.2. Descriptive statistics of automated body condition scores of lactating dairy cattle collected using a 3-D camera system at different lactation times and changes of interest when evaluated for disease and reproductive effects at a commercial dairy in Indiana, USA.

Lactation Time		n	ABCS Mean	SD	Minimum	Maximum
Static	Dry-Off	1587	3.47	0.20	2.70	4.30
	Calving	2832	3.41	0.22	1.40	4.00
	7 DIM	1396	3.40	0.21	2.60	4.00
	Conception	1533	3.16	0.24	2.10	3.90
	60 d Pregnant	1477	3.24	0.24	1.80	4.00
Change	dryCHANGE[1]	1490	-0.06	0.22	-1.40	0.90
	dry7CHANGE[2]	1368	-0.06	0.17	-1.00	0.90
	concCHANGE[3]	1170	-0.24	0.26	-1.40	1.10

[1]dryCHANGE = Calving BCS – dry BCS

[2]dry7CHANGE = 7 DIM BCS – dry BCS

[3]concCHANGE = conception BCS – calving BCS

Table 3.3. Evaluation for positive cases of subclinical ketosis (BHBA ≥ 1.2) and milk fever (calcium < 8.6) using logistic regression of lactating dairy cattle automated body condition scores collected using a 3-D camera system at different lactation times and changes of interest at a commercial dairy in Indiana, USA.

Comparison		n	Odds ratio[2,3]	95% CI[4]	*P* - value
Positive case	BCS				
Subclinical ketosis	Dry	345	1.23	1.01 – 1.50	0.04
	Calving	775	1.06	0.93 – 1.21	0.35
	dryCHANGE[1]	345	0.93	0.78 – 1.10	0.39
Subclinical milk fever	Dry	339	0.91	0.78 – 1.06	0.22
	Calving	750	1.04	0.96 – 1.13	0.35
	dryCHANGE[1]	339	1.16	1.00 – 1.35	0.05

[1]dryCHANGE = Calving BCS – dry BCS

[2]Odds ratio for BCS units of 0.1

[3]Adjusted for month of calving, lactation number, DIM, and 305 mature-equivalent

[4]95% confidence intervals for odds ratio

Table 3.4. Effect of automated body condition and change in automated body condition on the odds ratios of clinical disease occurrence evaluated utilizing logistic regression of lactating dairy cattle automated body condition scores collected using a 3-D camera system at different lactation times and changes of interest at a commercial dairy in Indiana, USA.

Time	Clinical Disease	Odds ratio[4,5]	95% CI[6]	*P* - value
Dry-Off	MF[3]	0.83	0.72 – 0.95	< 0.01
	RP[3]	1.06	0.92 – 1.21	0.44
	Metritis	0.82	0.73 – 0.92	< 0.01
	Ketosis	1.19	1.09 – 1.29	< 0.01
	DA[3]	0.94	0.79 – 1.13	0.52
Calving	MF[3]	0.85	0.75 – 0.96	< 0.01
	RP[3]	0.99	0.87 – 1.13	0.90
	Metritis	0.91	0.82 – 1.01	0.06
	Ketosis	1.00	0.92 – 1.08	0.97
	DA[3]	0.88	0.72 – 1.04	0.14
7 DIM	MF[3]	0.77	0.67 – 0.89	< 0.01
	RP[3]	0.94	0.82 – 1.08	0.37
	Metritis	0.77	0.69 – 0.86	< 0.01
	Ketosis	1.02	0.93 – 1.11	0.73
	DA[3]	0.86	0.71 – 1.04	0.13
dryCHANGE[1]	MF[3]	0.98	0.86 – 1.12	0.79
	RP[3]	0.99	0.86 – 1.14	0.92
	Metritis	1.06	0.94 – 1.19	0.32
	Ketosis	0.88	0.81 – 0.94	< 0.01
	DA[3]	0.96	0.80 – 1.16	0.66
dry7CHANGE[2]	MF[3]	0.93	0.77 – 1.11	0.40
	RP[3]	0.92	0.78 – 1.08	0.29
	Metritis	0.89	0.78 – 1.02	0.10
	Ketosis	0.79	0.72 – 0.88	< 0.01
	DA[3]	0.98	0.78 – 1.23	0.86

[1]dryCHANGE = Calving BCS – dry BCS

[2]7CHANGE = Day 7 BCS – dry BCS

[3]MF = milk fever; RP = retained placenta; DA = displaced abomasum

[4]Odds ratio for BCS units of 0.1

[5]Adjusted for month of calving, parity, and 305 mature-equivalent

[6]95% confidence intervals for odds ratio

Table 3.5. Effect of automated body condition and change in automated body condition on the odds ratios of abortion occurrence evaluated utilizing logistic regression of dairy cattle automated body condition scores collected using a 3-D camera system at different lactation times and changes of interest at a commercial dairy in Indiana, USA.

Time of BCS	n	Odds ratio[4,5]	95% CI[6]	*P* - value
Dry	1026	1.02	0.94 – 1.12	0.59
Calving	1027	1.02	0.94 – 1.11	0.58
7 DIM	1038	1.01	0.93 – 1.11	0.78
Conception	1046	0.92	0.86 – 0.99	0.03
60 d Pregnant	1023	0.91	0.85 – 0.98	0.01
dryCHANGE[1]	1003	1.00	0.92 – 1.08	0.91
dry7CHANGE[2]	1014	0.96	0.86 – 1.07	0.44
concCHANGE[3]	698	0.90	0.83 – 0.97	< 0.01

[1]dryCHANGE = calving BCS – dry BCS

[2]7CHANGE = Day 7 BCS – dry BCS

[3]concCHANGE = conception BCS – calving BCS

[4]Odds ratio for BCS units of 0.1

[5]Adjusted for month of BCS, lactation number, disease occurrence, and 305 mature-equivalent

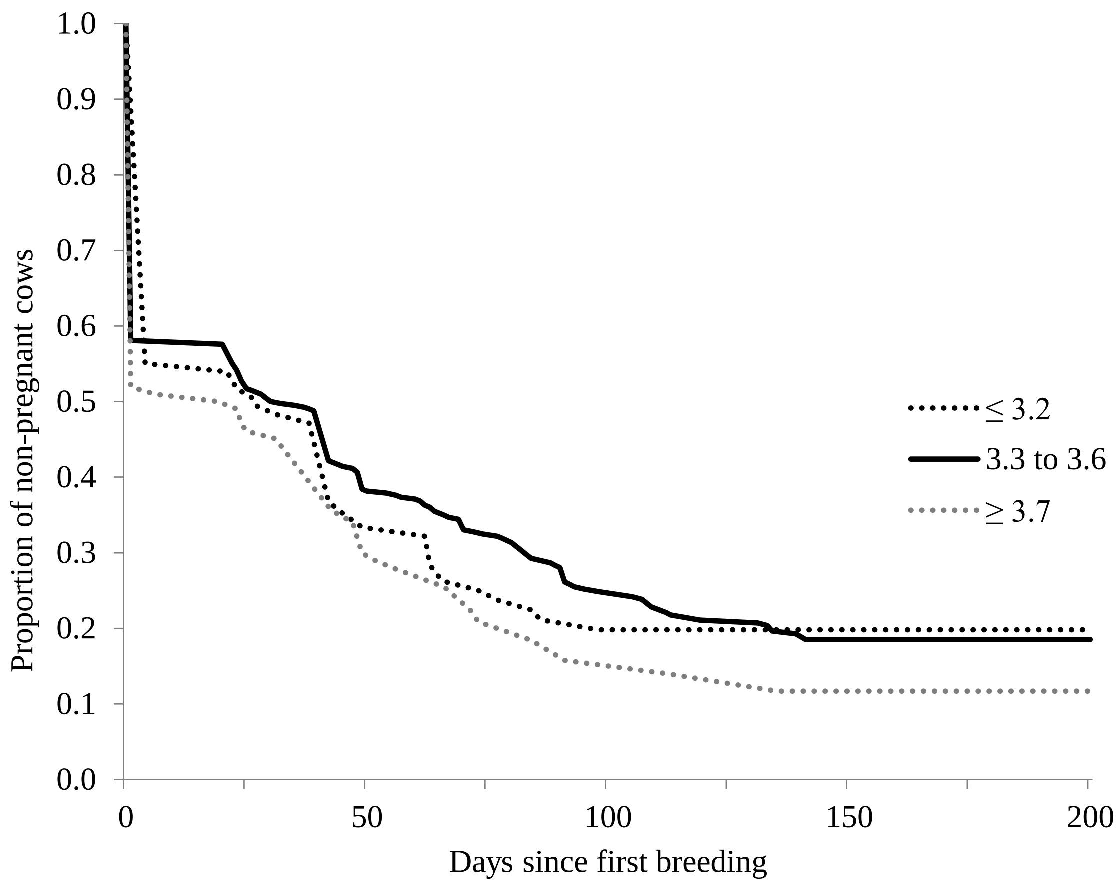
[6]95% confidence intervals for odds ratio

Table 3.6. Effect of automated body condition score on time to event occurrence for conception and abortion estimated from Cox proportional hazard models of lactating dairy cattle automated body condition scores collected using a 3-D camera system at different lactation times and changes of interest at a commercial dairy in Indiana, USA.

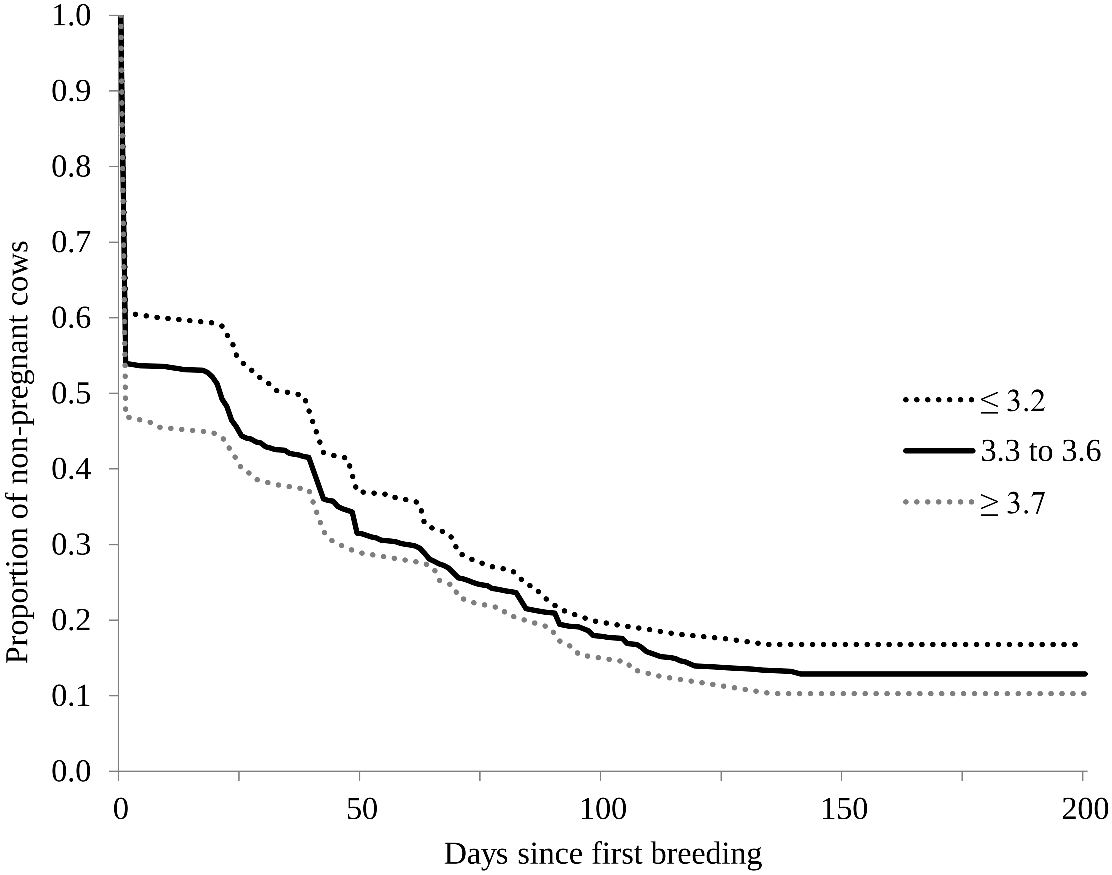
Analysis	BCS at Time	*P* - Value	
		0.1	Quartiles
Time to Conception	Dry-Off	0.61	1.00
	Calving	0.62	0.60
	7 DIM	0.56	0.83
	45 DIM	0.97	0.77
Survival of Pregnancy	Dry-Off	0.95	0.55
	Calving	1.00	0.66
	7 DIM	0.50	0.82
	Conception	0.08	0.08
	60 d Pregnant	0.03	0.14

