THE IMPACT OF STALL AND FEED RAIL STOCKING RATE ON COW WELFARE AND BEHAVIOR IN AUTOMATIC MILKING SYSTEMS

By

Ali Adil Mutlak Witaifi

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ABSTRACT

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Stocking rate at stalls and the feed rail are critical determinants of dairy cows' comfort and welfare. Overstocking in parlor-milked dairies leads to increased displacement or reduced time lying or feeding. However no studies have examined impacts of stocking rates for cows milked with an automatic milking system (AMS). Therefore, the aim of this thesis was to examine the impact of stocking rate in the stalls and at the feed rail on body condition score, time budgets, lying behavior, lameness (gait scores), and cleanliness of lactating dairy cows through two projects. The second chapter describes a survey of 39 AMS dairy farms, which were assessed with respect to the impact of stocking rate at the feed rail, stalls, and AMS on cow behavior and welfare. Stocking rates were generally not related to cow body condition, measures of lameness or cleanliness or lying behavior. However, stall stocking rate was related to leg cleanliness with cleaner cows found at lower stocking rates ($P < 0.01$). The third chapter examines the impact of experimentally reducing the number of stalls or feed rail headlocks per cow at an AMS dairy. Increasing stocking rates to 1:1.2 or 1:1.5 cows per stall or headlock did not affect stall use, feeding behavior, activity, rumination or displacement with the exception that more displacement occurred following fresh feed delivery at higher stocking rates ($P = 0.01$). Cows in AMS dairies were milk asynchronously rather than in groups as in parlor-based systems, which may result in less synchronous feeding and lying behavior. In contrast to findings from parlor-milked dairies, our results show a less clear link between stocking rates in AMS dairies and cow behavior and welfare.

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KEY TO SYMBOLS OR ABBREVIATIONS

AMS – Automatic milking system

ASY – Step asymmetry

ATV – Activity unit

AVLBD – Average lying bout duration

BCS – Body condition score

FC – Flank cleanliness

FED – Feed delivery

HB – Head bob

LC – Leg cleanliness

LIMP – Presence of a limp

NLB – Number of lying bouts

PU – Push up

RU - Rumination

SRA – Automatic milking system stocking rate

SRF – Feed rail stocking rate

SRS – Stall stocking rate

TL – Total lying time

UC – Udder cleanliness

INTRODUCTION

Stocking rate at the stalls and feed rail are critical determinants of dairy cows' comfort and welfare when they are housed in free-stall barns and milked in parlors. Overstocking may have impacts on animal welfare if there are not enough comfortable lying spaces and enough space at the feed rail so that all cows may lie or feed at the same time or for the amount of time needed. When stocking rate has been assessed at farms milking with traditional parlors, overstocking has been found to have a significant impact on cows' behavior and welfare through increased displacement at stalls and feed rail or reduced time spent lying or feeding, which can lead to increases in lameness and decreases in body condition of cows, thus affecting milk yield. However no studies have been conducted examining stocking rates for cows milked with an automatic milking system (AMS). Though cow behavior is no longer synchronized by a fixed milking routine in AMS, cows may still wish to sleep or feed synchronously or may follow a circadian pattern when performing these behaviors. Therefore, it is important to examine the impact of stall and feed rail stocking rates on dairy cows in AMS to determine the effects on production and behavior. Therefore, the aim of this thesis was to examine the impact of stocking rate in the stalls and at the feed rail on body condition score, lying behavior, lameness (gait scores), and cleanliness of lactating dairy cows through two projects.

The first chapter of this thesis describes a survey of thirty-nine dairy farms that milked their cows with AMS, which were assessed with respect to the impact of stocking rate at the feed rail, stalls, and AMS on cow behavior and welfare. Data were collected from 40 focal lactating cows over two visits to each farm. To measure stocking rate in the stalls, the number of cows in a pen was divided by the number of stalls in the same pen. To measure stocking rate at the feed rail, the length of feed rail in the pen was divided by 60 cm and compared to the number of cows in the same pen. Also, to measure stocking rate at AMS, the number of cows divided by the number of robots in the same pen. Stocking rates were related to measures of lameness and cleanliness as well as to body condition scores and lying behavior. An assessment was made to determine if the various stocking rates were correlated with one another (and thus interacted or acted independently). The impact on delivery of fresh feed and of pushing feed back to the rail where cows could reach it (feed push up) was also considered with respect to feed rail stocking rate and cow body condition score (BCS).

The second chapter of this thesis examines the impact of experimentally altering the number of stalls and amount of feed rail space provided per cow (stocking rate) at an AMS dairy. Specifically, this chapter examines the effect of reducing the number of stalls available or the amount of feed space per cow on displacement behavior. At the AMS study dairy, each of two the pens contained 60 cows/pen and 58 free-stalls and 60 headlocks. The impact of stocking rate was examined using 3 treatments: a 1:1 treatment with 58 stalls or 60 headlocks available for 60 cows; a 1:1.2 treatment with 50 stalls or 50 headlocks available for 60 cows; and a 1:1.5 treatment with 40 stalls or 40 headlocks available for 60 cows. Each stall or feed rail treatment was applied for one week in a randomized order that was different for each pen, with a one-week washout period between treatments. Observations of displacement behavior were made from video recordings on the last two days of each treatment week to examine whether treatment affected how often cows were displaced from stalls. In addition, data were recorded at the feed rail the by live observation for the 45 min before fresh feed delivery and for the 45 min before feed push up.

Cows in AMS have free movement to and from the AMS and may milk asynchronously as opposed to cows milking as a single group in parlor-based systems; this freedom may result in less synchrony of feeding and lying behavior. Additionally, the stocking rate in AMS systems may also be influenced by the design of barn and traffic system (forced, free, or guided), and producers' management decisions such as how often to fetch. Further, when AMS are used, farms typically alter management routines in their entirety as producers now spend less time milking cows and have more time to devote to cow health, feeding or breeding routines. Results from these studies may help producers determine optimal stocking rates for AMS dairies, allowing them to optimize facility design and management in ways that maintain good welfare and production without wasting space or resources.

CHAPTER 1

LITERATURE REVIEW

INTRODUCTION

Stocking rate in animal production systems refers to the number of animals with respect to a particular resource (e.g., cows per water trough), and stocking density refers to the number of animals for a given amount of space (e.g., cows per square meter of pen space). For simplicity, from this point forward, the term stocking rate will be used to refer to both situations. On dairy farms the two most commonly considered stocking rates are the number of cows per lying stall and the number of headlocks (or amount of space) per cow at the feed rail. In automatic milking systems (AMS), stocking rate can also be considered with respect to the number of cows per robot. Stocking rates can have important consequences to animal welfare as they may influence whether animals have adequate access to a resource in order to meet their needs. Increasing the stocking rate at the feed rail and stalls can lead to changes in the behavior and biology of cows (Huzzey et al., 2013). Overstocking of dairy free-stall barns (i.e., barns that allow cows to move between feeding areas and lying stalls and to choose where they feed and eat, respectively) reduces lying time and increases aggressive interactions (Friend et al., 1977; Weirenga, 1983; Weirenga and Hopster, 1990; Fregonesi and Leaver, 2002). However, overstocking is attractive to producers because it allows them to improve their return on facility investment (Bewley et al., 2001).

The European Food Safety Authority has stated that overstocking is one of the most important risks to the welfare of cattle in free-stall housing (EFSA, 2009a). Yet though dairy producers are often advised to keep stocking density below 120% (e.g., NFACC, 2009), overstocking is commonly found on commercial dairy farms in North America (USDA, 2007; von Keyserlingk et al., 2012). Further, many countries, including the U.S., do not have national guidelines for cow welfare. Canada does have national science-based guidelines, which specifically recommend that cows should be stocked at a rate of less than 1.2 cows per stall, and have 60 cm of space per cow at the feed bunk (NFACC, 2009). Although most dairy farm animal welfare standards are still reliant on resource-based criteria, such as recommended stall stocking rates, there is increased interest in assessing the outcomes or the consequences of these recommendations on the animals themselves (Rushen et al., 2011). With regard to stall stocking rate, the desired outcome is that cows are able to lie down as much as they need to; and the current Code of Practice for Care and Handling of Dairy Cattle now has best practice recommendations aimed at cows lying for 12 h per day (NFACC, 2009). However, many recommendations from producer groups remain vague, simply advising that stall stocking rate should allow for *adequate* rest, exercise and feed and water consumption (NMPF, 2010).

Interactive Impacts of Stocking Rate

Stocking rate of the milking herd is important for dairy cows in general because it can have a direct effect on cows' behavior, welfare, health and production as will be discussed below. In addition to considering the stocking rate for stable groups of animals, the impact of mixing animals into new groups or of group size changing for management reasons must also be considered (Talebi et al., 2014). For dairy cows, the transition period, when cows move from pregnancy to lactation, results in the entry of a cow into a new group. This is a risk factor for that individual cow that, for example, can make her less likely to feed when space at the feed rail is limited though a similar stocking rate may not affect her once she is an established member of the group. At the group level, entry and exit of cows to and from the milking herd during the start and end of lactation, respectively, can change stocking rate and impact behavior (Talebi et al., 2014).

Stocking Rates and Lying Time

In general, the current recommendation given in most dairy cow welfare guidelines is that cows in comfortable free stalls should spend an average of about 12 h/d lying down (EFSA, 2009b). However, in North America there are large differences between farms in herd lying time, with most farms having a herd mean lying time less than 12 h/d (Ito et al., 2009; USDA, 2007; von Keyserlingk et al., 2012). The stocking rate of free stalls in parlor-milked dairy herds is a significant element of cow comfort as it can impact lying time (von Keyserlingk et al., 2009) as well as individual behavioral variability in lying behavior (Ito et al., 2014). Reducing time spent lying down by cows leads to both behavioral and physiological stress (Munksgaard and Simonsen, 1996). For example, overstocking can lead to lower milk production on farms with fewer stalls per cow (Bach et al., 2008). According to Fregonosi and colleagues (2007), lying time decreased 1.7 hour when stall stocking rate was 150% compared with a 100% stocking rate. In particular, lying time decreased mid day and overnight as a result of overstocking (Fregonosi et al., 2007); two times when the circadian rhythm of cows motivates them to lie down to rest and synchronized lying behavior is commonly seen in herds (DeVries and von Keyserlingk, 2005; Overton et al., 2005; Tucker et al., 2008). One consequence of short lying times may be lameness (Chapinal et al., 2009; Proudfoot et al., 2010, Bell et al., 2009; Cook et al., 2004). However, overstocking has not yet been definitively proven to be a cause of lameness, but effectively, there is a positive relationship between lying time and lameness, where the healthy cows lie less than the lame cows (Chapinal et al., 2009; Chapinal et al., 2010a,b).

In addition to stall stocking density, the time away from the home pen for milking also likely affects the time cows spend lying down and may be responsible for some of the variation between farms in mean herd lying time. For example, several studies have shown that the time cows lie down in stalls is reduced by high stocking rates (Fregonesi et al., 2007; Krawczel et al., 2012; Telezhenko et al., 2012), while others have demonstrated an effect of time spent away from the home pen for milking on lying time as well (Botheras, 2006; Gomez and Cook, 2010). Further, stocking rate and time out of the pen for milking could interact to affect lying time, as competition for lying stalls would be higher if fewer stalls were available and if less time were available to lie down; but this interaction has not been studied explicitly.

Feed Rail Stocking Rates

Stocking rate at the feed rail is a key element that must be considered to ensure adequate feed intake at dairy farms as well as cow comfort. For example, increased or decreased availability of places per cow at the feed rail, depending on the level of competition, leads to a change in behaviors such as time spent eating (Nielsen, 1999; Olofsson, 1999). It is commonly recommended that each cow have approximately 60 cm of space at a linear feed rail (Grant and Albright, 2001; NFACC, 2009), though one study at least suggests that this recommendation is overly generous, as cows can have similar feed intake when given less feed space (Menzi and Chase, 1994). Generally, however, feeding space available for each cow has been related to the level of competition at the feed rail, and displacement at the feed rail increases when stocking rate is increased at the feed rail (DeVries et al., 2004; Huzzey el at., 2006; Proudfoot et al., 2009). However, reducing feed bunk space has not been directly linked with lower milk yield (Bach et al., 2008; Proudfoot et al., 2009).

Another important factor to consider when evaluating the impact of space at the feed rail is that cows prefer to feed at the same time, as they are social animals that naturally show synchronized behavior, which is (von Keyserling and Weary, 2010). For example, in the 90 min after fresh feed delivery, feeding activity was highest (DeVries and von Keyserlingk, 2005), and overstocking at the feed rail reduced the number of cows that feed at this time (Huzzey et al., 2006). This means all cows are motivated to feed at the same time, and so ensuring that all animals have the space to feed simultaneously will allow cows with less competitive ability (e.g., fresh or primiparous cows) to feed with the herd. Thus, competition at the feed rail affects feeding behavior and welfare as increased competition at high feed rail stocking density could limit the ability of some cows to access to the feed rail at time of fresh feed delivery translating into altered feeding behavior, reduced feed intake and lying time and increased time spent standing (Collings et al., 2011; DeVries et al., 2004; Grant and Albright, 2001; Huzzey et al., 2006; Krawczel et al., 2012).

Stocking Rate and Automatic Milking Systems

At present little is known about how stocking rate at stalls or the feed rail affects behavior or welfare in herds milked with automatic milking systems (AMS). Cows in AMS have free movement to and from the AMS and may milk asynchronously as opposed to cows milking together as groups in parlor-based systems. On the other hand, stocking rate in AMS dairies may also be influenced by other factors, such as the design of the barn and traffic system (forced, free, or guided), the number of cows per AMS and whether cows are fed in the AMS. For example, according to Uetake and colleagues (1997), the design of AMS milking and holding area impacts synchronization of cows' eating and resting and can reduce time spent eating, with a more pronounced effect seen for the AMS holding area. However, as return from the milking parlor appears to be one of the factors that synchronizes feeding in parlor-milked cows (DeVries et al., 2003), it is possible that cows who are milking individually in AMS may also eat and sleep more asynchronously compared to their parlor-milked counterparts. Regardless, cows may still wish to lie down synchronously (Rushen et al., 2001). A limited number of studies examining lying time for cows in AMS showed that cows spent between 10.8 -12.8 hours a day lying when stalls were stocked at ≤ 100% (Lexer et al., 2009; DeVries et al., 2011; Munksgaard et al., 2011; Deming et al., 2013). However, lying time in AMS has the potential to be greater than in parlor systems because cows might spend less time on their feet waiting to be milked.

Generally, according to all studies been mentioned previously increasing stocking rate at stall and feed rail have impact on cow behavior and welfare at the parlor-milk dairies. on other hand, AMS dairies the impact on the stocking rate may be not strong as found at the parlor farms. Cows in AMS have free movement to and from the robot and may milk asynchronously as opposed to cows milking as a single group in parlor-based systems. However, cows may still wish to lie down synchronously. Productively, AMS farms have more milk product from parlor farms. Also, the AMS robot reduce the laborers in farm, thus leads to reduce the amount of cost; unlike in parlor farms. Additionally, AMS farms alter management routines in their entirety as producers now spend less time milking cows and have more time to devote to cow health, feeding or breeding routines.

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CHAPTER 2

THE EFFECT OF STOCKING RATES ON LYING BEHAVIOR AND WELFARE OF COWS MILKED WITH AUTOMATIC MILKING SYSTEMS

Interpretive summary: Stall and feed rail stocking rate in AMS. Witaifi

Canadian and U.S. farms using automatic milking systems (AMS) were surveyed to understand how stocking rates of stalls, the feed rail, or the AMS may affect the behavior or welfare of cows milked with AMS. Stocking rates were related to gait scores, cleanliness, lying behavior, and body condition; however only decreased leg cleanliness was related to increased stall stocking rate. Other management factors may minimize the impact of stocking rate in AMS systems. For exampled increased stocking rate at the feed rail may have been compensated for by the frequent feed delivery and push up observed in this study.

OUR INDUSTRY TODAY

The Effect of Stocking Rates on Lying Behavior and Welfare of Cows Milked with Automatic Milking Systems

A. Witaifi,[*] G. Charlton,[†] J. Gibbons,[§] E. Vasseur,[‡] E. Pajor,[^] J. Rushen,[**] A. M. de Passille,[**] D. Haley,[††] D. Pellerin,[§§] T. DeVries,[‡‡] J. M. Siegford[*1]

[*]Department of Animal Science, Michigan State University, East Lansing, MI, US, 48824

[†]Department of Animal Production, Welfare and Veterinary Sciences, Harper Adams University, Shropshire, TF10 8NB, UK

[§]DairyCo, Agriculture and Horticulture Development Board, Stoneleigh Park, Kenilworth, Warwickshire, England, UK, CV8 2TL

[‡]Alfred Organic Dairy Research Center, University of Guelph, 10 St-Paul Street, Alfred, ON, Canada, K0B 1J0

[^]University of Calgary Veterinary Medicine, 2500 University Dr. NW, Calgary, AB, Canada, T2N 1N4

[**]Pacific Agri-Food Research Centre, Agriculture and Agri-Food Canada, PO Box 1000, 6947 Highway 7, Agassiz, BC, Canada, V0M 1A0

[††]Department of Population Medicine, University of Guelph, Guelph, ON, Canada, N1G 2W1

[§§]Department of Animal Science, Laval University, Quebec, QC, Canada, G1V 0A6

[‡‡]Department of Animal and Poultry Science, University of Guelph, Kemptville Campus, Kemptville, ON, Canada, K0G 1J0

[1]Corresponding author: Janice M. Siegford

Department of Animal Science, Michigan State University, 1290 Anthony Hall, East Lansing, MI 48824, Phone: 517-432-1388, Fax: 517-353-1699, Email: siegford@msu.edu

ABSTRACT

Thirty-nine dairy farms that milked their cows with automatic milking systems (AMS) were assessed with respect to the relationship of stocking rate at the feed rail, stalls, and AMS on cow behavior and welfare. Stocking rate on farms milking with traditional parlors has a significant impact on cows' behavior and welfare through increased displacement at stalls and feed rail, reduced lying time or reduced amount of time spent at the feed rail. These changes can lead to increases in lameness and decreases in body condition of cows and affect milk yield. However, no studies have examined stocking rate of farms milking with AMS. This portion of the study focused on AMS-milked cows and highlights differences relating to stocking rates in these systems versus traditional parlor-milked dairies. Data from each farm were collected from 40 focal lactating cows over two visits. On average, stalls were slightly understocked in this study, with 0.94 ± 0.16 cows per stall. Average stocking rate at the feed rail was 1.07 ± 0.33 cows per 60 cm, and there was an average of 55 ± 8.6cows per AMS. Leg cleanliness was related to stall stocking rate, with cleaner cows at lower stocking rates ($P < 0.01$). However, neither udder nor flank cleanliness were related to stall stocking rate ($P > 0.05$ for both), and feed rail stocking rate was not related to any cleanliness score ($P > 0.05$ for all). Cows spent an average of 11.2 ± 2.32 h lying down per day, but lying time was not related to stall, feed rail or AMS stocking rates ($P < 0.05$ for all). Stall, feed rail and AMS stocking rates were also not related to average lying bout duration or number of lying bouts ($P < 0.05$ for both). Stocking rate at the feed rail was not related to body condition score ($P = 0.74$). The presence of a limp, head bob, or gait asymmetry was not significantly related to stocking rate of stalls or feed rail ($P > 0.05$ for all). Results from this study indicate a less clear link between stocking rates in AMS dairies and cow behavior and

welfare than has been found in studies of parlor-milked dairies. Cows may milk asynchronously as opposed to cows milking in groups in parlor-based systems; this freedom may result in less synchrony of feeding and lying behavior. Additionally, impacts of stocking rate in AMS systems may be influenced by barn design and traffic system (forced, free, or guided). Further, when AMS are used, producers typically alter management routines in their entirety, spending less time milking cows and more time on cow health, feeding or breeding routines. To fully explore stocking rate implications in AMS, additional comparisons must be made between stocking rates of stalls and feed rails (and AMS) at AMS- and parlor-milked dairies.

Key Words: robotic milking, stocking density, lying, gait score, body condition**,** cleanliness

INTRODUCTION

Stocking rates are important for lactating dairy cows in general (regardless of milking system) because they can have direct effects on cows' behavior, welfare, health and production. Increasing the stocking rate at the feed rail and stalls can lead to changes in the behavior and biology of cows (for a review see Huzzey et al., 2013). For example, increased or decreased availability of places per cow at the feed rail, depending on the level of competition, can change the time spent eating (Nielsen, 1999; Olofsson, 1999). For an individual cow, the entry into the milking herd at the start of lactation (i.e., a new social group) is a risk factor that can make her more likely to feed less when space is limited or competition is increased. At the group level, entry and exit of cows to and from the milking herd during freshening and dry off respectively can change stocking rate and affect social behavior (Talebi et al., 2014).

Stall Stocking Rate

While the U.S. does not have national guidelines for cow welfare, some recommendations advise that the stocking rate should allow for adequate rest, exercise and feed and water consumption (NMPF, 2010). Canada has national guidelines, which specifically recommend that cows should have about 12 h of lying time per day and have 60 cm per cow at a linear feed bunk (NFACC, 2009). According to Fregonosi and colleagues (2007), lying time decreased 1.7 h/day when stalls were stocked at 150% compared with a 100% stocking rate. Most noticeably, lying time decreased in the overnight hours and during the mid-day period as a result of such overstocking (Fregonosi et al., 2007). Bach and colleagues (2008) also found a correlation between high stall stocking rate and lower milk production.

Feed Space Stocking Rate

Displacement at the feed rail has been found to increase when the feed rail stocking rate is increased (DeVries et al., 2004; Huzzey el at., 2006; Proudfoot et al., 2009). However, reducing feed bunk space has not been directly linked with lower milk yield (Bach et al., 2008; Proudfoot et al., 2009). Another important factor to consider when evaluating the impact of space at the feed rail is that cows are social animals that naturally show synchronized behavior and, thus, prefer to feed at the same time, (von Keyserlingk and Weary, 2010). For example, in one study, the feeding activity was highest in the 90 min after fresh feed delivery (DeVries and von Keyserlingk, 2005).

Stocking Rate in Automatic Milking Systems

The stocking rate at stalls and feed rails in automatic milking systems (AMS) may also be influenced by the design of barn and traffic system (forced, free, or guided), the number of cows per AMS, and whether cows are fed in the AMS. Because AMS cows have relatively free movement to and from the AMS, they may milk asynchronously as opposed to cows milking in groups in parlor-based systems. Therefore, as return from the milking parlor appears to be one of the factors that synchronizes feeding (DeVries et al., 2003), it is possible that cows in AMS who are milking individually may also eat or lie down more asynchronously compared to their parlor-milked counterparts.

A limited number of studies examining lying time for cows in AMS showed that cows spent between 10.8 -12.8 hours a day lying down even when stalls were stocked at $\leq$ 100% (Lexer et al., 2009; DeVries et al., 2011; Munksgaard et al., 2011; Deming et al., 2013). However, lying time in AMS has the potential to be greater than in parlor systems because cows might spend less time on their feet waiting to be milked.

Objectives

The stocking rates of stalls, feed rails, and AMS were assessed in herds of lactating dairy cows that were milked with AMS to examine the impact of stocking rate on the cows' behavior and welfare. Stall stocking rate at each farm was related to gait scores, cow cleanliness, and lying behavior while available space per cow at the feed rail was related to body condition and gait scores. The AMS stocking rate at each farm was related to gait scores and lying behavior.

Hypotheses

We hypothesized that increased stall stocking rate would be related to higher (worse) gait and cleanliness scores and more numerous lying bouts. Increased stall stocking rate would be related to less total lying time and shorter lying bouts. Increased feed rail stocking rates would be related to decreased BCS and shorter total lying time and lying bout durations. Increased feed rail stocking rate would also be related to higher (worse) gait scores. Increased AMS stocking rate would be related to higher (worse) gait scores and more numerous lying bouts. Finally, increased AMS stocking rate would be related to less total lying time and shorter lying bout durations.

MATERIALS AND METHODS

The Farms

Stocking rates in the free stalls, at the feed rail and at the automatic milking systems (AMS) were assessed in 39 lactating herds of dairy cows (30 Canadian and 9 Michigan farms). Characteristics of these farms are described in Table 2.1 This study is complementary to an on-farm assessment study examining cow comfort on AMS farms. Two trained technicians recorded data at each farm.

Animals

Prior to the start of the study, all animal-based protocols were approved by the Michigan State University Institutional Animal Care and Use Committee.

