EFFECTS OF STOCKING RATE AND SUPPLEMENTATION ON PASTURE UTILIZATION, COW PERFORMANCE, AND RUMEN ENVIRONMENT IN A PASTURE-BASED AND AUTOMATIC MILKING SYSTEM

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ABSTRACT

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Integration of automatic milking systems (AMS) into Midwestern pasture-based systems has been suggested as an alternative low cost and labor efficient dairy system, but proper integration of this technology into a pasture-based dairy system is not well understood. The objective of this thesis was to determine management guidelines for a pasture-based AMS system by examining the combined effect of stocking rate and feeding strategies on cow performance, AMS use, feed degradation, dairy cattle genotype, and pasture utilization. An investigation lasting 8 weeks was conducted using a completely randomized design with a 2 x 2 factorial of two stocking rate systems (high stocking rate (HSR 2.89 cows/ha); low stocking rate (LSR 1.92 cows/ha)) and two genotypes of Holstein cattle, United States Holstein (USH) and New Zealand Holstein Friesian (NZF). The HSR treatment received a partial mixed ration (PMR; 40% ground corn and 60% legume grass haylage) in variable amounts (average: 4.86 kg /cow; ± 0.14; mean and SEM) to supplement deficits in pasture growth rate and availability. Results indicated no differences in milk production or AMS use between treatments, although differences were found between genotypes. An *in situ* experiment showed no differences in feed degradation, suggesting that the rumen environment was not affected by PMR supplementation. No differences in pasture utilization or pasture growth were detected between the HSR and LSR treatments. The results of this thesis suggest that dynamic supplementation in the HSR treatment did not affect pasture utilization, cow performance, AMS use, or the rumen environment.

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ABBREVIATIONS

ADF = Acid Detergent Fiber

AMS = Automatic Milking System

CP = Crude Protein

DM = Dry Matter

DMI = Dry Matter Intake

HSR = High Stocking Rate

IVTD = *In Vitro* True Digestibility

LSR = Low Stocking Rate

MF = Milking Frequency

MY = Milk Yield

NDF = Neutral Detergent Fiber

NZF = New Zealand Holstein Friesian

OG = Orchardgrass

PMR = Partial Mixed Ration

RG = Ryegrass

RPM = Rising Plate Meter

SEM = Standard Error of the Mean

SR = Stocking Rate

TMR = Total Mixed Ration

USH = United States Holstein

GLOSSARY

Associative Effect: Decreases in the rate or extent of feed degradation in the rumen due to interactions between the fermentation of concentrates and forages.

Box Time: The total amount of time the cow occupies the AMS stall.

Fetch Cow: A cow with a milking interval of 12 hours or greater.

Forage Utilization: Amount of forage harvested per area.

Genetic Merit: Generally referred to as the level of genetic potential for a cow to produce milk.

Grazing Intensity: The amount of pasture consumed/amount of pasture offered.

Milk Time: The amount of time from which the teat cups successfully attach, to when the last teat cup detaches after milking.

Milking Frequency: The average number of successful milkings per day.

Milking Interval: The time between successful milkings.

Milking Refusal: Cows visiting the AMS without meeting the criteria for milking (i.e., the milking is not predicted to result in a harvest of greater than 9 kg or the cow is visiting before the full length of the set milking interval)

Pasture Residual: Biomass left in the pasture after grazing.

Prep Time: The amount of time from which the cow enters the AMS stall, until successful teat cup attachment.

Substitution Rate: Reduction in pasture intake per kg of concentrate or forage supplemented.

INTRODUCTION

The increased cost of milk production in Michigan puts small- and medium-sized dairies at a competitive disadvantage. The Michigan dairy industry, similar to the national trend, has seen a decrease in the number of farms and an increase in the number of cows per farm and the amount of milk per cow (USDA, 2007). The rising cost of fuel, feed, and labor contributes to the loss of small to medium sized dairy farms (Dartt et al., 1999). However, farmers with small operations have the option of adopting new management strategies, such as management-intensive rotational grazing that reduces feed and labor costs, and produces a variety of ecosystem services. Adoption of new technology, such as automatic milking systems (AMS) also decreases labor costs and can increase milk production (de Koning and Rudenburg, 2004); however, the initial cost of investment is high.

Well-managed pasture-based dairies can yield a net income higher or comparable to conventional confinement dairies. Pasture-based dairy profitability is a result of the increase in labor and operating efficiency (Dartt et al., 1999). However, pasture utilization is also a main factor for creating profit. Therefore, grazing dairies must also manage the pasture, such that pasture growth and utilization are optimized.

Assuming all aspects of management are correct, the integration of an AMS into a pasture-based dairy has potential to increase the labor efficiency of a small dairy farm and result in higher overall farm efficiency and profitability. However, AMS integration into a pasture-based system is poorly understood. There is little information regarding management strategies that will maintain milk production on pasture, maximize pasture utilization, and optimize efficient use of the AMS.

Chapter 1 of this thesis introduces the reader to most relevant aspects of pasture-based dairy management and AMS functionality. The literature review is centered on the potential impacts of stocking rates, supplementation strategies, and cow genotypes on pasture-based system production efficiency. This review then follows with a description of the operation and functional aspects of the AMS and concludes with a conceptual framework intended to provide general ideas for the proper integration of the AMS into Midwestern pasture-based systems. The original research presented in Chapter 2 compares feed intake, milkings, milk production and quality, and overall performance of dairy cows managed with AMS in two dairy systems. The systems differ in grazing and feeding strategy; a forage-based supplemented high stocking rate system vs. an un-supplemented low stocking rate system. Experimental cows used in this experiment include United States Holstein and New Zealand Holstein Friesians, therefore a comparative discussion between these two genotypes is also provided. The *in situ* research presented in Chapter 3 describes the supplementation strategy effects on the rumen environment and kinetics. The *in situ* experiment was designed to detect the occurrence of any associative effects and pH change resulting from the proposed feeding strategies tested in Chapter 2. Finally, the concluding study discussed in Chapter 4 uses a system-based approach to compare the forage utilization, milk production, and AMS utilization of the grazing systems presented in Chapters 2 and 3. Guidelines regarding stocking rate management and dynamic supplementation are outlined and their applications to manage forage utilization and milk production are described in the final discussion.

The combination of low feed and labor costs with the higher management efficiency of the AMS has potential to increase the profitability and production efficiency of small- to medium-sized dairy farms. However, information regarding the proper AMS management integration in a pasture-based systems is scarce and research needs to be conducted to help farmers better understand the potential of AMS integration in grazing dairy systems. This thesis aims to present new practical information to help fill gaps of knowledge focused on improving milk production efficiency and sustainability in pasture-based systems, through proper AMS incorporation and efficient pasture utilization.

CHAPTER 1

LITERATURE REVIEW

Supplementation of Pasture-based Diets

Low milk production associated with pasture-based dairy systems discourages the practice of grazing in the United States. Several studies comparing the feeding of a total mixed ration (TMR) with pasture-based diets show consistently higher milk production in TMR diets (Kolver and Muller, 1998; Bargo et al., 2002a and 2002b). Kolver and Muller (1998) found milk production per cow was 44.1 kg/d for cows fed a TMR compared to 29.9 kg/d in a diet of pasture alone. The difference in milk production between TMR and pasture-based diets is often due to lower dry matter intake in pasture-based diets (DMI; Kolver and Muller, 1998). The TMR feeding system allows maximum feed intake and therefore higher milk production per cow. A strategy to increase grazing cow DMI and milk production is to supplement the pasture diet with harvested feeds (Kolver and Muller, 1998).

Concentrate supplementation on pasture diets increases total DMI and milk production. Reis and Combs (2000) supplemented grazing dairy cows with 0, 5, and 10 kg shelled corn daily and determined that both DMI (13.9, 17.7, and 19.8 kg DM/d, for 0, 5, and 10 kg DM supplemented, respectively) and milk production increased with supplementation (21.8, 26.8, and 30.4 kg/d for 0, 5, and 10 kg DM of supplement, respectively). Further, Bargo et al. (2002a) reported milk production increases from 19.1 to 29.7 kg/d and intake from 18.3 to 24.1 kg/d when supplementing 8.6 kg DM/d of corn at a low pasture allowance. Both studies indicate that supplementation can increase milk per cow. However, as noted in these studies, as the level of concentrate intake increases the amount of pasture intake decreases, causing an increase in substitution rate of pasture by supplement.

Intake substitution occurs when pasture DMI decreases due to supplementation (Bargo et al., 2003). High substitution rates may be caused by a combination of many factors. One hypothesis suggests that supplements combined with pasture cause associative effects between digestive and metabolic interactions and the increase in energy intake, which result in lower pasture intakes (Bargo et al., 2003). A second hypothesis suggests that supplementation decreases grazing time, and therefore decreases pasture intake (Reis and Combs, 2000; Bargo et al., 2002a).

In grazing, associative effects can be caused by disruption of fermentation patterns induced by the presence of a concentrate. The readily fermentable starch can cause a decrease in pH and inhibits fiber degradation (Bargo et al., 2003), which may decrease intake and milk production. Walker et al. (2001) demonstrated associative effects when increasing levels of cereal grain-based supplements were fed to grazing dairy cattle. A curvilinear response in milk production, which is an indication of associative effects, was reported. However, a curvilinear response is not always found with increased concentrate supplementation (Reis and Combs, 2000; Bargo et al., 2002a and 2002b). Reis and Combs (2000) demonstrated that feeding increasing levels from 0, 5, to 10 kg DM/d of ground shelled corn to grazing dairy cows did not cause a curvilinear milk response. Using *in situ* dry matter digestibility trials, Reis and Combs (2000) indicated no differences in fiber DM ruminal degradability or pH (average 6.68), although there was a reduction in the potentially degradable fraction of the forage DM and an increase in the undegradable fraction for the treatment that received 10 kg DM/d.

In an attempt to decrease associative effects or to complement a pasture-based diet, forages have also been used to supplement grazing dairy cattle. Graf et al. (2005) supplemented grazing dairy cows with hay at night in an attempt to increase rumination activity and stabilize rumen pH and fermentation patterns. Hay supplementation in the evening led to decreases in rumen pH for longer durations of time during the day compared to the control (no supplementation). No increases in intake or milk production in response to the forage supplement were reported. Similarly, Holden et al. (1995) found that supplementation of 2.3 kg/d corn silage, plus 1 kg of corn-based grain per 4 kg or milk, did not affect milk production or DMI in cows grazing orchardgrass dominated pasture. However, supplementing corn silage at the rate of 1 kg per 4 kg of milk did not increase milk production or intake.

Forage may also be supplemented in the form of a partial total mixed ration (PMR) (Soriano et al., 2001; Bargo et al., 2002b). Supplementing with a forage-based PMR has the potential to increase energy intake, but discourages the formation of associative effects caused by concentrate only supplementation. Soriano et al. (2001) compared three treatment groups: cows consuming TMR only ration, cows supplemented with PMR in the morning and grazing on pasture in the afternoon, and cows supplemented with PMR in the afternoon and grazing on pasture in the morning. The researchers found PMR intakes for the half day PMR consumption and half day grazing groups were between 65.8 and 76.3% compared to the TMR only treatment. Yet, milk production in the two grazing groups was still comparable to the TMR-only treatment, and was 28.2, 27.6, and 29.1 kg/d for the afternoon grazers, morning grazers, and TMR only, respectively.

Bargo et al. (2002b) completed an extensive comparison between three diets, including pasture plus concentrate (PC), a total mixed ration (TMR) and a combination of pasture and

TMR defined as partial TMR (pTMR). Bargo et al. (2002b) found that the pTMR treatment group was moderate in DMI and milk production compared to the other groups. Dry matter intake was found to be 21.6, 25.2, and 26.7 kg/d ($P<0.05$) and milk production was 28.5, 32, and 38.1 kg/d for the PC, pTMR, and TMR groups, respectively. Ruminal pH was not found to differ among treatment groups (average pH of 5.87); rumen ammonia concentrations were significantly higher in the PC treatment indicating that the inclusion of a pTMR increases the capture of nitrogen. Bargo et al. (2002b) discovered that the pTMR group, although receiving a balanced TMR, still experienced associative effects. This was seen in the *in situ* results where the potentially degradable fraction of DM and the potentially degradable fraction of NDF were reduced compared to in the PC treatment. Although supplementing with a pTMR may result in some negative associative effects, the addition of pTMR into grazing cow diets allows cows to maintain or increase feed intake and milk production (Soriano et al., 2001; Bargo et al., 2002b).

Hoffman et al. (1993) supplemented cow diets with varying amounts of grain over the grazing season based on the quality and quantity of pasture. Cows received either 1 kg of grain per 4 kg of milk, 1 kg of grain per 4 or 5 kg of milk based on pasture quality and availability, or 1 kg of grain per 3 kg of milk as control. Grain supplementation was reformulated based on pasture quality, which was determined by chemical analysis of pasture samples collected one week prior to the supplement reformulation. Over the 24 week trial no difference was seen in milk production and only the control treatment of 1 kg of grain per 3 kg of milk gained body weight. This suggests that grain supplementation based on changes in pasture quality and quantity caused no difference in milk production. However, declining pasture availability over the grazing season (approximately 1,800 kg/ha in May to approximately 1000 kg/ha in September) in this study indicated the amount supplemented was not enough to compensate for the limited pasture availability. Supplementation should therefore be used to manage growth rates and future pasture availability, which manages pasture intake and thus helps to prevent subsequent pasture deficits.

Pasture Management

Pasture supplementation can be used to add dietary energy and aid in pasture management. Seasonal changes in pasture quality and quantity creates variability in the diet, affecting nutrient intake. Supplementation can compensate for seasonal pasture variation, but must interface with effective pasture management principles to ensure efficient pasture utilization. Fulkerson et al. (2005) reported that supplementing grazing dairy cattle based on pasture biomass can maintain milk production and post-grazing residuals. Maintaining desirable post-grazing residual pasture biomass favors high pasture growth rates and prevents overgrazing and eventual decline of pre-grazing biomass over the grazing season (Fulkerson et al., 2005). Supplementation in pasture-based dairy farms should be adjusted to encourage optimum pasture growth and utilization, and ultimately profitability (Gronow et al., 2010). However, the supplementation studies mentioned prior were interested in the effects of pasture management on animal production and not the effects on pasture growth rates and forage utilization. To optimize pasture production and overall farm efficiency, focus must also be placed on pasture productivity.

There are trade-offs between pasture growth and utilization. Plants require leaves for photosynthesis. As the plant reaches potential maximum leaf area for biomass accumulation, it will start to turn leaves over, or leaves will die and drop off the plant (senesce; Parsons et al., 1998). To optimize utilization, plants need to be grazed before the older leaves in a tiller start to senesce; however, pastures cannot be grazed so low that there is not enough leaf area to sustain the required rate of photosynthesis. Overgrazing removes nearly all leaf tissue, and reduces rates of photosynthesis and results in a decrease in biomass by requiring the plant to use reserves to restore leaf tissue (Parsons et al., 1998). Balance needs to be made between leaving sufficient leaf area behind for photosynthesis and growth versus pasture consumption.

Maximum pasture utilization is achieved when the sward is grazed at maximum average pasture growth rate (see Parsons et al., 1998; Figure 1.1). Maximum average pasture growth rate accounts for both biomass accumulated and the total time that has elapsed since previous defoliation. This strategy takes advantage of the high growth rate in the beginning of regrowth, but harvest is complete before the biomass reaches its ceiling yield and begins to senesce. Importantly, the growth rate changes seasonally; during early spring growth rate peaks, and as summer approaches growth rates slows. Supplementation and stocking rate management are tools to manage forage utilization as pasture growth changes throughout the season.