Figure 3.1. Kaplan-Meier survival curves displayed for time to conception in comparison to (A) Automated body condition (ABCS) at time off dry-off (n = 599), (B) ABCS at day of calving (n = 1404), (C) ABCS at 7 DIM (n = 1472), and (D) ABCS at 45 DIM (n = 1667) of lactating dairy cattle automated body condition scores collected using a 3-D camera system at a commercial dairy in Indiana, USA. Mean time to conception for all BCS was 24 d (95% CI: -10 to 58).

(A)

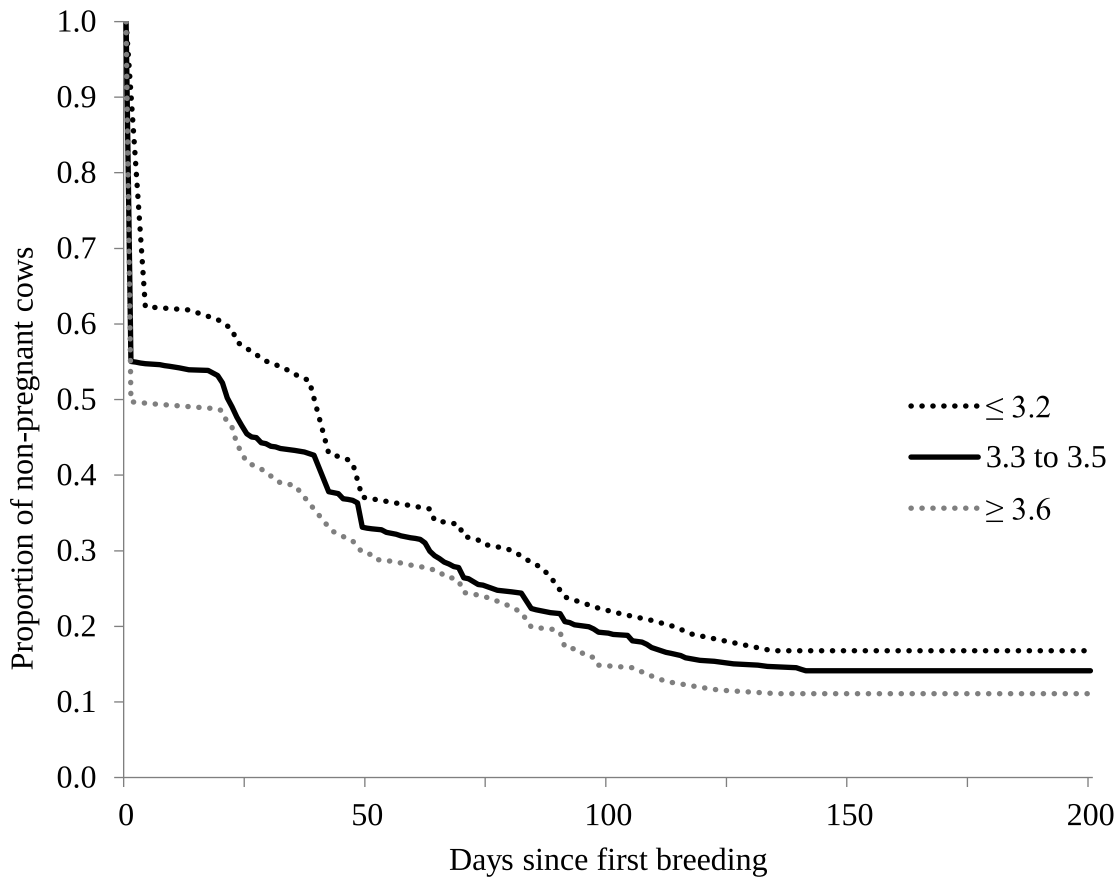


(B)



1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Proportion of non-pregnant cows
0
50
100
150
200
Days since first breeding
≤ 3.2
3.3 to 3.6
≥ 3.7

(C)



1.0
0.9
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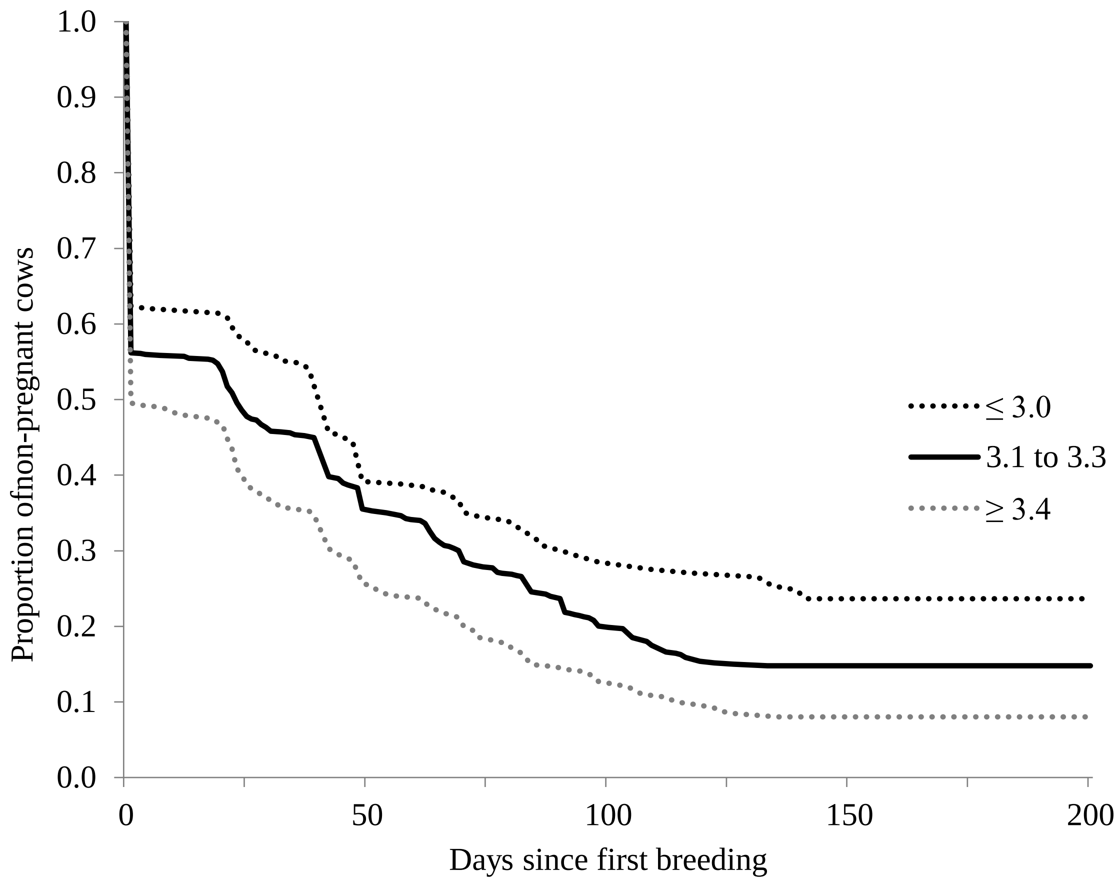
0.3
0.2
0.1
0.0
Proportion of non-pregnant cows
0
50
100
150
200
Days since first breeding
≤ 3.2
3.3 to 3.5
≥ 3.6