At each farm, 40 focal cows were selected for detailed measurements using a list of cow identification numbers obtained from the producer prior to the first farm visit. Focal cows at each farm were ideally < 120 days in lactation and from a range of parities. For this stocking rate study, body condition score (BCS), gait score parameters, cow width, and cow cleanliness were measures of interest. However, before the survey start; there was a training and reliability testing for observers. The width of cows was measured between the points of the hook bones. Gait was assessed using a 0-1 scale for limping, head bob, and step asymmetry. Specifically, for limping the following scores used: (0) no limp when all legs bear the weight of the cow equally, and (1) limp when the cow walks with uneven and uneasy steps. Head bob was scored as: (0) no head bob, just a natural up and down movement of the head when walking, and (1) an unnatural or exaggerated head bob is observed when the cow walks. Step asymmetry was scored as: (0) the feet hit the ground symmetrically with the rhythm of foot placement an even four beat gait, and (1) asymmetric steps are noted because the rhythm of foot placement is not even, for example 1, 2, ... 3,4. Cow cleanliness was scored for the 40 focal cows using a 0-3 scale for the lower half of the udder, the lower leg (the area from the top of the claw to the middle of the hock), and the flank (the area from middle tarsal joint to a virtual line between pin and hook bones). All regions were scored as follows: (0) the cow has fresh splashes of manure covering < 50% of the area; (1) the cow has fresh splashes of manure covering > 50% of the area; (2) dried, caked manure and fresh splashes of manure cover > 50% of the area; and (3) the entire area is covered with dried, caked manure. Body condition scoring of the 40 focal cows at each farm was performed by using the 1-5 scale and pictorial scorecard developed by Elanco Animal Health (2009) based on the work of Ferguson and colleagues (1994). The BCS was recorded in increments of 0.25 points with a lower limit of < 2.0 and an upper limit of 5.0 points. All focal cows scoring were performed on the first visit to the farm.

Cows at the 30 Canadian farms were fitted with HOBO data loggers (HOBO Pendant® G Data Logger - UA-004-64). Cows at the 8 Michigan farms were fitted with IceQube pedometers (IceRobotics, Edinburgh, Scotland). In both cases, the devices were attached to a rear leg of the cow between the fetlock and the pastern on the first visit to the farm. Loggers were removed during a second visit to the farm that occurred after a minimum of 4 days. Average daily lying time (hours/day) was then calculated for each cow from 4 complete days of data. Average lying time per farm was calculated by adding together the average lying time of each cow then dividing by the total number of cows that data were collected from at each farm. For further information on the development of the animal-based measures used in this study, see Gibbons and colleagues. (2012).

Barn Measurements

From the in-barn measurements that were taken as part of the on farm survey (Charlton et al., 2014), the following measures were used in this portion of the study: number of cows per pen, number of functional stalls per pen, amount of feeding space per pen (measured as length of feed rail(s)), and number of AMS per pen.

Analysis

Stocking rate at the free stalls was calculated by dividing the number of cows in a pen by the number of usable stalls in the same pen. The stocking rate at the feed rail was measured by dividing the length of feed rail by 60 cm then dividing this number by the number of cows in the same pen to create a cows/60 cm stocking rate (using the premise that each cow was approximately 60 cm wide, and, in fact, average width of cows in this study was 57 cm). Stocking rate at the AMS was measured by dividing the number of cows in the pen by the number of AMS in the pen. Data analyzed per pen totaled from 44 observations when all pens at each farm with focal were used. All analyses were completed using SAS (version 9.4, SAS Institute Inc., Cary, NC).

Analyses of gait and cleanliness scores were conducted using nonparametric statistics (PROC NPAR1WAY) because the data were not normal. The model was as follows:

$$Y_{ij1} = \mu + K_i + C_j + e_{ijk}$$

Where K_i is the fixed effect of stocking rate, C_j is the covariate of (lying behavior, gait score, BCS, and Cleanliness score), and eijk is the residual.

, Data for gait score, cleanliness score, and body condition score were analyzed using from 39 observations (the total number of farms surveyed) including the pasture-based farms. To examine the relationship between stocking rate and body condition score a mixed model was used (PROC MIXED). The model was as follows:

$$Y_{ijkl} = \mu + FD_i + CN_j + C_m + C_m \times GCBL + e_{ijk}$$

Where FD_i is random effect of farm, CN_j is the first fixed effect of cow, C_k is the second fixed effect of stocking rate, GCBL is the covariate of (lying behavior, gait score, BCS, and cleanliness score), $C_k \times GCBL$ is the interaction between stocking rate and covariate, and e_{ijk} is the residuals, while the relationship between feed delivery and push up were analyzed using PROC NPAR1WAY (for non-normal data). Data on feed delivery and feed push up were analyzed using 33 observations because 6 farms had a missing data. Total lying time, number of lying bouts, and lying bout duration were analyzed using a linear mixed model (PROC MIXED).Data were analyzed using 37 observations as pasture-based farms were excluded.

RESULTS

The average stocking rate in free stalls (SRS) was 0.94 ± 0.16 (i.e., 0.94 cows kept per 1 stall) with a minimum stocking rate of 0.56 cows per stall and a maximum of 1.26 cows per stall (Table 2.2). The average stocking rate at the feed rail was 1.07 ± 0.33 cows per 60 cm of rail space (i.e., 56.1 cm per cow), with a minimum feed rail stocking rate of 0.4 cows per 60 cm (i.e., 150 cm per cow) and a maximum feed rail stocking rate of 1.92 (i.e., 31 cm per cow; Table 2.2). In addition, the average stocking rate at the AMS was 55.1 ± 8.6 cows per AMS with a maximum stocking rate of 72 cows per AMS and a minimum of 36 cows per AMS (Table 2.2). There was no relationship between stall, feed rail, and AMS stocking rates (Figures 2.1, 2.2 and 2.3).

Descriptive data for total lying time (TL), number of lying bouts (NLB) and duration of lying bouts (AVLBD) are presented in Figures 2.4, 2.5 and 2.6. The minimum TL was 9.78 ± 1.96 h, the minimum NLB was 0.02 ± 0.14 bouts/60 min, and the minimum AVLBD was 0.89 ± 0.3 h for cows at all farms. Further, the maximum TL was 13.27 ± 1.66 h, maximum NLB was 0.22 ± 0.02 bouts/60 min, and maximum AVLBD was 1.58 ± 0.57 h. Stall stocking rate was not related to any measure of lying behavior ($P > 0.05$ in all cases). Stocking rate of the AMS was also not correlated to TL ($F_4 = 1.77$, $P < 0.16$), NLB ($F_4 = 0.45$, $P < 0.77$) or AVLBD ($F_4 = 0.37$, $P < 0.83$). Stall stocking rate was also not correlated to TL ($F_2 = 1.08$, $P < 0.35$), NLB ($F_2 = 0.99$, $P < 0.38$) or AVLBD ($F_2 = 0.90$, $P < 0.42$). Feed rail stocking rate was also not significantly correlated to TL ($F_3 = 1.82$, $P < 0.49$), NLB ($F_3 = 0.76$, $P < 0.53$) or AVLBD ($F_4 = 1.39$, $P<0.26$).

Figures 2.7, 2.8, and 2.9 display the descriptive data for gait score variables on a per farm basis (presence of a limp (LIMP), head bob (HB), and step asymmetry (ASY)). On average, cows were relatively sound as shown by average scores of less than 1, when 0 indicates no problem and 1 indicates the presence of a gait-related problem (Mean ± SD; LIMP = 0.16 ± 0.1; HB = 0.07 ± 0.1; and ASY = 0.55 ± 0.22). Stall stocking rate was not related to gait score parameters

(LIMP: $F_2 = 0.46$, $P < 0.63$; HB: $F_2 = 1.35$, $P < 0.26$; and ASY: $F_2 = 0.08$, $P < 0.93$). In addition, feed rail stocking rate was also not related to cow gait score parameters (LIMP: $F_3 = 0.75$, $P < 0.05$; HB: $F_3 = 1.81$, $P < 0.14$; and ASY: $F_3 = 0.92$, $P < 0.43$). Nor was stocking rate at the AMS related to LIMP ($F_4 = 0.47$, $P < 0.75$) HB ($F_4 = 1.02$, $P < 0.40$), or ASY ($F_4 = 0.76$, $P < 0.55$).

Feed rail stocking rate was not related to body condition score ($F_3 = 0.39$, $P < 0.7$), and the average BCS for the study was 2.88 ± 0.32 (with descriptive BCS data from all farms presented in Figure 2.10). Additionally, as Figures 2.11 and 2.12 show, there was no correlation between feed rail stocking rate and frequency of fresh feed delivery (FED, $F_{29} = 1.06$, $P < 0.57$) or between feed rail stocking rate and push up frequency (PU, $F_{29} = 1.33$, $P < 0.47$). Also, there was no correlation between BCS and frequency of FED ($F_{14} = 1.63$, $P < 0.16$; Figure 2.13), BCS or BCS and PU ($F_{14} = 0.504$, $P < 0.90$; Figure 2.14). In addition, there was no correlation between FED and PU ($F_3 = 1.99$, $P < 0.14$; Figure 2.15), meaning that farmers did not deliver fresh feed less often as they pushed feed up to the rail more frequently and vice versa.

Stocking rate at stalls was correlated with leg cleanliness (LC, $F_2 = 4.85$, P = 0.008) Average leg cleanliness scores were 0.45 ± 0.46 (Mean ± SD, on a score of 0 – 3 with a 0 = very clean and 3 = very dirty); and scores at each farm are presented in Figure 2.16. On the other hand, feed rail stocking rate was not correlated with LC ($F_3 = 1.76$, $P < 0.15$). Figures 2.17 and 2.18 show udder (UC) and flank cleanliness (FC) scores by farm. Stocking rate at the feed rail was not correlated with UC ($F_3 = 1.10$, $P < 0.35$) or FC ($F_3 = 1.71$, $P < 0.16$) nor was stall stocking rate correlated with UC ($F_2 = 0.11$, $P < 0.90$) or FC ($F_2 = 0.6$, $P < 0.55$).

DISCUSSION

In the present study, few relationships were found between stocking rates (at stalls, the feed rail or the AMS) and variables of interest including lying behavior or lameness. In fact, only leg cleanliness was significantly correlated with stall stocking rate. This is in contrast to what has generally been observed in parlor-milked systems where increases in the stocking rate at stalls and feed rail to a level greater than 100–113% have been found to lead to changes in behavior of lactating dairy cows, especially with regard to lying time (Christopher et al., 2008).

Stall stocking rate observed at the surveyed farms ranged from 56 to 126%, with an average of 94% (i.e., less than one cow per stall); while stocking rate at the feed rail ranged from 0.4 to 1.92 cows per 60 cm of feed rail with an average of 1.07 cows/60 cm (i.e., 56.1 cm of feeding space per cow). Stocking rate at the AMS ranged from 36-72 cows per AMS with an average stocking rate of 55 $\pm$ 8.6 cows per AMS. Thus, in all cases, the average stocking rates were in accordance with recommendations of various codes of practice and scientific studies (e.g., NFACC, 2009; Anderson, 2008; Armstrong, 1994; Brouk, 2008; Collier et al., 2007). There were no cases of extremely high stall stocking rate and only four cases when an AMS was stocked with more than 71 cows. However, 20% of the surveyed farms provided less than 45 cm of feed rail space per cow, which could be expected to cause reduced feed intake and thus lower body condition scores. It was surprising then, that our results found no effect of high feed rail stocking rate on body condition, measures of lamenes, or gait scores (Grant, 2009).

Cows synchronize their behavior as a result of circadian rhythms and group dynamics, with the result that reducing the number of stalls may lead to less lying and increased standing (Fregonesi et al., 2007), and may also influence to when cows feed or milk. Stocking rate at the stalls, feed rail, and AMS can each affect cow health and lying time individually, and it is also possible that effects of the various stocking rates may interact. Thus, we examined the correlation between stall stocking rate, feed rail stocking rate, and AMS stocking rate to better understand whether they were related, which would alter how we assessed the effects of these three stocking rates on our variables of interest such as lying behavior, body condition score, gait, or cleanliness. However, we found no significant relationships between the stocking rates in our study which may mean these variables may have stronger individual rather than interactive effects on cow behavior and welfare.

On average, cows spend between 8-12 hours in a day lying when the stocking rate in free stalls is 1:1 (Jensen, 2009F). Further, lying time decreases particularly in the overnight hours and during the mid-day period, as a result of stall overstocking (Fregonosi et al., 2007). However, in the present study, we found no relationship between stocking rate at the feed rail, stalls, or AMS with lying time, the number of lying bouts or lying bout duration.

According to our analysis, there was also no relationship between gait scores and the stocking rates at the 39 farms that were examined. Specifically, the data showed no relationship between presence of a limp, step asymmetry or head bob and the stocking rate at the stalls, feed rails or AMS at the surveyed farms. According to Galindo and Broom (2000), cows with lower access to stalls and feed rail had increased standing time, which increased their risk of becoming lame. However, it is important to note that there is also a positive relationship between lameness and lying time, where lame cows lay more than healthy cows (Chapinal et al., 2009; Chapinal, 2010a, b).

The average body condition score of cows in this study was 2.88 (on a 5 point scale). According to the Canadian Code of Practice for dairy cattle, the ideal body condition score for a dairy cow is 2.50-3.25 for the first third of lactation, the stage targeted for focal cows in our study (NFACC, 2009). We found that neither stocking rate at the feed rail or AMS had an effect on BCS. According to Thorne and colleagues (2007), high stocking rates lead to loss in body condition score and poor herd health. Given that we did not see an impact of high feed rail stocking rates on BCS in the farms we surveyed, it was possible that managers had increased frequency of feeding or feed push up frequency to compensate. Therefore, we analyzed the data to evaluate relationships between stocking rate at the feed rail and body condition score, frequency of fresh feed delivery, or push up of feed to the rail. We did not find any significant relationships between these variables; however, producers were typically delivering frsh feed or pushing up feed more than three times per day. According to Huzzey and colleagues (2006) the aggressive displacements seemed lessin headlocks feed barrier than at the post-and-rail barrier. This feeding management resulted in over 90% of cows having feed in front of them during all of our observations at each farm. Thus, good feeding management may have been compensating for high feed rail stocking rates at the eight farms with limited feed rail space. Another possibility is that the cows at farms with high feed rail stocking rates could be feeding asynchronously or adapting their feeding to times when the rail is less crowded.

According to Krawczel there is no relationship between udder and leg hygiene and stocking rate (Krawczel et al., 2012). Though another study reported that lower ranking cows were more likely to lie down outside of free stalls when there is overstocking (Gonzalez et al., 2003) and might be expected to be dirtier. In our study, stocking rate at the stall and feed rail did not correlate with udder and flank cleanliness, which may mean the producers were keeping the stall bedding clean and dry. Leg cleanliness, however, showed a significant correlation with stall stocking rate, but there was no relationship of leg cleanliness with feed rail stocking rate; perhaps indicating that time spent scraping alleys in the stall area has an effect on cow leg cleanliness.

CONCLUSIONS

In this study, we focused on examining the impact of stocking rates on cow behavior and welfare parameters rather than on milk production. Our data showed no strong relationships between stocking rates and lying behavior, body condition, gait scores, or cleanliness scores. However, cows in AMS have free movement to and from the AMS and may milk asynchronously, as opposed to cows milking as groups in parlor-based systems. This freedom may result in less synchrony of feeding and lying behavior. Also, the stocking rate in AMS systems may also be influenced by the design of barn and traffic system (forced, free, or guided) cow are also fed concentrate in the AMS; which may mitigate high stocking rates at the feed rail. Typically producers who adopt AMS alter management routines in their entirety, spend in less time milking cows and now have more time on cow health, feeding or breeding routines. This may allow producers to make management changes that can compensate for any issues caused by high stocking rates. For example, delivering or pushing up feed frequently to provide a constant source of feed for cattle when little feed rail space is available may reduce competition and mitigate any impacts on body condition score.

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APPENDIX

TABLES

Table 2.1 Characteristics of AMS farms in the survey

	Minimum	Median	Maximum
Number of AMS	1	2	8
Number of Stalls/AMS	1	1	8
Number of Cows/AMS	36	55	72
Number of AMS/pen	1	1	3
Months operating the AMS	6	23.5	108
Average number of milkings/cow/d	1	3	7
Minimum # visits to AMS/cow/d	1	2	3
Maximum # visits to AMS/cow/d	3	5	7
Average feed for cows in AMS/d (kg)	2	4.6	19.8
Average feed for heifers in AMS/d (kg)	2	4.3	8
Number of feed deliveries/d	1	>1	> 3
Number of feed push ups/d	0	>1	> 3
Permitted time between milkings (h)	3.5	6	8
Permitted yield between milkings (kg)	6.8	8	30
Number of times cows fetched/d	1	2.5	12
Number of cows fetched/d	1	12	60
Time elapsed between milkings before fetching cows (h)	8	12	16
Number of times AMS cleaned/d	1	2	4
Duration of AMS cleaning by a day (min)	5	25	60

Table 2.2 Descriptive data from the 39 farms surveyed showing stall stocking rate (cow/stall), feed rail stocking rate (cow/60 cm by 24 headlocks, 19 post-rail, and 1 swing rail), and stocking rate at the automatic milk system (cow/AMS).

Farm ID	# Cows/Pen	# Cows/Stall	# Cows/60 cm feed rail	# Cows/AMS
1	148	0.9	1.92	49
2	92	0.96	1.17	31
3A	57	1.02	1.4	57
3B	63	0.91	1.9	63
4	57	1	0.9	57
5	54	0.68	0.89	54
6	60	0.95	0.96	60
7	100	0.91	0.76	100
8	67	0.56	0.4	34
9	47	1	0.8	47
10	144	1.15	1.61	48
11A	60	1.05	0.87	60
11B	63	1.11	0.9	63
12	60	0.87	1.17	30
13	140	0.67	0.8	140
14	59	0.98	0.93	59
15	62	1.05	1.05	62
16	121	0.98	1.74	61
17	99	1.13	1.14	99
18A	119	1.08	1.12	59.5
18B	125	1.17	1.19	63
18C	127	1.19	1.21	64
19	87	0.75	0.7	44
20	60	0.92	0.97	60
21	56	0.85	0.9	56
22	58	0.95	1.22	58
23A	51	0.84	0.72	51
23B	51	0.84	0.6	51
24	65	0.99	1.05	65
25A	55	0.97	0.85	55
25B	52	0.96	0.8	52
26	68	0.85	0.62	34
27	71	0.93	1.06	71
28	42	0.64	0.77	42
29	96	1.04	1.23	96
30	64	0.96	1.15	64
31	50	0.78	1.12	50
32	55	0.98	0.87	55
33	63	1.26	1.38	63
34	190	1.09	1.43	63
35	57	0.95	1.14	57
36	60	0.95	1.16	60
37	48	0.68	0.85	48
38	59	1.07	1.7	59
39	83	0.66	1	41.5

FIGURES

Figure 2.1 Correlational analysis showing no relationship between stall stocking rate (SRS) and feed rail stocking rate (SRF; $P = 0.25$).

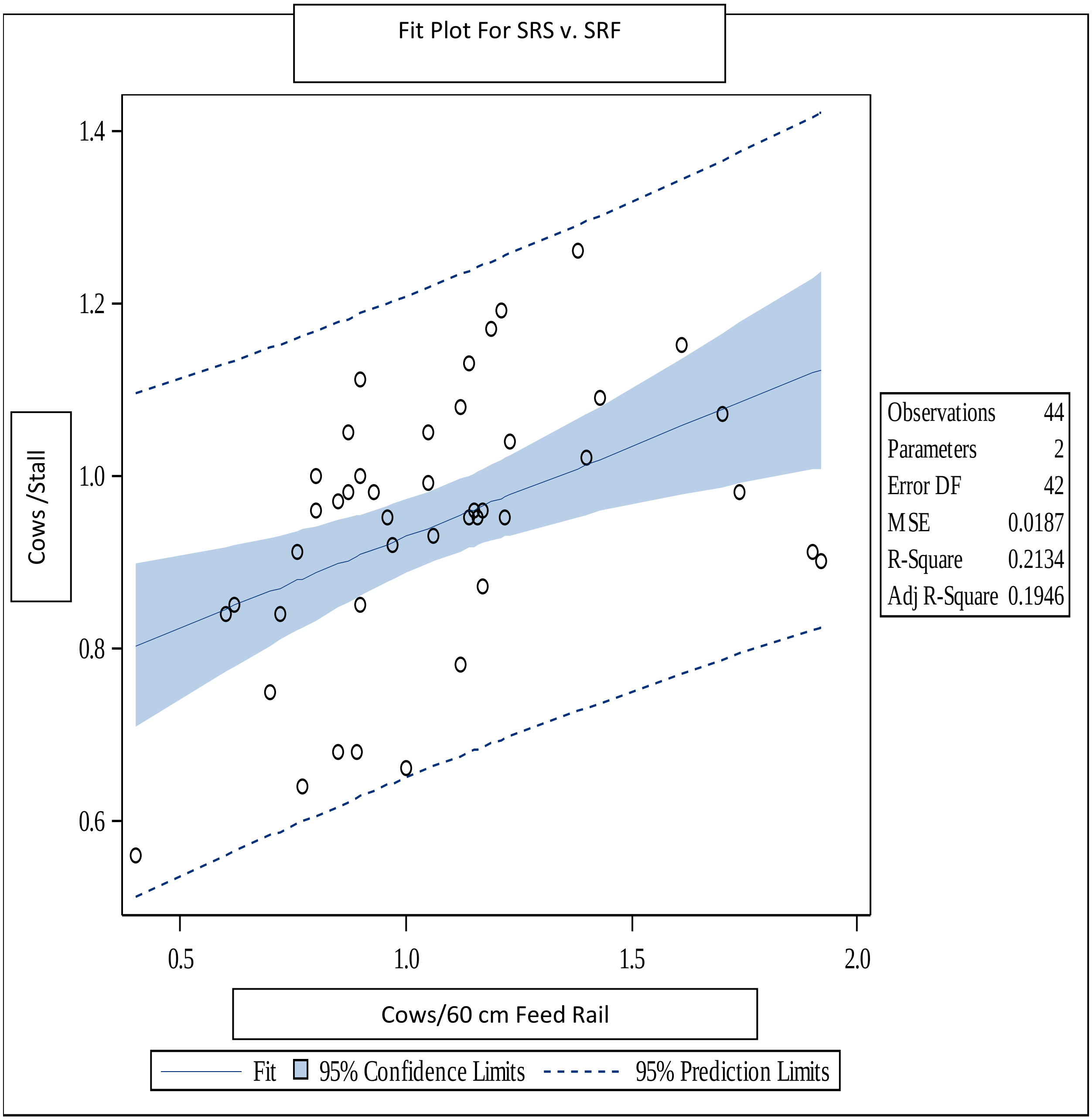


Figure 2.2 Correlational analysis showing no relationship between AMS stocking rate (SRA) and stall stocking rate (SRS; *P* = 0.08).

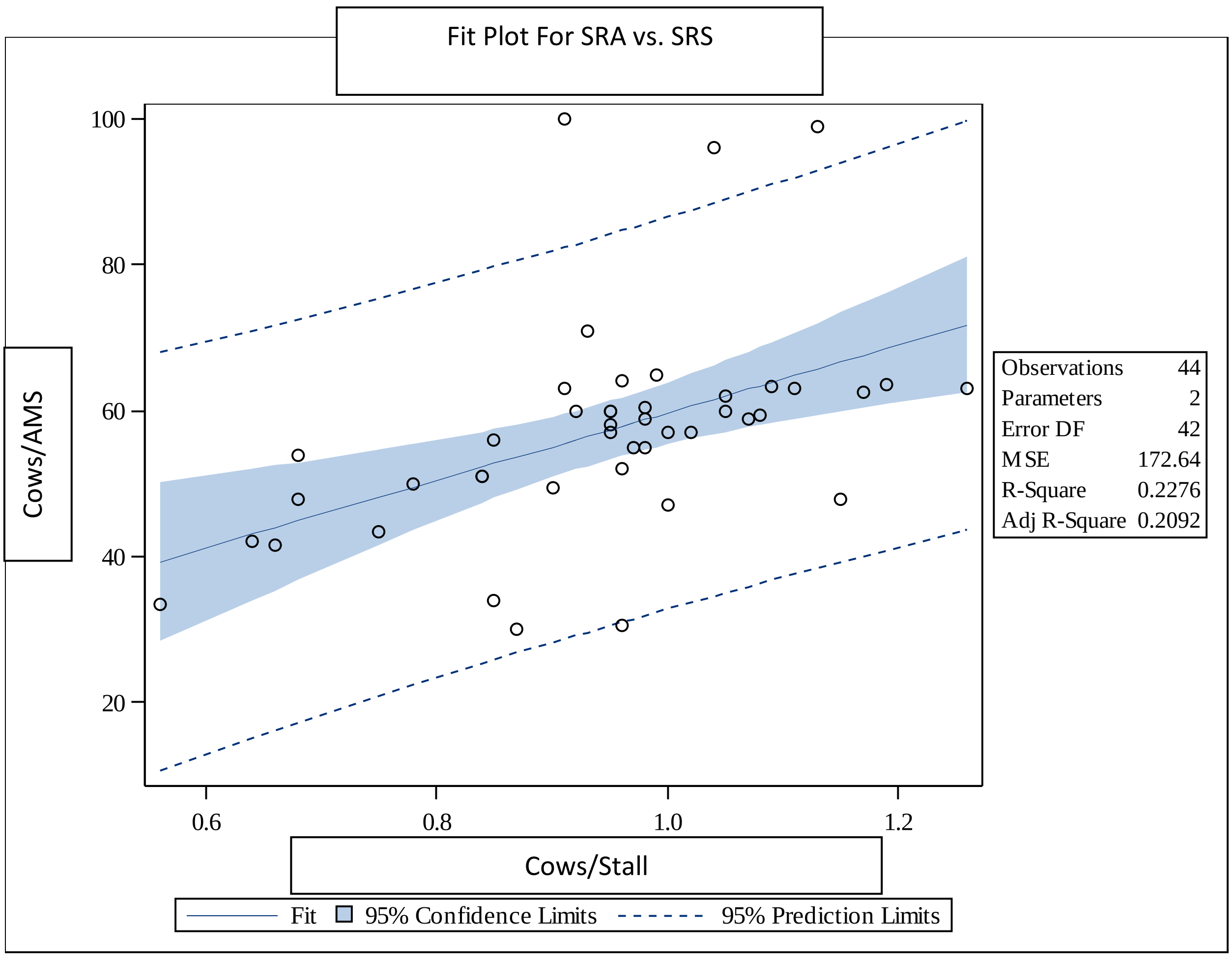


Figure 2.3. Correlational analysis showing no relationship between AMS stocking rate (SRA) and feed rail stocking rate (SRF; $P = 0.11$).