The Parsons et al. (1998) review showed that in order to optimize (i.e., maximize) pasture utilization, defoliation must occur at maximum average growth rate, which occurs after some accumulation of biomass over time. Farmers often use fixed time, height, or target biomass values to determine defoliation frequency. Fulkerson and Donaghy (2001) describe these methods as inaccurate. Time is the least accurate method as environmental factors greatly affect regrowth, and plant height is inaccurate because it does not fully reflect changes in biomass. Biomass is described as the one of the most accurate measurement, but is also affected by physiological and environmental factors. For example, the plant may not reach the target biomass for defoliation because it is subject to environmental stress (i.e., water, nutrients, temperature), or the plant may no longer continue to grow at a high rate if it has already reached an advanced stage of physiological development or maturity (Fulkerson and Donaghy, 2001).

In their review, Fulkerson and Donaghy (2001) described leaf number to be the best plant-related indicator associated with regrowth. Perennial ryegrass (*Lolium perenne*) develops three leaves per tiller before the oldest leaf starts to senesce, which sets the maximum grazing interval for this plant species. Ryegrass grazed before two leaves retards regrowth and reduces persistence and quality. However, when ryegrass is grazed at three leaves it has been shown to increase net accumulation of biomass, persistence and quality. Setting a general goal for pasture biomass is a useful strategy for grazing systems because future biomass can be estimated by the average growth rate, however, everyday decisions need to made based on leaf number to ensure that plants are not senescing (representing unused forage growth), decreasing pasture utilization. Maintaining and optimizing pasture growth can be managed by varying stocking rates over the season or by integrating supplementation.

Stocking Rates and Utilization

Stocking rate is the most important grazing management variable affecting milk production per cow and per area in a pasture-based system. Increasing stocking rate decreases milk production per cow, but increases milk production per area (Fales et al., 1995; Kennedy et al., 2006; Macdonald et al., 2008). The decrease in milk production is due to the decrease in pasture intake per cow (Macdonald et al., 2008). However, increasing stocking rates increases pasture utilization, and the amount of pasture consumed/amount of pasture offered, often referred to as grazing efficiency (Baudracco et al., 2011). The increase in grazing efficiency may be caused by a decrease in grazing selectivity particularly in early spring when forage availability is high (Baker and Leaver, 1986; Fales et al., 1995). Fales et al. (1995) reported that increasing the stocking rate from 2.5, 3.25, and 4.0 cows/ha resulted in less rejected forage, with rejected fractions decreasing from 43.6, 31.8, and 21.8% in spring for the low, medium, and high stocking rates, respectively. It is critical to harvest the forage before it reaches its ceiling biomass accumulation in early spring; otherwise it leads to decreased utilization due to senescence and cattle selectivity (Fales et al., 1995). Proper stocking rates also increase overall sward quality (Baker and Leaver, 1986, Fales et al., 1995) by encouraging uniform defoliation closer to the plant growing points resulting in the promotion of new tillers (Baker and Leaver, 1986). The short, uniform defoliation promotes new growth, which increases the total production of herbage per area (Baker and Leaver, 1986, Macdonald et al., 2008).

Pasture production is a major factor of farm profitability (Gronow et al., 2010), therefore, increasing pasture production is the main goal in most pasture-based dairies. A study conducted in New Zealand by Macdonald et al. (2008) demonstrates that high pasture production and utilization are possible with high stocking rates. The stocking rate treatments were 2.2, 2.7, 3.1, 3.7, and 4.3 cows/ha. Intake per cow decreased with increasing stocking rate from 5,438, 5,018, 4,575, 4,214, to 3,887 kg DM/cow per year, respectively, and milk production followed a similar decreasing trend from 5,032, 4,351, 4,128, 3,616 to 3,448 kg/cow/year. However, as stocking rates increased, the annual amount of forage consumed per hectare increased from 12,098, 13,785, 14,322, 15,609 to 16,597 kg of DM/ha per year, and milk production/ha increased from 11,071, 11,747, 12,796, 13,380 to 14,828 kg/ha, respectively. The increase in pasture consumed per hectare led to greater amounts of pasture production per hectare, increasing pasture utilization. Not only was milk production per hectare higher for the highest stocking rate system, but interestingly these values were achieved on shorter lactation lengths and grazing days. Lactation length was 291, 274, 258, 234, and 221 days for the treatments with 2.2, 2.7, 3.1, 3.7, and 4.3 cows/ha, respectively. The lower pasture residuals led to a decrease in pasture pre-grazing biomass, yet cows still produced more milk per hectare. Macdonald et al. (2008) was able to demonstrate how high stocking rates may increase pasture growth and milk production per hectare when all other aspects of pasture management (i.e. fertilization) are correct. However, this strategy of producing the greatest amount of milk per hectare, which is successful in New Zealand, may not be effective for Michigan, particularly when considering the genetic merit of cows involved.

Genetic Merit

Genetic merit is generally referred to as the level of genetic potential for a cow to produce milk and is an important factor for production in pasture-based dairy systems. Grazing genotypes are generally categorized into two or three levels of genetic merit; a low genetic merit or New Zealand grazing-based genetics, a high genetic merit or high production North American genetics, and a medium genetic merit or high durability genotype (McCarthy et al., 2006; Horan et al., 2005; Kennedy et al., 2003). High durability is a crossbred selected for milk production, fertility, and muscularity traits. In recent years, the role of genetic merit in grazing systems has been extensively examined. Countries with low genetic merit cows have been increasing their production per cow by incorporating North American genetics, but now there are rising concerns about reduced reproductive performance (Buckley et al., 2000; Fulkerson et al., 2001; Dillion et al., 2006). Other studies examined the existence of genotype by environment (G x E) interactions (Horan et al., 2005; Fulkerson et al., 2008). If a G x E interaction exists, and there is an indication that certain genotypes perform better in certain feeding systems compared to others, this information will guide farmers to choose their genetics accordingly.

The feeding systems that are generally tested for G x E interactions are often different combinations of concentrate level and stocking rates. Buckley et al. (2000a) compared two levels of genetic merit, high and medium, in three treatment groups including high stocking rate with concentrate, high stocking rate plus twice the concentrate as the high stocking rate system, and a high pasture allowance group with the same concentrate supplementation as the high stocking rate system. No G x E interaction was detected, but cows of high genetic merit consumed more pasture and total DM and produced more milk in each feeding system. A lack of a G x E interaction for milk production traits has been seen in similar studies. No G x E interaction in grazing-based experiments may suggest that there is not a substantial difference between either the environmental conditions or the genotypes compared in the studies, or that G x E interactions need more time to be detected.

Horan et al. (2005) compared three genetic genotype, including New Zealand Friesian, high durability, and high producing North American cows across three feeding systems: a control group (2.47 cows/ha and 368 kg concentrate/cow/yr), a high stocking rate (2.74 cows/ha and 364 kg concentrate/cow/yr), and a high concentrate diet (2.47 cows/ha and 1452 kg concentrates/cow/yr). The results for milk production for the high pasture allowance, high stocking rate, and high concentrate systems was 6,799, 6,283, and 7,877 kg/cow for the North American cows, respectively and 6,039, 5,940, and 6,444 kg/cow for the New Zealand cows, respectively. The differences in milk production between the two genotypes were 760, 343, and 1,433 kg/cow for high pasture allowance, high stocking rate, and high concentrate treatments, respectively. These differences suggests that the high production North American cows out performed in the three feeding systems and had a significantly higher milk yield response to concentrate supplementation compared to the New Zealand cows. Similar differences in milk production between high and low genetic merit genotypes are also reported in the studies conducted by Kennedy et al. (2003) and McCarthy et al. (2007).

Change in body condition score (BCS) is another metric often used to compare animal performance between different genotypes. Horan et al. (2005) reported above, BCS differed among the three feeding systems. Cows in the high concentrate feeding system lost less body condition from calving to nadir (0.51) compared with the high stocking rate and high allowance feeding systems (0.64 and 0.72, respectively). There was also a significant difference between genotypes for BCS. The New Zealand genotype had the highest BCS postpartum (3.37), at nadir BCS (2.84) and at dry-off (3.13) compared to the high production cows which scored a 3.17, 2.45, and 2.68 BCS at postpartum, nadir and dry off, respectively. A consistently higher BCS in New Zealand cows may suggest that this genotype is more suitable for production systems where pasture availability and feed intake is low. Conversely, in pasture-based systems that can sustain higher levels of pasture intake, a North American genotype may be more efficient.

The results from Horan et al. (2005) also indicate important differences between genotypes. In this study, high production cows had a higher milk response to concentrate compared to New Zealand genotypes, which may suggest that a pasture-only diet was not sufficient to meet the energy requirements of the high production cows. This is also supported by the larger decrease in BCS from post calving to nadir BCS, for high production cows (0.72) compared to New Zealand cows (0.53). The lack of response in the New Zealand cows indicates that they were closer to meeting their energy requirements and also a higher proportion of their potential milk production. Kennedy et al. (2003) found that high production cows on forage based diets are not capable of consuming more forage than cows of lower genetic merit, probably because of the physical bulkiness of the grass or low rate of pasture intake. Therefore, in situations where pasture intake is limiting, supplementation with digestible energy concentrates increases the energy density of the diet and may increase DMI, potentially resulting in a greater milk yield response. However, low genetic merit cows do not always show a high milk response to concentrate supplementation because in most cases, pasture intake is not a limiting factor for this genotype (Kennedy et al., 2003, McCarthy et al., 2006). Substitution rates are lower in high producing cows because their energy requirements are not fully met with pasture only diets. Therefore, adding concentrate supplementation to the diet of high producing cows generally increases total dry matter intake compared to pasture only diets (Kennedy et al., 2003).

Genotype may also influence grazing behavior. McCarthy et al. (2006) investigated the genetic effect (New Zealand, high durability, and high production) and feeding system (high pasture allowance, high stocking rate, or high concentrate supplementation) on grazing behavior, feed intake, and milk production. The high pasture allowance (2.47 cows/ha) and high stocking rate (2.74 cows/ha) did not receive concentrate supplementation and the supplemented treatment received 3.5 kg DM/day at a stocking rate of 2.47 cows/ha. McCarthy et al. (2006) reported that the high durability genotype had the shortest grazing time, while the New Zealand genotype had the longest grazing time and the high production genotype was intermediate. The high production and New Zealand cows had the same number of bites per day, which were significantly higher than the high durability cows. The high production cows had a significantly higher biting rate than the New Zealand cows, whereas the high durability cows were intermediate and not significantly different from the other genotypes.

These results are remarkable in two ways. The high biting rate by high producing cows suggested a greater eating drive, and higher motivation to graze or capacity to chew and harvest bites at the same time (Laca et al., 1994). The lower biting rate exhibited by the high durability cows suggested that these cows exhibited a higher degree of grazing selectivity. The grazing time for the high production and high durability cows decreased as stocking rate or pasture allowance increased. At high pasture allowance, grazing time was 615 and 573 min for the high durability and high production cows, respectively. At high stocking rate, grazing time was 553 min and 536 min for the high durability and high production cows, respectively. The longer time spent grazing (631 min) in the high stocking rate system for the New Zealand cows, may indicate that these cows have more drive to graze or willing to graze more selective compared to the other genotypes.

The genotype comparison studies reported above were completed in countries other than the U.S., namely Ireland and Australia (Kennedy et al., 2003; Horan et al., 2005; McCarthy et al., 2006; Fulkerson et al., 2008). The main drive to investigate G x E interactions in pasture-based systems is the concern that North American genetics may have decreasing reproductive performance, as a result of decreased pasture intake and BCS, as reported in Fulkerson et al. (2008). Kolver and Muller (1998) established that North American Holsteins are energy limited on pasture-based diets, and are not capable of reaching their genetic potential on pasture alone. For this reason, there is increased interested in incorporating New Zealand genetics into pasture-based systems in the US, as these cows have lower energy requirements (Kennedy et al., 2003; Horan et al., 2005; McCarthy et al., 2006). Further, there has been little research comparing genotypes of Holstein in the US, and the feasibility and economics of New Zealand genetics or New Zealand crosses in North American grazing systems has yet to be investigated.

Automatic Milking and Pasture-based Systems

There has been increased interest in investigating how the integration of AMS affects farm efficiency in various types of dairy production systems. Garcia and Fulkerson (2005) identified three potential benefits of integrating an AMS. The first benefit is an up to 20% reduction in labor hours (de Koning and Rudenburg, 2004). The reduction in hours also leads to a reduction in labor costs; Dijkhuizen et al. (1997) found an annual savings of up to $200/cow was possible. An AMS allows the farmer to devote time to other aspects of farm and pasture management, family, or recreation time. The second benefit was a potential increase in milk production/cow (de Koning and Rudenburg, 2004). In confinement systems, this potential increase in milk production is generally due to the increase in milking frequency from two to three milkings/day (de Koning et al., 2002). Lastly, AMS can result in reduced stress on cows and also gives the farmer access to data that can aid in management decisions.

Despite the extensive research conducted in AMS in recent years, there is little information available to aid farmers in the adoption of AMS into a pasture-based system. Grazing dairies must of manage the challenges of pasture-based systems with AMS, namely, motivating cows to voluntarily and independently visit the AMS from pastures located away from the milking barn.

Factors Affecting Traffic and Voluntary Milkings in AMS

Grain is generally offered in the AMS stall, as it has been shown to be the main motive for cows to visit the AMS (Prescott, 1998). Jago et al. (2007) offered either 0 kg or 1 kg of barley in the AMS to test system efficacy. While average milkings per day was not affected, the supplemented group visited the selection unit more often, indicating that the supplementation resulted in a higher motivation for cows to return to the barn. The supplementation treatment also increased milk yield per cow by 1.12 kg. Sporndly and Wredle (2004) compared feeding grass silage *ad libitum* versus feeding limited to 3 kg of grass silage, both in the barn, while cows also grazed equal distances from the barn. No increase in milk production or milking frequency for the *ad libitum* silage group was reported. Sporndly and Wredle (2004) suggest that milk production did not increase in the *ad libitum* silage group due to adequate amounts of high quality pasture available and most likely resulted in substitution of the pasture for silage.

Ketelaar-de Lauwere et al. (2000) also studied the effect of a low sward height (10.8-11 cm) or a high sward height (12.3-14.5 cm) on milking frequency in a pasture-based AMS farm. The researchers found an increase in total milking visits for cows on the low sward heights (2.65 and 2.95 milkings/d for high and low sward height, respectively), although grazing time did not differ. However, no information was given about the effects of these sward heights on intake or milk production. Depending on milk production, additional milkings may not be necessary because may not result in the harvesting of additional milk.

Distance to Pasture

Distance to pasture has been referred to as an obstacle to efficient AMS utilization in pasture-based systems. Ketelaar-de Lauwere et al. (2000) demonstrated that a distance of 360 and 355 m versus 146 and 168 m between the AMS milking barn and the pasture did not affect milking frequency. However, Sporndly and Wredle (2004) saw a decrease in milking frequency and milk production when cows traveled 260 m vs. 50 m from the milking barn to the pasture. The difference in milking frequency in Sporndly and Wredle (2004) may be caused by the extremely close pasture distance of 50 m, compared to Ketelaar-de Lauwere et al. (2000) where a difference in milking frequency between approximately 150 and 350 m from the milking barn was not seen. Sporndly and Wredle (2004) also noted that the motivation to graze decreased over time, as time spent grazing decreased from 20 to 9% for the long distance, while the cows that were a short distance from the barn maintained grazing time at 23 and 21%, respectively. Sporndly and Wredle (2004) concluded that cows alter their behavior as the season progressed. Further, a constant distance longer than 260 m decreases grazing time, and presumably DMI; although it is not known whether alternating close and far distances would have the same effect. This information may be valuable to farms with larger herds, in which cows must travel to distant pastures over 260 m but also have closer pastures available in their grazing rotation.