(D)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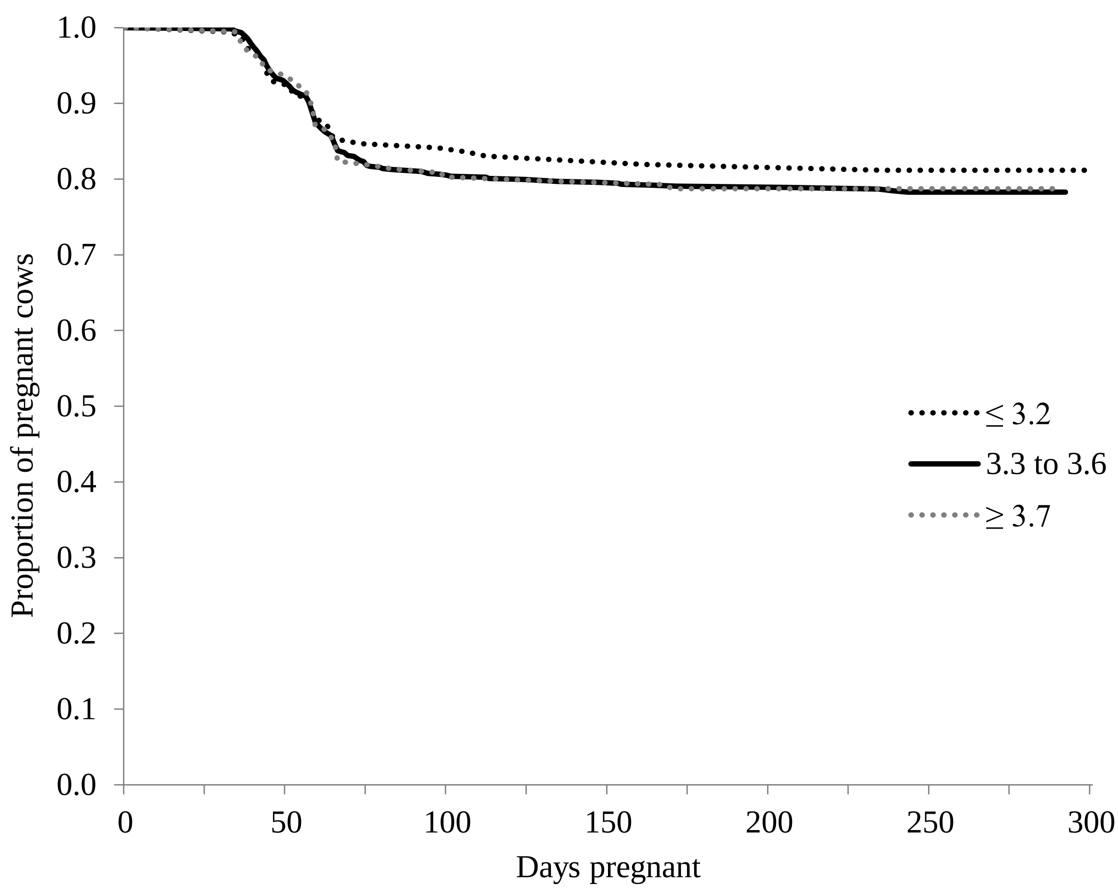
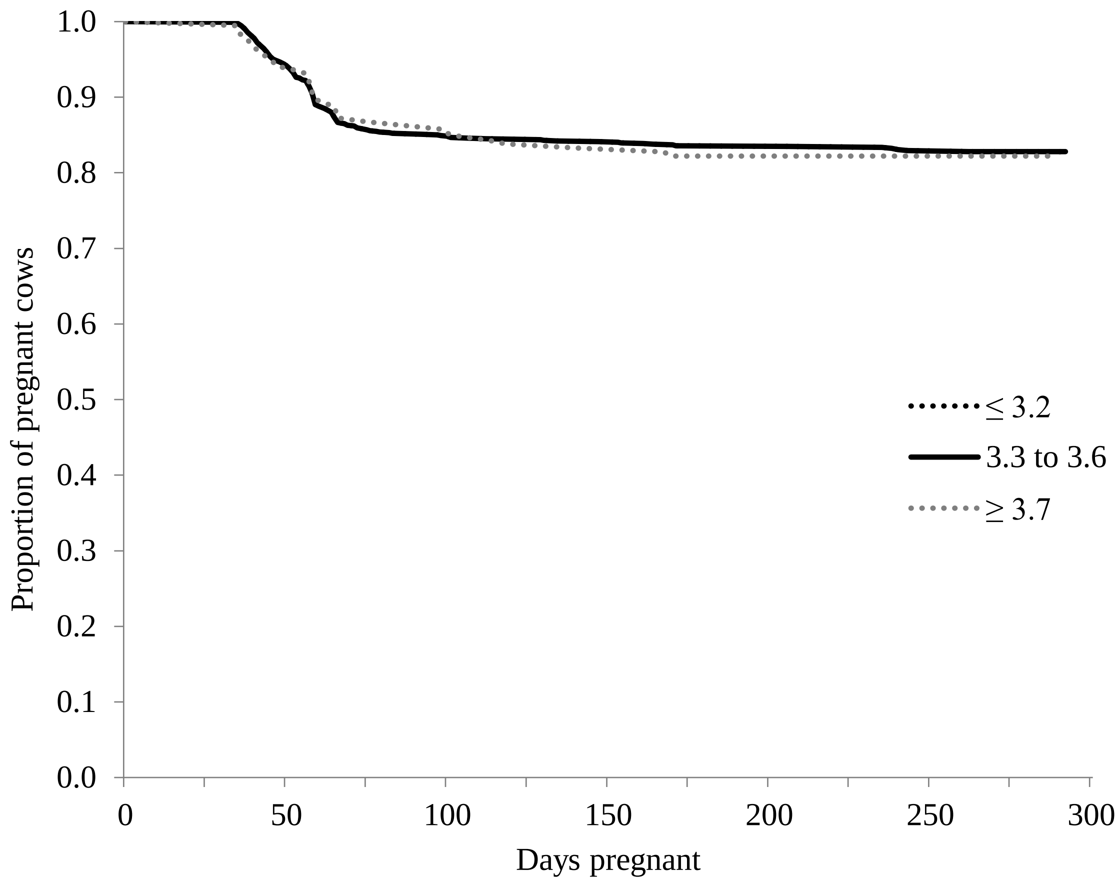
0.4
0.3
0.2
0.1
0.0
Proportion ofnon-pregnant cows
0
50
100
150
200
Days since first breeding
≤ 3.0
3.1 to 3.3
≥ 3.4

Figure 3.2. Kaplan-Meier survival curves displayed for survival of pregnancy from conception in comparison to (A) Automated body condition (ABCS)[1] at time off dry-off (n = 1140), (B) ABCS at day of calving (n = 1797), (C) ABCS at 7 DIM (n = 1843), (D) ABCS at day of conception (n = 2176), and (E) ABCS at 60 d pregnant (n = 2122) of lactating dairy cattle automated body condition scores collected using a 3-D camera system at a commercial dairy in Indiana, USA. Mean time to pregnancy loss for all BCS was 66 d (95% CI: 28 to 105).

(A)



(B)



1.0
0.9
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0.4
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0.1
0.0
Proportion of pregnant cows
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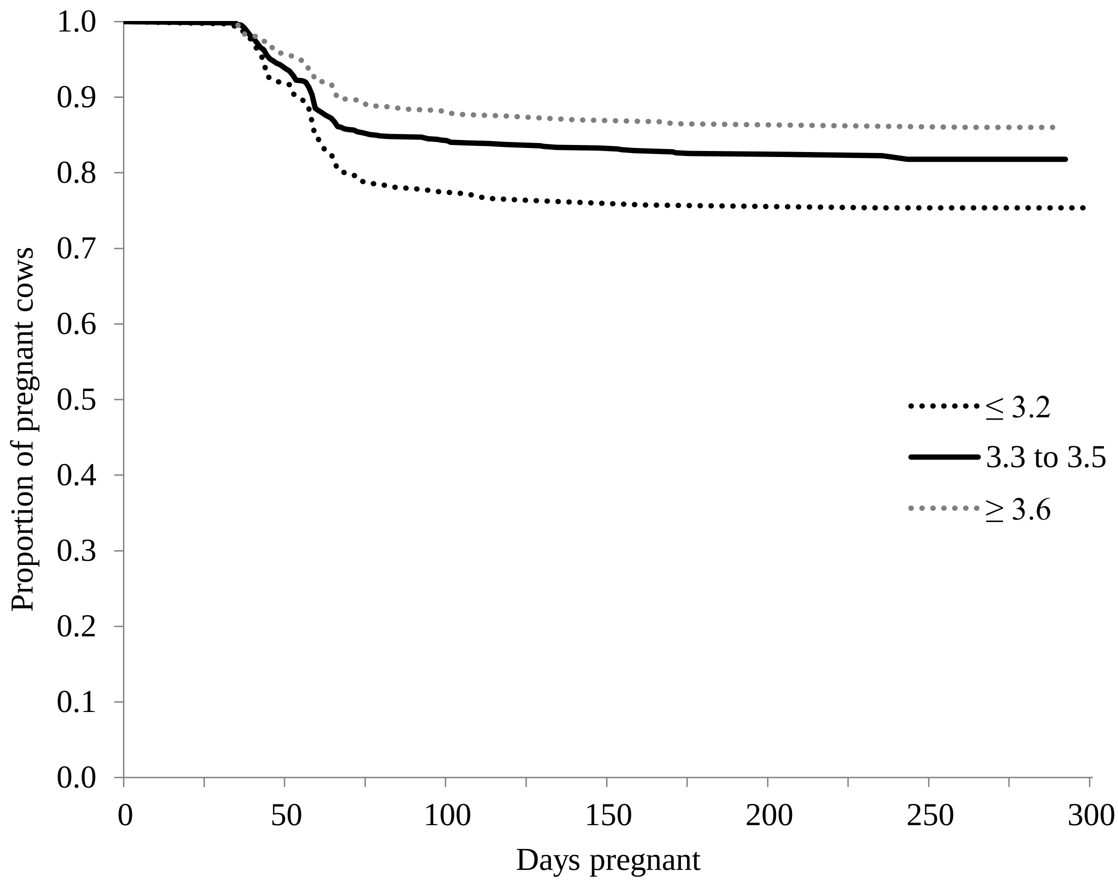
50
100
150
200
250
300
Days pregnant
≤ 3.2
3.3 to 3.6
≥ 3.7

(C)



1.0
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0.1
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Proportion of pregnant cows
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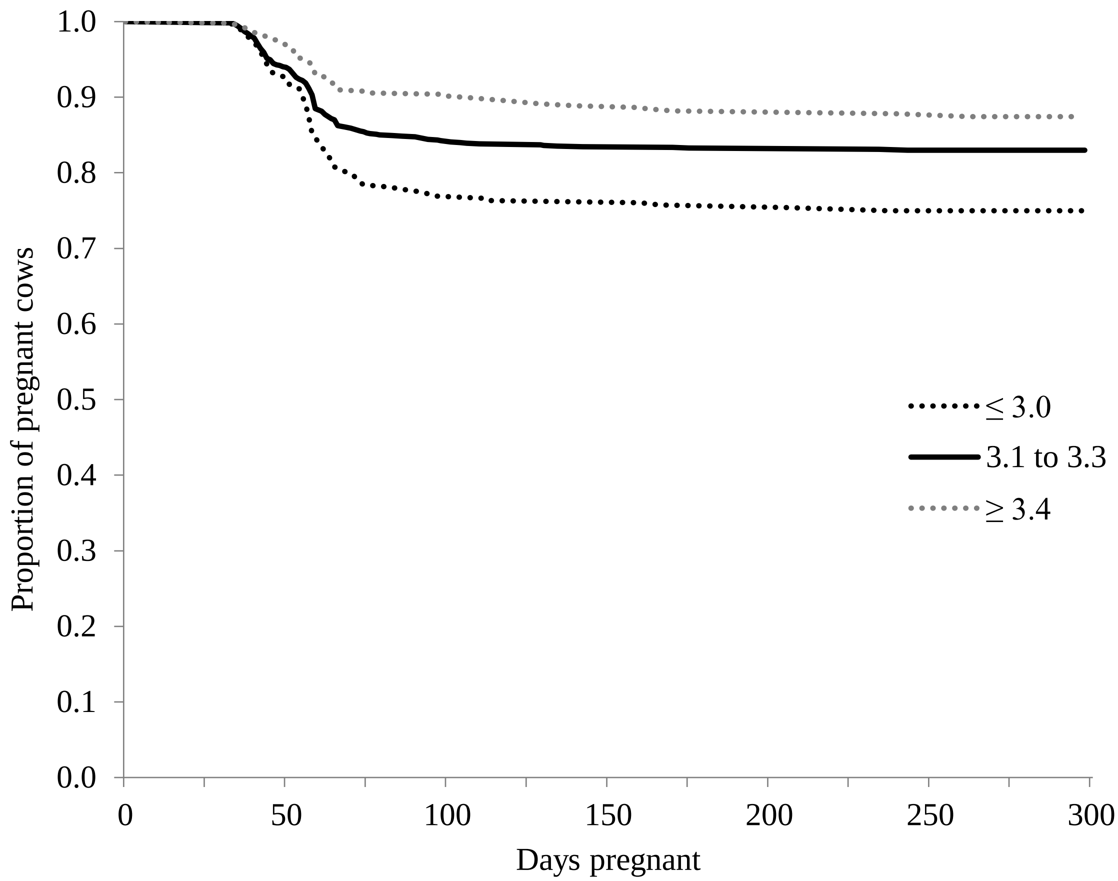
50
100
150
200
250
300
Days pregnant
≤ 3.2
3.3 to 3.5
≥ 3.6