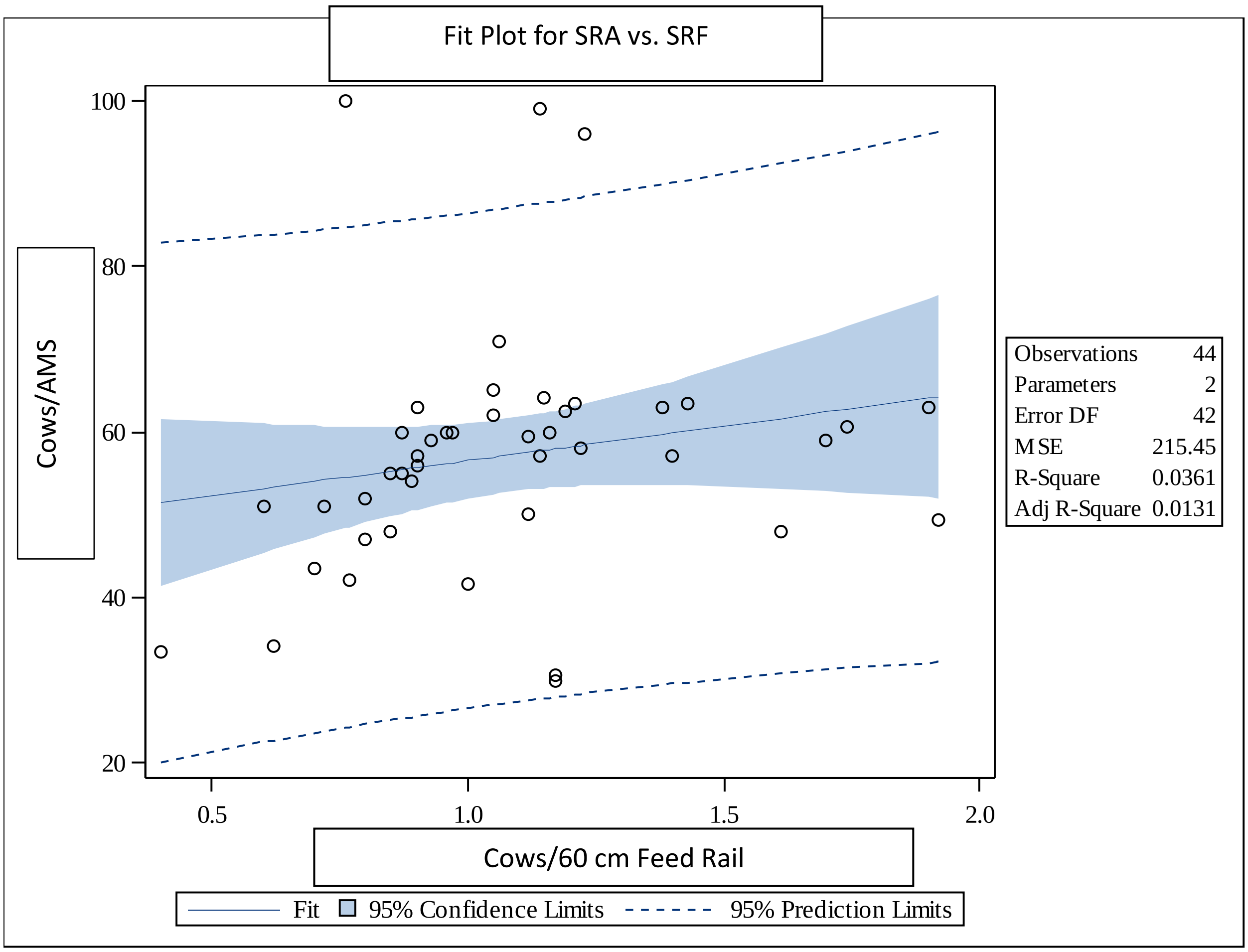


Figure 2.4 Descriptive data showing average total lying time for each farm over 24 h (created using an average from 4 days of data per cow then averaging all 40 focal cows on the farm). Data are presented according to number of AMS in each pen: orange = 3 AMS/pen, gray = 2 AMS/pen, and blue = 1 AMS/pen.

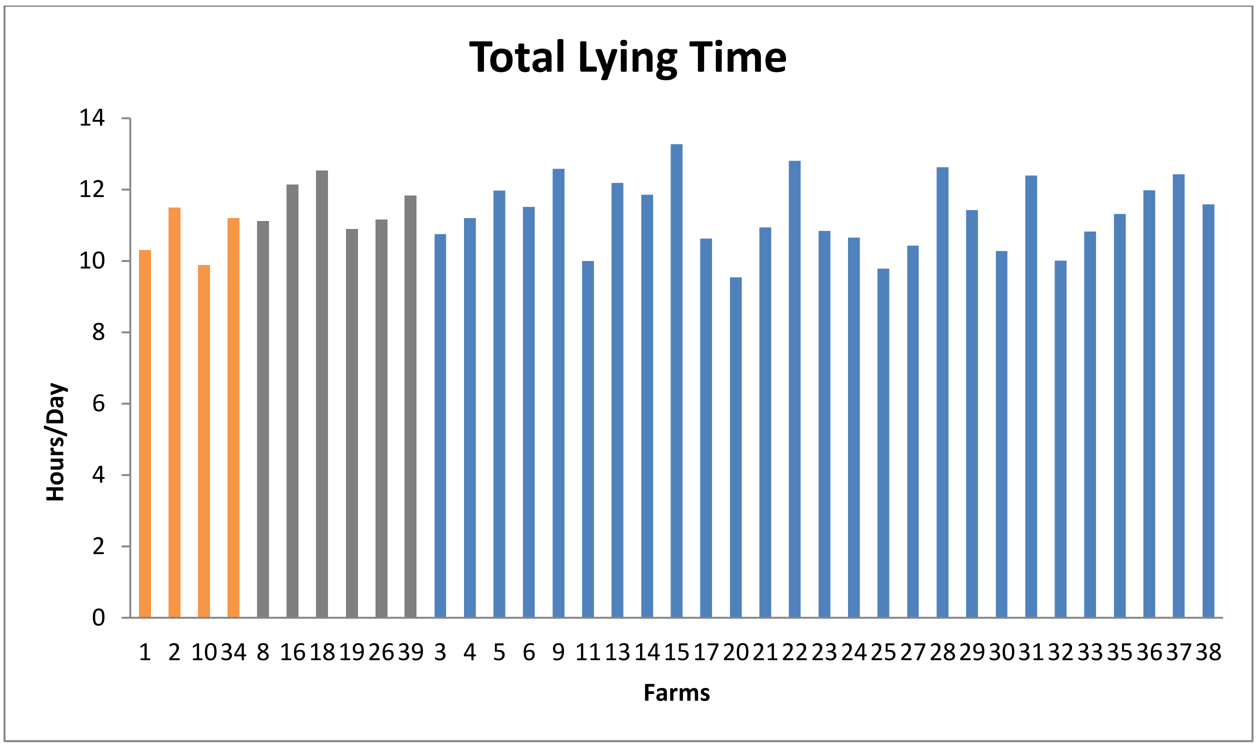


Figure 2.5 Descriptive data showing the average lying bout duration of each farm (created using an average from 4 days of data per cow then averaging all 40 focal cows on the farm). Data are presented according to number of AMS in each pen: orange = 3 AMS/pen, gray = 2 AMS/pen, and blue = 1 AMS/pen.

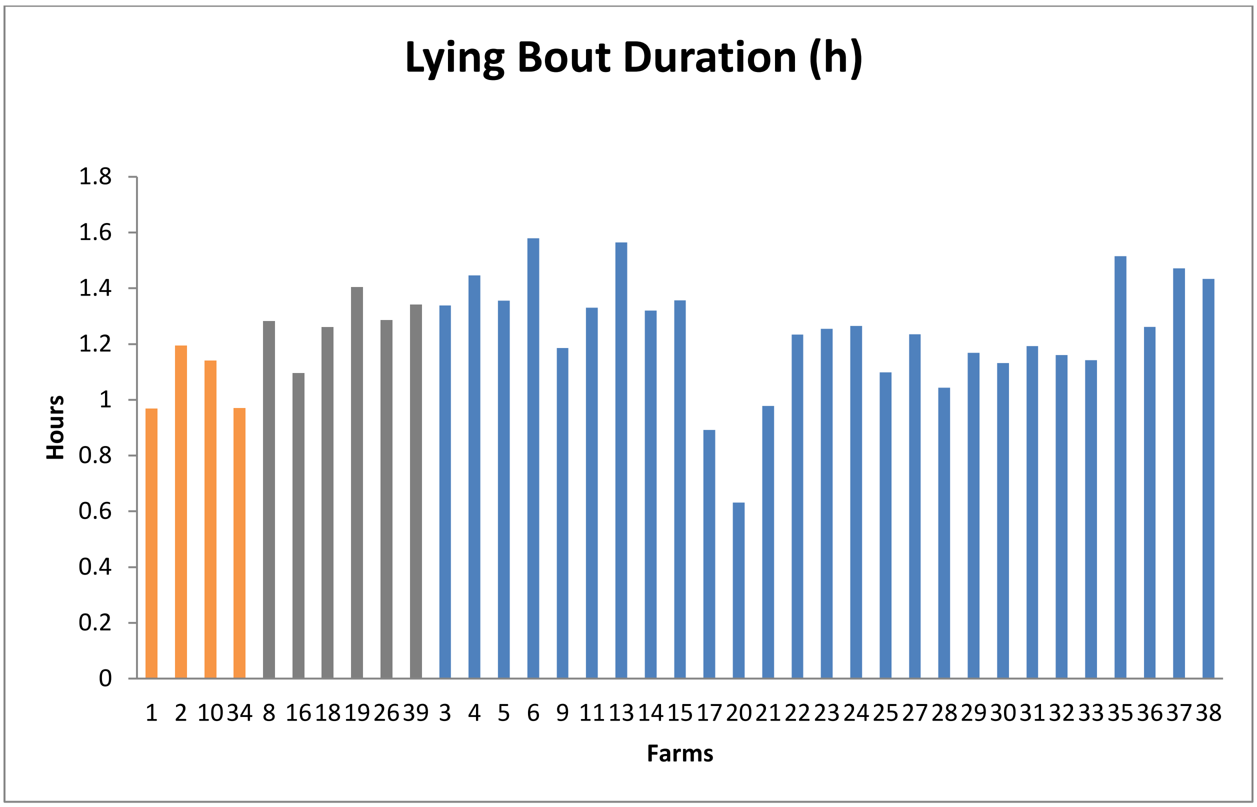


Figure 2.6 Descriptive data showing the average number of lying bouts for each farm (created using an average from 4 days of data per cow, then averaging all 40 focal cows on the farm). Data are presented according to the number of AMS in each pen: orange = 3 AMS/pen, gray = 2 AMS/pen, and blue = 1 AMS/pen.

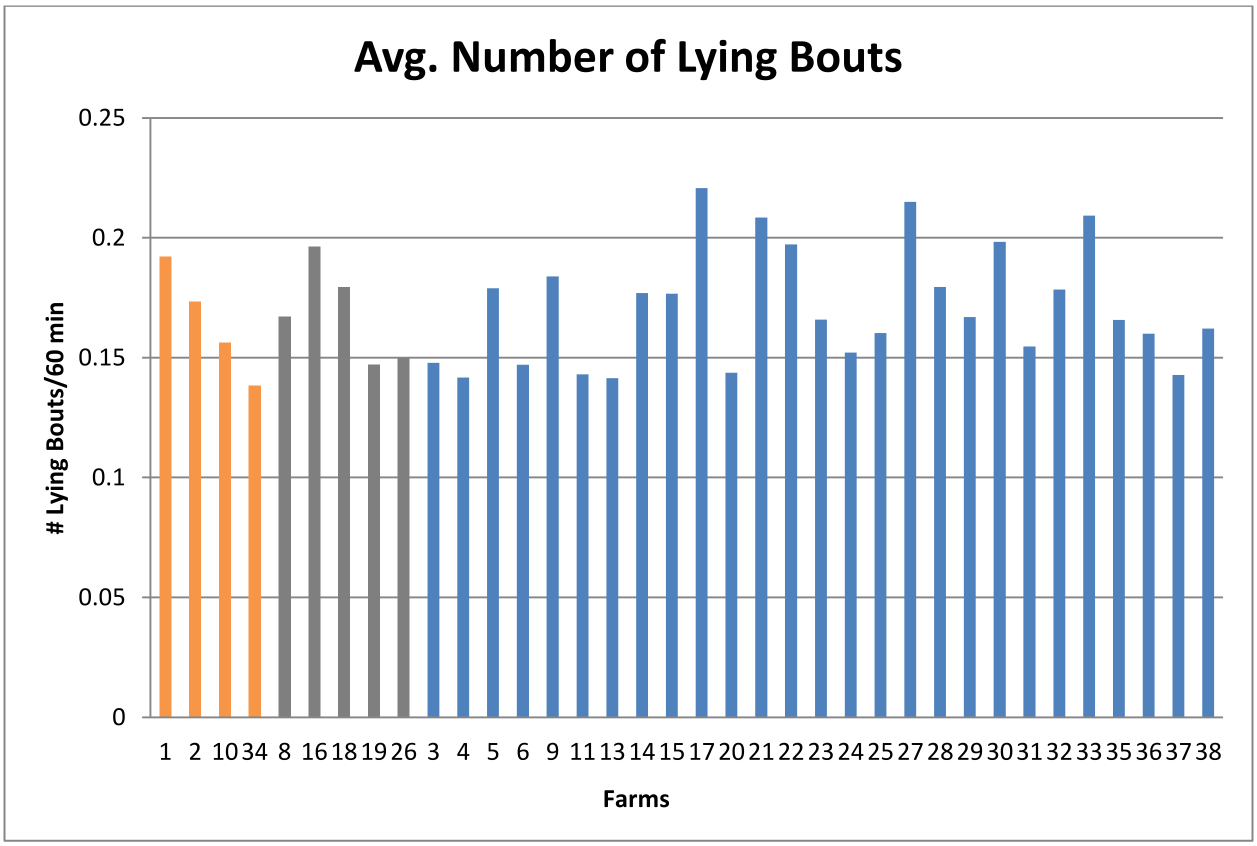


Figure 2.7 Descriptive data showing presence of a limp (which was scored as either absent (0) or present (1)) for 40 focal cows at each farm. Data are presented according to number of AMS in each pen: orange = 3 AMS/pen, gray = 2 AMS/pen, and blue = 1 AMS/pen.

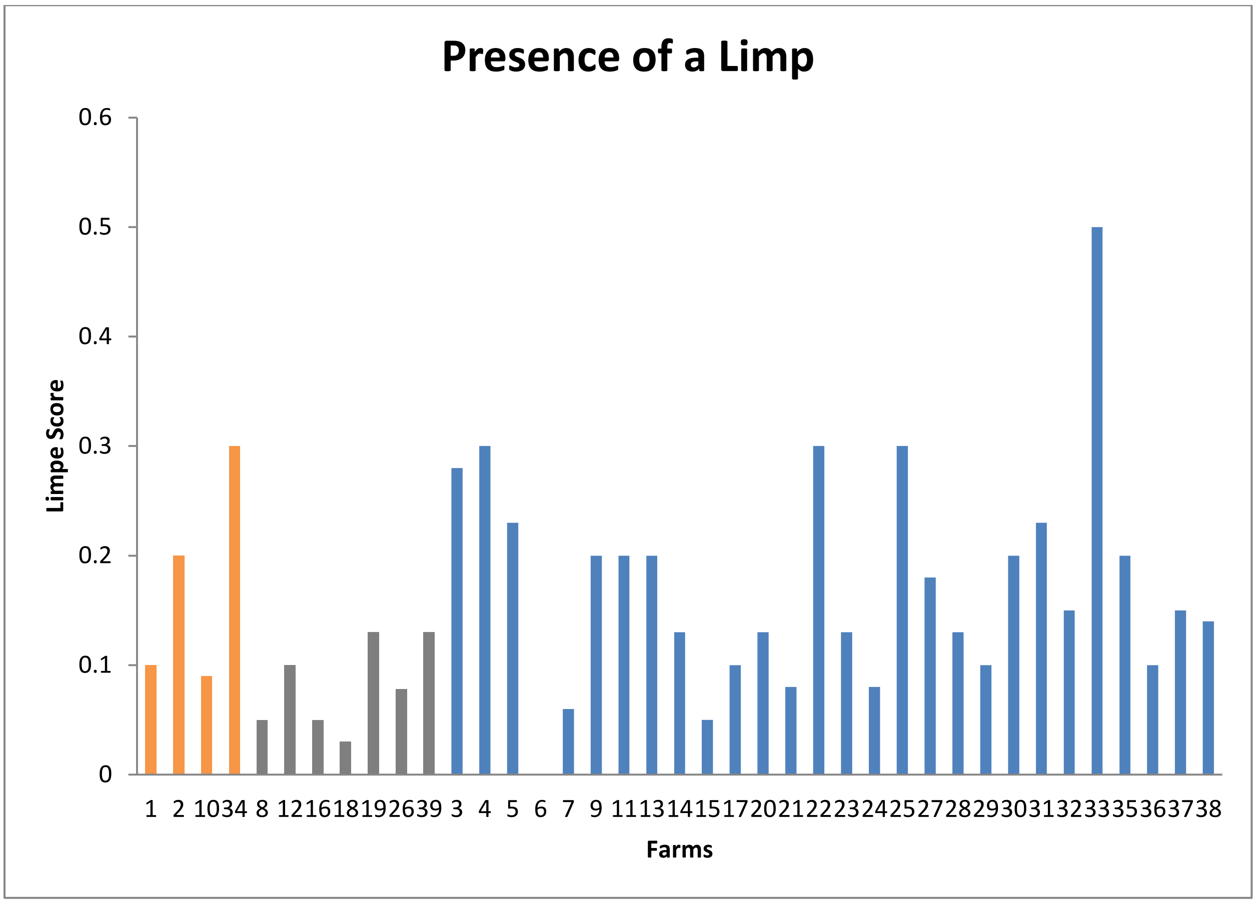


Figure 2.8 Descriptive data showing head bob (which was scored as either absent (0) or present (1)) associated with lameness for 40 focal cows at each farm. Data are presented according to the number of AMS in each pen: orange = 3 AMS/pen, gray = 2 AMS/pen, and blue = 1 AMS/pen.

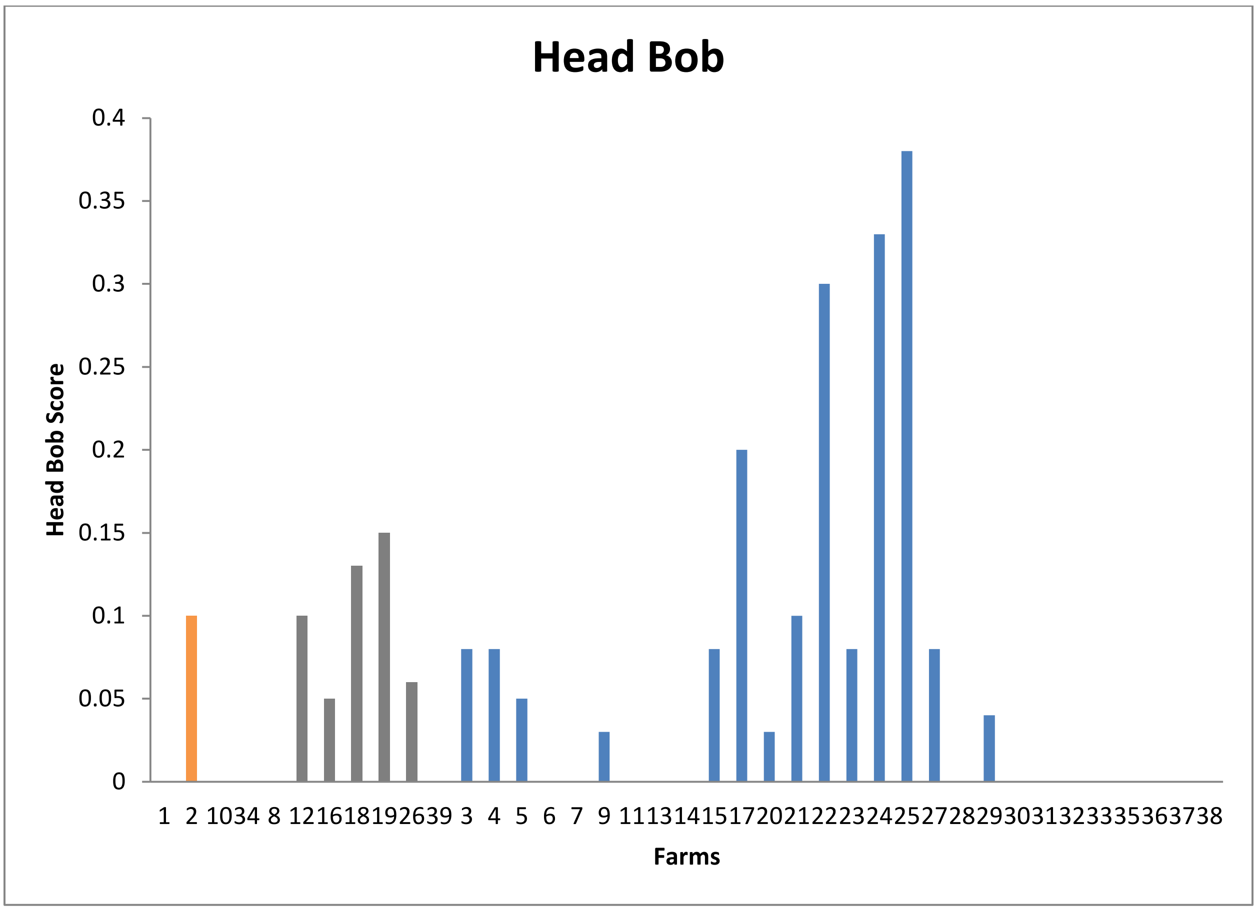


Figure 2.9 Descriptive data showing step asymmetry (which was scored as either absent (0) or present (1)) associated with lameness for 40 focal cows at each farm. Data are presented according to number of AMS in each pen: orange = 3 AMS/pen, gray = 2 AMS/pen, and blue = 1 AMS/pen.

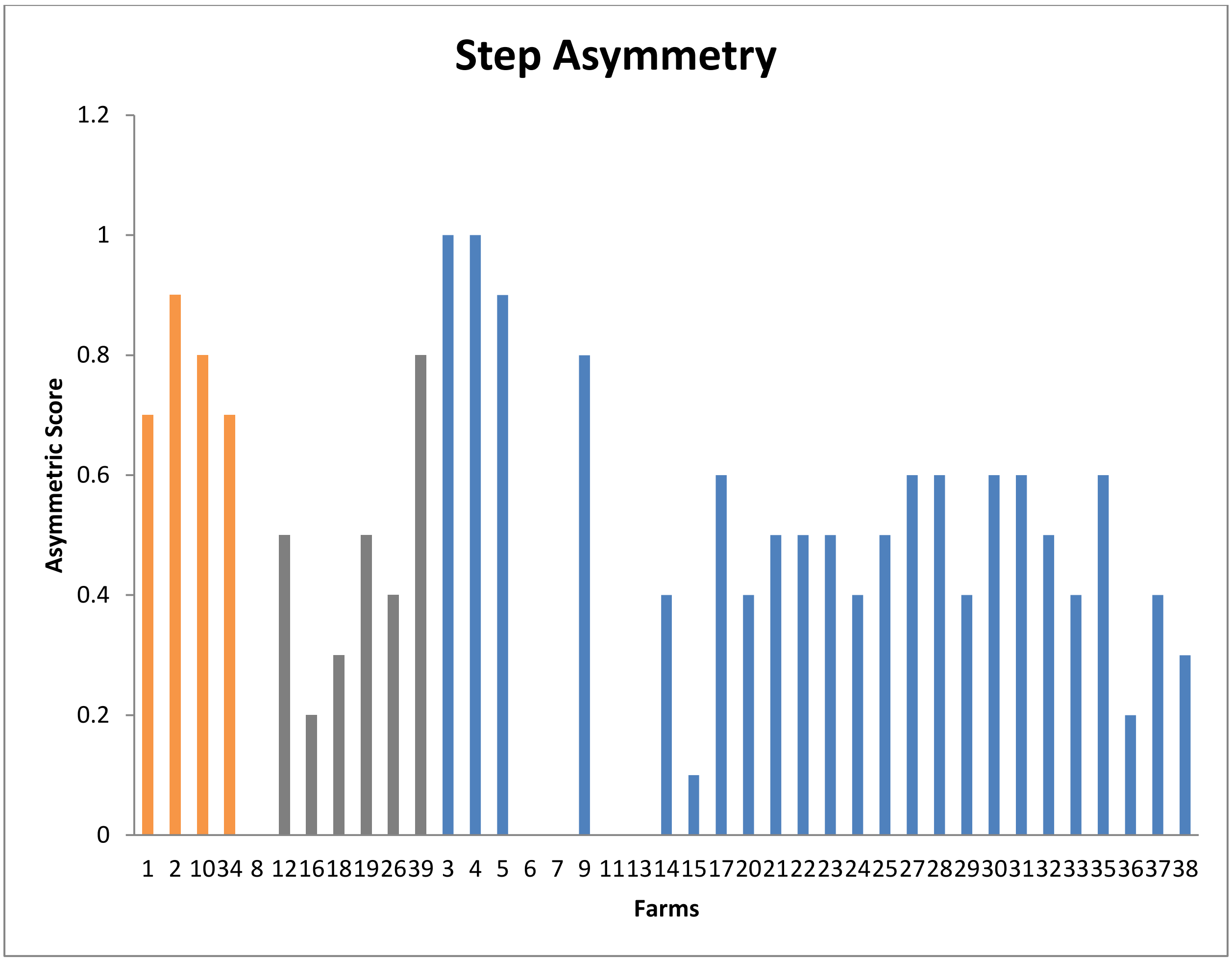


Figure 2.10 Descriptive data showing body condition (which was scored on 1-5 scale in 0.25 increments with 1 = a very thin cow and 5 = an obese cow) of 40 focal cows at each farm. Data are presented according to number of AMS in each pen: orange = 3 AMS/pen, silver = 2 AMS/pen, and blue = 1 AMS/pen.