Location of Water Source

Water location has been investigated as a source of motivation for cows to visit the AMS. Ketalaar-de Lauwere et al. (1999) found that pasture-based dairies with AMS and water only available in the milking barn may be restricting water consumption. Cows on restricted pasture access (12 hours) and full pasture access spent less time drinking water than cows with no pasture access (20.3, 21.6, and 27.5 min, for the restricted, full, and no pasture access treatments, respectively). Although, the values for the cows with pasture access are lower, it may be due to luxury water consumption in the restricted treatments or grazing dairy cows are obtaining their required water from the high water content of fresh pasture. Sporndly and Wredle (2005) investigated the effects of offering water in the barn only versus offering water in both the milking barn and in the pasture. The researchers found no difference in milking frequency, milk production, or water intake. The group with water only offered in the milking barn drank 40% of their daily water intake within 30 min of entering the barn and the group with water in the barn and field drank 50% of their water in the field. The researchers concluded that water does not motivate cows to visit the AMS, as milking frequency did not differ between groups. However, cows in the treatment with water in the field and barn had spent more time outdoors and grazing, indicating that cows in the treatment offering water in the milking barn only spent more time in the barn. The researchers did not record grazing bouts, but it may be possible that cows in the barn only treatment may have had a higher number of grazing bouts that did not result in additional milkings. Cows receiving water in the barn only may also have gone to the barn to drink and stayed there for an extended period of time without having additional motivations (i.e. supplemental feed) to visit the AMS more frequently. Although offering water in the field resulted in more time spent grazing on pasture, offering water in the pastures often results in uneven distribution of nutrients or differences in pasture productivity as a result of uneven grazing pressures, soil compaction and concentration of urine and feces near water source (Mathews et al., 1994). It may also be important for farmers to consider the possibility of added labor and installation cost for providing water in the field at least in small to medium sized pasture-based systems with relatively short distances to pastures (< 350 m).

Milking Frequency

Increasing daily milkings generally increases milk production per cow (Stelwagen, 2001; Andre et al., 2010,). Stelwagen (2001) indicated an increase from two to three milkings per day resulted in an increase in milk production of 18%. The AMS has the potential to increase milk production per cow without increasing labor costs. Daily milking frequency and duration are restricted by the amount of time the AMS has available for milking, which subsequently defines the AMS capacity. Other time considerations for the AMS are rinsing, cleaning, and idle time. Idle time is necessary to prevent overcrowding and waiting time at the AMS.

Milk yield per milking depends on the preceding milking interval (time between milkings; Hogeveen et al., 2001; Andre et al., 2010). Shorter intervals increase milk production per cow per hour; a greater response is seen in high production cows (Hogeveen et al., 2001). Hogeveen et al. (2001) found that intervals greater than 18 hours can result in decreased daily milk production. Similarly, Guinard-Flamnet (2006) stated that daily milk yield displayed a curvilinear pattern with increasing milking intervals from 8 to 24 hours. The challenge for any AMS system is balancing milk yield, milk duration, milking intervals, and number of cows per AMS stall.

Milk yield per cow on a daily basis increases as the length of the interval between milkings decreases, however, the total milking duration per day increases exponentially (Andre et al., 2010; Figure 1.2). The increase in milking duration is restricted by the capacity of the AMS, which is dependent on the cleaning time, frequency of cleaning, and idle time (Andre et al., 2010). Decreasing milking intervals must create a balance between milk yield and milk duration. Particularly because the amount of milk collected must justify the amount of time a cow spends in the AMS, the milking duration of a cow is affected by the time that the AMS requires to clean, prepare and attach teat cups to the cow. Therefore, the ideal or optimal milking interval should maximize the amount of milk production per unit of milking time and AMS occupation (i.e. box time). The optimal milking interval is therefore expected to differ as milking speed changes and/or as feed intake and milk secretion change between cow breeds, feeding systems, and lactations. The milking interval will differ based on stage of lactation, parity, and time of day.

Maintaining short milking intervals is especially challenging in pasture-based AMS. In a pasture-based AMS farm, management focuses on motivating cows to voluntarily return to the

AMS from pasture. Compared to a confinement feeding system, cow behavior and herd activities are more synchronized and gregarious on pasture (Ketelaar-de Lauwere et al., 2000), creating poorly distributed milkings throughout the day and in some situations longer waiting periods for milking in the AMS. Compared to confinement feeding systems, feeding patterns in a grazing system are more gregarious and also more erratic or variable as they are increasingly affected by environmental conditions, varying feed quality and quantity, distance to pasture, and distance to shading and water sources.

As previously stated, short milking intervals result in higher milk production. However, in a pasture-based AMS cows are physically farther away from the AMS and need to exert time and energy to return to the barn. In addition, cows on pasture, compared to TMR diets, produce less milk (Kolver and Muller, 1998; Bargo et al., 2003). Not only do pasture-based AMS have to motivate cows to visit the AMS, but cows must have sufficient milk to collect. A pasture-based AMS may expect to find longer milking intervals, resulting in higher milk production per AMS, but not per cow. Jago et al. (2007) studied the effects of two intervals of milking permissions from pasture, 6 h vs. 12 h, in a New Zealand grazing system. In this study the permission of a cow to visit the AMS was controlled with the use of a selection unit in the pasture that determined whether cows could leave the pasture to visit the AMS for milking or to stay in the pasture. Jago et al. (2007) found milking intervals of 12.56 h and 16.90 h for 6 h and 12 h interval treatments respectively, and fewer number of milkings per cow for the 12 h interval (1.42 milkings/day) compared to the 6 h interval (1.91 milkings/day). The 12 h permission treatment had a higher milk yield per milking (16.40 kg) compared to the 6 h treatment (11.96 kg), but milk yield per day was not significantly different between permission treatments. Also, milk production of a low producing cow in a low input pasture-based system was not affected by a longer milking interval. The decrease in milking frequency with the greater milking permission interval may allow farmers to increase their stocking rate to compensate for the fewer milkings per cow without affecting the production per cow.

Production Efficiency of Pasture-based Dairy Farms

Recently, system-based or farmlet studies determined the efficiency of whole farm systems with varying supplementation amounts, stocking rates or combinations of both factors (MacDonald et al., 2008;Farina et al., 2011). MacDonald et al. (2008) observed increases in milk production and pasture utilization with increases in stocking rate up to 4.3 cows/ha. In this study, milk production per cow was sacrificed but milk production per ha increased as stocking rate increased, indicating pasture utilization importance.

Another strategy to increase milk yield per ha is to increase milk production per cow, a practice which is particularly important in systems where stocking rate and forage utilization is near maximum. Farina et al. (2011) investigated the differences in milk production efficiency between farming systems increasing milk production per cow by feeding supplements, increasing stocking rates, or a combination. The researchers incorporated four total treatments: 1) a low stocking rate (2.5 cows/ha) with low milk production used as control (C); 2) a low stocking rate with high production (HMY); 3) a high stocking rate (3.8 cows/ha) with low production (HSR); 4) high stocking rate with high production (HH). Milk production goals for low and high production levels were 6000 and 9000 kg/cow/lactation, cows were fed supplements to reach those production goals. The pasture management was based on pasture growth rate and supplemented if necessary, ensuring that pastures met the pre and post grazing targets of 2400 and 1500 kg DM/ha to optimize pasture growth. This pasture management should allow for cows on the high stocking rate systems to maintain moderate milk production, compared to systems in which high stocking rate treatments are not supplemented, leading to decreased milk production (Macdonald et al., 2008). Due to the use of this grazing management strategy, Farina et al. (2011) did not find any difference between treatments for total pasture utilized.

Farina et al. (2011) established that the milk production per ha increased with both increased stocking rate and that the combination of high stocking rates and supplementation. The system with increased stocking rate (HSR) led to a proportional increase in milk production/ha of 49%. The system with the combination of both higher stocking rates and supplementation (HH) led to a proportional increase in milk production/ha of 66%. Interestingly, the increase in stocking rate did not affect cow performance at either high or low target levels of milk yield/cow, although at each stocking rate level, milk yield/cow was higher for the high milk yield groups (HH, HMY).

The high milk/cow systems maintained a higher mean BCS ($P<0.0001$), but this higher BCS did not lead to increased reproductive performance, indicating that the cows were receiving excess feed to the requirements for normal reproductive performance. The high BCS also indicates a higher marginal efficiency of supplements for the HSR system. The lack of response in milk production and increased body condition score may also indicate a low to moderate genetic merit of the cows used in this study, which may also influence the feed conversion efficiency of the farming system.

Optimizing feed conversion efficiency (FCE) in grazing dairy systems is challenging. The FCE is generally evaluated as kg of energy-corrected milk (ECM) per kg DM consumed or utilized by animals. Inclusion of the North American Holstein genotype in grazing systems has potential to increase the FCE because of their high milk response when feed availability is not a limiting factor (Kennedy et al., 2003; Horan et al., 2005). The North American Holstein genotype was selected on high energy TMR diets, and their production on pasture is limited due to behavioral and physiological constraints that limit intake (Kolver et al., 1998; Bargo et al., 2002). As previously mentioned, Kennedy et al. (2003) determined that there is not much difference between genetic merit in total pasture intake when North American and New Zealand Friesians are offered unlimited amounts of high quality pasture. Pasture allowance, biomass and structure determine the upper limit to total pasture intake in a grazing system. To take advantage of the high genetic potential of the North American dairy cow, supplements need to be added to increase energy intake and production, which will result in higher FCE. Proper pasture management will also increase FCE by ensuring the availability and quality of forage, which can impact milk yield and FCE (Beever and Doyle, 2001).

Beever and Doyle (2001) stated that the decrease in intake and milk production in grazing dairy cows increase the maintenance cost and, therefore, decrease FCE. A supplement with high metabolizable energy (ME) contents should increase milk production and FCE. However, at some point increasing supplementation may lead to high substitution rates and/or a curvilinear pattern for milk production and FCE due to negative associative effects. Tozer et al. (2004) found significant differences between supplemented and un-supplemented groups in FCE for milk yield but not for fat yield. Farina et al. (2011) also investigated the level of supplementation on FCE and found that there was no difference between the high and low supplementation groups.

In most dairy grazing systems, there is a relationship between stocking rate and FCE. McCall and Clark (1999) described a trade-off between pasture utilization and FCE, concluding that at higher stocking rate pasture utilization was higher, but FCE decreased. Tozer et al. (2004)

reported FCE for milk yield or milk fat did not decrease from pasture allowances of 40 kg DM/cow/day vs. 25 kg DM/cow/day (total intake differed significantly by 2.9 kg DM). The authors concluded that high genetic merit cows in grazing systems with low pasture allowance convert pasture DMI into milk or milk components as efficiently as in a high pasture allowance system. Farina et al. (2011) found similar results; no significant different in FCE with increasing stocking rates. Farina et al. (2011) credited the lack of difference to the maintenance of constant feed intake levels through a supplementation plan that covered pasture availability deficits. It was also noted that supplements in a high stocking rate system resulted in a higher marginal feed efficiency. However, the high yielding cow group had significantly higher BCS which was most likely the cause of the lack of difference in FCE as energy was partitioned to body reserves and not to milk production.

Integration of AMS and Farm Efficiency

To increase farm efficiency in pasture-based AMS dairies, one must balance all aspects of the farm. Supplementation of cow diets with concentrates will increase milk production per cow and FCE, but that requires very high levels of concentrate supplementation (greater than 10 kg of concentrates) and undesirable associative effects may occur (Reis and Combs, 2000; Bargo et al., 2003). Ultimately, high levels of concentrate supplementation can decrease milk production and FCE (Walker et al., 2011). Supplements, particularly forages, may cause substitution and decrease pasture intake (Bargo et al., 2003). However, forage supplements may be used to maintain post-grazing pasture residuals and improve pasture growth and utilization by preventing overgrazing, which is particularly important during periods or seasons of low pasture growth (Fulkerson et al. 2005). Increasing stocking rates may decrease pasture intake and milk production and FCE per cow, but increases forage utilization and milk production per hectare (Macdonald et al. 2008). In pasture-based systems with AMS, the increase in stocking rate may increase AMS occupation and milking efficiency if the number of cows allotted to an AMS or the stocking rate of the AMS is a limiting factor (Jago et al., 2007). New Zealand based genetics may require less feed to reach their genetic potential, which improves BCS and reproduction performance (Fulkerson et al., 2008), but North American Holsteins are high yielding and have potential to increase milk production due to their higher marginal response to high quality pasture and energy concentrates. Increasing milk production per visit or milking intervals in the AMS will increase milking duration, possibly decreasing the number of total milkings per robot per day (Andre et al., 2010), and potentially decreasing milk production per robot if no adjustments in the AMS stocking rate (cows per AMS) are made (Jago et al., 2007). Farmlet studies have the opportunity to investigate the consequences of stocking rates, grazing management, supplementation and genetic merit on the overall efficiency of the farm. Further investigation is required to determine the necessary conditions to maximize farm efficiency in pasture-based systems using AMS. This could be a particularly important alternative to decrease inputs and labor costs that may help small and medium sized dairy farms remain profitable in Michigan.

APPENDIX

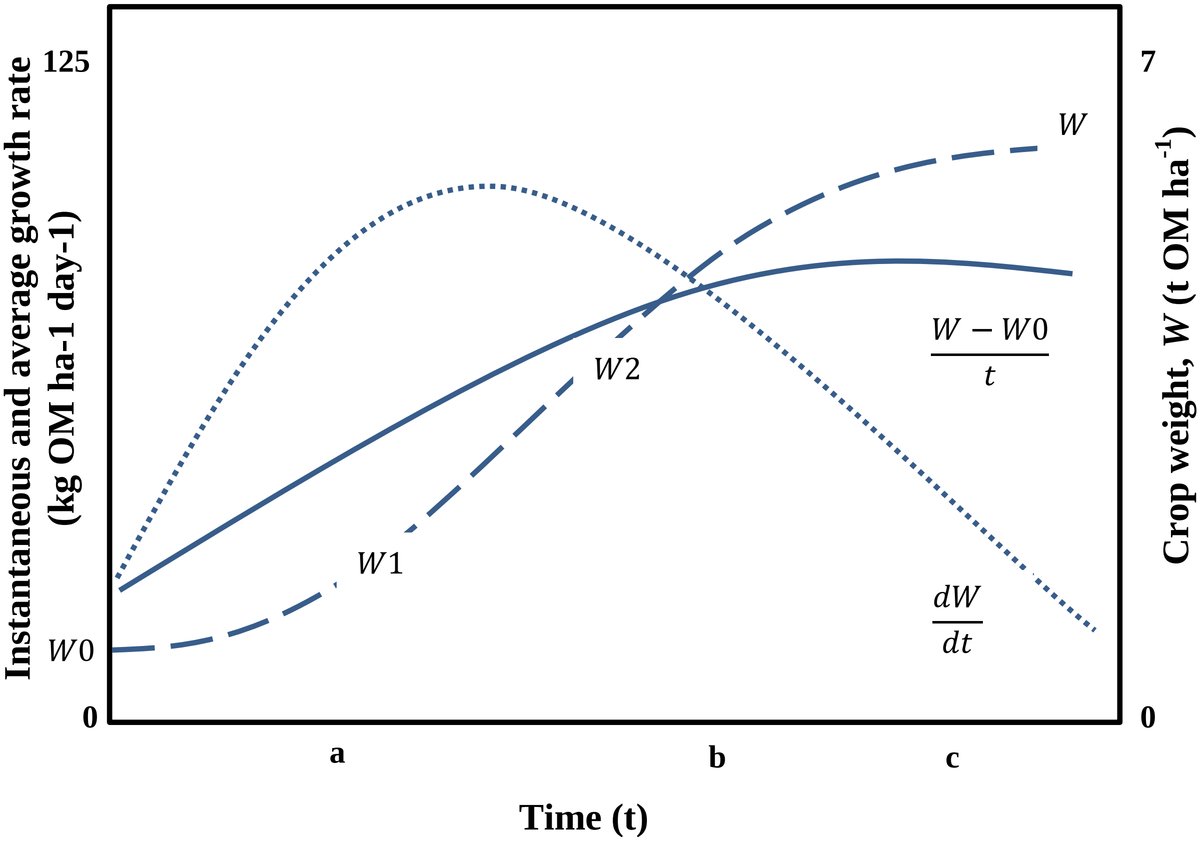

Figure 1.1. The change in pasture instantaneous growth rate (dW/dt), the weight of the forage (W), and the average growth rate $(W\text{-}W_0)/t$ (based on Parsons 1998). Grazing at maximum yield would occur at time ‘c’ from a single period of regrowth between $W\text{-}W_0$. Harvesting the sward at time ‘a’ would interrupt pasture growth when instantaneous growth rate was at maximum, but the amount of forage harvested would be reduced. Maximum utilization is achieved when the forage is harvested when the average growth rate $(W\text{-}W_0)/t$ is at maximum. Maximum average plant growth rate is identified at time ‘b’.