(D)


1.0
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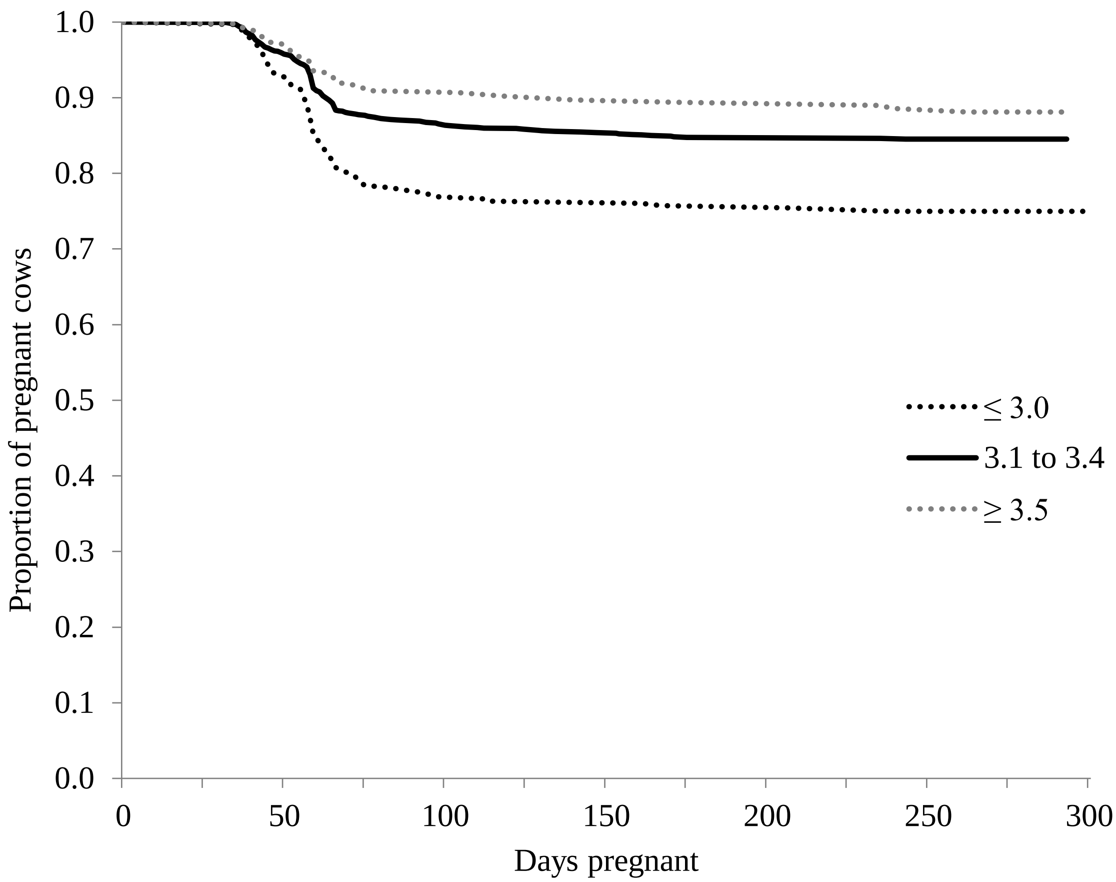
0.4
0.3
0.2
0.1
0.0
Proportion of pregnant cows
0
50
100
150
200
250
300
Days pregnant
≤ 3.0
3.1 to 3.3
≥ 3.4

(E)


1.0
0.9
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0.1
0.0
Proportion of pregnant cows
0
50
100
150
200
250
300
Days pregnant
≤ 3.0
3.1 to 3.4
≥ 3.5

CHAPTER FOUR

Study Two:

Body Condition Score Change Throughout Lactation Utilizing an Automated BCS Scoring System: A Descriptive Study

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INTRODUCTION

Body condition scoring (**BCS**) allows for an instantaneous appraisal of fat reserves of the cow. Fat reserves and changes in fat reserves over time are indicative of cows' energy balance (Edmonson et al., 1989). Body condition score has been evaluated as a factor affecting many aspects on farm and used to make managerial changes. Traditionally, BCS is determined visually by staff or caretakers, leaving the accuracy of the scoring up to the training and experience of the individual scorer. Thus, accurate scoring requires time and training to provide qualitative data with limited influence of subjectivity (Edmonson et al., 1989; Ferguson et al., 1994).

The time around parturition influences BCS of dairy cattle. Commonly cows around parturition reduce their fat reserves by 30% to 40% (Chilliard et al., 2000). Negative energy balance, or when the cows nutritional demands exceed intake, is experience by over 80% of dairy cows during each lactation (i.e. Reid et al., 1966, Coppock et al., 1974). In the beginning of lactation cows lose condition, followed by a slow gain of condition thereafter (Broster and Broster, 1998). Grummer and Rastani (2003) found that on average cows reached positive energy balance by 45 DIM and 90% of cows at 63 DIM. The greatest BCS loss occurs in the first 30 DIM, thereafter cows tend to maintain their condition up until 90 DIM, when they start to regain BCS (Hady, 1994). Gallo et al. (1996) found cows to have their lowest BCS by 100 DIM while Mao et al. (2004) found the lowest BCS to be reached between 60 to 80 DIM. Cows tend to exert resources towards milk production until the next pregnancy whereas body reserves begin resumption (Yan et al., 2006).

Body condition can be affected by parity, DIM, and previous BCS score (Meikle et al., 2004). Parity influences BCS of dairy cattle. Previous studies have shown that first and second lactation cows have higher BCS compared to older cows (Frood and Croxton, 1978). Likewise, in a recent study it was found that first lactation cows tended to have a higher BCS than multiparous (Shin et al., 2015). Others have reported similar results of either BCS decreasing with parity (Enzanno et al., 2003) or declining to a certain parity then increasing (Berry et al., 2011). In addition, it has been reported that second lactation cows lost significantly less BCS within 7 weeks post-calving compared to older cows (Mao et al., 2004). Although, Sakaguchi (2009) found multiparous cows tended to have greater losses in BCS from dry to nadir than primipirous cows. Moreover, in a study done by Ruegg and Milton (1995), primiparous cows lost less BCS than multiparous cows during the first months after parturition. Meikle et al. (2004), found that while primiparious cows lost condition quicker they put on condition faster afterwards and primiparous cows reached nadir sooner than multiparous cows (Sakaguchi, 2009). In contrast, Berry et al. (2007) found BCS change and parity to be unrelated and Mao et al. (2004) reported BCS prior to calving was lower cows during their second lactation compare to their older counterparts.

Cows that develop transition disease have metabolic changes and decreased dry matter intake (**DMI**), both influential to BCS (Bareille et al., 2003). Cincovic et al. (2012) found that diseased cows lost more points on their BCS compared to healthy cows by 4 weeks post-calving. Cows that experienced ketosis had an extended period of BCS loss and cows with ketosis had higher BCS in the first 2 weeks in milk prior or during the disease bout (Shin et al., 2015). Although Ruegg and Milton (1995) found no difference in BCS between diseased and healthy cows, most evidence supports an association between BCS in dairy cows and disease occurrence. Selection for milk production has been strongly associated with increased body reserves mobilization (Koenen et al., 2001; Dechow et al., 2002; Berry et al., 2003). Although Koenen and Veerkamp (1997) reported lower BCS to be related to higher milk production, Holter et al. (1990) found that full lactation milk production was not correlated with BCS. Grummer and Rastani (2003) concluded that energy balance was affected by more than solely milk production because of the low correlation between time to positive energy balance and milk production.

The condition of cows at the start of lactation can impact their future progression and curve of BCS. It has been observed that higher conditioned cows have decreased DMI in the start of the lactation period resulting in greater loss of condition as lactation progresses (Broster and Broster, 1998). Moreover, Gheise et al. (2017) observed the loss to be quicker in fat cows compared to less conditioned cow. Additionally, cows with higher calving BCS have been described to reach maximum DMI later in the lactation period compared to lower BCS cows (Garnsworthy and Jones, 1987) and higher conditioned cows maintained the highest BCS while low conditioned cows maintained low BCS within 4 to 5 months post-calving (Jílek et al., 2008). It has been assumed that the smallest change in BCS, 0.25 BCS, would not be possible to detect using manual visual observation techniques for > 3 weeks in lactation (Grummer and Rastani, 2003). Other researchers have modeled BCS across DIM using manual BCS data (Friggens et al., 2004; McCarthy et al., 2007; Roche et al., 2007). However, the limitation of time and labor reduce the frequency of data collected per animal. Utilizing an automated body condition scoring (**ABCS**) system allows for a more sensitive measure to more quickly notice BCS changes and estimate a more precise BCS change. Thus, the aim of this study was to determine the different trajectories of ABCS according to various cow factors and the factors affecting ABCS.

MATERIALS AND METHODS

Data was collected from a commercial dairy farm in Southern Indiana. The farm and methods previously detailed in the last thesis chapter follow through into this study chapter. Although the farm set-up and data collection followed the prior descriptions, this study used the collected data to evaluate ABCS across time stratified by various factors. The farm housed approximately 3,200 dry and lactating cows. Holstein cows (n = 2,343) used in this study were 2.1 ± 1.1 (mean ± SD) lactation number, 186.1 ± 111.1 DIM, 3.42 ± 0.24 calving BCS, and 12,720 ± 2028 Kg of predicted milk yield (**305PMY**). The farm had two automatically recording BCS cameras (DeLaval International AB, Tumba, Sweden), one mounted on each of the two sort-gates at parlor exits (n = 2). The technology operated by filming a 3-D video, automatically selecting the best image, and generating a BCS score based on the classified algorithm based on Edmonson et al. (1989). All BCS were viewed and downloaded from DelPro Farm Manager (DeLaval International AB, Tumba, Sweden). Scores were reported on a 1 to 5 scale, in 0.1 increments. All lactating cows passed under the camera one time per day and their BCS was obtained. Daily automated body conditions scores were matched on the related DIM of the animal for analysis.