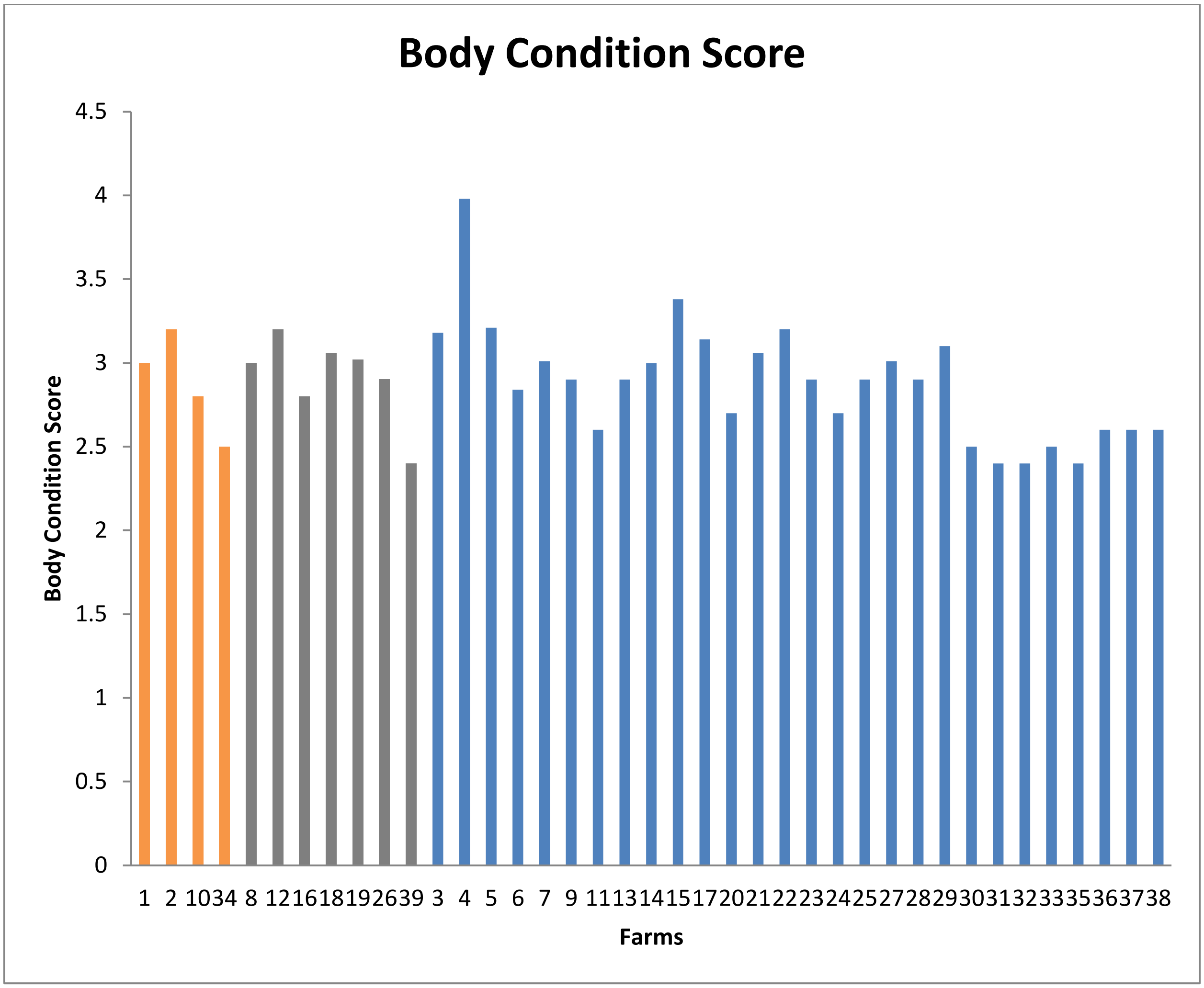


Figure 2.11 Correlational analysis showing no relationship between feed rail stocking rate and frequency of feed delivery (*P* = 0.57).

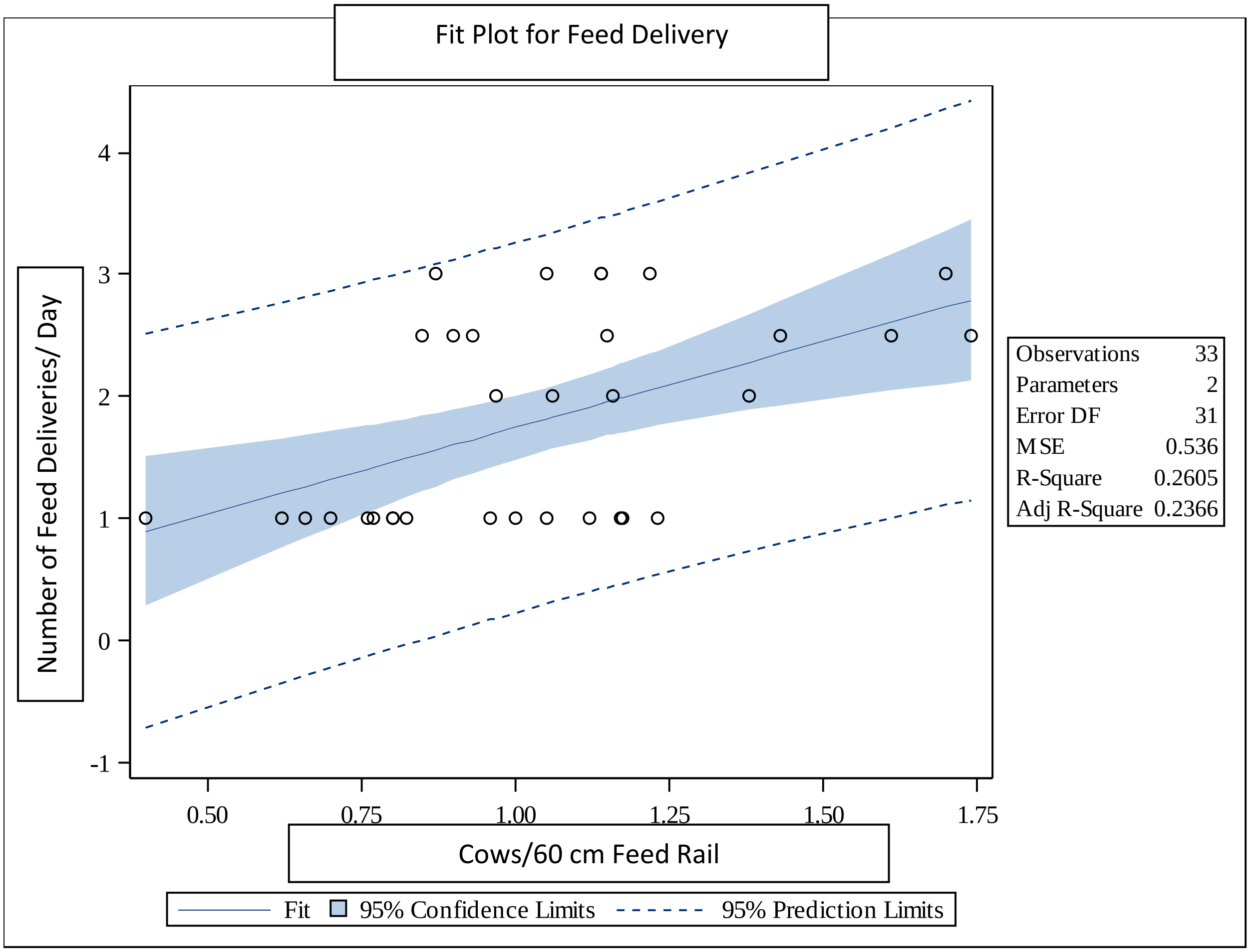


Figure 2.12 Correlational analysis showing no relationship between frequency of feed push up and feed rail stocking rate (*P* = 0.47).

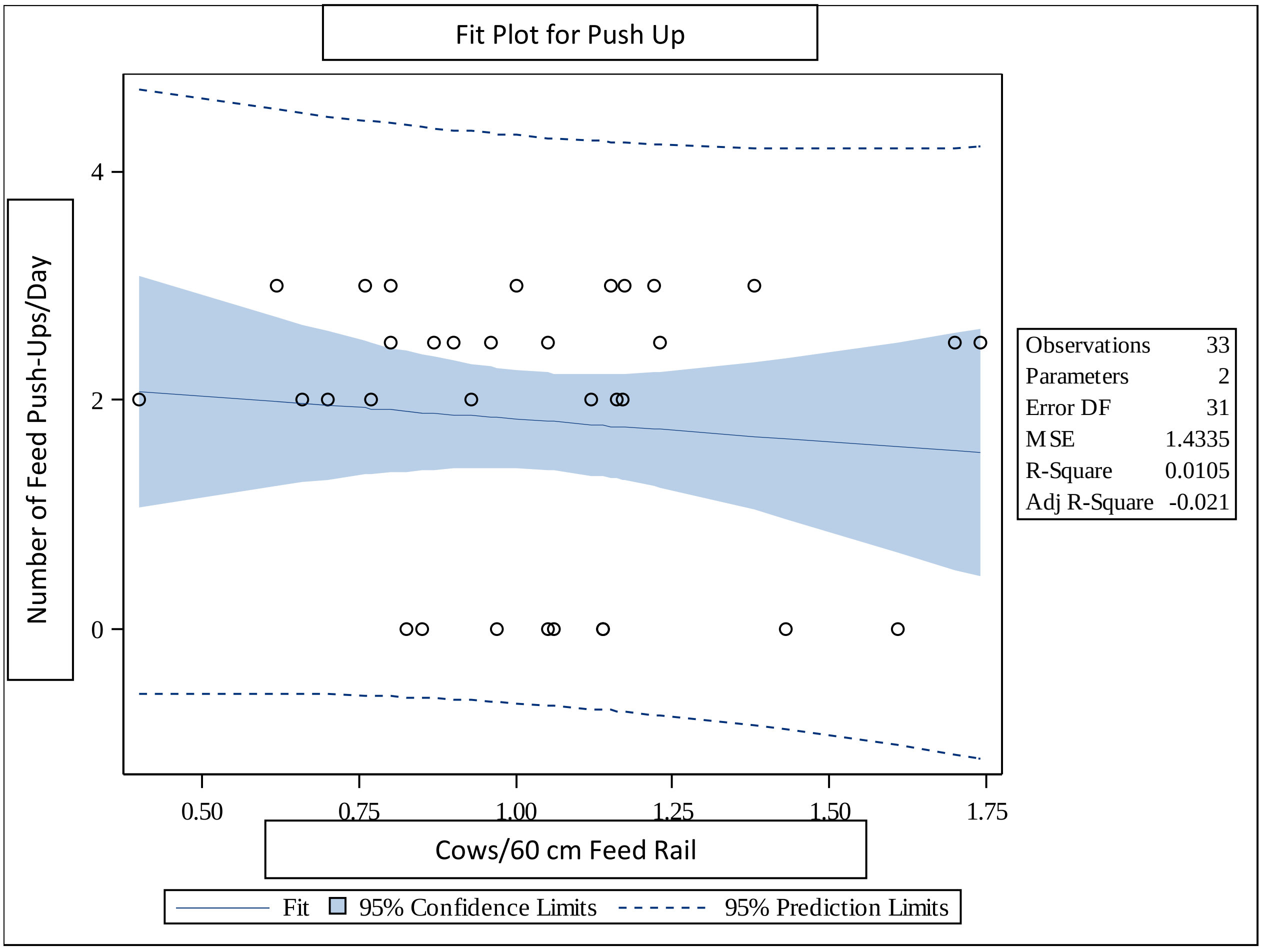


Figure 2.13 Correlational analysis showing no relationship between body conditions score and frequency of feed delivery (*P* = 0.16).

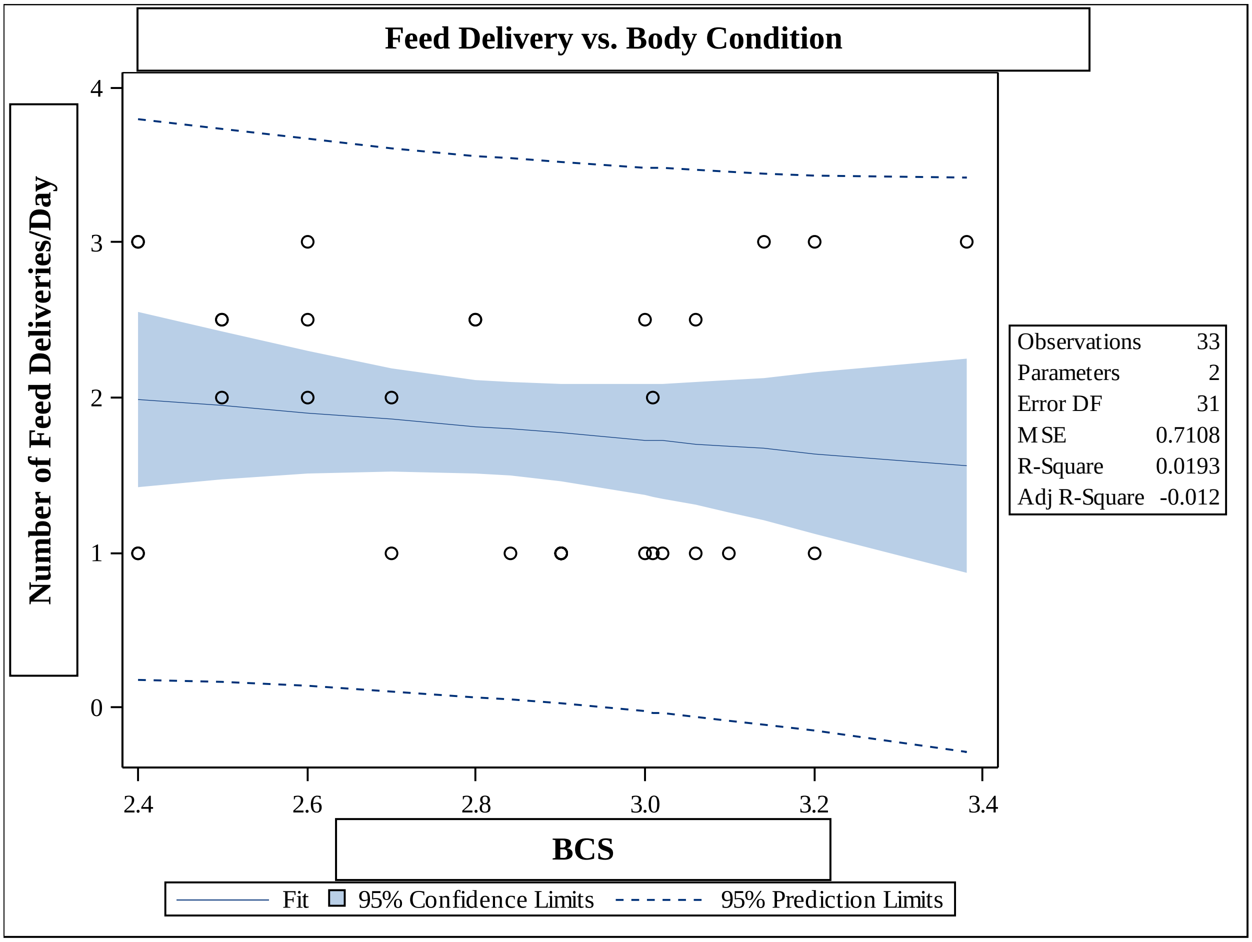


Figure 2.14 Correlational analysis showing no relationship between BCS and frequency of feed push up (P = 0.9).

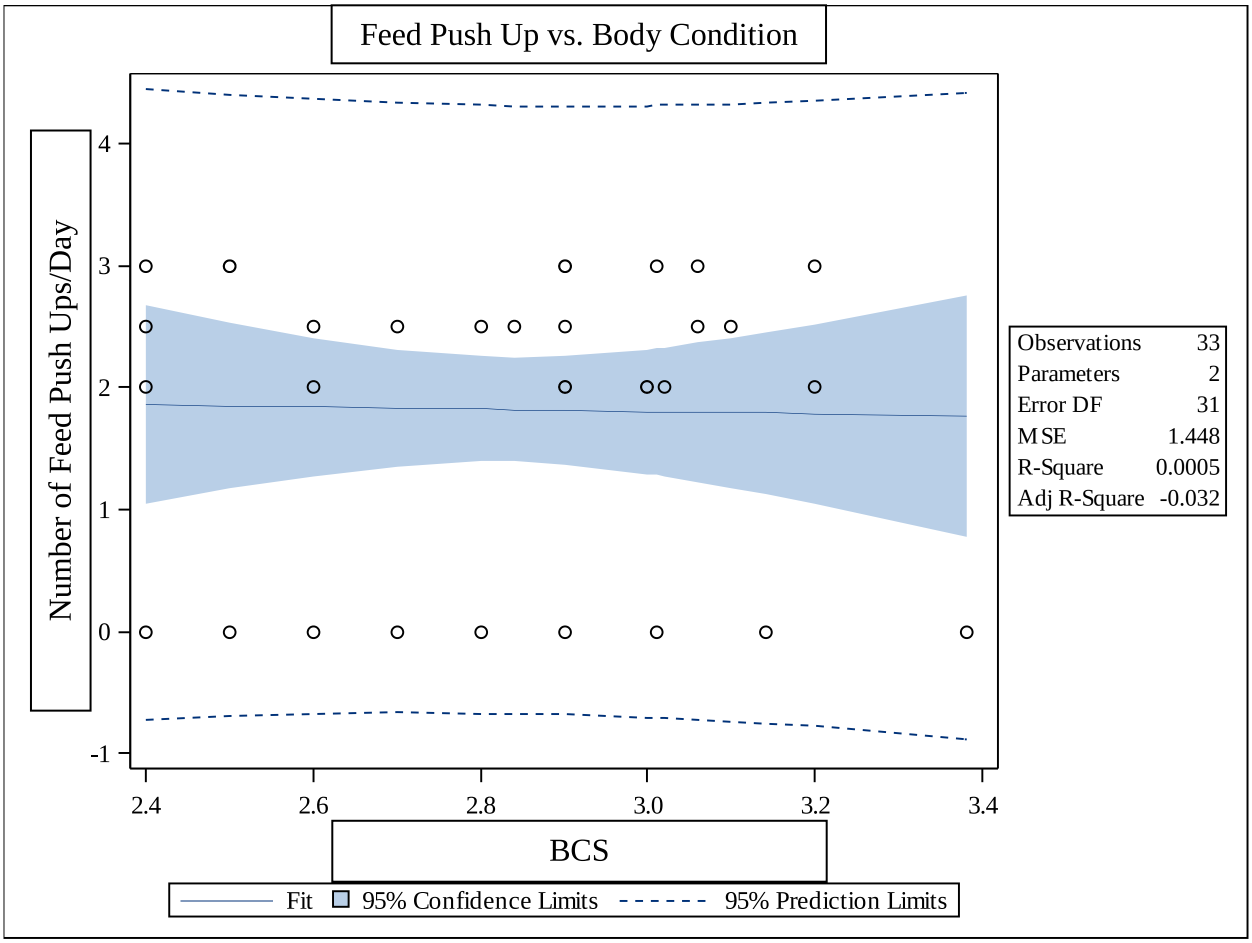


Figure 2.15 Correlational analysis showing no a relationship between push up and feed delivery (P = 0.14).

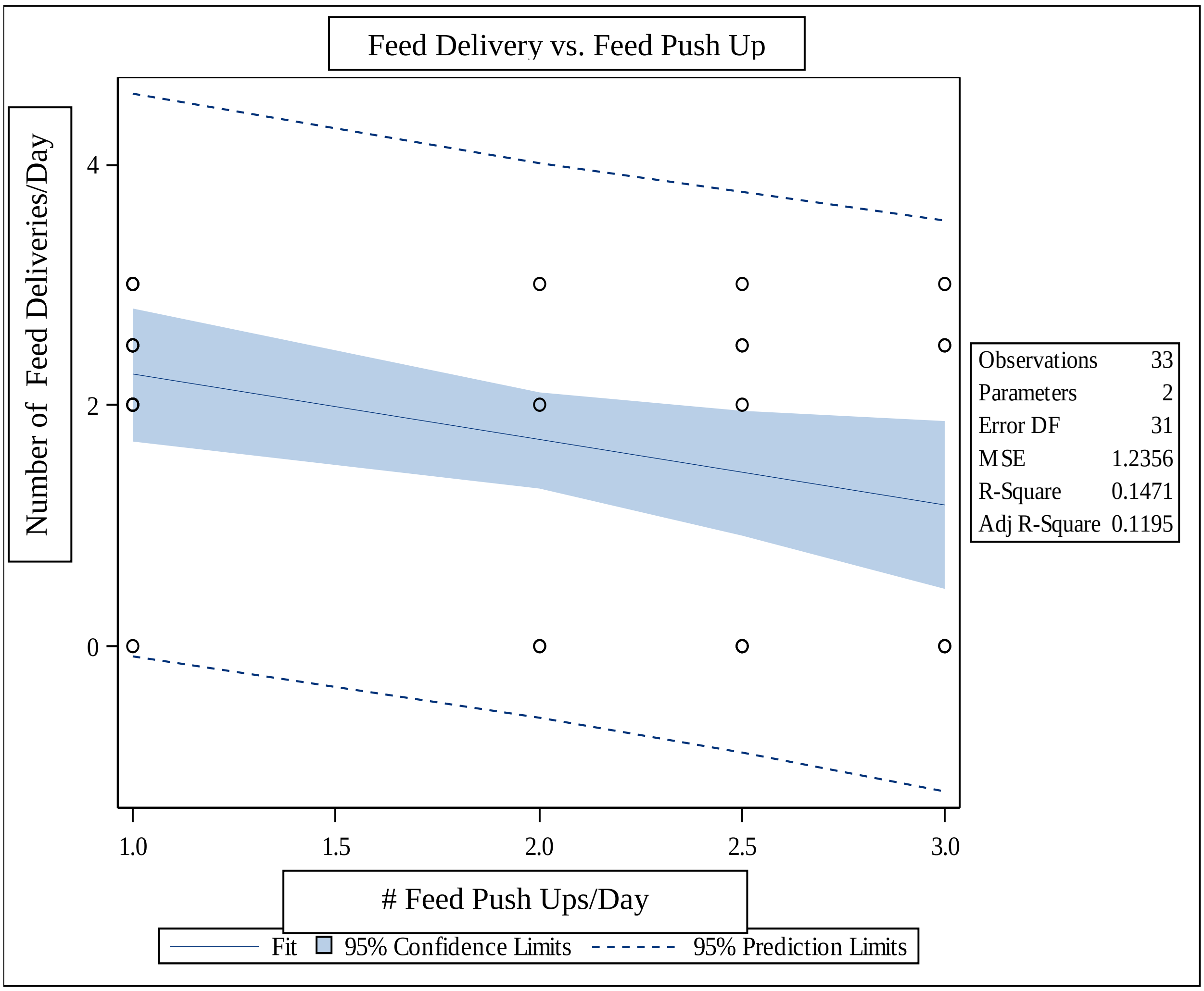


Figure 2.16 Descriptive data showing leg cleanliness (which was scored on a 0-3 scale, with 0 representing clean and 3 representing very dirty) for 40 focal cows on each farm. Data are presented according to the number of AMS in each pen: orange = 3 AMS/pen, gray = 2 AMS/pen, and blue 1 = AMS/pen.