For interpretation of the references to color in this and all other figures, the reader is referred to the electronic version of this thesis.

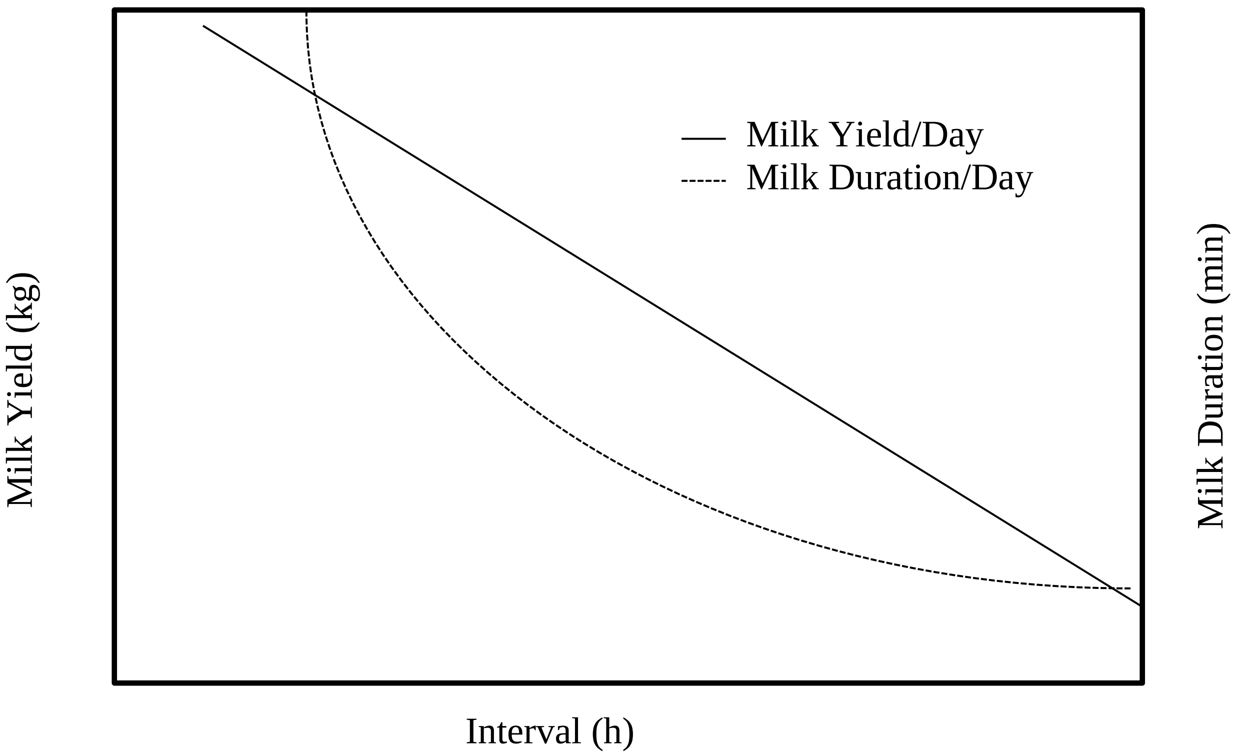

Figure 1.2 Effects of milking interval on milk yield and milking duration per day (Andre et al., 2010).

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CHAPTER 2

EFFECTS OF STOCKING RATE AND DIET SUPPLEMENTATION ON THE PERFORMANCE OF TWO GENOTYPES OF HOLSTEIN FRIESIAN COWS IN A PASTURE-BASED AND AUTOMATIC MILKING SYSTEM

ABSTRACT

Despite the numerous investigations of Automatic Milking Systems (AMS) in recent decades, management guidelines for the proper integration of this technology into a pasture-based system are not yet well developed. The study objective was to determine the effects of stocking rate and supplementation strategies on milk yield, milk quality and milking frequency of mid-lactation cows managed in an AMS pasture-based system. A farmlet-based experiment lasting 8 wk was conducted using a completely randomized design with a 2 x 2 factorial arrangement of two stocking rate systems and two genotypes of Friesian cows, United States Holstein (USH) and New Zealand Friesian (NZF). At study onset, fourteen mid-lactation (154 ± 25 DIM; mean ± SD) USH (BW: 564 ± 38 kg; Parity: 1.43 ± 0.10; mean ± SD) and NZF (BW: 393 ± 27 kg; Parity: 1 ± 0; mean ± SD) cows were randomly assigned to one of two SR treatments, a low stocking rate treatment (LSR; 1.92 cows/ha) and a high stocking rate treatment (HSR; 2.89 cows/ha). The HSR treatment received a partial mixed ration (40% ground corn and 60% legume grass haylage) in variable amounts (average: 4.86 kg /cow ± 0.14; mean ± SEM) to supplement deficits in pasture growth rate and availability across the 8 weeks of the study. In the two stocking rate treatments cows received 1 kg of pellet concentrate (ME: 0.65 Mcal, CP: 17.61%, NDF: 42.81%) per 6 kg of milk in the AMS stall and 1.36 kg of grounded corn. Cow performance responses included milk production and milking frequency and were analyzed as repeated measures using a mixed model. Several significant differences ($P < 0.05$) existed between genotypes, indicating important differences in genetic merit particularly for milk production (15.3 and 27.9 g/cow per d, ± 1.3 SEM) for NZF and USH, respectively, $P < 0.0001$). However, few differences existed between stocking rates, with no significant difference between milk yield per cow (20.85 and 22.41 kg/cow per d, ± 1.11 SEM for LSR and HSR, respectively). There was a significant time effect, as well as time by treatment interactions related to changes in pasture availability and quality throughout the study. As predicted, few differences were detected between stocking rates, but both the duration of grazing and the genotype resulted in strong differences in milk production and use of the AMS system.

Keywords: pasture-based, stocking rate, genotype, automatic milking systems

INTRODUCTION

Despite the extensive research conducted in recent decades on AMS, few evaluations of the performance of this technology have been conducted in a pasture-based system. This information is still particularly important to develop appropriate management guidelines for the successful integration of AMS in dairy systems where grazed pastures remain as the main dietary component of cow diets.

Multiple management and animal related factors could potentially affect the efficiency of AMS in pasture-based systems. The stocking rate of pastures and the stocking rate of the AMS (cows per AMS stall) could influence cow traffic, milking frequency, and overall AMS occupation. Pasture stocking rate and supplementation strategies are two grazing management factors that have potential to affect pasture utilization, feed intake and milk production (Fales et al., 1995; Farina et al., 2011).

Previous grazing studies show that the number of milking visits and total AMS occupation (i.e. time that the AMS spent milking) are not strongly affected by the amount of supplemental feed offered in the AMS milking barn (Sporndly and Wredle, 2004) or by levels of concentrate supplementation delivered in the AMS (Jago et al., 2007). However, conclusions on AMS performance developed from the comparative analysis of different pasture-based systems are difficult due to the large differences in feeding and grazing practices, management of the AMS, and cow genotype used.

Recent research has focused on the comparison of different genotypes of Holstein dairy cattle and their adaptability to different feeding practices in a pasture-based system (Buckley et al., 2000; Kennedy et al., 2003; Horan et al., 2005; Fulkerson et al., 2008). In most of these studies, the genotype of cows was tested using conventional milking, therefore direct extrapolations of cow performance to an AMS using free traffic and voluntary grazing systems are difficult to conduct. The AMS milking efficiency could be significantly impacted by the genetic potential of cows, through differences in milking intervals, milk yield and the overall AMS use.

The objective of the present study was to determine the effects of stocking rate and dynamic feeding of supplemental TMR on pasture utilization, feed intake, milk production and milking distribution of two genotypes of Holstein Friesian cows in a dairy system using the same AMS milking stalls. Specific predictions were that: 1) Dynamic supplementation would not affect pasture utilization, total feed intake, or milk production, but would alter the visitation patterns to the AMS; and 2) The United States Holstein genotype would out-perform the New Zealand Friesian genotype in milk production.

MATERIALS AND METHODS

Animals, Experimental Design, and Treatments. The study was conducted at the Michigan State University's Pasture Dairy Research Center (PDRC) located at the W.K. Kellogg Biological Station, Hickory Corners, MI, during the months of July, August, and September of 2011. Protocols for animal handling and husbandry have been previously approved by the Michigan State University's IACUC office. The PDRC has 64 ha of pasture growing on soils that consist mostly of sandy loam of the Kalamazoo loam soil series (USDA-NRCS, 2009). The mean annual precipitation ranges from 760 to 915 mm, the mean annual air temperature ranges from 7 to 9ºC, and the frost-free period ranges from 140 to 150 d.

The study employed a completely randomized design with a 2 x 2 factorial treatment arrangement of two genotypes and two stocking rate systems: a high stocking rate system (HSR, 2.89 cows/ha) and a low stocking rate system (LSR, 1.92 cows/ha). Fourteen United States Holstein cows (USH) and 14 New Zealand Friesian cows (NZF) were randomly assigned at study onset to one of two stocking rate treatments. A partial mixed ration (PMR) of 60% legume grass haylage and 40% ground corn supplemented the cows' diets in the high stocking rate system. The amount of PMR fed was adjusted weekly and was used to supplement any deficit in pasture growth rate (PGR) and availability. The supplementation criterion for target pasture intake per cow was 14 kg DM/d or approximately 36.4 Mcal of ME from grazed pasture. Based on this criterion, PMR supplementation occurred weekly if PGR and/or pasture availability for grazing were lower than the expected values (PGR x SR). Target PGR values were 26.88 kg/ha/day (1.98 cows/ha x 14 kg/cow per d) or 40.46 kg/ha per d (2.98 cows/ha x 14 kg cow/d) for the LSR and HSR treatments, respectively. Similarly, the total amount of PMR fed in a given day was the deficit between pasture availability and the target pasture intake. The diet of cows in the LSR treatment included 1 kg of pellet concentrate per 6 kg of milk (Table 2.1) fed in the AMS and 1.36 kg of ground corn fed at the automatic Cosmix feeder (Lely Cosmix, Lely Industries, N. V., Maassluis, Netherlands). The HSR treatment included the same pasture and concentrate feeding system as LSR plus the addition of the PMR fed at the bunk. The PMR was fed at 0500 h daily and consisted of 60% legume-grass haylage and 40% ground corn mixture (Table 2.2). As indicated above, the PMR amount fed was adjusted weekly based on weekly changes in pasture growth rate. Therefore the amount of PMR fed varied by week, but average was 4.86 ± 0.14 kg DM/cow/day (mean ± SEM) during the study.

Milking Barn and Pasture Layout. The milking barn was a split free stall barn equipped with two automatic milking systems (AMS, Lely Astronaut 3, Lely Industries, N. V., Maassluis, Netherlands), two automated grain feeders (Lely Cosmix, Lely Industries, N. V., Maassluis, Netherlands), two automatic manure scrapers and free stalls equipped with double chamber water beds. Based on the barn design, number of free stalls and feed rail space per side, this barn had capacity to house and milk two separate herds of approximately 60 cows each in a free traffic system.

Two automated gates (Lely Grazeway, Ley Industries, N. V., Maassluis, Netherlands) and split two-way lanes controlled the free traffic of cows between the pastures and the milking barn (Figure 2.1). The freestall allowed for free traffic; cows had free access to stalls, the AMS, or pasture if the criteria for exit had been met. Pasture access was monitored by the automated gate which allowed cows to leave the free-stall milking barn if they had been milked within a set milking interval given by a minimum and maximum number of milkings per day, or if their expected milk production was less than 9 kg, whichever applied first. Maximum and minimum number of milkings per day were: 5 and 4 for cows < 30 DIM: 4 and 3 for cows between 31 and 30 d prior to dry off, and, 3 and 2 for cows with less than 29 days prior to dry off. Dry off occurred at 256 DIM.

Pastures and grazing management. The LSR treatment had access to twenty-four 1 hectare strips (Figure 2.2). Sixteen of the 24 strips were a mix of 5 dominant plant species (OG) including orchardgrass (*Dactylis glomerata*), tall fescue (*Festuca arundinacea*), alfalfa (*Medicago sativa*), white clover (*Trifolium repens*), and red clover (*Trifolium pratense*). The remaining 8 strips were a mix of 2 species (RG) including white clover and perennial ryegrass (*Lolium perenne*). The HSR treatment had access to sixteen 1 hectare strips. The strips contained the same OG and RG mixes as LSR, but there were 8 hectares of each pasture mixture in the LSR treatment. Fresh pasture allocations were opened for grazing at 0500 h every morning. Pastures were rotationally grazed based on approximate targets of 2,400 kg DM and of 1,600 kg DM for pre- and post-grazed biomass, determined by a rising plate meter. When necessary, pastures were grazed based on maturity, indicated by leaf number for grasses and flower maturity for legumes, in order to harvest the mature material and stimulate regrowth.

The HSR treatment had access to a fresh 0.5 ha at any one time. A temporary fence was used to prevent cows from grazing the second half of the 1 ha strip. On the second day of grazing the temporary fence was removed, opening the new allocation allowing cows to back-graze. The barn’s traffic exit system allowed for separating the cows' traffic to either north or south strips of the dairy barn (Figure 2.2).

Allocations were switched every other day from north to south for the LSR treatment, forcing cows to enter the barn before moving to the next allocation. The traffic was similar for HSR, except that they switched from north to south every two days because they stayed on one strip for two days. An attempt was made to balance distance to the dairy by alternating far and near pasture for both treatments, however, pasture maturity and biomass took precedence over distance. The PGR in the HSR and LSR treatment was measured weekly using a rapid pasture meter (C-Dax rapid pasture meter, C-Dax, Agricultural Solutions, Ltd., Palmerston North, NZ)

Feeds and pasture sampling. A composite haylage sample was taken from the bunk and ground corn samples were taken from the automatic feeder. A sample of each pasture species was taken weekly with clippings from three 50 x 50 cm quadrats taken both before and after grazing. Quadrat clippings were taken randomly, but spaced over the length of the entire grazing strip. The first quadrat was placed approximately 50 steps from the end of the pasture, the remaining quadrats were spaced approximately 50 steps from each other, resulting in one clipping taken from each third of the one ha strip. Forage samples were dried in a forced air oven for 48 h at 60°C and ground with a Christy mill through a 1 mm screen and stored for analysis of CP, NDF, ADF, and *in vitro* true digestibility.