Statistical Analysis

Statistical analyses were performed using SAS 9.3 (SAS Institute Inc., Cary, NC, USA). All descriptive statistics used to stratify factors related to ABCS were determined utilizing PROC MEANS and PROC UNIVARIATE. Body condition score data was used from DIM

0 to 300 because of limited cows available to score after this threshold. Only one lactation period per cow was included in the dataset, the lactation chosen was the one with more scores. Lactation, DIM, and disease status were obtained from a data integration software (Bovisync, Dairy LLC, Eden, WI), which synced data entered by farm personnel from the on-farm computer. Milk production data was gathered from DelPro Farm Manager software (DeLaval International AB, Tumba, Sweden). Outlying ABCS were identified and removed. Scores ≤ 2.3 and ≥ 4.1 represented 0.11 and 0.13 % of the total scores, respectively, and were not used. Of all scores collected, 99.76 % were plotted. Additionally, mean daily BCS were stratified and modeled by lactation number (1, 2, 3, 4 and ≥ 5), calving ABCS (≤ 3.2, 3.3, 3.4, 3.5, or ≥ 3.6), and disease status (“diseased” or “non-diseased”). Positive diseased status was determined if cows developed metritis, retained placenta, or milk fever within 14 DIM or ketosis or displaced abomasum within 30 DIM. Lastly, mean daily BCS was plotted against mean daily milk yield. Data was evaluated to determine future BCS to nadir. All data after the mean nadir, 71 DIM, was removed. Separate univariate linear regression models were created using the PROC GLM for each evaluated explanatory variable. The variables included were DIM, lactation number, calving ABCS, calving month, diseased or non-diseased, and 305-d predicted milk yield (305PMY). Variables with $P < 0.05$ in the univariate models were offered to the multivariable model. The relationship of ABCS with all combined factors was analyzed using the MIXED procedure, where cow was used as a repeated subject. Variables were retained in the multivariable model if $P < 0.05$. The following describes the function from the final multivariable mixed model:

$$y_{ijklm} = \beta_0 + \beta_1 \times DIM_i + \beta_2 \times LACT_j + \beta_3 \times CABCS_k + \beta_4 \times DIS_l + \beta_5 \times PMY_m + e_{ijklm}$$

where Y_{ijklm} is the response variable of automated body condition; β_0 is the intercept; β_1 is the regression days in milk; DIM_i is effect of days in milk; β_2 is the regression coefficient of lactation number; $LACT_j$ is the effect of lactation (lactation = 1, 2, 3, 4, 5 and ≥ 6); β_3 is the regression coefficient of calving automated body condition score; $CABCS_k$ is the effect of calving automated body condition score; β_4 is the regression coefficient of disease status; DIS_l is the effect of disease status (positive or negative); β_5 is the regression coefficient of 305-d predicted milk yield; PMY_m is the effect of 305-d predicted milk yield and e_{hijklm} is the residual error.

RESULTS

Descriptively, the distribution of collected body condition scores (n = 561,228) are displayed in Figure 4.1, with a 2-period moving average trendline. Mean ABCS for all scores collected was 3.29 (± 0.25 ABCS; 1.50 to 5.00) and mean calving BCS was 3.42 (± 0.22 ABCS; 1.55 to 5.00). The range of BCS at calving was 2.2 to 4.0 (3.42 ± 0.24 ABCS). The curves showed a decrease in ABCS until nadir followed by an increase in condition. After the loss of BCS post-calving, cows reached their calving ABCS in average by day 256, 3.42 ABCS (± 0.23 ABCS). On average, cows lost 0.24 ABCS (± 0.25 ABCS) by 71 DIM (Figure 4.2). Thereafter cows regained condition and were at 3.47 ABCS (± 0.22 ABCS) at 300 DIM. As DIM progressed the number of records per day decreased which is agreeable with previous work (Banos et al., 2004), increasing the variability in the dataset in later DIM. Additionally, a spike is shown in the dataset from calving day through the first week (Figure 4.1). This is most likely because of the increase in records available, as seen by Banos et al. (2004). When stratified by lactation number a similar ABCS path is seen across lactation in all lactations (Figure 4.2). Mean calving BCS was 3.43 (± 0.21), 3.38 (± 0.25), 3.44 (± 0.29), 3.45 (± 0.26), 3.42 (± 0.30 ABCS) for lactation numbers 1, 2, 3, 4, and ≥ 5, respectively. Cows in their first lactation had markedly less loss and consistently stayed heavier across lactation. Cows in their ≥ 5 lactation lost more condition and remained lower conditioned across lactation. When separated into primiparous and multiparous, primiparous cows reached their nadir score sooner and with less BCS loss (Table 4.1). Multiparous cows lost more than twice the the calving body condition percentage compared to primiparous cows by nadir although they reached nadir 16 days later. Yet multiparous cows had dipped to 3.13 ABCS by 38 DIM, primiparous cows nadir (Table 4.1).

While average calving BCS for cows that remained healthy or developed a disease was similar, 3.42 (± 0.21 ABCS) and 3.41 (± 0.23 ABCS), respectively, the loss thereafter was not. Healthy cows reached nadir at 65 DIM at 3.18 ABCS (± 0.23 ABCS). Cows that acquired a disease reached 3.12 ABCS nadir (± 0.25 ABCS) at 59 DIM. Loss to nadir was 0.24 and 0.29 for healthy and diseased cows, respectively. By 300 DIM, healthy cows were at 3.48(± 0.22 ABCS) and diseased cows were at 3.44 ABCS (± 0.20 ABCS). Cows stratified by their initial calving ABCS of ≤ 3.2, 3.3, 3.4, 3.5, and ≥ 3.6 had similar paths of ABCS across lactation and maintained their levels in difference from their counterparts. Nadir ABCS was reached at 46, 76, 69, 53, and 56 for calving ABCS of ≤ 3.2, 3.3, 3.4, 3.5, and ≥ 3.6, respectively. Additionally, their nadir BCS were 3.05 (± 0.25), 3.10 (± 0.25), 3.13 (± 0.24), 3.21(± 0.27), and 3.29 (± 0.30), respectively. When plotted against milk yield, the negative energy balance associated with ABCS mobilization can be observed (Figure 4.3). As milk production began to increase, ABCS decreased to attain the energy needed for maintenance and milk production. Once cows become pregnant, milk production decreases to divert energy to develop the pregnancy and next lactation, and ABCS begins to regain.

The multivariate model that best explained the ABCS curve through lactation was found as:

$$ABCS_{ijk} = 1.4838 + -0.00452 * DIM_i + -0.03851 * \text{Lactation number}_j + 0.5970 * \text{Calving ABCS}_k + 0.02998 * \text{Disease Status (negative)}_l + -1.52E^{-6} * \text{305-d predicted milk yield}_m + e_{ijklm}$$

Mean and SD of all parameters used in individual univariate analysis are included in Table 2. Days in milk, lactation number, calving ABCS, calving month, disease status, and 305PMY were all significant predictors of ABCS in each of their individual univariate models ($P < 0.0001$; Table 4.3). Both DIM and calving ABCS had higher R^2 values, 0.11 and 0.16 respectively (Table 4.3). When entered into the full multivariate model, calving month was not significant ($P > 0.05$) and removed from the model. All variables remaining in the multivariate model were significant ($P < 0.001$; Table 4.4).

DISCUSSION

The BCS curve through the lactation found in this study utilizing an automated BCS system was like recent descriptions of BCS curves measured manually (Koeck et al. 2014; Gomez et al., 2018). Descriptively, mean calving BCS for all cows in this study was higher than generally found, which may have affected the relative BCS found across lactation, although changes may of not be affected. Others have found calving BCS of similar to the found in this study (Horan et al., 2004; Kennedy et al., 2007). Additionally, the same studies found the nadir BCS to be much larger losses to nadir than was seen in this study. Body condition score loss of ≥ 0.25 by 6 weeks post-calving was found in one-third of cows, with no difference between primiparous and multiparous cows by Hoedemaker et al., 2009. Conflicting BCS results could be due to the diet fed in the trial and that some studies use pastures as a source of the diet, which affects DMI and energy intake (Tilahun, 2016). Ferguson (2002) argued that a quarter point change in BCS cannot be accurately evaluated by the difference in 2 observations, instead recommending 2 observations at each time point. As well, genetic accuracy has been markedly higher (53 v. 28 %) for daily rather than single measured BCS (Banos et al., 2004). The modeled ABCS curves allow for observations to be made regarding factors potentially affecting the progression of ABCS throughout lactation. Investigating these effects can provide useful information to incorporate into predictive models for ABCS or to assist in management on farm.

The initial univariate models provided that all individual parameters used were originally associated with the predictive outcome, ABCS. Calving month was not significant when entered the full multivariate model, likely because the other parameters accounted for this variability in calving month. This study chose to use the initial drop in ABCS after parturition as the predictor phase only. It has been noted that three different periods within lactation have different uses and applications of BCS, early lactation for disease risk, middle lactation for breeding, and late lactation and dry for next lactation preparation (Emmans, 1994; Lovendahl et al., 2010). The single phase chosen for this herd incorporated both disease risk and initial breeding time periods. When using ABCS, all cows are automatically scored on a daily basis and by incorporating a predictor function to the system, this would allow for an accurate individual on-farm management strategy for specific cows of interest. For example, Gomez et al. (2018) recommends only inseminating cows with a BCS > 2.5, an alert ABCS program could determine individual cow breeding preparation needs. Additionally, Mansouryar et al. (2018) reported increased prediction of disease detection when combining all monitored parameters, including calving BCS, a possibility with ABCS. Body weight has been used to predict a disease prior to a milk yield decrease 50% of the time, with BCS being more accurate than body weight (Maltz, 1997). A potential issue with managing ABCS is the genetic predetermination of BCS. The importance of the early lactation monitoring revolves around the lack of the environment to allow the cow to reach its full genetic potential. In later lactation, cows are less energy stressed and can biologically attempt to re-establish their genetic path, although attention does need to focus on over conditioning (Friggens, 2007; Friggens and Newbold, 2007). The Wilmink function, described by McCarthy et al. (2007), incorporated 3 phases, involving the curve height, initial lactation phase, final phase, and DIM. As a result, the equation represented the majority of BCS variation, higher than found in this study. Roche et al. (2007) also developed a function to describe BCS, Roche-Berry-Boston (RBB) function, which has an additional phase included in the total function model.

Although reliable genetic records were unavailable in this study, Friggens et al. (2004) hypothesizes an improvement in BCS prediction when incorporating genetics. Many have discussed the idea that body tissues have predetermined genetic trajectories such as milk production potential or BCS (Waddington, 1957; Emmans, 1988; Friggens et al., 2004). The cow will try to maintain this predetermined BCS trajectory by control nutrient intake, unless the environmental factors do not allow, thus upon availability of resources to increase or decrease BCS to obtain the trajectory (Wright and Russel, 1991; Friggens et al., 2004). This control of BCS is theorized to have an evolutionary advantage, where Friggens et al. (2003) argued that increased condition raises energy costs and reduces the ability to evade predators. Some have discussed an ultimate low of BCS for cows to obtain (Wildman et al., 1982; Neilson et al., 1983; Oldham & Emmans, 1989). Others have hypothesized that cows would merge towards the same BCS by 16 weeks in milk (Forbes, 1977; Forbes, 1983). Body condition and mobilization have genetic aspects, affecting the cows predisposed BCS path, while environment affects the ability to stay on that path. Garnsworthy and Jones (1987) have reported that cows with lower BCS at calving direct more DMI than body mobilization towards milk production, resulting in increased efficiency. Genetic merit also affects the condition lost from calving to AI, with high merit cows losing more BCS (Kennedy et al., 2003). Cows with higher genetic merit achieved their nadir BCS later in DIM (Dillon et al., 2004).