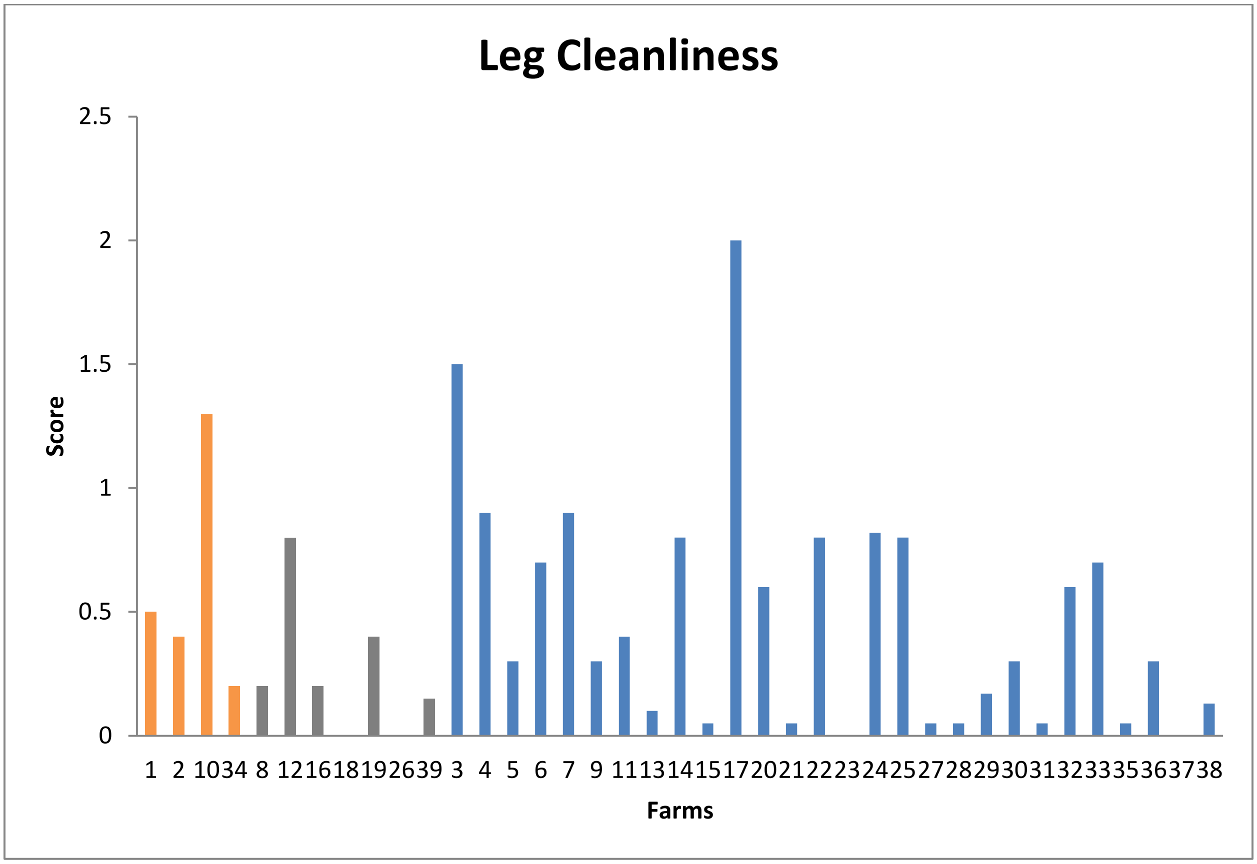


Figure 2.17 Descriptive data showing udder cleanliness (which was scored on a 0-3 scale, with 0 representing clean and 3 representing very dirty) for 40 focal cows on each farm. Data are presented according to the number of AMS in each pen: orange = 3 AMS/pen, gray = 2 AMS/pen, and blue 1 = AMS/pen.

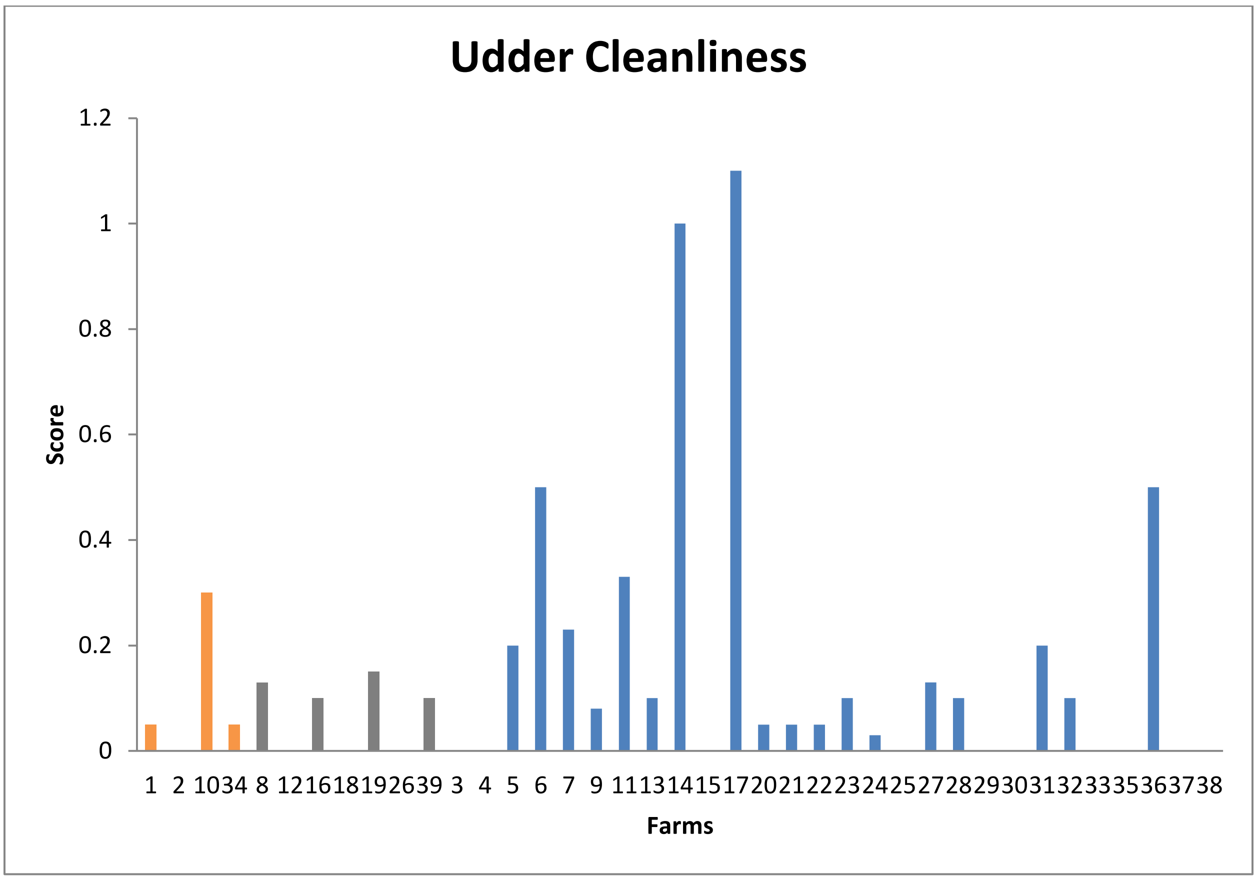
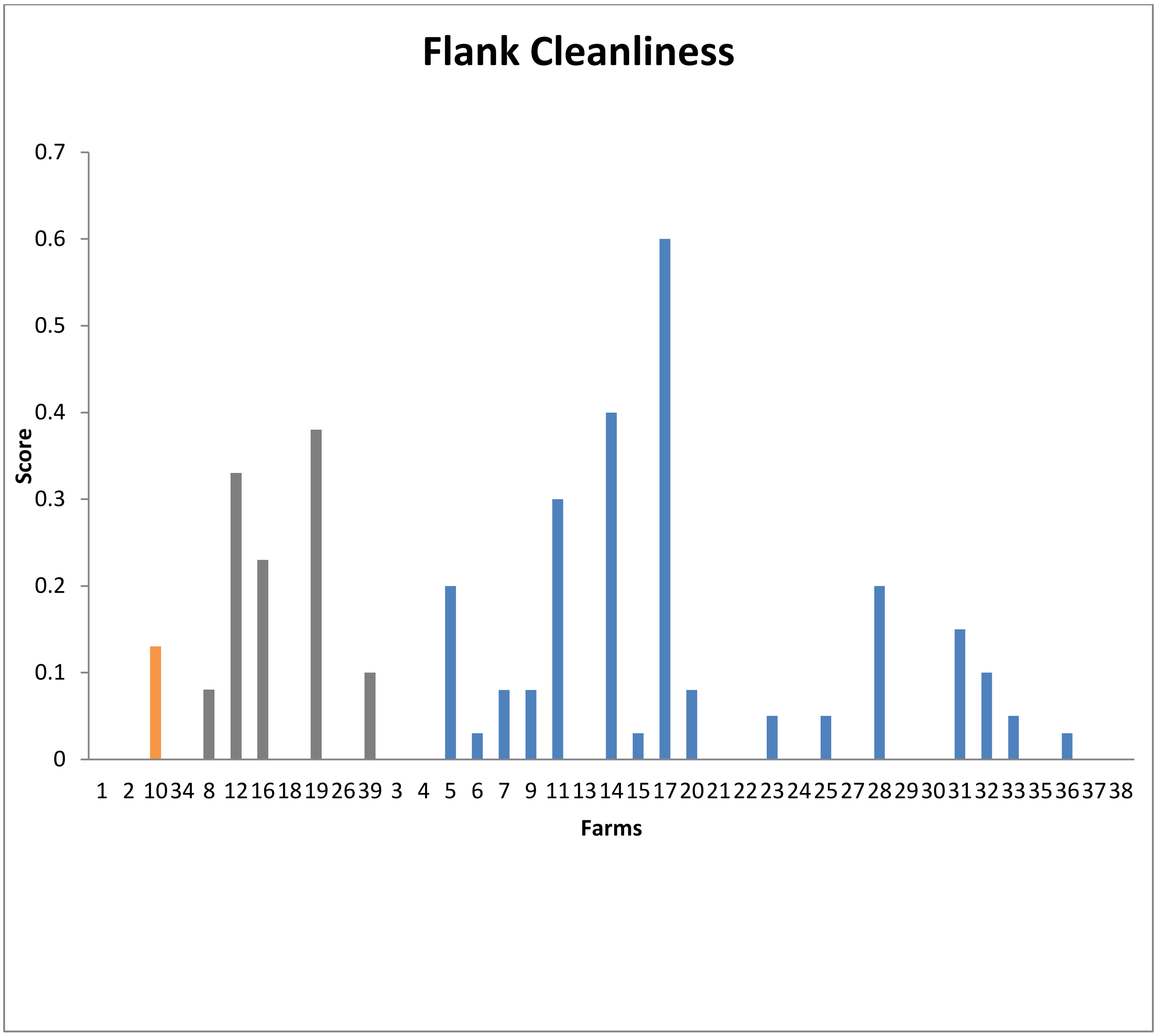


Figure 2.18 Descriptive data showing flank cleanliness (which was scored on a 0-3 scale, with 0 representing clean and 3 representing very dirty) for 40 focal cows on each farm. Data are presented according to the number of AMS in each pen: orange = 3 AMS/pen, gray = 2 AMS/pen, and blue = 1 AMS/pen.



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CHAPTER 3

IMPACT OF STALL AND FEED RAIL STOCKING RATE ON COW BEHAVIOR AND PRODUCTION IN AUTOMATIC MILKING SYSTEMS

Interpretive summary: Stall and feed rail stocking rate affects behavior in AMS. Witaifi
This experimental study examined the impact of stall and feed rail stocking rates at AMS on cow behavior and welfare. Three experimental treatments (at stalls or feed rail separately) were 1:1 (100%), 1:1.2 (120%), and 1:1.5 (150%) stocking rates. These stocking rates were related to stall and feed rail displacement (after feed delivery and push up) and time budgets for stalls and feed rails; however, only after fresh feed delivery did displacement increase due to high stocking rates. Cow behavior and welfare in AMS does not appear as tightly linked to stall and feed rail stocking rates as in parlor-milked dairies.

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Impact of Stall and Feed Rail Stocking Rate on Cow Behavior and Production in Automatic Milking Systems

A.A. Witaifi[*] and J.M. Siegford[*1]

[*]Animal Behavior and Welfare Group, Department of Animal Science, Michigan State University, East Lansing, 48824.

[1]Corresponding author: Janice M. Siegford

Department of Animal Science, Michigan State University, 1290 Anthony Hall, East Lansing, MI 48824, Phone: 517-432-1388, Fax: 517-353-1699, Email: siegford@msu.edu

ABSTRACT

The number of stalls and amount of space at the feed rail provided per cow (stocking rate) on dairy farms is important because overstocking may impact animal welfare if there are not enough comfortable lying spaces or space for feeding. Research has shown the impact of high stall stocking rates on cows in parlor-milked systems; however, no studies have examined stocking rates for cows milked with automatic milking systems (AMS). Though cow behavior is no longer synchronized by a fixed milking routine in AMS, cows may still wish to lie down or eat synchronously). Therefore, it is important to examine the impact of stocking rates on dairy cows in AMS to determine effects on production and behavior. This experiment examined the effect of reducing the number of stalls available or the feeding space per cow on displacement and other behaviors in an AMS dairy farm. Each of two pens contained 60 cows/pen and 58 free-stalls and 60 headlocks. The impact of stocking rate was examined using three treatments: 1) 1:1 treatment with 58 stalls or 60 headlocks available for 60 cows; 2) 1:1.2 treatments with 50 stalls or 50 headlocks available for 60 cows; and, 3) 1:1.5 treatment with 40 stalls or 40 headlocks available for 60 cows. Each stall or feed rail treatment was applied separately, and each was applied for 1wk in a randomized order that was different for each pen, with a 1-wk washout period between treatments. Observations of displacement behavior were made from video recordings on the last 2 d of each treatment week to examine whether treatment affected how often cows were displaced from stalls. Displacement data were recorded at the feed rail by live observation for the 45 min after fresh feed delivery and for the 45min after feed push up. Results revealed no difference in number of displacements at the stalls between the treatments ($F_2 = 5.22$, $P = 0.16$). However, a difference in number of displacements among three treatments was found in the period immediately after feed delivery ($F_2 = 86.33$, $P = 0.01$), when a difference was seen

between treatments 1:1.1 and 1:1.2 ((18 ± 1.56 vs. 24.5 ± 1.56 displacements, respectively; F_2 = 0.71, P = 0.02) and between 1:1.1 and 1:1.5 (27 ± 1.56 displacements for 1:1.5; F_2 = 0.71, P = 0.01). The number of displacements observed after push up of feed was not different among the three feed rail stocking rates (F_2 = 6.09, P = 0.14). Stall stocking rate treatments also did not impact activity or time spent ruminating (F_2 = 1.39, P = 0.43 and F_2 = 0.2, P = 0.84, respectively). There was no difference among the treatments for the average number of cows lying in stalls (F_2 = 4.95, P = 0.17), standing in stalls (F_2 = 11.99, P = 0.08), perching in stalls (F_2 = 0.28, P = 0.76), standing in the alley (F_2 = 9.04, P = 0.1), or walking in the alley (F_2 = 1.09, P = 0.36). There was no difference among the treatments for number of cows eating (F_{18} = 0.5, P = 0.93), with heads in the headlocks but not eating (F_{18} = 0.96, P = 0.53), standing at the feed rail with heads not in headlocks (F_{18} = 0.31, P = 0.99), or standing in the alley behind the feed rail (F_{18} = 0.72, P = 0.76). There were no differences among the treatments for number of cows eating (F_{18} = 1.36, P = 0.27), with heads in the headlocks but not eating (F_{18} = 1.11, P = 0.42; F), standing at the feed rail with heads not in headlocks (F_{18} = 1.14, P = 0.39), or standing in the alley behind the feed rail (F_{18} = 0.91, P = 0.59). Additionally, activity and rumination results in response to feed rail stocking rates showed no difference among treatments (F_2 = 0.55, P = 0.65 and F_2 = 0.12, P = 0.89, respectively). This study is the first to examine the impact of stocking rate in stalls and at the feed rail on displacement and general behavior of lactating cow in an AMS dairy. Our results suggest that increasing the stocking rate at either feed rail or stalls to 1:1.2 and 1:1.5 in AMS dairies may not affect cow behavior to the degree that these stocking rates do in parlor-milked dairies. Results may help producers determine optimal stocking rates for AMS dairies, allowing them to optimize facility design and management in ways that maintain good welfare and production without wasting space or resources.

Key Words: robotic milking, stocking density, lying, displacement, rumination

INTRODUCTION

Stocking rate of stalls in parlor-milked dairy herds can have effects on cow behavior, health and production, and there is evidence of a positive relationship between the stocking rate and lying time at the stalls and milk production (Huzzey et al., 2013). Stocking rate is a significant element of cow comfort, with particular importance related to its effect on lying time (von Keyserlingk et al., 2009). Echoing this sentiment, the European Food Safety Authority stated that overstocking is one of the most important risks to the welfare of cattle in free-stall housing (EFSA, 2009a). However, while dairy producers are often advised to keep stocking density below 120% (e.g., NFACC, 2009), overstocking is commonly found on commercial dairy farms in the North America (USDA, 2007; von Keyserlingk et al., 2012). This is true despite the fact thatoverstocking can lead to lower milk production on farms with fewer stalls per cow (Bach et al., 2008).

Current recommendations suggest that most cows in comfortable free stalls spend an average about 12 h/d lying down (EFSA, 2009b). Although, animal welfare standards for dairy farms have generally been related to resource-based criteria, such as stall stocking rate, there is increased interest in assessing the consequences of these recommendations on the animals themselves (Rushen et al., 2011). Some studies showed that increased time spent away from the pen can also decrease lying time (Botheras, 2006; Gomez and Cook, 2010). Other studies have shown the relationship between high stocking rate and reduced time of lying in stalls (Fregonesi et al., 2007; Krawczel et al., 2012; Telezhenko et al., 2012). Some studies showed that increased time spent away from the pen can also decrease lying time (Botheras, 2006; Gomez and Cook, 2010).in North America survey studies have shown average lying times of 10-11 h/d for high-producing lactating cows (Ito et at., 2009; Von Keyserlingk et at., 2013; Ito et al., 2014).

Reducing time cows spend lying down can lead to both behavioral and physiological stress (Munksgaard and Simonsen, 1996). According to Fregonosi, and colleagues (2007) lying time decreased 1.7 hr/per d, when stall stocking rate was 150% compared with a 100% stocking rate. In addition, short lying times may also lead to lameness (Bell et al., 2009; Chapinal et al., 2009; Cook et al., 2004; Proudfoot et al., 2010). However, Chapinal and colleagues did not prove that overstocking was a main factor of lameness but effectively, there is a positive relationship among lying time and lameness, where the healthy cows lie less than lame cows (Chapinal et al., 2009; Chapinal, 2010a,b).

Stocking rate at the feed rail is another key element that must be considered to ensure cow comfort and adequate feeding behavior in dairy farms. It is commonly recommended that each cow have approximately 60 cm of feeding space at the feed rail (Grant and Albright, 2001), although one study suggested that this recommendation is overly generous, as cows had similar feed intake when given less feed space than recommended (Menzi and Chase, 1994). Generally, however, feeding space available for each cow was related to the level of competition at the feed rail (DeVries et al., 2004); and displacement at the feed rail increased when stocking rate was increased at the feed rail (DeVries et al., 2004; Huzzey el at., 2006; Proudfoot et al., 2009).

Cows often prefer to feed at the same time, as they are social animals that naturally show synchronized behavior, which is another important factor to consider when evaluating the impact of space at the feed rail (Von Keyserlingk and Weary, 2010). For example, in the 90 min after fresh feed delivery, feeding activity was greatest compared to the rest of the day (Huzzey el at., 2013). This means cows are motivated to feed at the same time, and so ensuring that all animals have the space to feed simultaneously will allow cows with less competitive ability (e.g., fresh or primiparous cows) to feed with the herd.

Thus, competition at the feed rail affects feeding behavior and welfare as increased competition at high feed rail stocking density could limit the ability of some cows to access to the feed rail at feeding time this could translate into altered feeding behavior, reduced feed intake and lying time and increased time spent standing (Grant and Albright, 2001; DeVries et al., 2004; Huzzey et al., 2006; Collings et al., 2011; Krawczel et al., 2012). However, reducing feed bunk space has not been directly linked with lower milk yield (Bach et al., 2008; Proudfoot et al., 2009).

At present little is known about how stocking rate affects cow behavior in herds milked with automatic milking systems (AMS). Cows in AMS have free movement to and from the robot and may milk asynchronously as opposed to cows milking as a single group in parlor-based systems. On the other hand, stall stocking rate in AMS dairies may also be influenced by other factors not present in parlor-milked dairies, such as the design of the barn and traffic system (forced, free, or guided) and the number of cows per AMS. For example, according to Uetake and colleagues (1997), the AMS milking and holding areas impact synchronization of cows eating and resting and can reduce time spent eating relative to cows that are parlor milked. As return from the milking parlor appears to be one of the factors that synchronizes feeding (DeVries et al., 2003), it is possible that cows in AMS who are milking individually may also eat and lie down more asynchronously compared to their parlor-milked counterparts. However, there is some evidence to suggest that cows may still wish to lie down synchronously or are most motived to lie down at certain parts of the day based on their circadian rhythms (Rushen et al., 2001; Tucker, 2009)

The objective of this research was to examine the effect of reducing the number of lying stalls available per cow or the amount of available space at feed rail on cow behavior in an AMS dairy. Cows should spend less total time lying and have shorter lying bouts when stalls were overstocked. Further, more displacement of cows from stalls and the feed rail should occur at higher stocking rates compared to a 1:1 stocking rate.

MATERIALS AND METHODS

Prior to the start of the study, all protocols were submitted to and approved by the Michigan State University Institutional Animal Care and Use Committee.

Animals and Facility

The study was conducted at Kellogg Biological Station Pasture Dairy Research and Education Center of Michigan State University. This study occurred during the winter months when the cows were kept in the barn and not given access to pasture. This farm consisted of one barn with two pens each with 60 cows, 58 free stalls, and 65 headlocks. No cows entered or left either pen during the 12 wk of the study. Cows were balanced between two pens according to stage of lactation (1st, 2nd, 3rd) and breed (i.e., Holstein or New Zealand Friesian). One AMS (Astronaut A3, Lely, Maassluis, and The Netherlands) was present in each pen. A total mixed ration was delivered twice a day at the feed rail at 04:00 and 12:00, with feed push-ups occurring four times a day. In addition, cows received a concentrate mix in the AMS each time they were milked. The amount of concentrate received over a 24-h period was based upon expected milk yield and stage of lactation.

Treatments

Three stocking rate treatments applied to the 2 pens in a random order were used to alter the number of free-stalls or feed space available per cow. The treatments were as follows: 1:1 treatment = 58 stalls or 60 headlocks for 60 cows; 1:1.2 treatment = 50 stalls or 50 headlocks for 60 cows; and 1:1.5 treatment = 40 stalls or 40 headlocks for 60 cows. When reducing the number of stalls to change the stocking rate, stalls were blocked by hanging double-stranded chain barriers across the rear of the stall to prevent cows from entering. When reducing the number of headlocks to increase the stocking rates at the feed rail, headlocks were blocked by boarding them up in order prevent cows for putting their heads in to the headlocks. The first six weeks (12- wk experimental period) examined alterations to stall stocking rate and the subsequent six weeks examined alterations to feed rail stocking rate. Data were collected during the last 2 d of each weeklong treatment. A washout period of 1 wk was applied between treatments. During the washout period, all stalls or headlocks in the pen were unblocked.

Data Recording

Two point-tilt-zoom cameras (HAD 480 PTZ Speed Dome SPE-CAMCCD55, Sony Super, and Sony Corporation, Tokyo, Japan) and two-fixed angle cameras (1/3" Sony Super HAD Color CCD 540, Sony Corporation, Tokyo, Japan) were used per pen to allow for recording of areas of interest. Digital video was recorded using a 16-channel digital video recorder (G-Max 9000 Series, Skyway Security, Mauldin, SC). Individual cows were identified on video by matching their unique spot patterns to a picture database containing photos of each cow's head, rear, and right and left sides. This method of identification has been used extensively to identify wild animals (Peterson, 1972; Wursing and Jefferson, 1990; Kelly, 2001) and has been validated by comparing accuracy of photo-identification against various forms of electronic identification (Irvine et al., 1982; Scott et al., 1990).

Video was recorded during the last 2 d of each stall stocking rate treatment. Video was decoded using instantaneous scan sampling to capture time budgets of cows in the stall area. Every 10 minutes during the morning (0400-1000), afternoon (1000-1600), and evening (1600-2200), a scan sample was taken to record the number of cows in a pen that were lying, standing, walking and perching in the free stall area. Lying and standing were further classified according to whether they occurred in a stall or in the alley. All displacements from stalls in the last 2 d of treatment were recorded. A displacement was defined as occurring when one cow (actor) came into contact with another cow (reactor), resulting in the reactor leaving the stall.

At the feed rail, live observations were made using instantaneous scan sampling in the 45 min after a feed delivery and in the 45 min after a push up. Every 5 min we recorded the number of cows doing the following behaviors: cows eating at the feed rail, cows with heads in headlocks but not eating, cows with heads out of headlocks but remaining at the rail, and cows standing in the alley immediately behind the feed rail. All instances of displacement from the feed rail were recorded during live observations.