Each week and one week prior to the study onset, biomass was recorded in the HSR and LSR treatments with a portable optical measurement system (C-Dax rapid pasture meter, Agricultural Solutions, Ltd., Palmerston North, NZ). The difference in biomass between weeks divided by the number of days determined the PGR of each strip. An average PGR was used to determine the amount of supplementation, so that the amount of PMR supplemented covered the deficit in PGR. If a pasture had been grazed in between readings it was not included in calculation of the average.

AMS Data Collection and Milk Samples. The AMS identified each cow by an assigned collar equipped with electronic ID and collected information on body weight, milk production, milking frequency, AMS visits, and amount of pellets distributed. Milk samples were taken three times during the study and analyzed for fat, protein, and milk urea nitrogen at the DHIA lab in Lansing, MI.

Pasture Measurements and Dry Matter Intake. An estimate of pasture pre- and post-grazing biomass was made with a rising plate meter (F300 plate meter, Farmworks, Palmerston North, NZ). The difference between the pre- and post-grazing biomass (i.e., the disappearance of pasture) was considered pasture harvested. The units for height measurements given by the plate meter are “clicks”; 1 “click” equals 0.5 cm of pasture compressed by the plate meter. The plate meter was calibrated in the previous year and the calibration factor to determine biomass (y) as a function of RPM clicks (x) in the orchardgrass, tall fescue, white clover, alfalfa, and red clover pasture was $y = 92\,x$. The factor to determine biomass in the ryegrass and white clover pasture was $y = 78\,x$. Pellet and corn consumption were known through AMS the computer system. An estimate of PMR intake per cow was made by dividing the total amount fed to the herd by the total number of cows in that treatment.

During week 4 of the experiment an indigestible marker, Cr_2O_3, was used to determine total dry matter intake (DMI). Twelve of the 14 experimental cows from each treatment were orally dosed with 10 g of Cr_2O_3 once daily for 10 days. In the final five days of dosing fecal grab samples were collected once daily at dosing. Fecal samples were dried at 55°C in a forced air oven. Samples were ground through a 1 mm screen and the grinder was cleaned with compressed air between samples to avoid cross contamination. Samples were combusted at 600°C for 2 h. The ash was dissolved in the crucible by a phosphoric acid-manganese sulfate solution and potassium bromate over a hot plate until effervescence ceased, approximately 30 min. Once the sample was cool it was washed into a beaker with distilled water and then poured into a 50-ml flask. Calcium chloride was added and the flask was brought to a volume of 50 ml with distilled water. Standards were made following the same procedure, with the exception of the use of a blank fecal sample and stock chromium added in concentrations of 0, 2.5, 5, 10, and 20 ppm. The standards were used to create a standard curve to derive the Cr content for the samples. Flame atomic absorption spectroscopy (AAS; Model 3100, Perkin Elmer, Waltham, MA) using an acetylene-air flame was used to measure Cr in the samples. The wavelength setting was set at 358 nm and fuel:oxidant ratio was 3.5:2.5. The AAS recorded five readings per sample and the average was used for calculations.

Fecal Cr concentration (ppm) was used to calculate fecal output by the equation: Cr dosed per day (6.842 g/Cr ppm in sample x 100)/1,000,000. Total dry matter intake was calculated by dividing the total fecal output by the percent indigestibility of the diet, determined to be 26.64%. Indigestibility was determined by 48 *in vitro* true digestibility (IVTD) of all feeds in the diet and their approximate amount in the diet. Total diet digestibility did not differ between the two treatments; therefore the same value of indigestibility was used for both.

Laboratory Analysis. Neutral detergent fiber (NDF) analysis was completed with the filter bag technique (Ankom 200 Fiber Analyzer, Ankom Technology, Macedon, NY). Filter bags (Ankom F57) with pore size of 25 microns were weighed and filled with 0.5 g of sample and sealed with a heat sealer (Model AIE-200, American International Electric Inc., Industry, CA). Sample preparation and NDF determination were conducted in duplicate. A premixed solution of NDF (30.0g Sodium dodecyl sulfate, USP; 18.61g ethylenediaminetetraacetic disodium salt, dehydrate; 6.81g sodium borate; 4.56 g sodium phosphate dibasic anhydrous) and 10.0 ml triethylene glycol were added to 1 L of distilled water. Twenty four complete filter bags and one blank were placed in the carousel and placed in the Ankom 200 vessel. The NDF solution, 4 mL of alpha amylase, and 20g of sodium sulfite anhydrous were added to the vessel.

The unit was set for 1 hour and 15 min with agitation, at a temperature of 100°C. After incubation, the unit and the samples were rinsed twice with water plus 4 mL of alpha amylase, and rinsed once with only water, for a total of three 5 min rinses. Samples were dried in a forced air oven at 60°C for 24 hours and reweighed. The equation for NDF determination was NDF% = $\frac{(W3-(W1\ x\ C1)}{W2}$ x 100, where W1 = bag tare weight, W2=sample weight, W3=dried weight of bag with fiber after extraction process, and C1 = blank bag correction (final oven dried weight divided by the original blank bag weight).

Acid detergent fiber (ADF) analysis was also completed with the filter bag technique (Ankom 200 fiber analyzer, Ankom Technology, Macedon, NY). After NDF was completed on the samples they were saved and kept for ADF analysis. An Ankom ADF liquid premix (20 g cetyl trimethylammonium bromide to 1 L 1.00/V H_2SO_4) was used and duplicate samples were heated to 100°C and agitated for 1 hour in the Ankom 200 vessel. After analysis, the samples were rinsed in the vessel 3 times for 5 min with water. Samples were dried in a forced air oven at 60°C for 24 hours and reweighed. The equation to determine % ADF was same as the previous equation given for NDF.

In vitro true digestibly (IVTD) was completed with the Ankom DAISY^{II} Incubator (Ankom Technology, Macedon, NY). The two buffer solutions for the procedure were made in the laboratory. Buffer Solution A combined 10.0 g KH_2PO_4, 0.5 g $MgSO_4 \cdot 7H_2O$, .05 g NaCl, 1 g $CaCl_2 \cdot 2H_2O$, and 0.5g of reagent grade urea in 1 liter of distilled H_2O. Buffer Solution B combined 15 g Na_2CO_3 and 1 g $Na_2S \cdot 9H_2O$ in 1 liter of distilled H_2O. The buffers were warmed to 39°C with a hot plate and combined in a 1:5 ratio. The amount of the combined buffer solution added was adjusted to obtain a final pH of 6.8 at 39°C. A total of 1600 ml of the combined A/B solution mixture was added to each digestion jar.

Two 2 L thermo bottles were warmed to 39°C with water and were not emptied until just before collection of rumen inoculum. Two ruminally fistulated cows managed under the same feeding systems as the experimental cows were used to collect approximately 4 L of rumen inoculum. A filter attached to a rubber tube was inserted into the rumen. The rubber tube was also attached to flask to capture the fluid. Another attachment on the plastic flask allowed for another plastic tube fitted with a rubber hand pump to create a vacuum. Fluid was taken from both cows and mixed in the thermos. From both cows approximately one fistful of rumen digesta was added to each thermos.

The inocula were brought back to the lab within 30 min and added to a previously warmed blender (39°C) and the fluid and the digesta were blended for approximately 30 sec. While blending, the blender was purged with CO_2. After blending, the inoculum was squeezed through four layers of cheese cloth and 400 ml of filtered inoculum was added to each warm digestion jar. The digestion jar was purged with CO_2 for 30 s and samples were added before sealing. Duplicate filter bags (Ankom F57, Ankom Technology, Macedon, NY) were weighed and filled with 0.5 g of sample material and sealed with an impulse sealer (American International Electric Inc., Model AIE-200, Industry, CA) before the IVTD procedure began. Blanks and standards were also included in each jar to determine correction factors and indicate possible variation between jars. The jars were placed in the incubator and rotated and heated to 39°C for 48 hours of incubation.

After incubation samples were soaked in cold water and rinsed by hand over a sink for approximately 2 min each. Samples were dried in a forced air oven at 60°C for 24 hours and reweighed. To calculate the % IVTD the following equation was used, % IVTD = $\frac{\left(100-\left(W3-(W1xC1)\right)\right)}{W2}$ x100; where W1 is bag tare weight, W2 is sample weight, W3 is final bag weight after *in vitro* incubation, and C1 is blank bag correction (final oven-dried weight/original blank bag weight).

Nitrogen determination was conducted by combustion using an automated analyzer (Costech Elemental Combustion System 4010 CN, Costech Analytical Techologies Inc., Valencia, CA). This system uses a helium carrier gas to bring combustion gases to a gas chromatographic separation column and thermal conductivity detector. Therefore, the results give the percentage N, which was multiplied by 6.25 to obtain the % CP. The analyzer uses a small sample size of 2 to 5 mg, weighed using a micro balance and packed into tin containers for analysis. Every run included a standard to detect variation between runs. CN analysis of samples was conducted in triplicate.

Statistical Analysis. Forage quality, pre- and post-biomass, grazing intensity, and pasture utilization were analyzed by least-squares ANOVA using the MIXED procedure of SAS (Version 9.2, SAS Institute Inc.). Weekly measurements were analyzed as repeated measures. The covariance structure of models was previously tested and the selection among UN, CS and AR(1) covariance structures were determined based on the lowest Akaike’s Information Criterion and Bayesian Information Criterion (Little et al., 1996). Kenward-Rogers was the method used for estimation of degrees of freedom. Individual strips were considered experimental units. The fixed effects were treatment, species, genotype x treatment, week, treatment x week, species x week, and species x week x treatment. The random effect was the individual strip within each species by treatment group.

Cow performance data were analyzed by least-squares ANOVA using the MIXED procedure of SAS (Version 9.2, SAS Institute Inc.). Weekly data on milk yield, milking frequency, and weight were analyzed as repeated measures. Following Little et al. (1996) the covariance structure of models was previously tested and the selection among UN, CS and AR(1) covariance structures determined based on the lowest Akaike's Information Criterion and Bayesian Information Criterion. Kenward-Rogers was the method used for estimation of degrees of freedom. Individual cows were considered as the experimental unit for animal-related variables, as is common in whole farm systems. For the animal related measurements the fixed effects were treatment, genotype, genotype x treatment, week, treatment x week, genotype x week, genotype x week x treatment. The random effect for the animal related measurements was the individual cow within each genotype by treatment group.

Analyses of milking distribution and milking interval data were done using the FREQUENCY procedure of SAS (Version 9.2, SAS Institute Inc.). In this procedure a Chi-squared test was used to determine the frequency of milkings at a particular hour and the frequency of milkings at a particular interval. All milking failures (i.e. unsuccessful teat cup attachment) and the 7 milkings following a milking failure were removed from the analysis, as they may not be considered normal milkings (Bach and Busto, 2005).

RESULTS

Pasture and forage quality. There were no stocking rate effects on pasture biomass. However, significant variation across weeks was detected in the pre-grazing and post-grazing pasture herbage mass (Figure 2.3). The difference over weeks is likely caused by changing environmental conditions and precipitation that occurred at the trial onset. Environmental conditions became more favorable, encouraging plant growth as indicated by sharp increases in pasture biomass by week 3 of the study in both the HSR and LSR treatments (Figure 2.3). Significant differences were detected between pasture species for CP, NDF, ADF, and %IVTD ($P < 0.05$; Table 2.2).

Cow milk performance and milk composition. Milk production per day was significantly affected ($P = 0.03$) by a stocking rate (SR) by genotype by week interaction (Figure 2.4), while there was a marginal tendency ($P = 0.09$) for a SR by genotype by week interaction effect on MF (Figure 2.5). Despite the differences in milk production and milking frequency, energy corrected milk (ECM) production was not affected ($P = 0.15$) by a SR by week by genotype interaction, but significant differences in ECM were detected between genotypes (Table 2.4).

Milk production showed a significant genotype by week interaction ($P < 0.0001$; Figure 2.4), while MF showed only a tendency ($P = 0.06$) to decrease in NZF cows by the end of the study (Figure 2.5). A significant ($P = 0.0032$) treatment by week interaction (Table 2.4) was seen for milk fat, likely explained by the increase in milk fat for the low stocking rate treatment (LSR) and decrease in milk fat in the high stocking rate treatment (HSR). Milk urea nitrogen and protein did not show any significant SR by week interactions. Milking frequency had a significant treatment by week interaction ($P = 0.0002$). Milk production had a tendency towards significance for a SR treatment by week interaction (*P* = 0.09), likely explained by a more steady milk production by cows in the high stocking rate treatment receiving PMR supplementation.

The only milk composition variable that demonstrated a treatment by genotype interaction was milk urea nitrogen (MUN; *P* = 0.0013); cows in the LSR-USH group (15.46 ± 0.65 mg/dl) had a higher MUN compared to the cows in the HSR-USH group (12.78 ± 0.66 mg/dl). Across stocking rate treatments, the MUN was 13.62 ± 0.46 mg/dl and 15.7 ± 0.46 mg/dl for LSR and HSR, respectively. Across genotypes, MUN was 14.12 ± 0.46 mg/dl and 14.66 ± 0.46 mg/dl for USH and NZF, respectively. There was a marginal tendency (P = 0.08) for milk fat percent to be higher in the LSR (4.04 ± 0.12%) than in the HSR treatment (3.75 ± 0.12%).

Significant differences in milk production and AMS milkings between genotypes existed (Table 2.3). The USH cows had higher (*P* < 0.0001) milk production (27.92 ± 1.33 kg) than NZF cows (15.34 kg ± 0.83 kg). The USH cows voluntarily milked at the AMS with higher (*P* =0.02) frequency (2.51 ± 0.07 milkings/day) than NSF cows (2.25 ± 0.07 milking/day). Conversely, milk fat and milk protein percentages were higher for NZF (milk fat: 4.21± 0.12%, milk protein 3.34 ± 0.09%) than USH cows (milk fat: 3.58 ± 0.12%, milk protein 3.05 ± 0.09%).

Significant differences in feed intake and feed conversion efficiency (FCE) were also detected between the two genotypes (Table 2.4). Intake of pellet concentrate, forage intake (pasture only or pasture plus PMR), and total feed intake were higher for USH than NZF cows. On average, the USH cows consumed a total of 22.32 ± 0.82 kg of DM, whereas the NZF cows consumed 16.30 ± 0.82 kg of DM. Interestingly, differences in feed intake disappear when intake is corrected by differences in body weight (Table 2.4). Differences in milk production and feed intake reported above resulted in significant differences in FCE between genotypes (Table 2.4). The FCE was higher (*P* = 0.01) for USH (1.24 ± 0.06 ECM/kg DM/d) than NZF cows (1.01 ±

0.06 ECM/kg DM/d). Differences in CP, NDF, and ADF intake between genotypes (Table 2.5) were also detected as a consequence of the differences in feed intake reported above.

Differences in milking distribution and milking intervals existed between SR treatments and genotypes. As shown in figure 2.6, AMS occupation between 0300 and 0400 h was always low regardless of the stocking rate treatment, but feeding of PMR at 0500 h in the HSR treatment enticed cows to increase utilization of the AMS from 0500 to 0900 h. Cows in the LSR treatment increased the use of the AMS from 0600 to 1000 h and maintained a steady use of the AMS unit from 1100 to 2100 h. The PMR feeding in the HSR treatment also resulted in shorter intervals and very few milkings exceeding 16 h (Figure 2.7). Conversely, milking intervals were more variable for the LSR treatment (Figure 2.7)

Genotypes differed significantly in their use of the AMS, both for distribution of milkings and milking intervals. Visitations for USH peaked at hours 0700 to 0900, 1600 to 1700, and 2300 to 2400. Conversely, visitations for NZF peaked at hours 1100 to 1300, 1900 to 2200, and 0500 to 0600 (Figure 2.8). There was also a difference in milking interval between genotypes. Intervals for USH were shorter and had fewer milking intervals that exceeded 10 hours, while NZF had longer milking intervals and more that exceeded 10 hours compared to USH (Figure 2.9).