Although this study was able to find various factors within cow that can impact future ABCS, incorporating this into farm management is still far from possible. The model estimates a small portion of the entire factors that influence the future ABCS of the cow. In the future, studies should include other factors that can improve the accuracy of the model would increase its applicability on farm. Additionally, using the ABCS scoring model in a study set instead of the modeling set, to predict future ABCS scores would help to conclude the usefulness of the model.

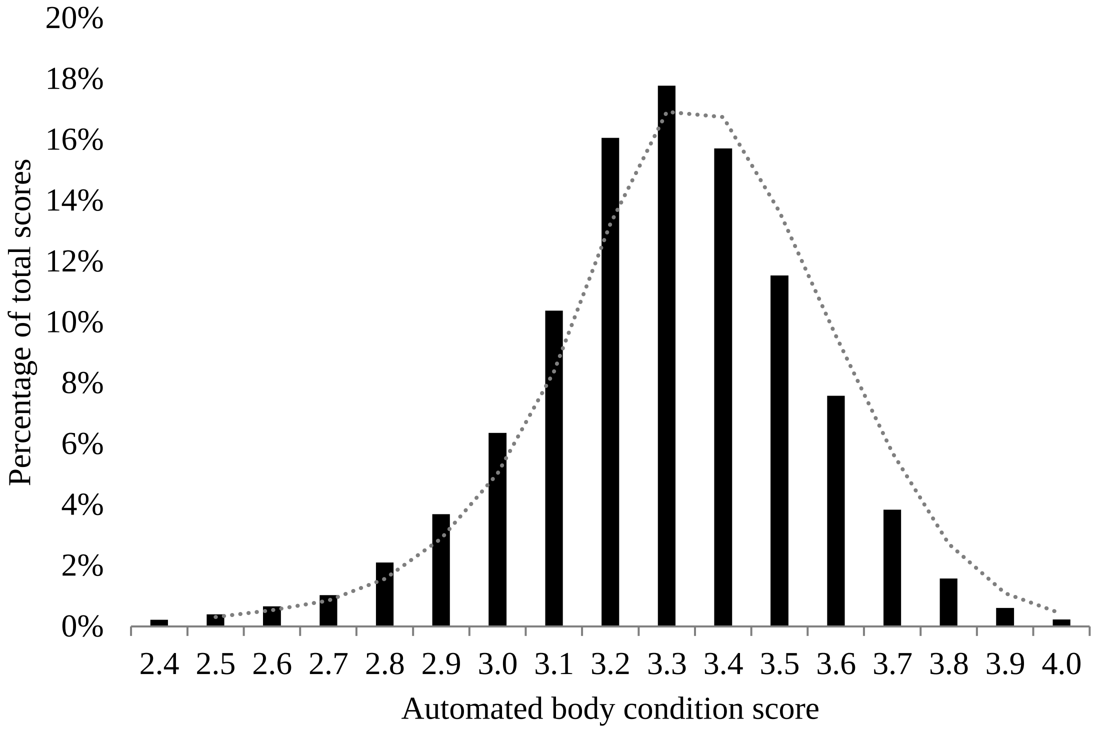
CONCLUSIONS

Body condition score can vary depending on many aspects relative to a specific cow. Incorporating genetics into the newly available automatic and constant BCS data may allow for equations to be formed to alleviate negative energy balance symptoms associated with the transition period. Although other studies have evaluated and observed the impact and progression of BCS across lactation, this study aimed to determine these effects with a new, commercially available automated body condition scoring system. The automatization of BCS may provide additional information from the advantage of constant BCS monitoring that previous studies may have lacked from using only manual BCS. Descriptively, the BCS curve trough lactation was like other studies utilizing manual scoring. Merging automated body condition scoring into future studies on commercial dairies may assist in providing protocols regarding management of an automated BCS system.

ACKNOWLEDGEMENTS

This research was supported by DeLaval International AB. The authors thank the participating herd for their cooperation, time, and enrollment in the study.

Figure 4.1. Distribution of all automated body condition scores (n = 561,237)[1] collected at a commercial dairy in Indiana[2].



[1] From 2,345 cows

[2] Plotted with a 2-period moving average trendline

Table 4.1. Calving automated body condition scores (ABCS) and loss to nadir[1] averages for lactating dairy cows, overall and stratified by primiparous (lactation = 1) and multiparous (lactation ≥ 2) of ABCS collected using a 3-D camera system at a commercial dairy in Indiana, USA.

Parameter	Primiparous	Multiparous	Total
Calving BCS	3.40	3.40	3.42
Nadir BCS	3.26	3.10	3.17
Days to Nadir	38	54	71
% of BCS Loss	4.12	8.82	7.31

[1] Defined as the 1st lowest day by the hundredth decimal place

Table 4.2. Descriptive statistics of automated body condition scores (ABCS) of lactating dairy cows collected using a 3-D camera system at a commercial dairy in Indiana, USA.

Parameter	Mean	SD	Minimum	Maximum
DIM	158.10	110.22	0	505
Lactation number	2.07	1.11	1	7
Calving ABCS[1]	3.42	0.24	1.55	5.00
Calving month	6.2	4.4	1	12
Disease status[2]	0.17[4]	0.37	0	1
305PMY[3]	12,720	2028	7,418	22,621

[1] ABCS = Automated body condition score

[2] Disease status = Positive if cows developed metritis, retained placenta, or milk fever ≤ 14 DIM, or ketosis or displaced abomasum ≤ 30 DIM

[3] 305PMY = 305-d predicted milk yield

[4] 16.5 % of data were from disease status positive cows

Table 4.3. Results of individual variable univariate model's associations with automated body condition score (ABCS) lactation curve of dairy cattle using a 3-D camera system at a commercial dairy in Indiana, USA.

Parameter	Intercept	Estimate[4]	SE[5]	R^2	*P*-Value[6]
DIM	3.38	-0.0038	< 0.0001	0.11	< 0.0001
Lactation number	3.33	-0.043	0.00054	0.040	< 0.0001
Calving ABCS[1]	1.74	0.44	0.0026	0.16	< 0.0001
Calving month	0.16	0.00015	< 0.0001	0.0064	< 0.0001[*]
Disease status[2]	3.20	0.062	0.0016	0.0095	< 0.0001
305PMY[3]	3.34	$-0.327E^{-5}$	< 0.0001	0.0090	< 0.0001

[1] ABCS = Automated body condition score

[2] Disease status = Positive if cows developed metritis, retained placenta, or milk fever ≤ 14 DIM, or ketosis or displaced abomasum ≤ 30 DIM

[3] 305PMY = 305-d predicted milk yield

[4] Estimate for disease status refers to no negative disease status, positive disease status estimate is zero

[5] Standard error is for parameter estimates

[6] Significance declared for parameter estimates

[*] Non-significant intercept

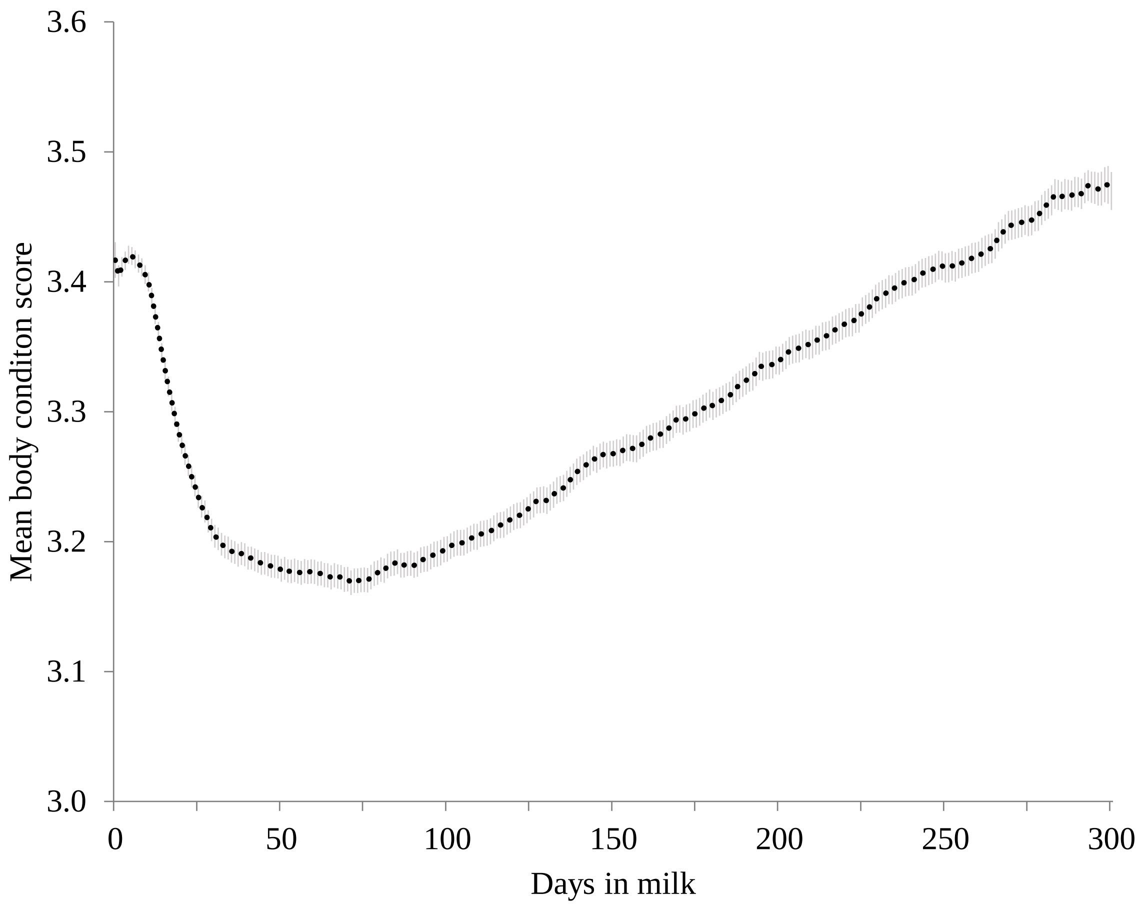
Table 4.4. Results of individual variables in a multivariate model association with automated body condition score (ABCS) lactation curve of dairy cattle using a 3-D camera system at a commercial dairy in Indiana, USA.