Activity (ATV) and rumination (RU) data were collected using hardware built into AMS identification tag worn by each cow (Lely Qwes-HR, Lely, Maassluis, The Netherlands). At milking, data from these specific devices was read by the AMS and downloaded to the farm computer. Data were collected and cleaned by Time for Cows (T4C; Lely, Maassluis, The Netherlands), the management program associated with the AMS. In brief, ATV measures time spent moving by the cow, specifically by measuring vertical movements of the cow's head, such as head bobs that occur during walking or during mounting (Ben Smink, Lely USA Inc., Madison, WI, personal communication). The ATV data were reported in "activity units." Time spent ruminating was recorded using a microphone built into the AMS to tag detect regurgitation of a bolus for rumination (Ben Smink, personal communication). Both types of data were recorded in 2-h blocks (e.g., 0600 - 0800, and 0800 - 1000 , so on), and the management program deleted duplicate data to create a single data set of unique 2-h blocks. Previous work in our lab has linked higher activity unit values to live observation of greater activity by cows as well shown a correlation between live observation of rumination and values obtained from the Lely Qwes- HR (Elischer et al., 2013).

Analysis

All analyses were completed using SAS (SAS version 9.4, and SAS Institute Inc., Cary, NC) and significance was declared at $P < 0.05$. Treatments were applied to pens, all analysis were conducted at the level of pen. The effect of stocking rate in the stalls was examined using video recordings of the final 2 d of each stall stocking treatment. The effect of stocking rate at the feed rail was examined using live observation of cow behavior during the 45 min after one push up event and in the 45 min after one feed delivery event for each feed rail stocking rate treatment in each pen.

Analyses of frequency of displacement at the stall and feed rail (at feed delivery and push up) were conducted using a mixed model (PROC MIXED) after verifying that data were meet assumption of normality and equality of variance. The model was as follows:

$$Y_{ijkl} = \mu + PN_i + TP_j + C_k \times GCBL + e_{ijk}$$

Where PN_i is the random effect of pen, C_k is the fixed effect of treatments (1:1, 1:1.2, and 1:1.5), TP_j is the repeated measure of time period, GCBLis the covariate of (displacements and scanning data of stall and feed rail), $C_k \times GCBL$ is the interaction between treatments and covariate, and e_{ijk} is the residual. Counts of cows performing specific behaviors at the feed rail collected via instantaneous scan sampling were analyzed using a mixed model (PROC MIXED) after verifying that data met assumption of normality and equality of variance. Counts of cows performing specific behaviors in the stall area in response to stall stocking rate treatments collected via instantaneous scan sampling were analyzed using a mixed model (PROC MIXED) for the average number of cows lying in stalls, standing in stalls, or standing in the alley. Tukey-Kramer tests were used as needed following mixed model analysis to determine which treatments were different. However, the average number of cows perching in stalls and the number of cows walking in the alley were analyzed with a Kruskal-Wallis test (PROC NPAR1WAY) because the data were not normal. The model was as follows:

$$Y_{ij1} = \mu + T_i + V_j + e_{ijk}$$

Where T_i is the fixed effect of treatments, V_j is the covariate of (Stall scanning data), and e_{ijk} is the residual.

RESULTS

Stall Stocking Rate

There was no effect of stocking rate treatment on number of displacements at the stalls (F_2 = 5.22, *P* = 0.16; Figure 3.1). In addition, overstocking did not appear to affect the time budgets of cows in the stall area (*P* < 0.05). In particular, there was no effect of treatment on average number of cows lying in stalls (F_2 = 4.95, *P* = 0.17; Figure 3.2), standing in stalls (F_2 = 11.99, *P* = 0.08; Figure 3.3), perching in stalls (F_2 = 0.28, *P* = 0.76; Figure 3.4), standing in the alley (F_2 = 9.04, *P* = 0.10; Figure 3.5), or walking in the alley (F_2 = 1.09, *P* = 0.36; Figure 3.6). Stall stocking rate treatments did not affect the activity level of cows (F_2 = 1.39, *P* = 0.34; Figure 3.7) or the time spent ruminating (F_2 = 0.12, *P* = 0.89; Figure 3.8).

Feed Rail Stocking Rate

Overstocking at the feed rail led to differences in displacement at the feed rail during fresh feed delivery between the treatment (F_2 = 86.33, *P* = 0.01; Figure 3.9). Specially, more displacement occurred in both overstocking treatments (1:1.2 = 24.5 ± 1.56 displacements; 1:1.5 = 27 ± 1.56

displacements) compared to the 1:1 treatment (18 $\pm$ 1.56 displacements; vs. 1:1.2: $F_2 = 0.71$, P = 0.02; vs. 1:1.5: $F_2 = 0.71$, P = 0.01). However, overstocking at the feed rail did not affect the number of cows performing behaviors of interest at the feed rail. Specifically, there were no differences among the treatments for number of cows eating ($F_{18} = 0.5$, $P = 0.93$; Figure 3.10A); with heads in the headlocks but not eating ($F_{18} = 0.96$, $P = 0.53$; Figure 3.10B), standing at the feed rail with heads out headlocks (F_{18} = 0.31=, $P = 0.99$; Figure 3.10C), or standing in the alley behind the feed rail ($F_{18} = 0.72$, $P = 0.76$; Figure 3.10D).

Stocking rate did not affect number of displacements at the feed rail in response to push up of feed ($F_2 = 9.06$, $P = 0.14$; Figure 3.9). Additionally, there were no differences among the treatments for number of cows eating ($F_{18} = 1.36$, $P = 0.27$; Figure 3.11A), with heads in the headlocks but not eating ($F_{18} = 1.11$, $P = 0.42$; Figure 3.11B), standing at the feed rail with heads out headlocks ($F_{18} = 1.14$, $P = 0.39$; Figure 3.11C), or standing in the alley behind the feed rail ($F_{18} = 0.91$, $P = 0.59$; Figure 3.11D). Activity levels of cows were not affected by feed rail stocking rates ($F_2 = 0.55$, $P = 0.65$; Figure 3.7), nor was time spent ruminating ($F_2 = 0.2$, P = 0.84; Figure 3.8).

DISCUSSION

Stall Stocking Rate

Typically, studies of parlor-milking dairies show more displacement of cows from stalls and less lying time when cows are overstocked (Cook et al., 2005; Fregonesi et al., 2007). However, when we analyzed similar data from an AMS dairy, we did not find significant differences in frequency of displacement as a result of stall overstocking. In addition, time budget analysis via instantaneous scan sampling of behavior in the stall area showed no significant difference between the stall stocking rate treatments in number of cows lying, standing or perching in stalls or the number of cows standing or walking in alleys. This suggests that the stocking rate treatments used in this study did not impact cows' use of stalls. Further, there was no effect of stall stocking rate on activity or rumination as recorded by the AMS monitors. Suggesting that the cows did not change the amount of time spent performing these behaviors as a result of overstocking.

Our findings are unlike those of other studies, which have shown that stocking rates of 120% or greater lead to an increase in standing time of 15 to 25% (Grant, 2001). Conversely, in previous studies of parlor-milked cows, increased stocking rate at the stalls has led to decreased lying time (Cook et al., 2005; Fregonesi et al., 2007). Therefore, our findings may suggest that cows milked with AMS may adapt their behavior to lie more at other times of day. However, our data do not suggest different patterns of stall use, at least not across the daylight hours; in response to overstocking.

Feed Rail Stocking Rate

Displacement of cows from the feed rail has been found to increase when stocking rate is increased at the feed rail (DeVries et al., 2004; Huzzey el at., 2006; Proudfoot et al., 2009). In our study, there was a significant difference in number of displacements from the feed rail between the 1:1 treatment and the two overstocked treatments after fresh feed delivery, while there was no difference between 1:1.2 and 1:1.5 treatments. However, there were no significant differences between the treatments in number of displacements from the feed rail following feed push up. This may emphasize the synchronicity of cows' response to fresh feed delivery and competition between cows for access to fresh feed when any degree of feed rail overstocking leads to displacement.

However, there were no differences among the treatments particularly with respect to the number of cows eating but also with heads in headlocks but not eating, standing at the feed rail with heads out of headlocks, or standing in the alley behind the feed rail. This suggests that the impact of increasing stocking rate on cow feeding behavior was minimal. These findings are unlike these from parlor studies that have shown increase in stocking rate at the feed bunk leads to increased competition and changed feeding behavior (Collings et al., 2011). Particularly, our data from the feed rail found no effect on eating behavior when the stocking rate increased, while parlor-based studies have found feeding time decreased when the stocking rate at the feed rail increased (Huzzey et al., 2006).

CONCLUSIONS

Stall and feed rail stocking rates for cows in AMS systems may have little direct impact on cow behavior and lying time, unlike what is seen when parlor-milked farms are overstocked. However, AMS dairies may still experience some effects of overstocking, but not to a greater degree than in in parlor-milked systems such as in displacements; when fresh feed is deliverd.

This study showed there was no real impact on cow behavior and welfare when the stocking rate increased either at the stalls or feed rail, which could mean that cows are adapting to stocking rates by becoming more asynchronous. Overstocking in AMS may affect cows differently from what is seen in the parlor dairies due to cow having control over their milking routines as well as over feeding and lying times. Thus studies on cow behavior and welfare related to stocking rate in parlor dairies may not be directly applicable to dairies milking with AMS.

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APPENDIX

Figure 3.1 Average counts of stall displacement (± SEM) by time period during the final 2 d of each treatment for the three stocking rate treatments.

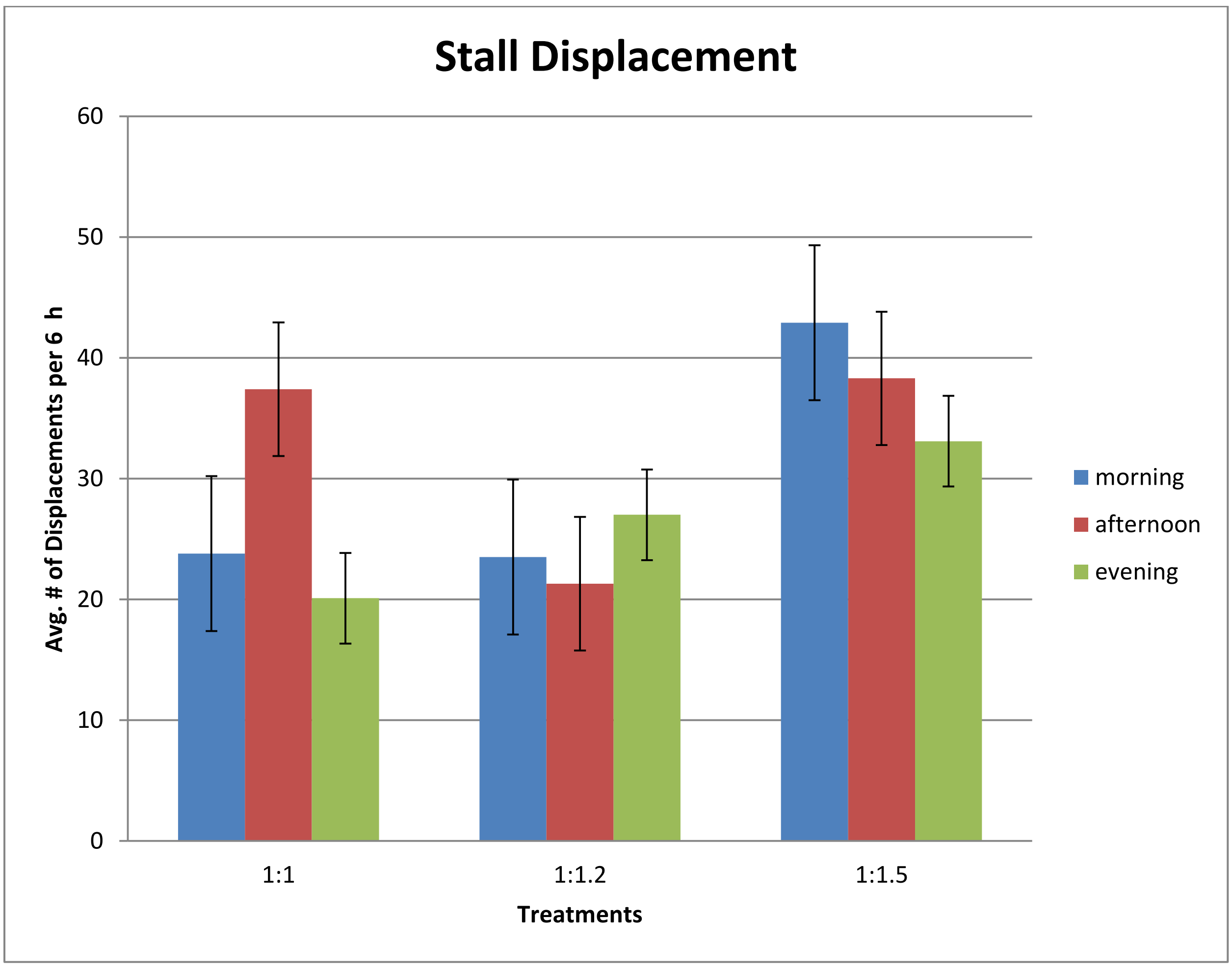


Figure 3.2 Average number of cows lying down in stalls (± SEM) presented by time period during the final 2 d of each treatment for the three stocking rate treatments.

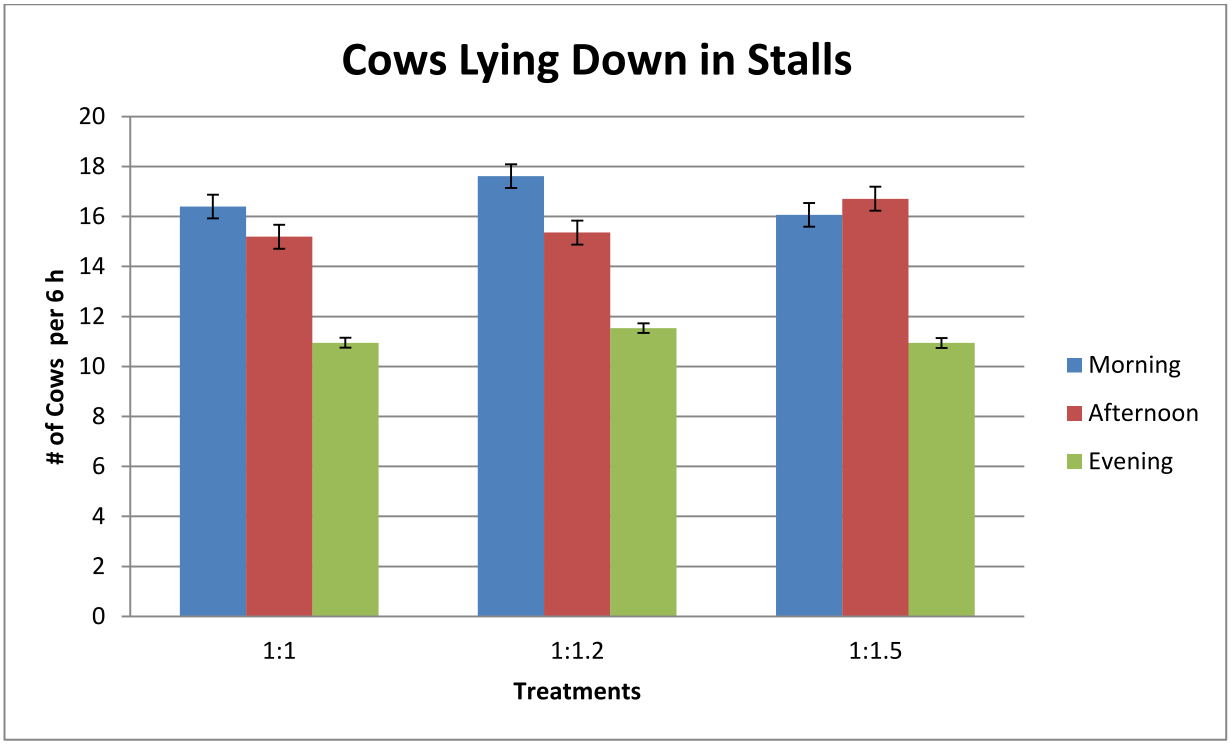


Figure 3.3 Average number of cows standing in stalls (± SEM) presented by time period during the final 2 d of each treatment for the three stocking rate treatments.

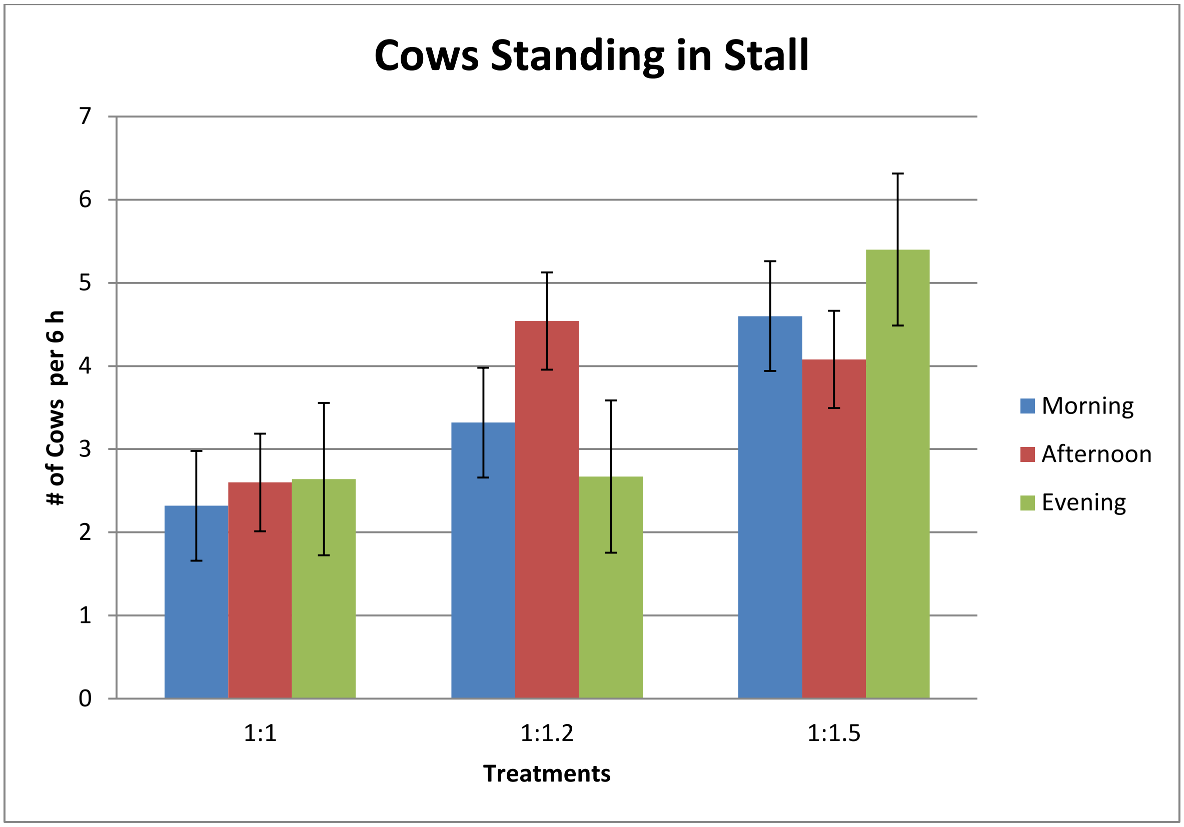


Figure 3.4 Average number of cows perching in stalls (± SEM) presented by time period during the final 2 d of each treatment for the three stocking rate treatments.

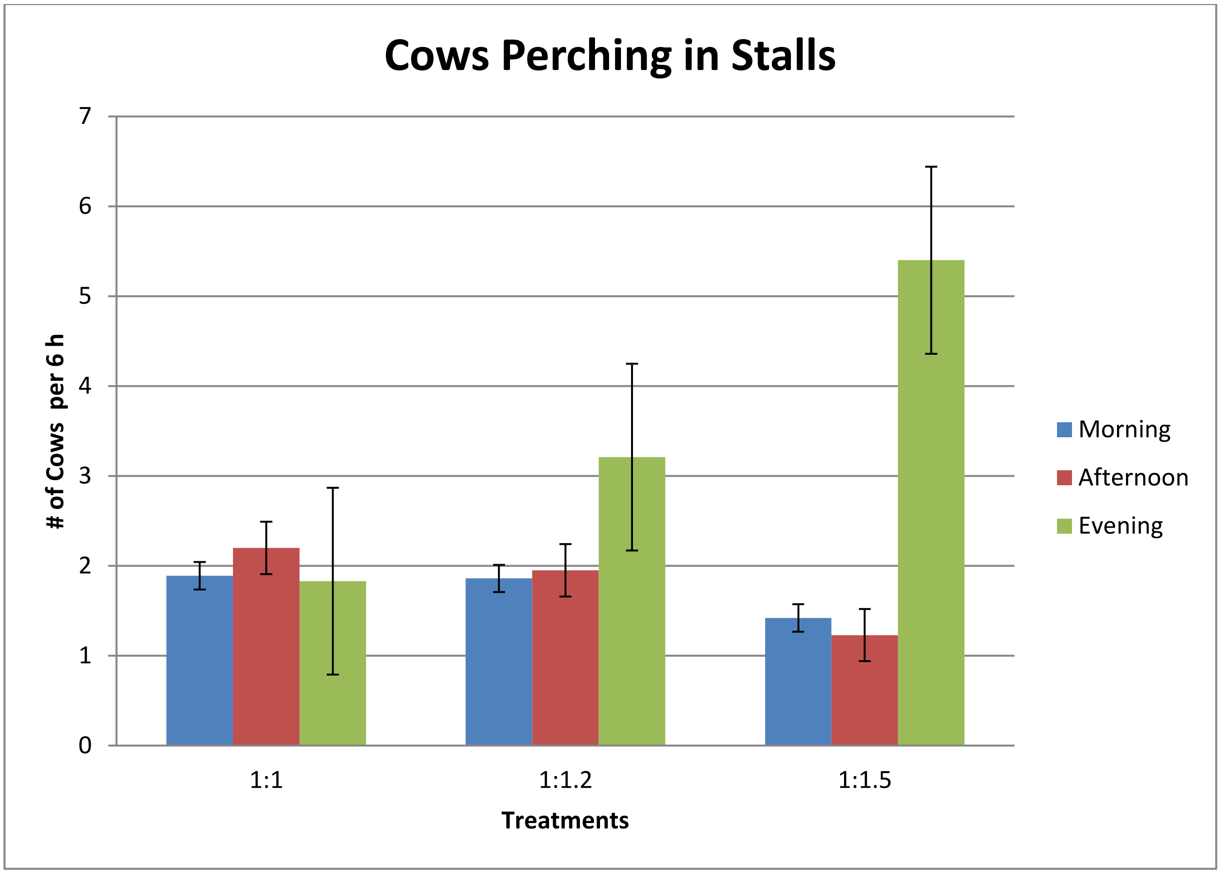


Figure 3.5 Average numbers of cows standing in alley (± SEM) presented by time period during the final 2 d of each treatment for the three stocking rate treatments.

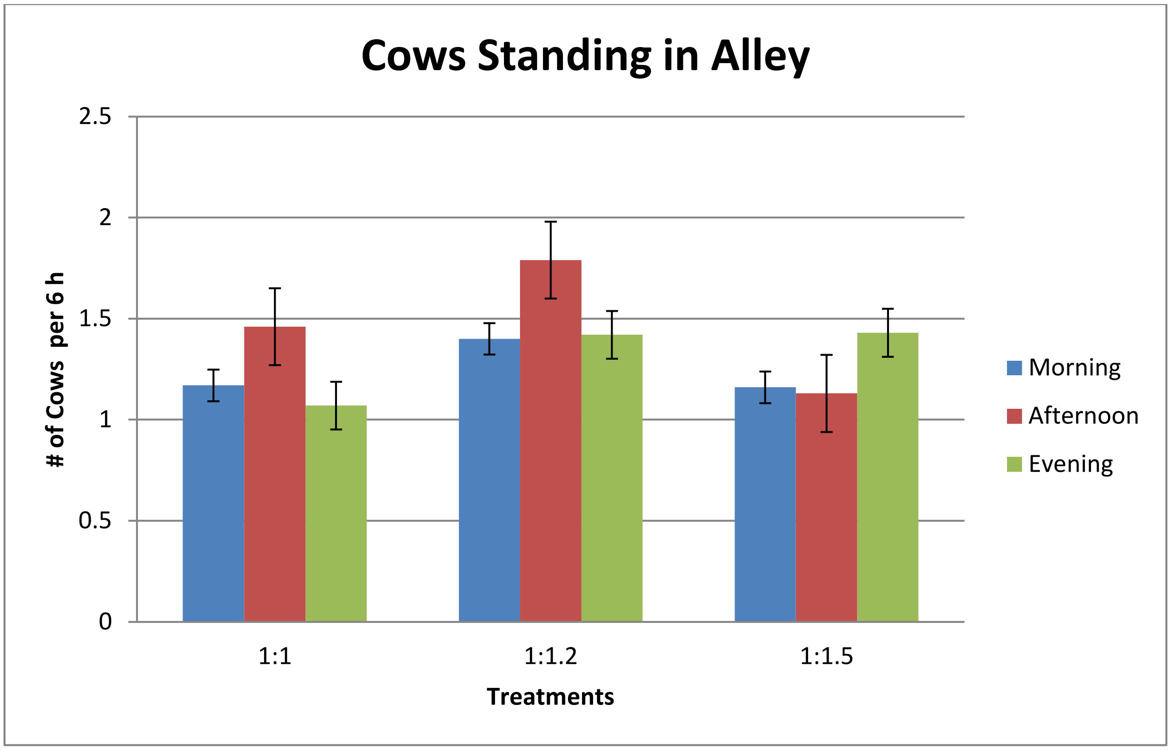


Figure 3.6 Average number of cows walking in the alley (± SEM) presented by time period during the final 2 d of each treatment for the three stocking rate treatments.