DISCUSSION

Cow Performance. The main effect of week was significant for nearly all cow performance variables, except milk fat % and kg fat /d. This time effect was related to changes in soil water availability and resultant differences in forage growth and availability. At study onset, low precipitation and low soil moisture negatively affected pasture growth rate and pasture availability (Figure 2.3), thereby reducing pasture intake and milk production (Figure 2.4). As the study progressed and soil moisture was replenished by rainfall, pasture biomass (Figure 2.3) and milk production recovered.

All cow performance parameters were significant for the main effect of genotype, except milk urea nitrogen (MUN). As expected USH had a higher milk, protein, and fat yield, while NZF had higher % protein and fat. MUN was affected by a SR by genotype interaction. The values for MUN in USH cows were higher in the LSR treatment (15.46 mg/dl) than in the HSR (12.78 mg/dl) treatment, whereas MUN values for NZF cows were higher for the HSR (15.7 mg/dl) treatment than for the LSR (13.62 mg/dl) treatment. In similar studies un-supplemented USH cows have, in general, higher levels of MUN. Bargo et al. (2002a) reported MUN levels of 13.9 and 11.6 mg/dl for un-supplemented and supplemented cows receiving 8.6 kg concentrate. In another study, feeding pasture plus concentrate (PC) or pasture plus total mixed ration (PMR). Bargo et al. (2002b) found MUN levels of 14.9 and 12.0 mg/dl for PC and PMR, respectively. In both studies, MUN decreased with supplementation with either concentrates or total mixed ration. This response was detected in the USH cows in the present study, but the opposite occurred with the NZF cows. It is possible that the combination of the higher proportion of ryegrass and white clover pastures containing higher levels of crude protein (Table 2.2), together with lower eating drive and reductions in PMR intake by NZF cows, may have resulted in higher pasture consumption and MUN levels. The PMR supplementation may decrease CP in diets as compared to a pasture only diet, or the starch from the PMR (PMR was 40% grounded corn) may have increased the capture of ammonia nitrogen in the rumen of USH cows. This mechanism of nitrogen capture was probably absent in the NZF due to lower PMR consumption. The PMR intake for USH and NZF cows was derived from average group estimates, as no individual PMR intake measurements were collected

Near peak milk production was reached sooner in HSR (week 3) compared to the LSR treatment (week 4; Figure 2.4). This increase in milk production was quicker for USH than NZF cows, which indicates higher milk production response to PMR supplementation, particularly when pasture availability was low (Week 1 to 4 of the study). Stockdale (1994) indicated supplementation with corn silage resulted in a marginal response of 1.2 kg milk of milk for each of the first 4 kg DM of silage offered, but no response in milk production was detected when supplementation exceeded 4 kg of corn silage. The review by Phillips (1988) also showed increases in total intake with forage supplementation but only if the forage supplement is of higher quality than the pasture offered. Conversely, if forage quality of the supplement is lower than the pasture offered, intakes may decrease. Phillips (1988) suggested that the use of a forage-based supplement was appropriate when low pasture allowance limits intake. This may be true only for the first four weeks of this study, when a marginal milk production response to PMR supplementation was detected. Once pasture availability recovered, the milk response appears to be non-existent due to high pasture allowance and the similar quality between the PMR and pasture forage (Table 2.2).

In this study the supplemental PMR containing 60 % forage and 40% concentrate was used to compensate deficits in forage growth and availability. This combined use of alfalfa haylage forage and concentrates (Table 2.2) in a PMR may not cause the same effects as supplementing the diet with either haylage or concentrates alone. Bargo et al. (2002) compared treatments of pasture plus concentrate (PC) and pasture plus TMR (PMR) and found intakes to be higher in the PMR treatment compared to the PC treatment (21.6 and 25.2 kg/d for PC and PMR, respectively). Milk production was also higher in PMR than PC treatment (26.9 and 32.0, for PC and PMR, respectively). It is important to note that the PMR diet in Bargo's study consisted of 15.5 kg/d of PMR. In the present study the amount of PMR fed averaged 4.8 kg/d. This lower level of supplementation, together with the adjustments in PMR fed based on the change in pasture availability and growth, may have explained the lack of response in both feed intake (Table 2.4) and milk production (Table 2.3)

Milk production exhibited a significant triple interaction among SR, week and genotype, but no main effect for SR was detected. This triple interaction is most likely the result of genotype x environmental interactions, since PMR supplementation in HSR resulted in steeper increases in milk production in the early weeks of the study only for USH cows. Other factors may be contributing to the triple interaction. There is a small amount of milk response of the NZF in HSR from supplementation and also a minimal response in NZF-LSR due to recoveries in pasture quality and quantity over time. Due to the lower overall requirements of NZF cows, dry matter intake and milk production were not affected by the low pasture allowance in the beginning of the study. This finding is supported by Horan et al. (2005), in which supplementation created a low milk response and increased substitution for similar NZF genetics. The lack of response in milk production is believed to be related to the lower genetic merit of this genotype of Holstein cattle (Horan et al., 2005).

Table 2.4 shows the estimated intakes for both SR and Genotype. The technique used chromium oxide as an external marker, possibly resulting in a 10% overestimation of total dry matter intake (Holden et al., 1994). As expected no significant differences were seen between SR treatments. However, significant differences existed in estimated forage DMI between genotypes (16.30 and 22.32 kg DM/cow per d for NZF and USH, respectively). Table 2.5 shows the estimated ADF, NDF, and CP in the farmlets. Intakes for PMR for USH were estimated based on the total amount fed divided by the number of cows. Intakes for PMR for NZF were calculated based on the percent intake of PMR by USH. Therefore Table 2.5 shows rough estimates, but is shown to give a general idea of the estimated quality of the diet and intakes in both stocking rate systems.

An estimate of feed conversion efficiency (FCE; kg of ECM produced per kg of feed DM) is given in Table 2.4. There were no significant differences between SR treatments, but significant differences existed between genotypes (1.01 and 1.24 for NZF and USH, respectively). The difference between genotypes is most likely due to the increased genetic potential in USH, and perhaps the slight difference in parity between genotypes. It has been proposed that there is a trade-off between stocking rates and FCE; this trade-off is quite often the result of reduced production per cow at high stocking rates (McCall and Clark, 1999). Tozer et al. (2004) proposed that diet supplements could be used to increase milk production per cow by increasing intake. The increase in intake and milk production would help dilute maintenance requirements of the cow and increase FCE (Beever and Doyle, 2007). The current study showed no difference between SR, therefore supplementation added enough energy to compensate for high stocking rates and maintained FCE. In the present study PMR supplementation was strategically used to compensate deficits in pasture availability in the HSR system. Therefore, adjustments in both quality and quantity of PMR fed have been used to minimize any adverse substitution of pasture by supplement. This study therefore suggest that timely management of PMR supplementation in HSR dairy systems could be used as a tool to manage feed intake and milk production without severely affecting pasture utilization (i.e. total forage consumed per area).

Milking frequency. Average milking frequency (MF) per day and number of refusals per day are reported in Table 2.3 Frequency of voluntary milkings differed between genotypes, but not between SR, as predicted. Interestingly, at the beginning of the study MF is nearly the same for each group (2.6 milkings/day), except NZF HSR, which started at 2.4 milkings/day. Other than the drop in MF in week five for USH HSR, the HSR treatment maintained MF, ending at the nearly the same MF in which they started. The USH LSR group declined in MF, but after week 4 remained relatively constant. However, NZF LSR decreased in MF almost linearly over the 8 weeks (from 2.6 to 1.75 milkings/day). All groups began to decrease in MF by week 8, possibly due to increase in DIM or perhaps due to change in environmental factors such as cooler temperatures or shorter day length.

The data on milk production (Figure 2.4) and MF (Figure 2.5) suggest that milk production was not directly related to increases in MF. As the study progressed, milk production may have increased as a result of increased pasture quality and availability, because MF did not exhibit important changes over time except for NZF cows in the LSR treatment. At study onset, both MF and refusals were relatively high, probably because low pasture availability or high temperatures during daylight enticed cows to seek more feed resources from the AMS (i.e., feed pellets). As the study progressed and temperatures dropped and forage quality and quantity in the pastures recovered, refusals begin to decrease, indicating that cows were spending more time grazing on pasture. However, towards the end of the study (fall season) there was a decrease in milk production for both USH and NZF cows in the LSR treatment, probably related to decreases in MF. Interestingly, the NZF-LSR group started with a high MF and had a linear decline in MF compared to the NZF-HSR group, yet MP was not greatly affected until week 7. This change in MF may indicate that for NZF cows higher MF was not resulting in higher MP. An increase in MF without an increase in MP reduces AMS efficiency, since the extra time spent in the AMS did not result in any additional milk production. However, a large decrease in MF into fall created a steep decrease in MP for the NZF-LSR cows. The PMR feeding may have given cows more motivations to return to the barn and visit the AMS. Lack of additional PMR supplementation in the barn together with lower levels of pellet supplementation in the AMS in response to the lower milk production in later stages of lactation, may have caused the NZF cows in the LSR treatment to visit the AMS less frequently.

The NZF-HSR cows may have maintained their MF throughout the study because the PMR motivated them to return to barn and visits the AMS regularly. Although the results were not significant, USH-LSR had numerically fewer refusals than NZF-LSR cows (0.89 and 1.53 refusals/day for USH-LSR and NZF-LSR, respectively). The refusals for the NZF-LSR group are actually the same as the NZF-HSR group and not significantly different from USH-HSR (1.54 and 1.83 refusals/day for NZF-HSR and USH-HSR, respectively), but MF is still lower for NZF-LSR. It appears that NZF-LSR were visiting the AMS, but not during the qualified time or at regular intervals. The low refusals for USH-LSR show that they are not visiting the AMS often enough to be refused, perhaps the higher eating drive of USH-LSR and lack of PMR supplementation forced high producing Holsteins to graze longer hours. The low refusals for USH-LSR may indicate that they are using their time more efficiently, in the pasture, or that their grazing and visitation patterns differ from USH-HSR, due to the lack of PMR supplementation.

Milking interval also affects MF, MP, and AMS utilization. In the current study milking interval did not differ between treatments (Table 2.3). Jago et al. (2007) examined the management strategy of increasing milking interval for low producing New Zealand Holstein Friesians. As it would be expected, decreases in MF were correlated with increases in MP per milking. The MF of cows managed with milking intervals of 6 or 12 h was 1.92 and 1.43 milkings/day, respectively. Despite this difference in MF, the amount of milk produced was not significantly different and was 22.78 and 23.27 kg/d for the cows in the 6 h and 12 h intervals, respectively.

The NZF cows in the current study, all in their first parity, produced milk at an average rate of 15.34 kg/cow per d, with a MF of 2.25 and a milking interval of 10.67 h. As MF decreased for NZF LSR, MP did not decrease until late in the study, indicating that increases in MF did not result in any additional milk. This observation is supported by Jago et al. (2007), in which MP did not change with decreased MF for low producing NZF cows grazing ryegrass pasture. Therefore, as genetic merit for milk production decreases, cows may require longer milking intervals to maintain a high level of milk production per milking. The study by Jago et al. (2007) suggested that an increase in number of cows and the use of prolonged milking intervals between 16.9 and 18 h increased milk production per robot in grazing systems using NZF or low-producing dairy cows.

The availability of PMR may have enticed cows in the HSR treatment to maintain their MF. Sporndly and Wredle (2004) examined the effects of distance to pasture and level of supplementation on MF and MP. The treatments in the study were near pasture (NP; 50 m from the barn), a distant pasture (DP; 260 m from the barn), and a distant pasture plus *ad libitum* silage supplementation in the barn (DP+S). Both NP and DP received a small amount of silage, 3 kg DM of silage per cow, in the barn, so it is not possible to determine if silage supplementation increased MF since there was no un-supplemented treatment. However, the amount of supplement offered did not affected MF. Further, similar to our study, cow behavior changed over the grazing season. Early in the season, Jun 5 to Jul 13, the milking frequency was the same for DP and DP+S (2.3 milkings/day, MP), although significantly different compared to NP (2.5 milkings/day). Milk production was not significantly different between DP and DP+S (26.4 and 26.1 kg/d, for DP and DP+S) but was significantly higher in NP (30.5 kg/day). Also, Sporndly and Wredle (2004) found that in the DP and DP+S treatments, cows spent less time grazing and showed reductions in milk production. This decrease in MP occurred despite the increase in MF in DP (2.5 milkings/d), which may suggest an attempt of these cows to increase intake from the feed delivered by the AMS unit. These results show that the cows' motivation to travel the distance to pasture changed over the grazing season and that offering *ad libitum* silage was no more effective as offering 3 kg of silage DM in the barn to entice cows to visit the AMS regularly. In the current study a change over time was also seen, indicating that in a system where cows have more free choice, a better understanding of their behavior is required to maintain milk production and AMS efficiency.

The addition of a PMR did change the distribution of milkings. This distribution was similar for both SR treatments, but higher frequency of shorter milking intervals was observed for the HSR treatment. This difference is most likely due to the feeding of the PMR at 0500 h, motivating cows to return to the barn. There is a diurnal pattern shown by the reduced number of milkings from 0200 to 0500 h.

The average milking interval appears to be slightly longer for LSR, however, the interesting difference was the frequency of longer milking intervals. The percent of intervals above 23 hours for LSR was 1.19 %, which was low, but HSR did not have any milkings over 23 h. Thus feeding PMR in the barn may decrease the frequency of long intervals, since the PMR was motivating cows to return to the barn at a certain time every day. Perhaps, feeding and milking patterns in the HSR treatment were more synchronized compared to the LSR treatment, and this synchronization may have resulted in more regular milking intervals and milk production.

Genotype. Genotypes role on milk production and AMS utilization was examined in this study. The average MP for USH was significantly higher than NZF (27.92 and 15.34, for USH and NZF, respectively), but this differential response was also affected by differences in parity. Parity was 1.3 and 1 lactations for USH and NZF, respectively. The MP for NZF is lower than other studies using cows with New Zealand genetics (Jago et al., 2007), most likely due to the low parity of these cows. The interest in NZF stems from their lower maintenance requirements and therefore better adaptation to pasture dairy systems where energy intake could be a limiting factor for milk production. Early in this study herbage availability was low (less than 2000 kg DM/ha), which may have caused the low MP in USH. However, NZF did not increase MP once pasture conditions improved, suggesting that NZF cows had lower energy requirements and are better suited for conditions where pasture availability per cow is lower. Conversely, a response in MP was clearly seen in USH when pasture availability increased from week 1 to week 4 of the study (Figures 2.3 and 2.4). The MP for USH is similar to other USH studies grazing high producing Holstein cows (Bargo et al., 2002a, 2002b, Kolver and Muller, 1998).Despite this increase in MP by USH cows, their potential maximum MP was not achieved in this study, particularly because grazing behavior often sets an upper limit to feed intake even in a situation where pasture availability and quality are high. In pasture-based systems using high producing cows, controlled supplementation with concentrates based on MP, parity, days in milk and/ or genotype could be used to improve MP performance of high producing dairy cows.

The hypothesis that different genotypes of Holstein may also utilize the AMS in different ways was also tested. The AMS milking interval settings were based on expected milk production and maximum and minimum number of daily milkings. This flexible milking schedule allows dairy farmers to efficiently manage cow milking frequency in order to maximize milk responses at each milking. For example, the expectation for early lactation cows was to harvest at least 9 kg of milk per milking while achieving a high milking throughput with the AMS. Decreasing the minimum limit of expected milk production per milking could have increased milking frequency to 3 times a day. However, in our system of low producing NZF cows a third milking may have been an inefficient use of the AMS, since it probably would not result in additional milk. For NZF, longer milking intervals and higher stocking rates of cows per AMS unit may be the most efficient use of the AMS, as was seen in Jago et al. (2007).