Parameter	Estimate[4]	SE	*P*-Value
Intercept	1.48	0.054	< 0.0001
DIM	-0.0045	< 0.0001	< 0.0001
Lactation number	-0.038	0.0029	< 0.0001
Calving ABCS[1]	0.60	0.015	< 0.0001
Disease status[2]	0.030	0.0083	0.0003
305PMY[3]	$-1.52E^{-6}$	0.00	< 0.0001

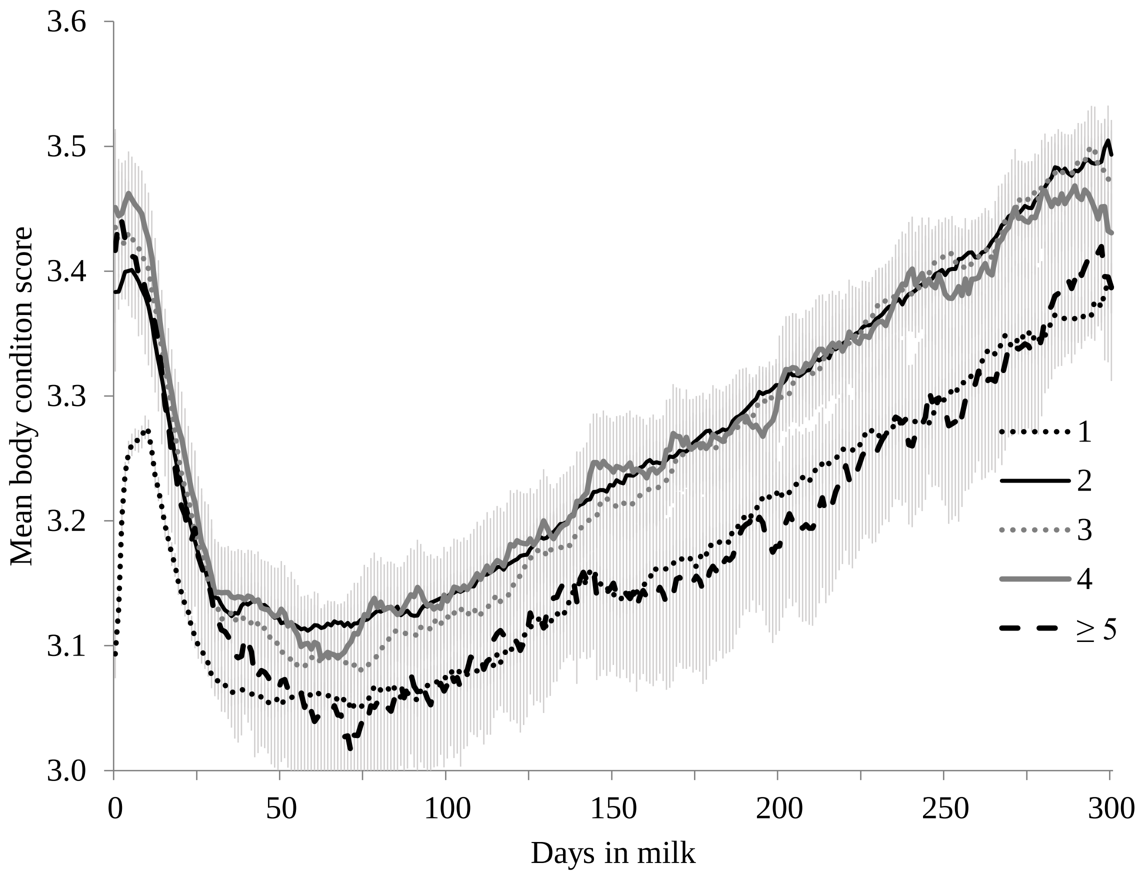
[1] ABCS = Automated body condition score
[2] Disease status = Positive if cows developed metritis, retained placenta, or milk fever ≤ 14 DIM, or ketosis or displaced abomasum ≤ 30 DIM
[3] 305PMY = 305-d predicted milk yield
[4] Estimate for disease status refers to no negative disease status, positive disease status estimate is zero

Figure 4.2. Mean (95% CI) automated body condition score (ABCS) of dairy cattle collected using a 3-D camera system at a commercial dairy in Indiana, USA. Data presented across days in milk to 300 days in milk (DIM) stratified by: (A) Overall[1], (B) Lactation number, (C) Calving ABCS[2], and (D) Disease status[3].

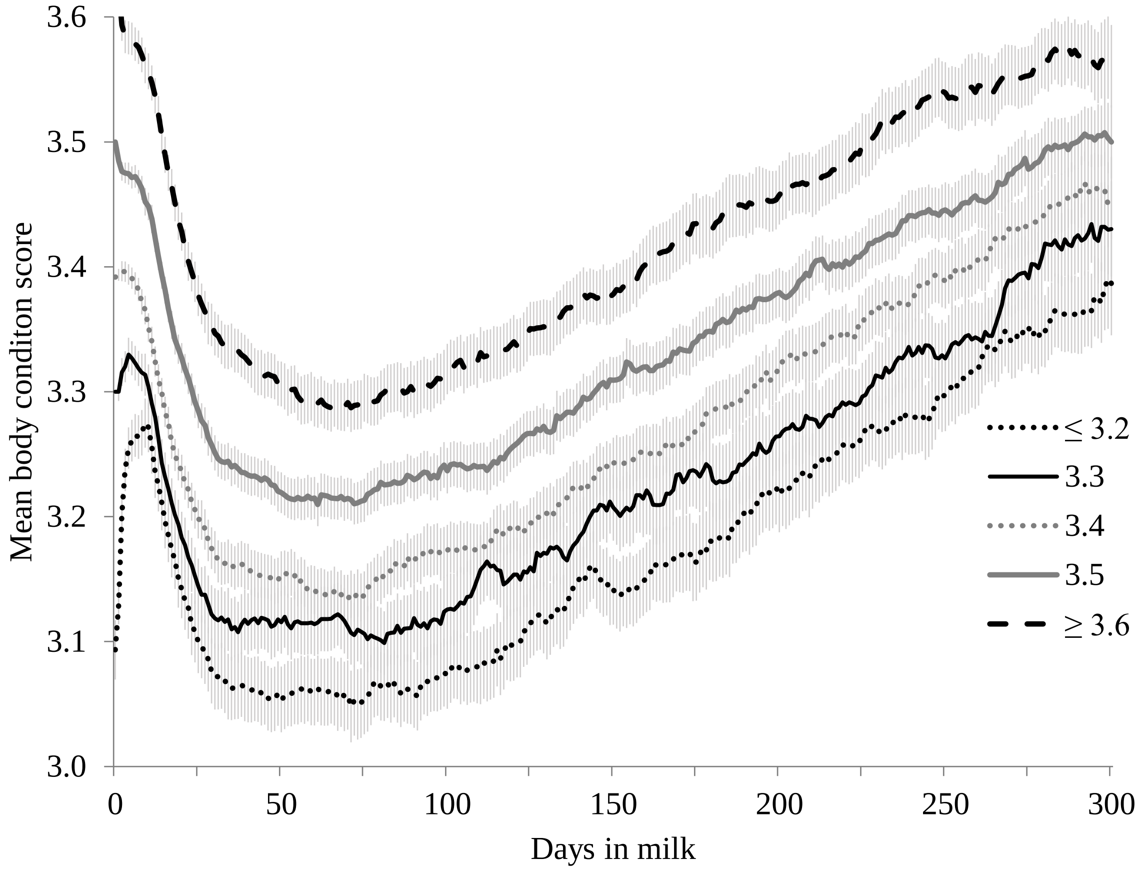
(A)



(B)

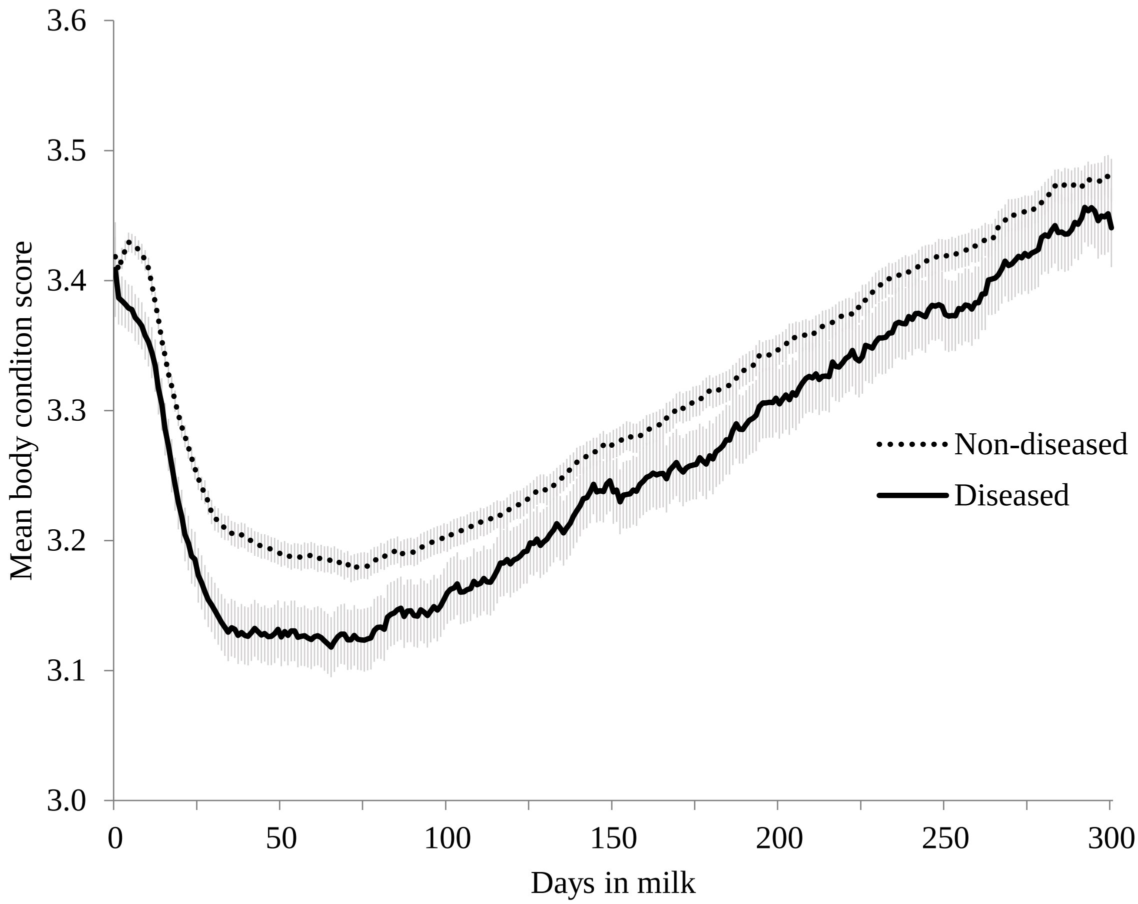

3.6
3.5
3.4
3.3
3.2
3.1
3.0
Mean body conditon score
0
50
100
150
200
250
300
Days in milk
1
2
3
4
≥ 5

(C)



3.6
3.5
3.4
3.3
3.2
3.1
3.0
Mean body conditon score
0
50
100
150
200
250
300
Days in milk
≤ 3.2
3.3
3.4
3.5
≥ 3.6