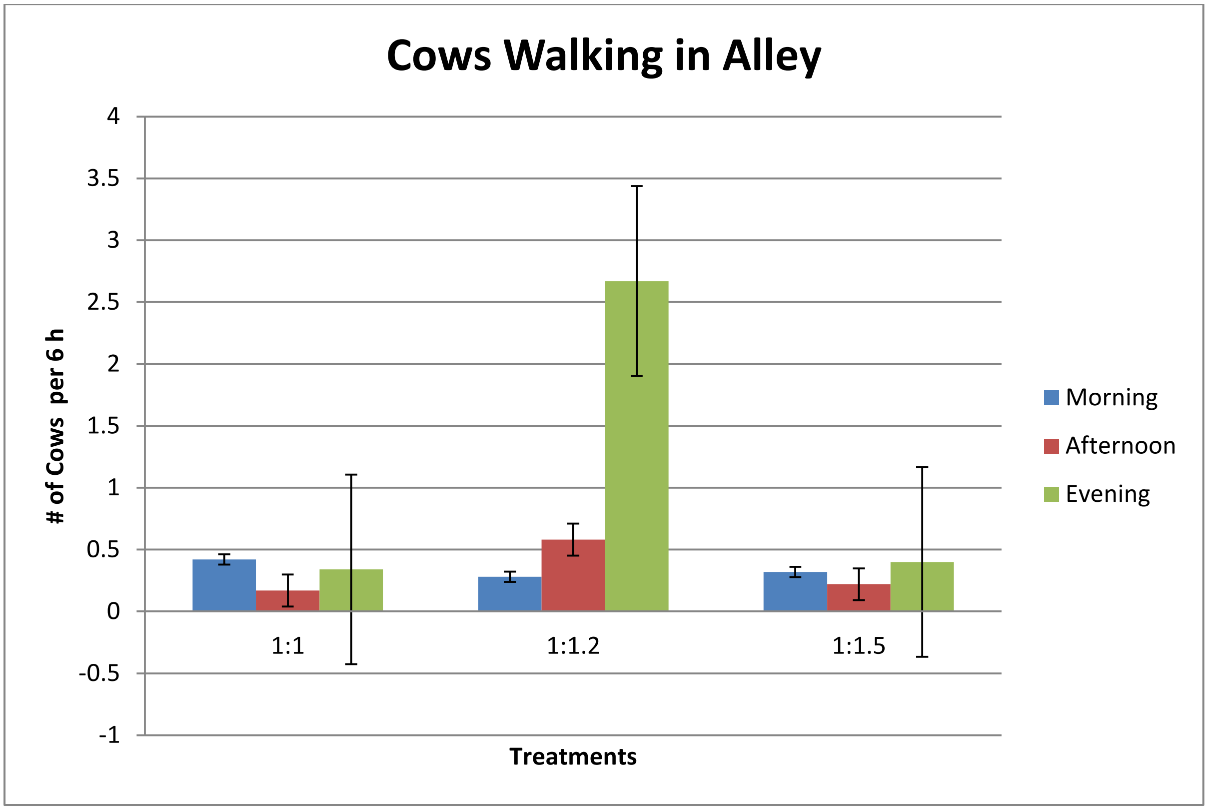


Figure 3.7 Cow activity in response to stocking rate during the final 2 d of each stocking rate treatment.

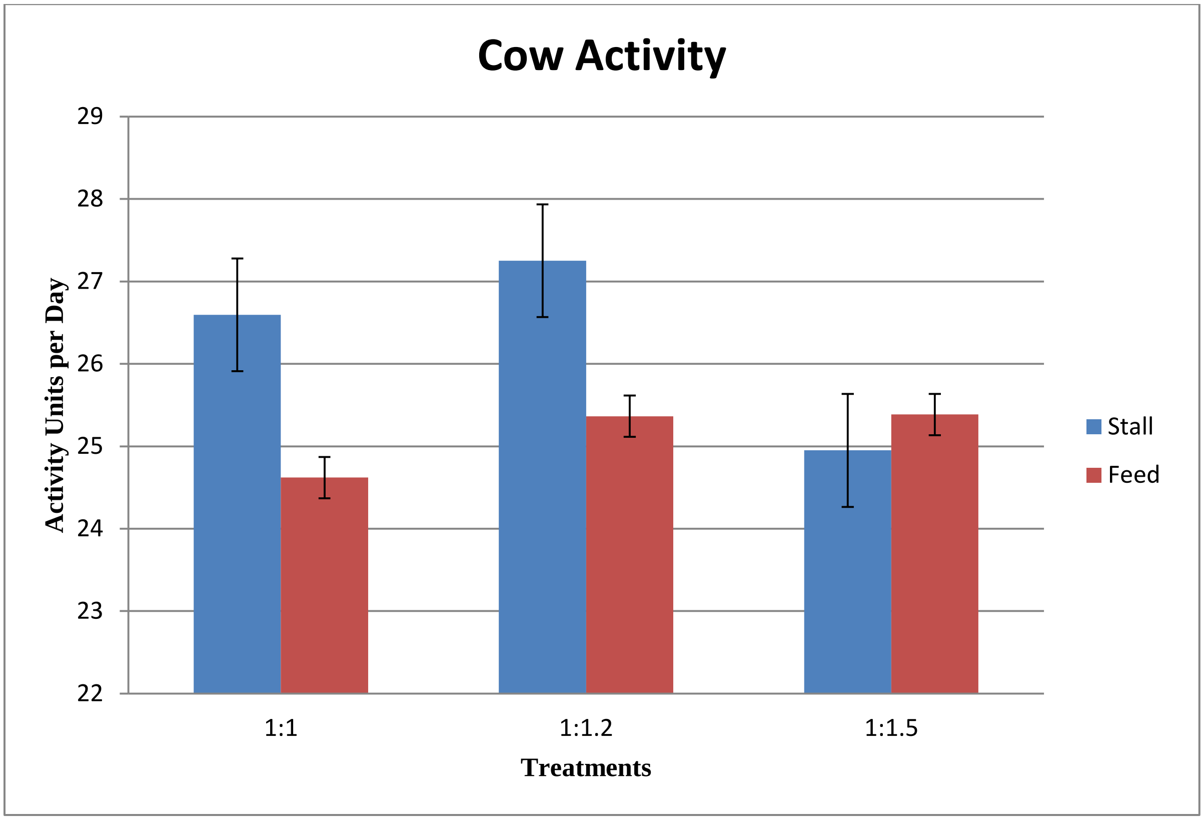


Figure 3.8 Descriptive data showing the time cows spent ruminating during the final 2 d of stocking rate treatments at stalls and feed rail.

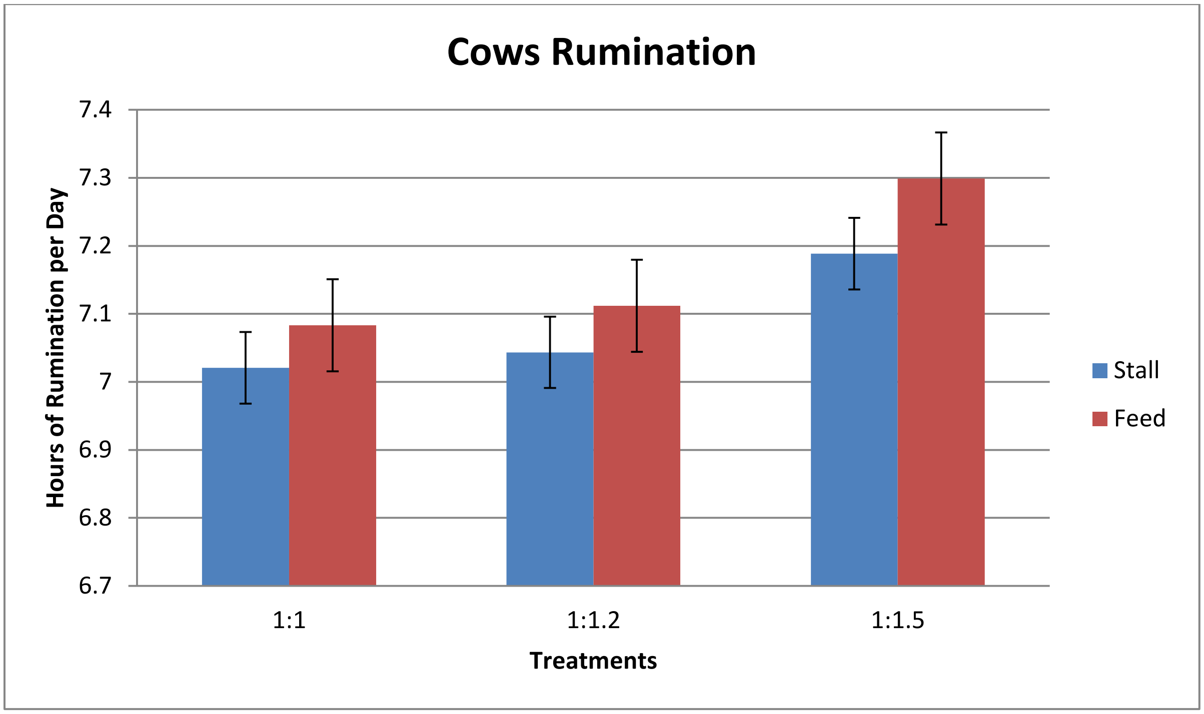


Figure 3.9 Average number of displacements (± SEM) was occurring during feed delivery and push up at the feed rail during the final 2 d of each stocking rate treatment.

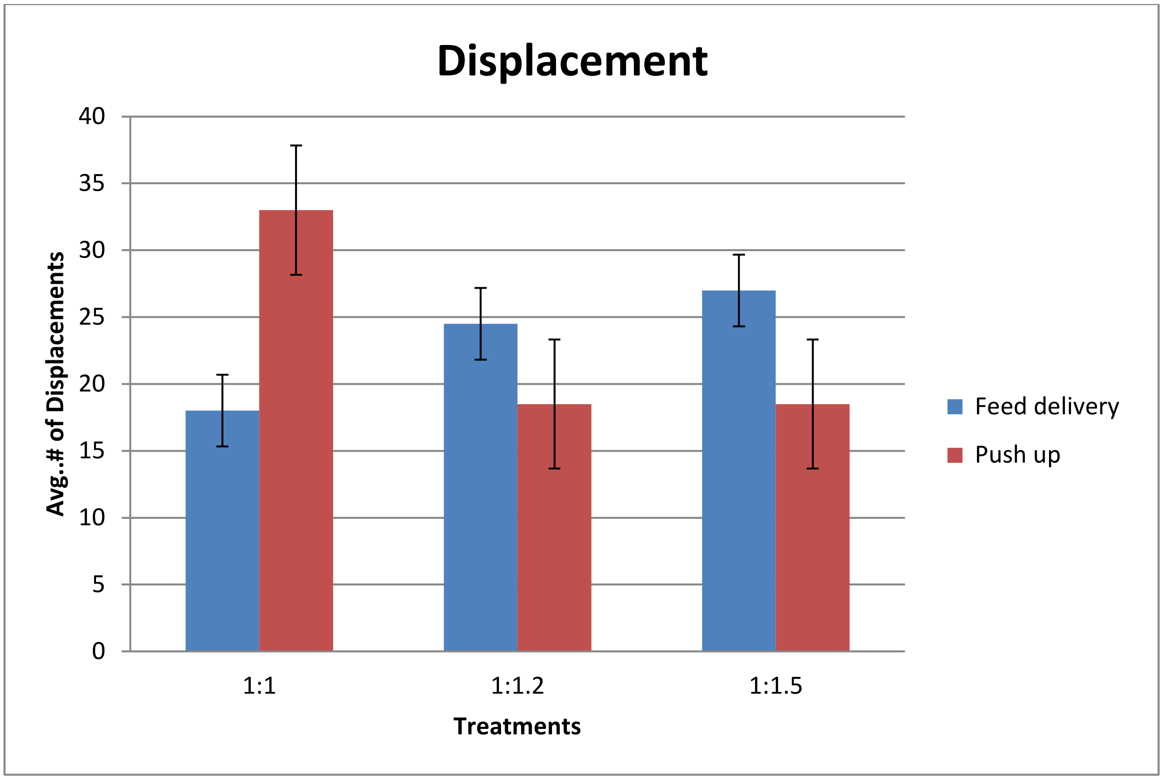


Figure 3.10A. Descriptive data showing number of cows eating at the feed rail for each treatment after delivery of fresh feed. Numbers are presented as total number of cows eating along the entire length of the feed rail (averaged between the 2 pens).

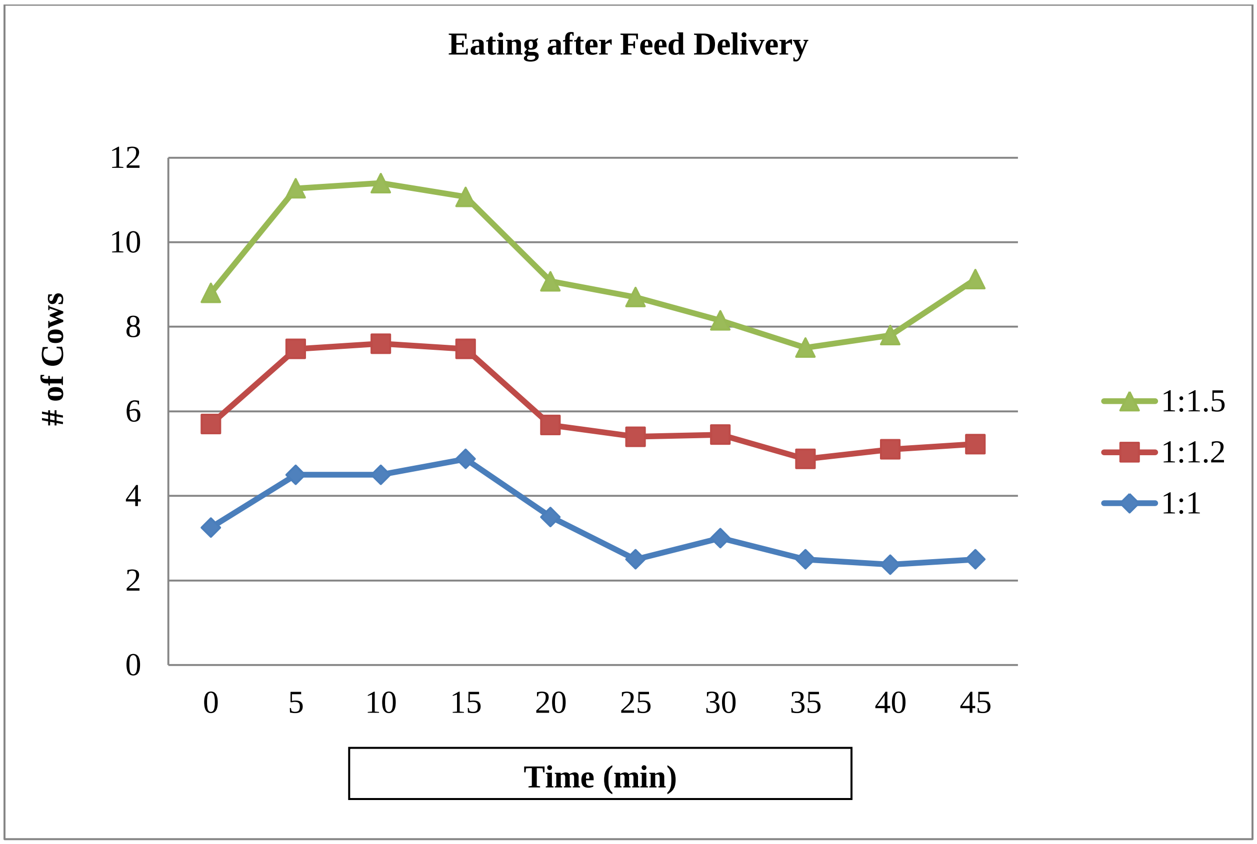


Figure 3.10B. Descriptive data showing number of cow with heads in headlocks at the feed rail for each treatment after delivery of fresh feed. Numbers are presented as total number of cows eating along the entire length of the feed rail (averaged between the 2 pens).

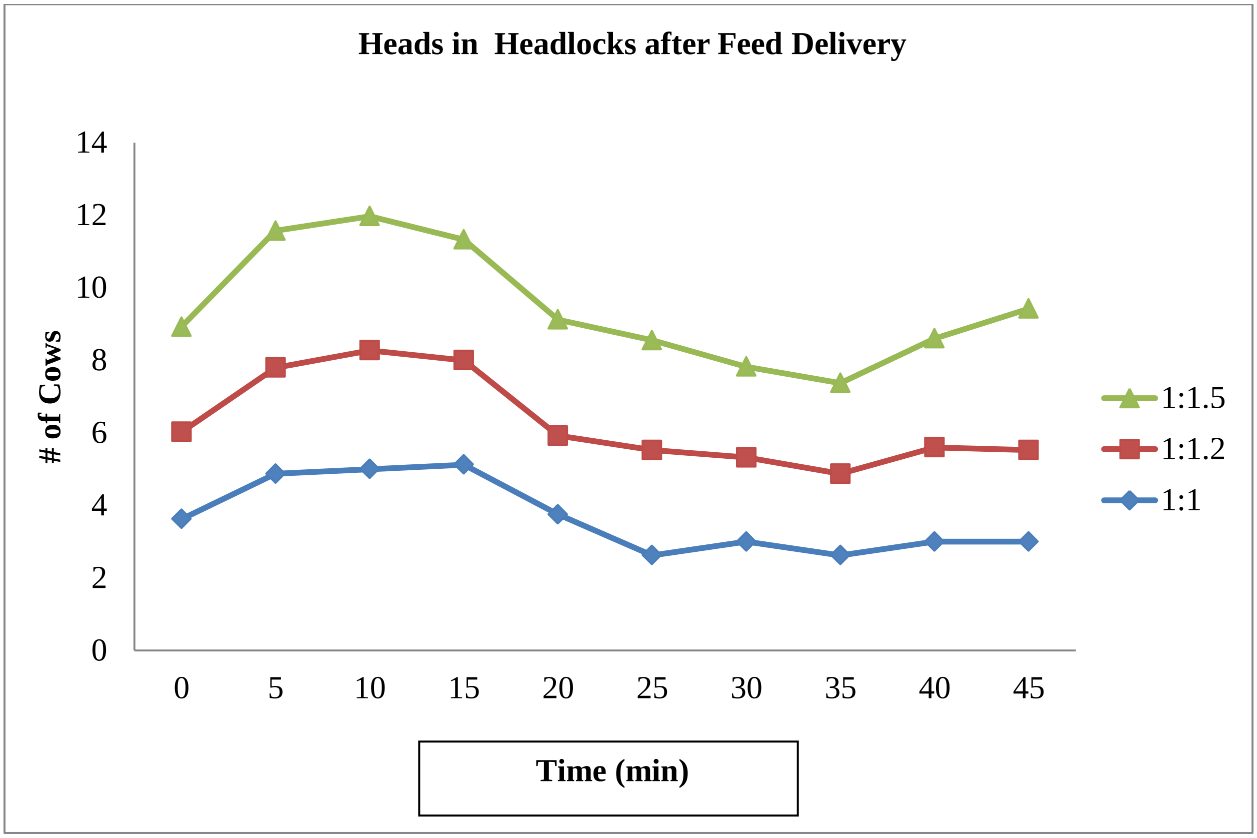


Figure 3.10C. Descriptive data showing number of cow with heads out of headlocks but standing at the feed rail for each treatment after delivery of fresh feed. Numbers are presented as total number of cows eating along the entire length of the feed rail (averaged between the 2 pens).

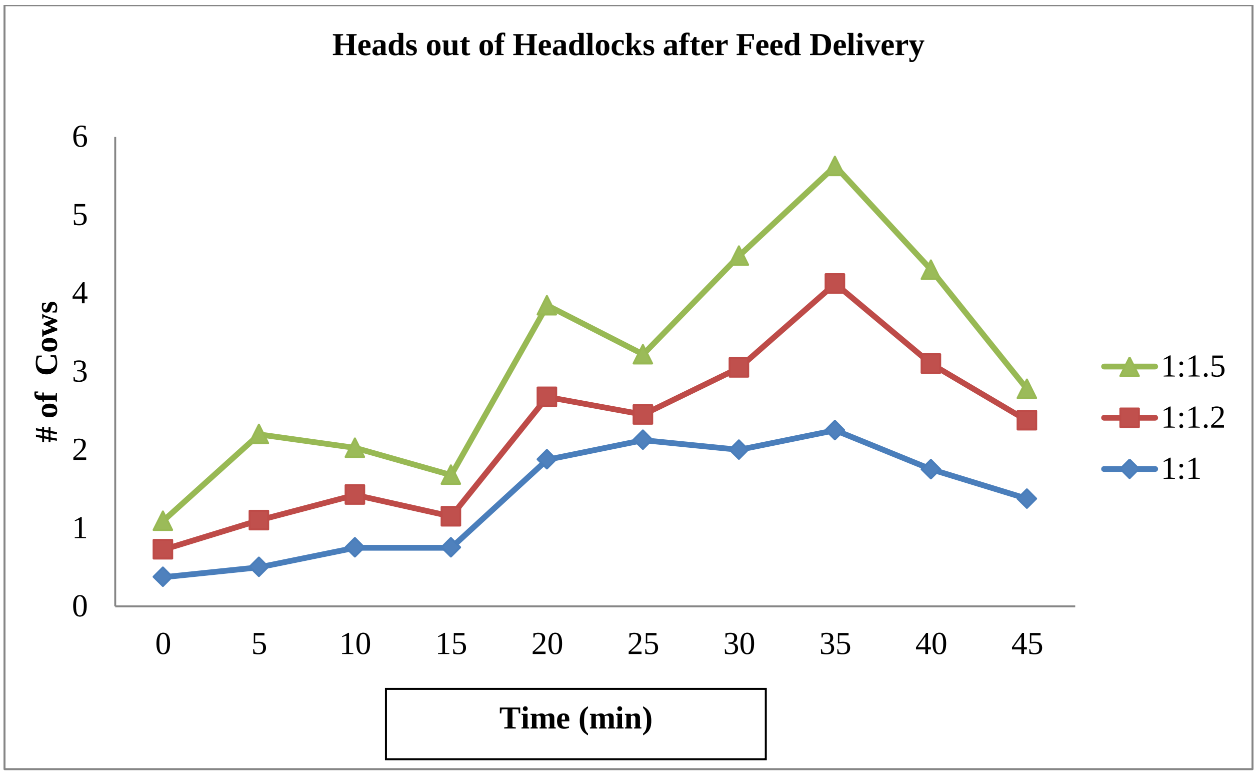


Figure 3.10D. Descriptive data showing number of cow standing behind the feed rail for each treatment after delivery of fresh feed. Numbers are presented as total number of cows eating along the entire length of the feed rail (averaged between the 2 pens).