Differences in milking interval were detected between NZF and USH cows. Due to differences in milk production, resulting in differences in concentrate intake from the AMS and the pre-established milking settings (see Materials and Methods), NZF cows had longer milking intervals than USH cows (Figure 2.8). Interestingly, the NZF cows had no milking interval shorter than 7 h, whereas USH cows had around 9% of the milkings before 7 h (Figure 2.8). There is a clear differential pattern of AMS milkings for both genotypes (Figure 2.9) suggesting complementary uses of the AMS. While both NZF and USH cows had a low frequency of milkings between 0200 and 0400 h, NZF cows appeared to use the AMS more opportunistically by avoiding hours of high AMS use by USH cows. Probably, due to differences in body size, USH cows behaved as a dominate genotype forcing NZF cows to use the AMS at hours of lower visitations. There may be potential to exploit the adaptation of NZF to USH milking patterns. Due to the low milk production and longer milking interval of NZF, their visitations to the AMS may be more flexible. Since USH produces more milk, requiring shorter intervals and more frequent milkings, they are less flexible. Although no grazing behavior data are included in this study, it may be possible that the NZF cows altered their grazing times.

It is possible that USH may have filled the NZF milking distribution if the stocking rate had been higher. Ketelarr-de Lauwere et al. (1996) found that cows with determined low dominance values adapt their visits to the AMS by visiting at times when they would not have to compete with dominant cows. This conclusion was supported by the timing of the visits to the AMS with cows of higher dominance visiting the AMS more between 1200 and 1800 h, while the lower rank cows made visits at a complementary time, outside of peak visitation hours for the USH cows. It is possible that a combination of genotypes may utilize the AMS more efficiently, due to their different milking requirements and milking distributions, but more research is needed in this area to make a sound conclusion.

Conclusion. As used in this study, PMR supplementation did not affect MP or MF for either genotype of dairy cows used. However, trends in decreased MP and MF for NZF LSR indicate that supplementation may have motivated cows to return to the barn, which resulted in a more stable MF. High stocking rates at both the pasture and AMS levels may be best for NZF, because of their lower energy requirements. The low genetic merit of NZF also indicates that their milking interval can be lengthened to increase AMS efficiency. Supplementing with a PMR did not result in an increase in milk production except when pasture availability was low, indicating that supplemental concentrates may be required to increase MP in this system.

APPENDIX

TABLES

Table 2.1 Ingredients and nutrient composition of pellet feed in the AMS

Ingredients	%
Soy Hills	62.3
Ground Corn	15.0
Sure Pro	9.5
Soybean Meal 47.5 Solv	6.1
Molasses	3.1
Salt (NaCl)	2.5
Tallow	1.5
Nutrient Composition	
DM, %	89.45
CP %	17.61
RUP(%CP)	14.12
RDP (%CP)	85.88
RDP %	15.12
ME (MCal/kg)	0.65
Nel (MCal/kg)	0.42
ADF %	32.68
NDF %	42.81

Table 2.2
Differences in pasture species quality and partial mixed ration quality

Variable	RG[1]	OG[2]	SEM	*P* value <
CP, %	20.92	17.57	0.58	< .0001
NDF, %	35.33	50.29	1.2	< .0001
ADF, %	24.35	29.38	1.39	< .0001
IVTD, %	76.38	71.11	0.68	< .0001
Partial Mixed Ration				
CP,%	14.86			
NDF,%	32.00			
ADF, %	23.32			
IVDMD, %	72.64			

[1] Ryegrass pasture

[2] Orchardgrass pasture

Table 2.3 Milk production, milk quality, weight change, milking frequency, and milking refusal of dairy cows managed with automatic milking systems and two different stocking rates.

	LSR[1]		HSR[2]			*P* value		
	USH[3]	NZF[4]	USH	NZF	SEM	SR x G	SR	G
Milk, kg/d	27.24	14.46	28.6	16.22	1.89	0.9	0.33	<0.01
ECM[5], kg/d	24.87	15.22	26.37	16.97	1.66	0.8	0.45	<0.01
Milk Protein								
%	2.99	3.35	3.12	3.34	0.09	0.42	0.52	<0.02
kg/d	0.8	0.48	0.89	0.54	0.05	0.74	0.14	<0.01
Milk Fat								
%	3.59	4.50	3.57	3.92	0.16	0.1	0.08	<0.01
kg/d	0.97	0.65	1.01	0.64	0.06	0.69	0.8	<0.01
MUN[6], mg/dl	15.46	13.62	12.78	15.7	0.66	<0.01	0.64	0.41
Weight Change[7], kg	9.05	3.04	13.16	3.19	1.45	0.32	<0.01	<0.01
Milking Frequency[8]/d	2.38	2.22	2.65	2.27	0.1	0.34	0.13	0.02
Milking Interval[9], h	10.48	11.23	9.23	10.71	0.56	0.56	0.17	0.09
Refusals[10]/d	0.89	1.53	1.83	1.54	0.53	0.3	0.28	0.7

[1] Low Stocking Rate Treatment

[2] High Stocking Rate Treatment

[3] United States Holstein Friesian

[4] New Zealand Holstein Friesian

[5] Energy corrected milk

[6] Milk urea nitrogen

[7] Weight change per week

[8] Milking frequency, average successful milkings per day

[9] Milking interval (24 h/MF)

[10] Denied milking by the AMS as a result of not meeting milking criteria, average refusals per day

Table 2.4 Intake estimates and feed conversion efficiency by dairy cows in an automatic milking system with two different stocking rates.

	HSR[1]		LSR[2]			P value		
Variable	USH[3]	NZF[4]	USH	NZF	SEM	SR x G	SR	G[5]
Total intake, kg DM	21.99 a	16.25 b	22.65 a	16.35 b	1.26	0.81	0.75	<0.01
Pellet intake, kg DM	4.43 a	2.68 b	4.56 a	2.45 b	0.27	0.51	0.85	<0.01
Corn intake, kg DM	1.15 a	0.96 a	0.79 a	0.95 a	0.18	0.36	0.32	0.95
Forage Intake, kg DM	16.41 a	12.61 b	17.3 a	12.95 b	0.95	0.76	0.5	<0.01
FCE[6]	1.26 a	0.98 b	1.21 a	1.04 b	0.08	0.48	0.97	0.01
Total intake, %BW[7]	3.93 a	4.05 a	3.99 a	4.20 a	0.25	0.86	0.68	0.53

[1] High stocking rate treatment

[2] Low stocking rate treatment

[3] United States Holstein Friesian

[4] New Zealand Holstein Friesian

[5] Genotype

[6] Feed conversion efficiency; energy corrected milk kg/dry matter intake kg

[7] Body weight

Means within a row with different subscripts differ ($P < .05$)

Table 2.5

Diet composition and estimates of crude protein, acid detergent fiber, and neutral detergent fiber intakes by dairy cows in a pasture-based automatic milking system with two different stocking rates.

	HSR[1]		LSR[2]			*P* value		
Variable	USH[3]	NZF[4]	USH	NZF	SE	SR x G	SR[6]	G[5]
CP Intake, kg/d								
Total	3.92	2.89	4.1	2.92	0.21	0.73	0.63	<0.01
Pellet	0.84	0.51	0.86	0.46	0.05	0.51	0.85	<0.01
Corn	0.12	0.1	0.08	0.1	0.02	0.36	0.32	0.95
PMR[7]	0.77	0.56	NA	NA	0.008	NA	NA	<0.01
Pasture	2.19	1.73	3.38	2.36	0.19	0.17	<0.01	<0.01
NDF Intake, kg/d								
Total	8.53	6.27	9.83	6.97	0.48	0.54	0.05	<0.01
Pellet	2.04	1.23	2.1	1.13	0.12	0.51	0.85	<0.01
Corn	0.13	0.11	0.09	0.11	0.02	0.36	0.32	0.95
PMR	1.5	1.08	NA	NA	0.02	NA	NA	<0.01
Pasture	4.87	3.85	7.64	5.73	0.42	0.3	<0.01	<0.01
%BW	1.56	1.1	1.77	1.19	0.09	0.49	0.12	<0.01
ADF Intake, kg/d								
Total	5.72	4.17	6.3	4.4	0.3	0.58	0.19	<0.01
Pellet	1.56	0.94	1.6	0.86	0.09	0.51	0.85	<0.01
Corn	0.05	0.04	0.03	0.04	0.01	0.36	0.32	0.95
PMR	1.06	0.77	NA8	NA	0.01	NA	NA	<0.01
Pasture	3.06	2.41	4.67	3.5	0.26	0.32	<0.01	<0.01
Diet, %								
CP	17.81	17.81	18.1	17.88	0.12	0.35	0.13	0.32
NDF	38.79	38.56	43.47	42.56	0.42	0.42	<0.01	0.19
ADF	26.02	25.62	27.91	26.92	0.31	0.36	<0.01	0.04

[1] High stocking rate treatment

[2] Low stocking rate treatment

[3] United States Holstein Friesian

[4] New Zealand Holstein Friesian

[5] Genotype effect

[6] Stocking rate effect

[7] Partial mixed ration; values for PMR were estimated by dividing the total amount of group fed PMR by the number of cows in the herd. Values of PMR intake for USH and NZF cows were derived estimations of average PMR intake of the herd expressed in a % body weight basis

FIGURES

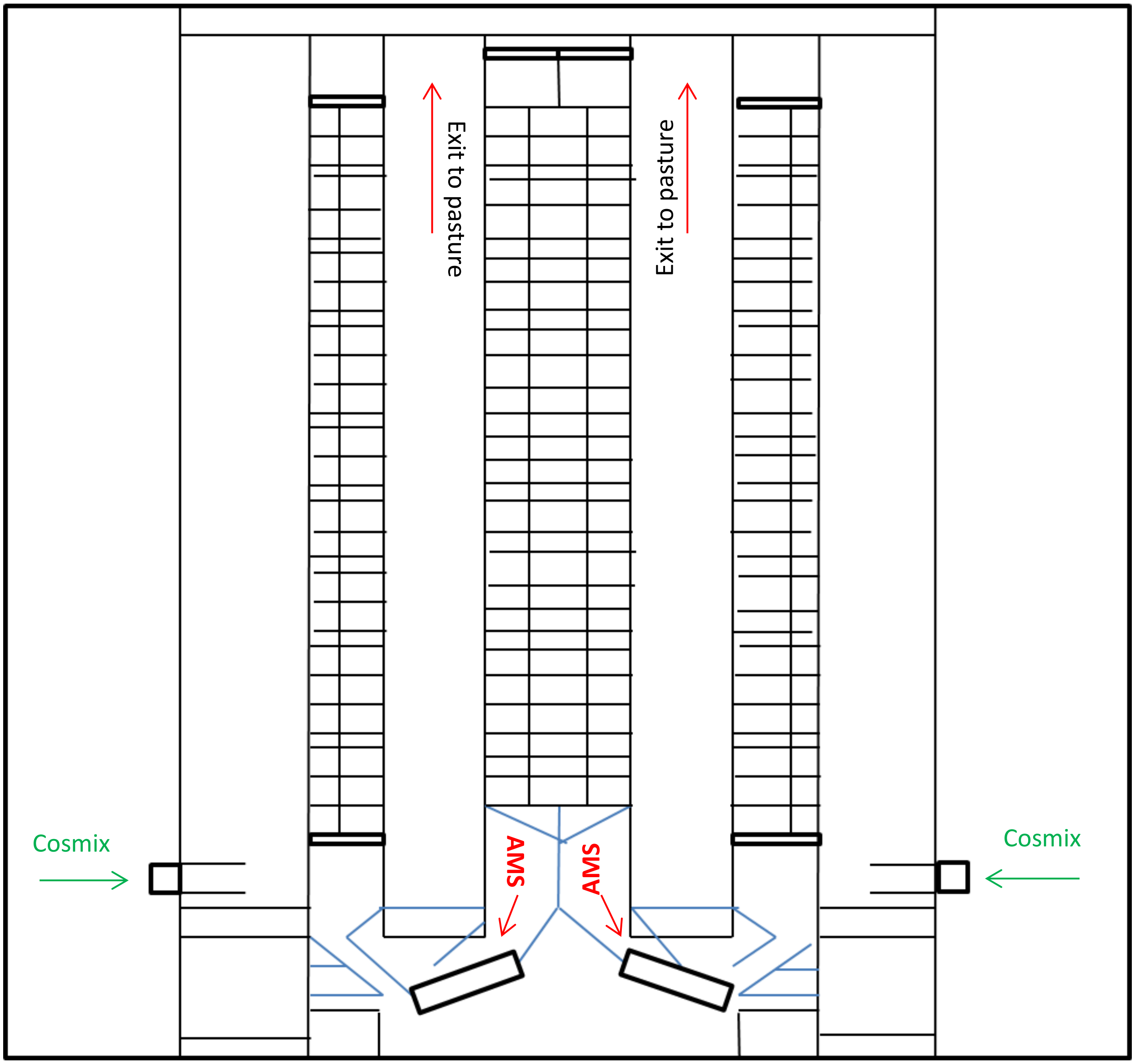

Figure 2.1 Layout of the split freestall

Figure 2.2. Paddock layout showing paddocks used for the high stocking rate (HSR) and low stocking rate (LSR) groups.