(D)

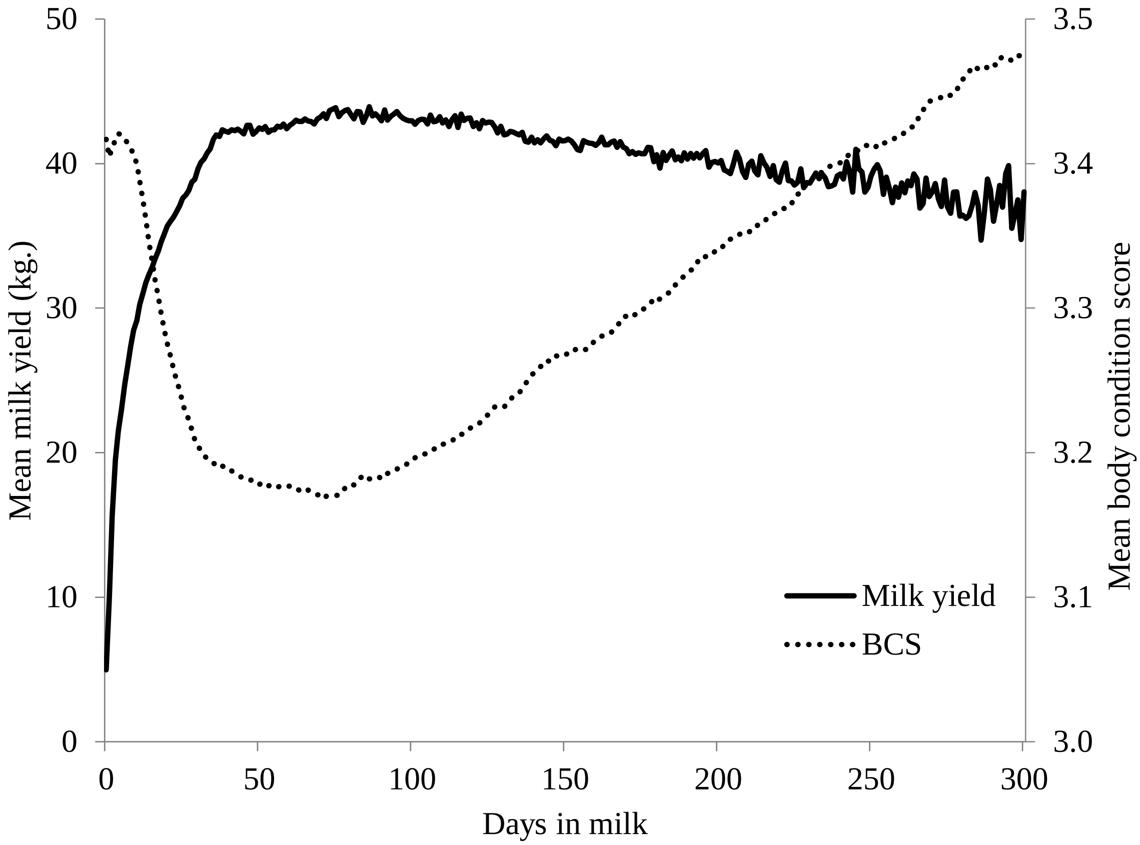


[1] From 2,345 cows

[2] ABCS = Automated body condition score

[3] Disease status = Positive if cows developed metritis, retained placenta, or milk fever ≤ 14 DIM, or ketosis or displaced abomasum ≤ 30 DIM

Figure 4.3. Mean automated body condition score (ABCS) and mean daily milk yield of dairy cattle collected using a 3-D camera system at a commercial dairy in Indiana, USA. Data presented across days in milk to 300 days in milk (DIM).



CHAPTER FIVE

Summary of Results:

Automated body condition scoring: progression across lactation and its association with disease and reproduction in dairy cows

CONCLUSIONS

The potential of managing dairy herds using automated body condition scoring may increase producer adoption rates, in comparison to manual body condition scoring. While previous relationships of manual body condition and disease and reproduction have varied, this system may allow for a more uniform scoring compared to studies comparing other manual scoring results. The first original research study presented found similar results as those found with manual body condition scoring. The second original research study found similar related factors as those seen with manual scoring research. Investing in automated body condition scoring systems may allow for easier integrated into management decisions and practices.

FUTURE RESEARCH

Future studies should focus on producer decision making regarding the potential implementation of the technology based on the effect of regular body condition scoring on management protocols and herd management and cost-benefit calculations on an individual herd level. Projects using body condition score as a practice versus not should be done to examine the impact of automated body condition score usage on disease, reproduction, and feeding economics. In addition, farm practices that are practical for producers should be investigated so proper practice recommendations can be made. Examples are suggested monitoring of feed rations to manage body condition or the incorporation of automated body condition into concentrate feeder usage, to automatically adjust concentrate intake based on body condition.

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Professional Positions

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Peer Reviewed Publications

1) **Truman, C.M.** 2018. Organic Milk Production. Progressive Dairyman. In Press.

2) Bewley, J.M., M.B. Borchers, K.A. Dolecheck, A.R. Lee, A.E. Stone, and **C.M. Truman**. Precision dairy monitoring technology implementation opportunities and challenges. Large Dairy Herd Management Third Edition. ADSA Foundation. 2017. ISBN: 978-0-9634491-3-9.

3) **Truman, C.M.** and J.M. Bewley. 2017. Organic Milk Production. Kentucky Dairy Notes. December.

4) **Truman, C.M.** and J.M. Bewley. 2017. Group Housing Calves. Kentucky Dairy Notes. June.

5) Atkins, S., K. Loewen, M. Jones, K. Kelly, A. Lee, S. Mac, H. Reichenbach, and **C.M. Truman**. 2017. The Dairy Industry in the Netherlands. Kentucky Dairy Notes. January.

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Scientific Abstracts

1) **Truman, C.M.**, I.L. Mullins, M.L. Falk, J.M. Bewley, and J.H.C. Costa. 2018. Automated body condition scoring: Evaluation of effects of BCS around calving on metabolic disease. Abstract M22. American Dairy Science Association Annual Meeting. Knoxville, Tennessee.

2) Mac, S.E., **C.M. Truman**, and J.H.C. Costa. 2018. Use of tail movement to predict calving time in dairy cattle: Validation of a calving detection technology in dairy cattle. Abstract 28438. Congress of the International Society for Applied Ethology. Prince Edward Island, Canada.

3) Mac, S.E., **C.M. Truman**, and J.H.C. Costa. 2018. Use of tail movement to predict calving time in dairy cattle: Validation of a calving detection technology in dairy cattle. Abstract 232. American Dairy Science Association Annual Meeting. Knoxville, Tennessee.

4) Mullins, I.L., **C.M. Truman**, J.M. Bewley, and J.H.C. Costa. 2018. Validation of an Automated Body Condition Scoring Technology for Dairy Cattle. Abstract M37. American Dairy Science Association Annual Meeting. Knoxville, Tennessee.

5) Mullins, I.L., **C.M. Truman**, J.M. Bewley, and J.H.C. Costa. 2018. Validation of an Automated Body Condition Scoring Technology for Dairy Cattle. University of Kentucky Undergraduate Showcase. Lexington, Kentucky.

6) Mac, S.E., **C.M. Truman**, and J.H.C. Costa. 2018. Evaluation of a calving time detection technology that monitors tail movement in dairy cattle. University of Kentucky Undergraduate Showcase. Lexington, Kentucky.

7) Mullins, I.L., **C.M. Truman**, J.M. Bewley, and J.H.C. Costa. 2018. Validation of an Automated Body Condition Scoring Technology for Dairy Cattle. Tri-State Dairy Nutrition Conference. Fort Wayne, Indiana.

8) Mac, S.E., **C.M. Truman**, J.M. Bewley, and J.H.C. Costa. 2018. Evaluation of a calving time detection technology that monitors tail movement in dairy cattle. National Conference for Undergraduate Research. Edmond, Oklahoma.

9) Mullins, I.L., **C.M. Truman**, J.M. Bewley, and J.H.C. Costa. 2018. Validation of an Automated Body Condition Scoring Technology for Dairy Cattle. National Conference for Undergraduate Research. Edmond, Oklahoma.

10) Mac, S.E., **C.M. Truman**, and J.H.C. Costa. 2018. Evaluation of a calving time detection technology that monitors tail movement in dairy cattle. Abstract P24. Fifth Annual DairyCare Conference. Thessaloniki, Greece.

11) Mac, S.E., **C.M. Truman**, and J.H.C. Costa. 2018. Use of tail movement to predict calving time in dairy cattle: Validation of a calving detection technology in dairy cattle. Southeast Regional American Dairy Science Meeting. Morgantown, West Virginia.

12) Mac, S.E., **C. M. Truman,** and J.M. Bewley. 2018. Evaluating the ability to detect calving time in dairy cattle using a precision technology that monitors tail movement. Abstract P06. Posters-at-the-Capitol. Frankfort, Kentucky.

13) Mullins, I.L., **C. M. Truman,** and J.M. Bewley. 2018. Validation of an automated body condition scoring camera for dairy cattle. Abstract P14. Posters-at-the-Capitol. Frankfort, Kentucky.

14) Mac, S.E., **C. M. Truman,** and J.M. Bewley. 2017. Health benefits of whole milk in comparison with other milk fat options. Abstract 132. American Dairy Science Association Annual Meeting. Pittsburgh, Pennsylvania.

15) Mac, S.E., **C. M. Truman,** and J.M. Bewley. 2017. Evaluating the Ability to Detect Calving Time Using Precision Technologies That Monitor Tail Movement and Lying Bouts. Abstract 4C. University of Kentucky Showcase of Undergraduate Research Scholars. Lexington, Kentucky.

16) Mac, S.E., **C. M. Truman,** and J.M. Bewley. 2017. Health benefits of whole milk in comparison with other milk fat options. Southeast Regional American Dairy Science Meeting. Baton Rouge, Louisiana.

17) **Truman, C.M.**, I.L. Mullins, M.L. Falk, and J.M. Bewley. 2017. Effect of automatically recorded body condition score at calving on subclinical hyperketonemia. Abstract M22. American Dairy Science Association Annual Meeting. Pittsburgh, Pennsylvania.

18) **Truman, C.M.** and J.M. Bewley. 2016. Potential economic returns associated with weekly body condition scoring. Abstract 1247. Joint Annual Meeting of ASAS, ADSA, CSAS, and WSASAS. Salt Lake City, Utah.

19) **Truman, C.M.** and J.M. Bewley. 2016. Economics of body condition scoring. Abstract 22331. Precision Dairy Farming Conference. Leeuwarden, Netherlands.

20) **Truman, C.M.** and J.M. Bewley. 2016. Economics of body condition scoring. University of Kentucky Graduate Poster Symposium. Lexington, Kentucky.

21) **Truman, C.M.** and J.M. Bewley, 2015. Automated body condition scoring economics. Precision Dairy Farming Conference. Rochester, Minnesota.