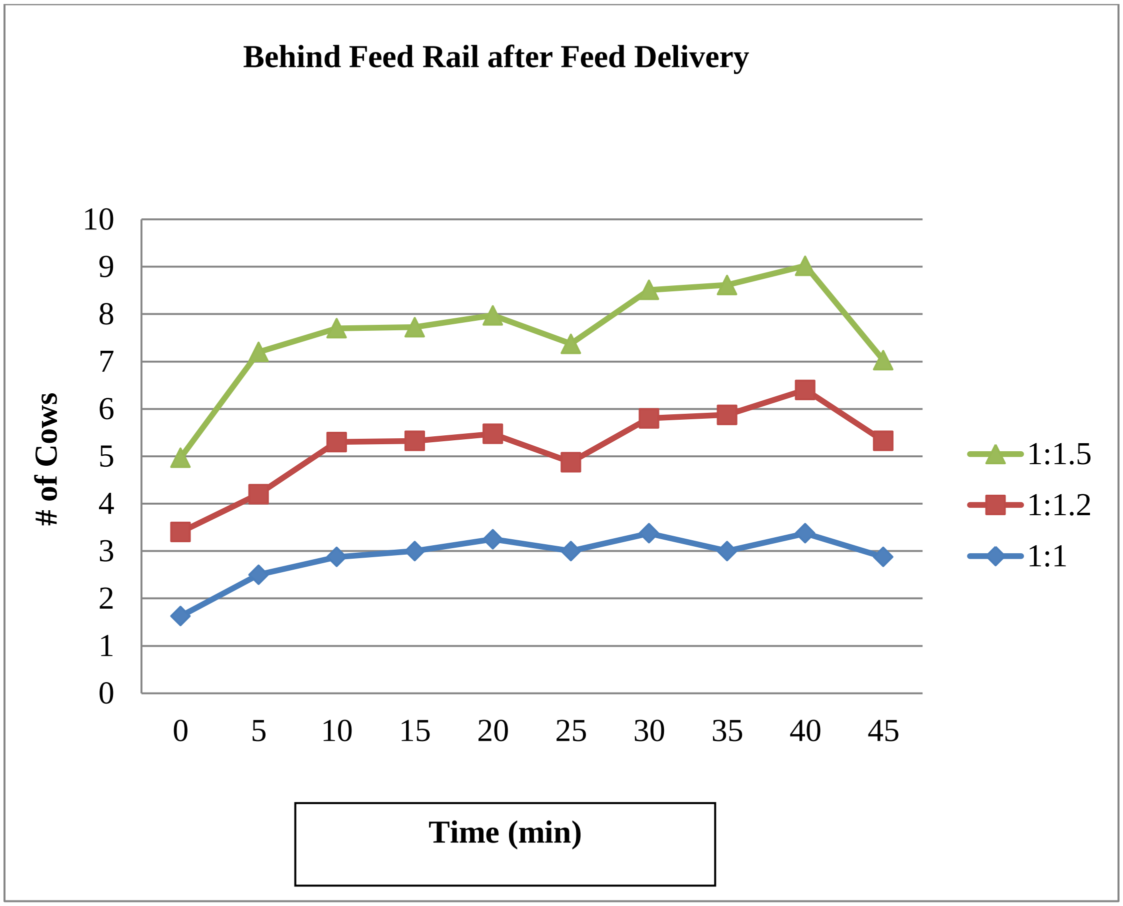


Figure 3.11A. Descriptive data showing number of cows eating at the feed rail for each treatment after push up of feed.. Numbers are presented as total number of cows eating along the entire length of the feed rail (averaged between the 2 pens).

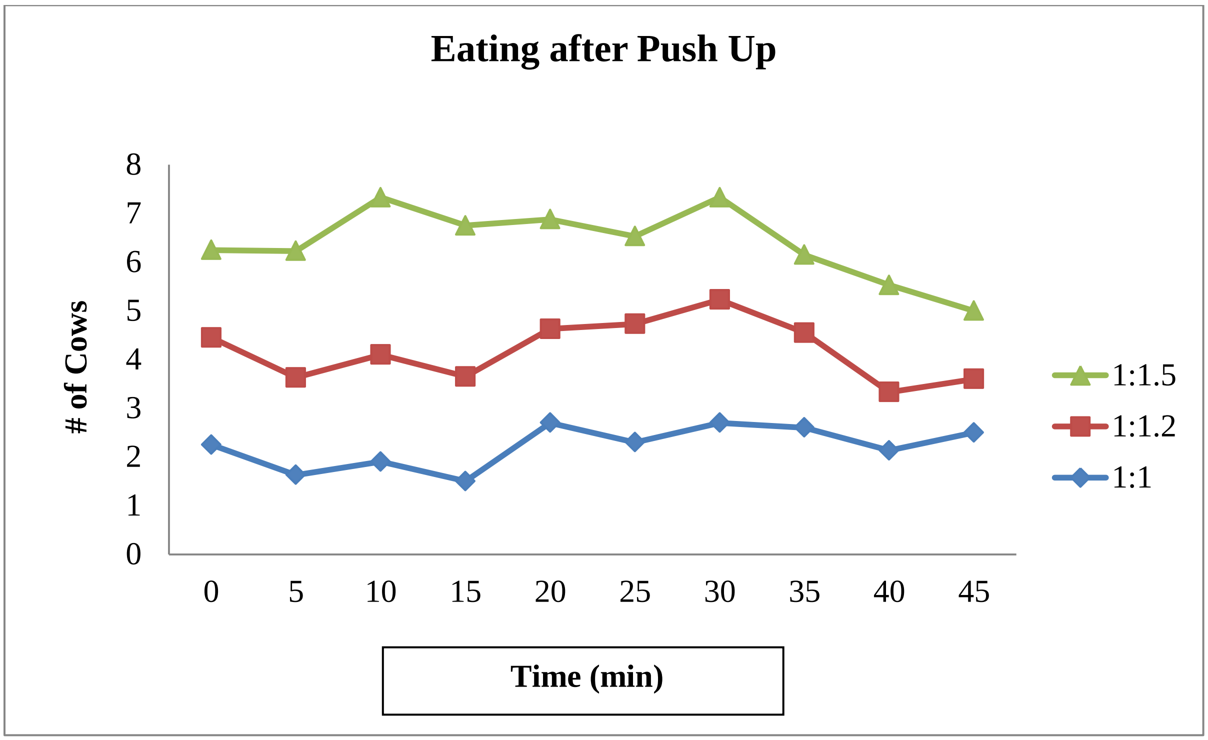


Figure 3.11B. Descriptive data showing number of cow with heads in headlocks at the feed rail for each treatment after push up of feed. Numbers are presented as total number of cows with head in headlocks but not eating along the entire length of the feed rail (averaged between the 2 pens).

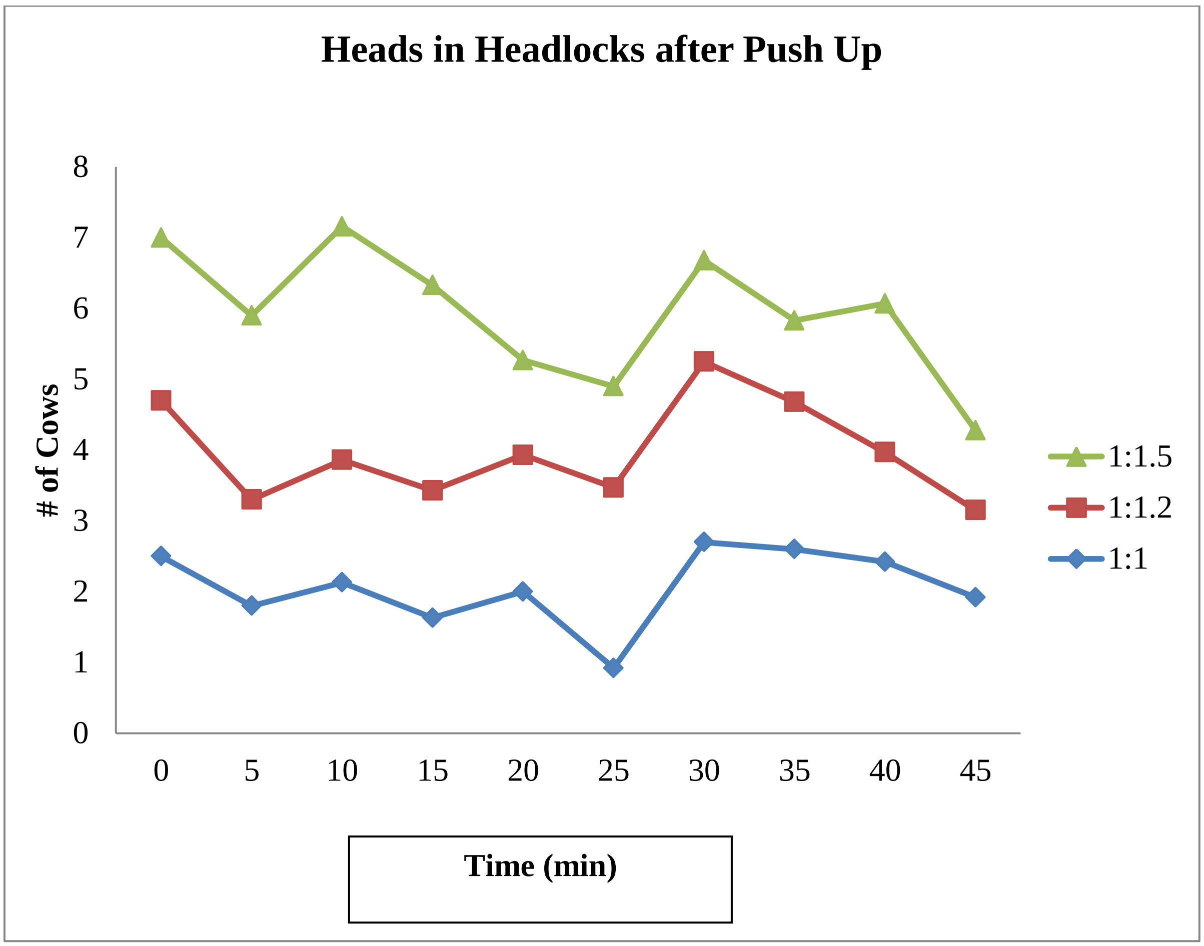


Figure 3.11C. Descriptive data showing number of cow with heads out of headlocks but standing at the feed rail for each treatment after push up of feed. Numbers are presented as total number of cows with heads out of headlocks but standing at the feed rail along the entire feed rail (averaged between the 2 pens).

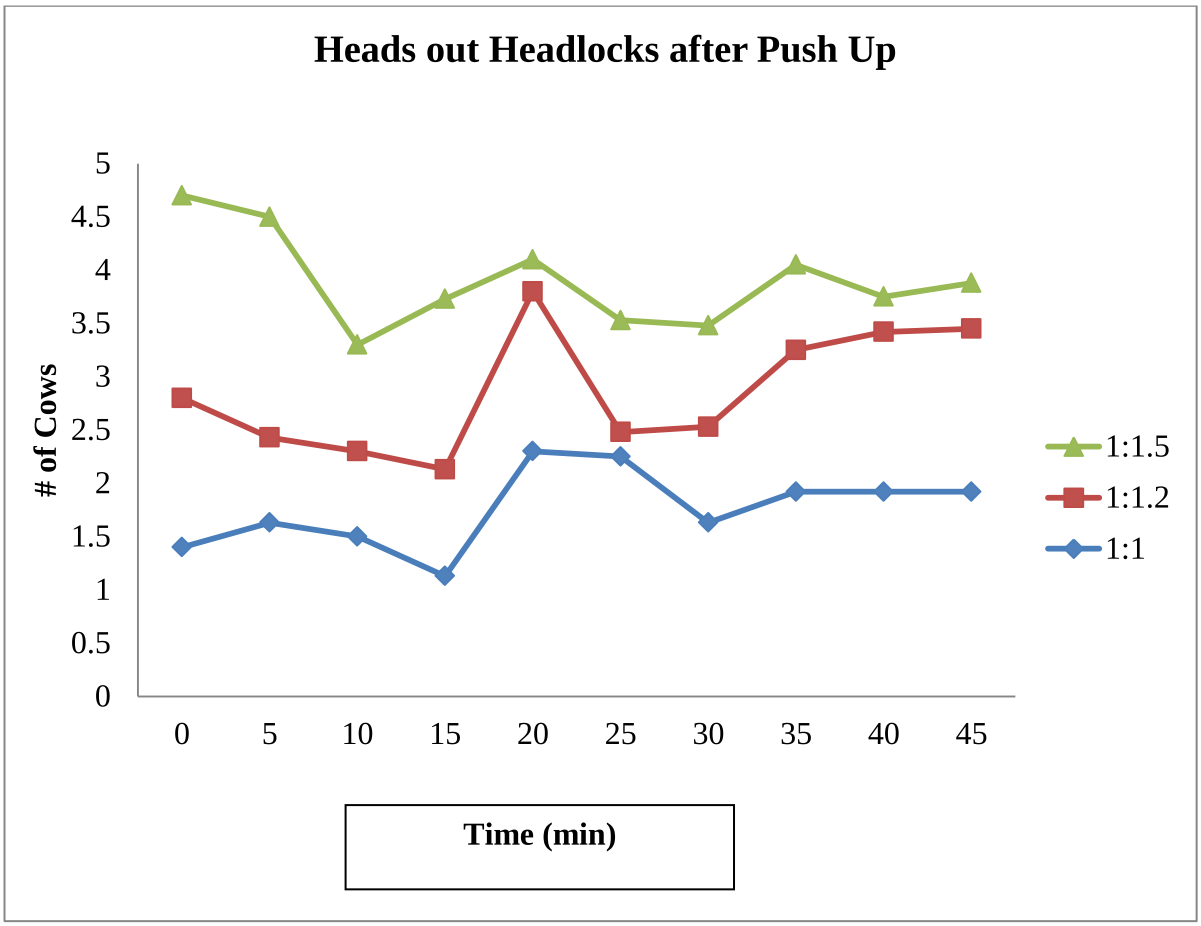
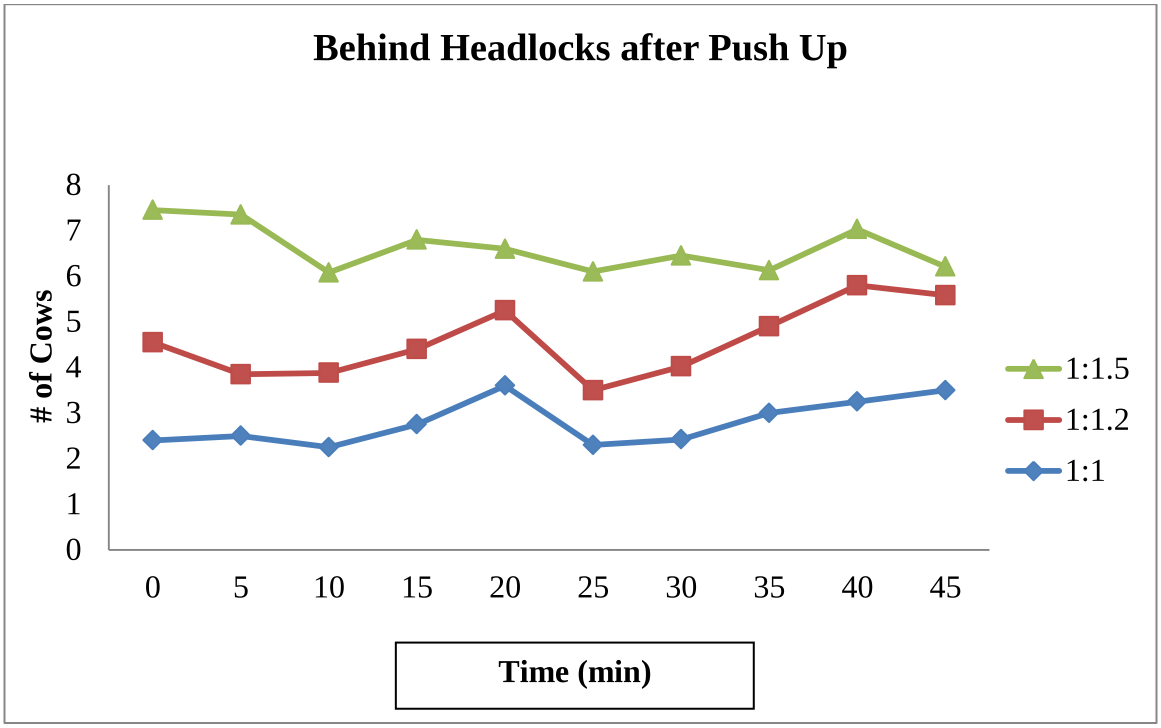


Figure 3.11D. Descriptive data showing number of cow standing behind the feed rail for each treatment after push up of feed.. Numbers are presented as total number of cows standing behind the feed rail along the entire feed rail (averaged between the 2 pens).



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CHAPTER 4

SUMMARY AND CONCLUSIONS

SUMMARY

Survey Stocking Rates at AMS Dairies

In first study presented in this thesis, few relationships were found between stocking rates (at stalls, the feed rail or the AMS) and variables of interest including lying behavior or measures of lameness. In fact, only leg cleanliness was significantly correlated with stall stocking rate. This is in contrast to what has generally been observed in parlor-milked systems where increases in the stocking rate at stalls and feed rail to a level greater than 100–113% have been found to lead to changes in behavior of lactating dairy cows, especially with regard to lying time (Christopher et al., 2008).

Stall stocking rate observed at the surveyed farms ranged from 56 to 126%, with an average of 94% (i.e., less than one cow per stall); while stocking rate at the feed rail ranged from 0.4 to 1.92 cows per 60 cm of feed rail with an average of 1.07 cows/60 cm (i.e., 56 cm of feeding space per cow). Stocking rate at the AMS ranged from 36 to 72 cows per AMS with an average stocking rate of 55$\pm$8.6 cows per AMS. Thus, in all cases, the average stocking rates were at or below recommendations of various codes of practice and scientific studies (e.g., NFACC, 2009; Anderson, 2008; Armstrong, 1994; Brouk, 2008; Collier et al., 2007). There were no cases of extremely high stall stocking rate and only four cases when an AMS was stocked with more than 71 cows. However, 20% of the surveyed farms provided less than 45 cm of feed rail space per cow, which could be expected to cause reduced feed intake and thus lower body condition scores. It was surprising then that our results found no effect of high feed rail stocking rate on body condition, measures of lamenes, or gait scores (Grant, 2009).

Cows synchronize their behavior as a result of circadian rhythms and group dynamics, with the result that reducing the number of stalls may lead to less lying and increased standing (Fregonesi et al., 2007), and may also impact cows' feeding or milking behavior. Stocking rate at the stalls, feed rail, and AMS can each affect cow health and lying time individually, and it is also possible that effects of the various stocking rates may interact within a dairy. Thus, we examined the correlation between stall, feed rail, and AMS stocking rates to better understand whether they were related, which would have impacted how we assessed the effects of these three stocking rates on variables of interest such as lying behavior, body condition score, measures of lameness (gait scores), or cow cleanliness. However, we found no relationship between the stocking rates in our study, which may mean these variables have stronger individual rather than interactive effects on the cow behavior and welfare.

On average, cows spend between 8-12 hours a day lying when the stocking rate in free stalls is 1:1 (Tucker, 2009). Further, lying time decreased 1.7 h/day when stalls were stocked at 150% compared with a 100% stocking rate in parlor-milked farms (Fregonosi et al., 2007). Specifically, in the overnight hours and during the mid-day period, lying time decreased as a result of such stall overstocking (Fregonosi et al., 2007). However, in the present study, we found no relationship between stocking rate at the feed rail, stalls, or AMS with lying time, the number of lying bouts or lying bout duration.

According to our analysis, there was no relationship between gait scores and the stocking rates at the 39 farms that were examined. Specifically, the data showed no relationship between presence of a limp, step asymmetry or head bob and the stocking rate at the stalls, feed rails or AMS at the surveyed farms. According to Galindo and Broom (2000), cows with less access to stalls and feed rail had increased standing time, which increased their risk of becoming lame. However, it is important to note that there is also a positive relationship between lameness and lying time, where lame cows lie more than healthy cows (Chapinal et al., 2009; Chapinal, 2010a,b).

The average body condition score of cows in the first study was 2.88 (on a 5 point scale). The ideal body condition score for a dairy cow is 2.50-3.25 for the first third of lactation, the stage targeted for focal cows in our study (NFACC, 2009). We found that neither stocking rate at the feed rail or AMS had an effect on BCS. Given that we did not see an impact of high feed rail stocking rates on BCS in the farms we surveyed, it was possible that managers had increased frequency of feeding or feed push up frequency to compensate. Therefore, we analyzed the data to evaluate relationships between stocking rate at the feed rail and body condition score, frequency of fresh feed delivery, or push up of feed to the rail. We did not find any significant relationships between these variables; however, producers were typically delivery fresh feed or pushing up feed more than three times per day. This feeding management resulted in over 90% of cows having feed in front of them during all of our observations at each farm. Thus, good feeding management may have been compensating for high feed rail stocking rates at the eight farms with limited feed rail space. Another possibility is that the cows at farms with high feed rail stocking rates could be feeding asynchronously or adapting their feeding to times when the rail is less crowded. It is also important to remember that cows in AMS receive concentrate in the AMS; which may mitigate the impacts of high feed rail stocking rate.

According to Krawczel and colleagues (2012) there is no relationship between udder and leg hygiene and stocking rate. However, other studies have reported that lower ranking cows are more likely to lie down outside of free stalls when there is overstocking (Gonzalez et al., 2003) and might be expected to be dirtier. In our study, stocking rate at the stall and feed rail did not correlate with udder and flank cleanliness, which may mean the producers were keeping the stall bedding clean and dry. Leg cleanliness, however, showed a significant correlation with stall stocking rate, but there was no relationship of leg cleanliness with feed rail stocking rate; perhaps indicating that time spent scraping alleys has an effect on leg cleanliness.

Experimental Overstocking at AMS Dairy

In second study presented in this thesis, we examined the effect of reducing the number of stalls available or the feeding space per cow on displacement and other behaviors in an AMS dairy farm. Each of two pens contained 60 cows/pen and 58 free-stalls and 60 headlocks. The impact of stocking rate was examined using three treatments: 1) 1:1 treatment with 58 stalls or 60 headlocks available for 60 cows; 2) 1:1.2 treatments with 50 stalls or 50 headlocks available for 60 cows; and, 3) 1:1.5 treatment with 40 stalls or 40 headlocks available for 60 cows. Each stall or feed rail treatment was applied separately, and each was applied for 1wk in a randomized order that was different for each pen, with a 1-wk washout period between treatments.

Stall Stocking Rate

Typically, studies of parlor-milking dairies show more displacement of cows from stalls and less lying time when cows are overstocked (Cook et al., 2005; Fregonesi et al., 2007). However, when we analyzed our data from an AMS dairy, we did not find significant differences in frequency of displacement as a result of stall overstocking. In addition, time budget analysis via instantaneous scan sampling of behavior in the stall area showed no significant difference between the stall stocking rate treatments in number of cows lying, standing or perching in stalls or the number of cows standing or walking in alleys. This suggests that the stocking rate treatments used in this study did not impact cows' use of stalls. Further, there was no effect of stall stocking rate on activity or rumination as recorded by the AMS monitors. This may mean that the cows did not change these behaviors as a result of overstocking.

Our findings are unlike those of other studies, which have shown that stocking rates of 120% or greater in parlor-milked dairies lead to an increase in standing time of 15 to 25% (Grant, 2001). Also, in previous studies of parlor-milked cows, increased stocking rate at the stalls has led to decreased lying time (Cook et al., 2005; Fregonesi et al., 2007). Therefore, our findings may suggest that cows milked with AMS may adapt their behavior to lie more at other times of day.

Feed Rail Stocking Rate

Displacement of cows from the feed rail has been found to increase when stocking rate is increased at the feed rail (DeVries et al., 2004; Huzzey el at., 2006; Proudfoot et al., 2009). In our study, there was a significant difference in number of displacements from the feed rail between the 1:1 treatment and the two overstocked treatments after fresh feed delivery, while there was no difference between the 1:1.2 and 1:1.5 treatments. However, there were no significant differences between any treatments in number of displacements from the feed rail following feed push up. This may emphasize the synchronicity of cows' response to fresh feed delivery and competition between cows for access to fresh feed, where any degree of feed rail overstocking leads to displacement.

No differences were seen among the treatments particularly with respect to the number of cows eating but also, with heads in headlocks but not eating, standing at the feed rail with heads out of headlocks, or standing in the alley behind the feed rail. This suggests that the impact of increasing stocking rate on cow feeding behavior was minimal. These findings are unlike these from parlor studies which have shown that increase in stocking rate at the feed bunk leads to increased competition and changed feeding behavior (Collings et al., 2011). particularly on our farm data from the feed rail stocking rate has no effect on the eating behavior when the stocking rate increased, while other parlor studies the feeding time decreased when the stocking rate at the feed rail increased (Huzzey et al., 2006).

CONCLUSIONS

In our first study, we focused on examining cow behavior and welfare rather than on milk production. Our data showed no strong relationships between stocking rates and lying behavior, body condition, measures of lameness (gait scores), or cleanliness scores. However, cows in AMS have free movement to and from the AMS and may milk asynchronously as opposed to cows milking as groups in parlor-based systems; this freedom may result in less synchrony of feeding and lying behavior. Also, the stocking rate in AMS systems may also be influenced by the design of barn and traffic system (forced, free, or guided). Cows are also feed concentrate in the AMS, while milking; which may mitigate high stocking rates at the feed rail. Typically producers who adopt AMS alter management routines in their entiretyspending less time milking cows more time devoted to cow health, feeding or breeding routines. This may allow producers to make management changes that can compensate for any issues caused by high stocking rates. For example, delivering or pushing up feed frequently to provide a constant source of feed for cattle when little feed rail space is available may reduce competition and mitigate any impacts on body condition score.

The second study in this thesis suggests that stall and feed rail stocking rates for cows in AMS systems may have little direct impact on cow behavior and lying time, unlike what is seen when parlor-milked farms are overstocked. However, AMS dairies may still experience some effects of overstocking, but not to a greater degree than in parlor-milked systems such as in displacement; when fresh feed is delivered. This study showed there was no real impact on cow behavior and welfare when the stocking rate increased either at the stalls or feed rail, which could mean that cows are adapting to stocking rates by becoming more asynchronous.

Overstocking in AMS may affect cows differently from what is seen in the parlor dairies due to cow having control over their milking routines as well as over feeding and lying times. Thus studies on cow behavior and welfare related to stocking rate in parlor dairies may not be directly applicable to dairies milking with AMS.

Finally, both studies in the thesis looked at stocking rates at the stalls and feed rail in AMS in comparison with parlor system. However, these two studies indicate there may be less effect of stocking rates on cow behavior and welfare at AMS dairies, which means producers could increase number of cows in their barns without impacting cow welfare in a negative way.