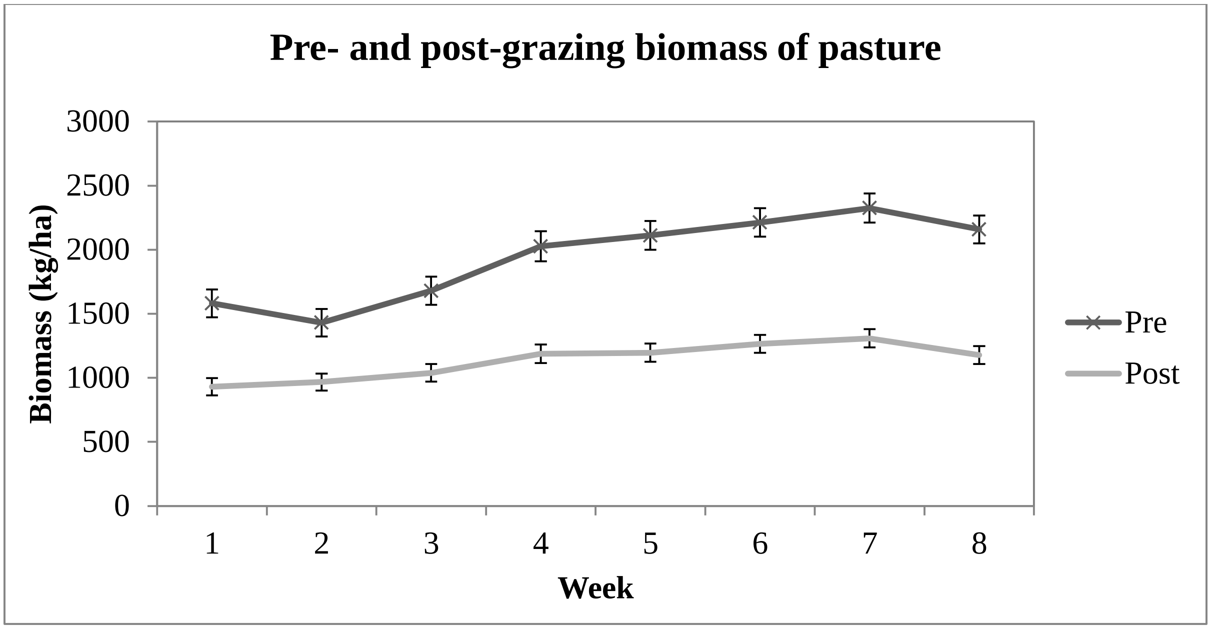

Figure 2.3 Pre-grazing (Pre) and post-grazing (Post) biomass of pastures grazed at high and low stocking rate by dairy cows managed with AMS. There was no stocking rate treatment effect (P = 0.89 for pre and P = .07 for post), but significant differences across weeks of the study were detected (*P* <0.0001 for both pre and post measurements). Bars denote standard errors of means (SEM) for pre grazing (SEM = 11.44) and post grazing (SEM = 72.97) biomass

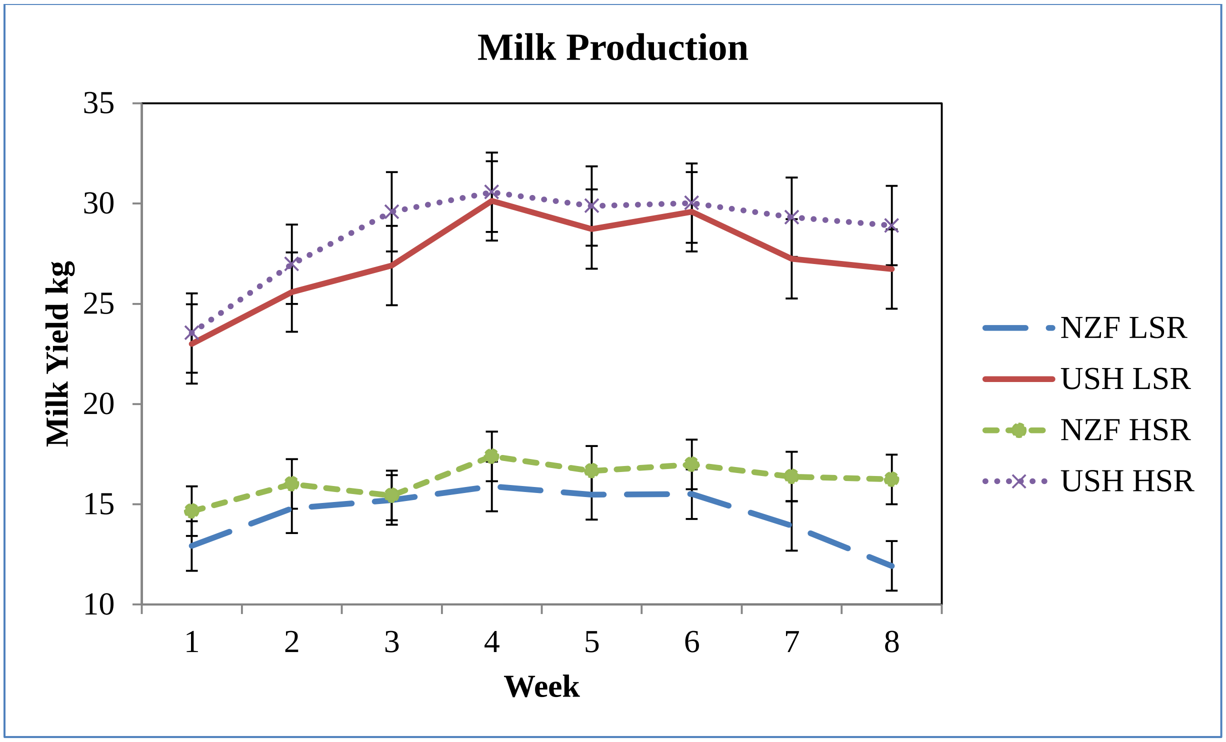

Figure 2.4. Milk production by New Zealand Friesian (NZF) and United States Holstein (USH) dairy cows grazed at high stocking rate (HSR: 2.89 cows/ha) or low stocking rate (1.92 cows/ha) in a pasture-based automatic milking system. There was a significant stocking rate x week x genotype interaction (*P* < 0.03.0value). Bars denote standard error of means (SEM = 1.98).

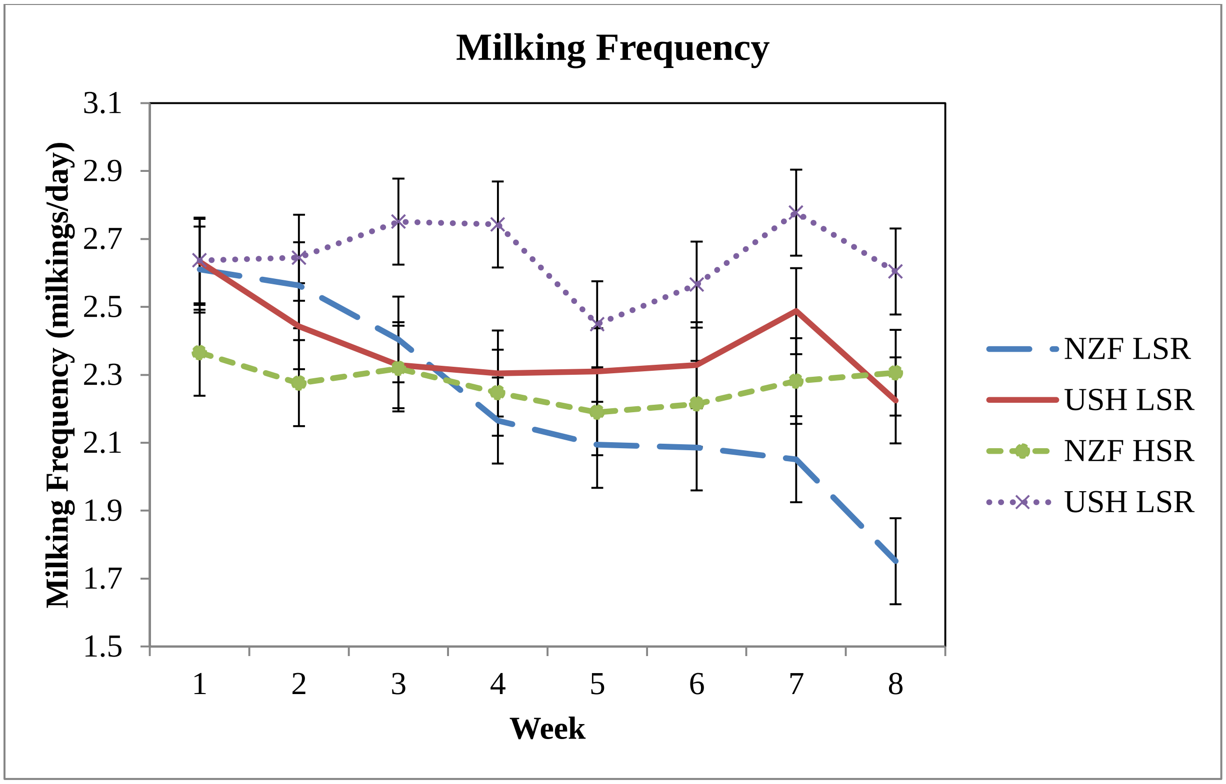

Figure 2.5. Milking frequency of New Zealand Friesian (NZF) and United States Holstein (USH) dairy cows grazed at high stocking rate (HSR: 2.89 cows/ha) or low stocking rate (1.92 cows/ha) in a pasture-based automatic milking system. There was a trend for a stocking rate x week x genotype interaction (P =.09). Bars denote standard error of means (SEM = 0.13).

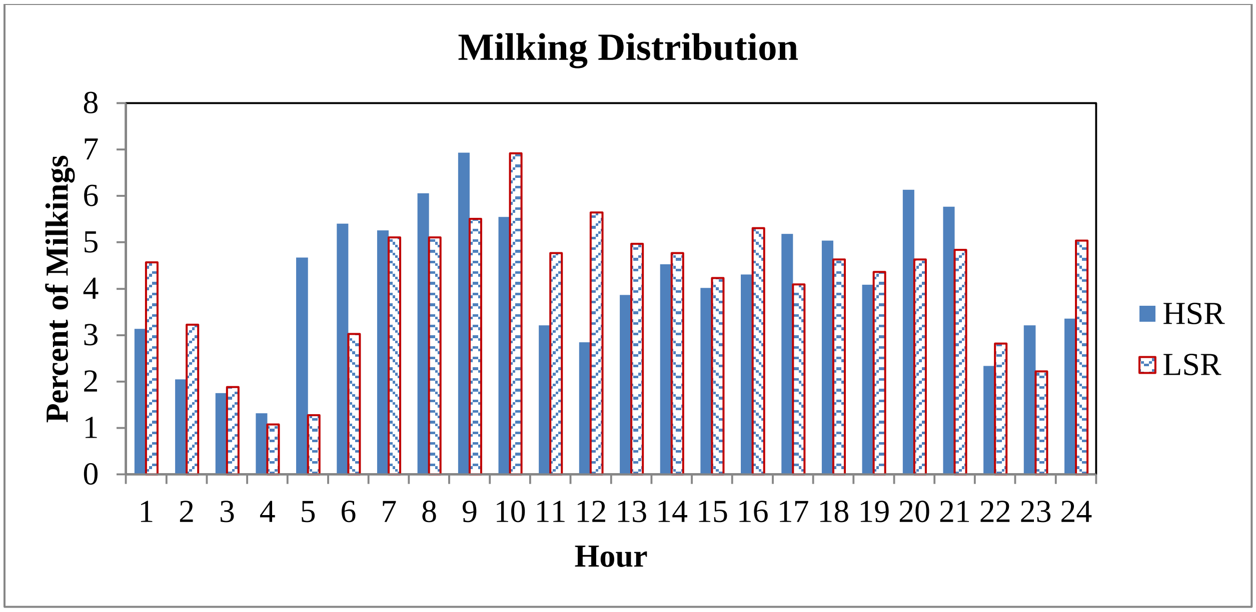

Figure 2.6. Milking distribution of dairy cows grazed at a high stocking rate (HSR: 2.89 cows/ha) or a low stocking rate (1.92 cows/ha) in a pasture-based automatic milking system. There was a significant interaction for stocking rate by hour ($P < 0.05$).

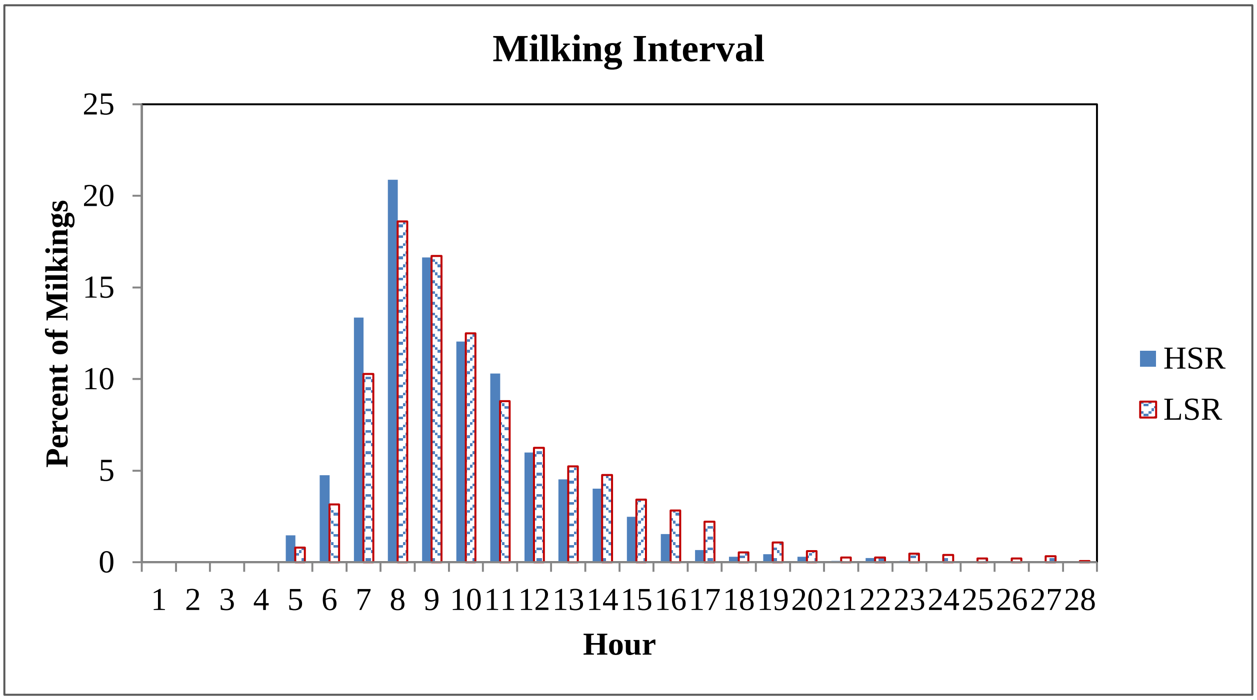

Figure 2.7. Milking interval of dairy cows grazed at a high stocking rate (HSR: 2.89 cows/ha) or a low stocking rate (1.92 cows/ha) in a pasture-based automatic milking system. There was a significant interaction for stocking rate by interval ($P < 0.05$).

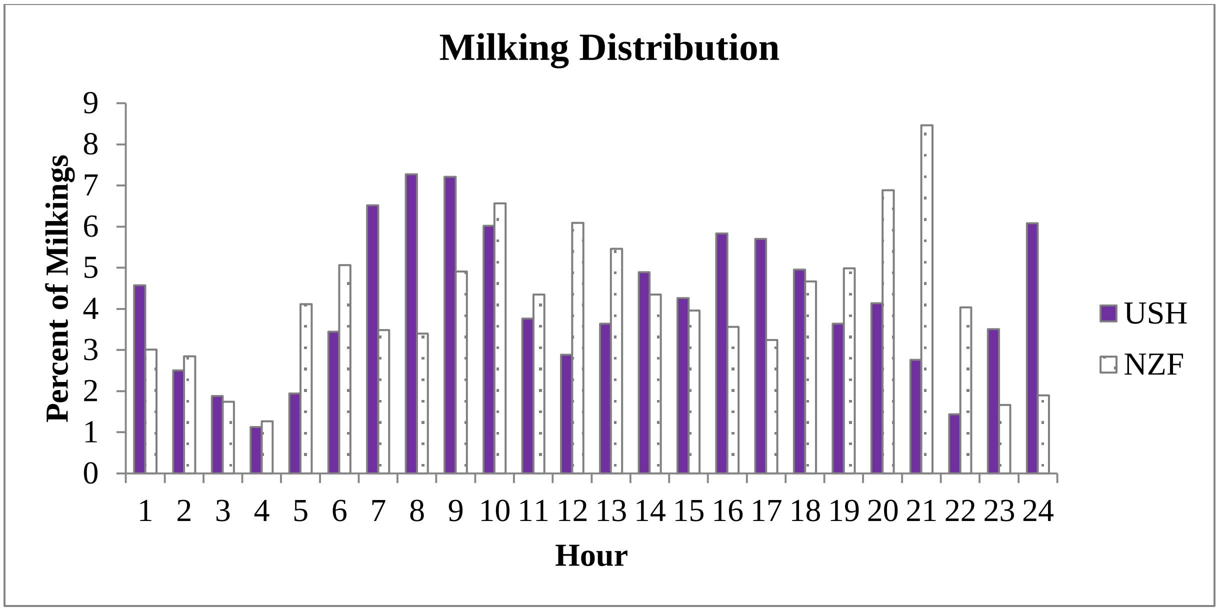

Figure 2.8. Milking distribution of New Zealand Friesian (NZF) and United States Holstein (USH) dairy cows grazed at a high stocking rate (HSR: 2.89 cows/ha) or a low stocking rate (1.92 cows/ha) in a pasture-based automatic milking system. There was a significant stocking hour x genotype interaction (*P* = 0.05).

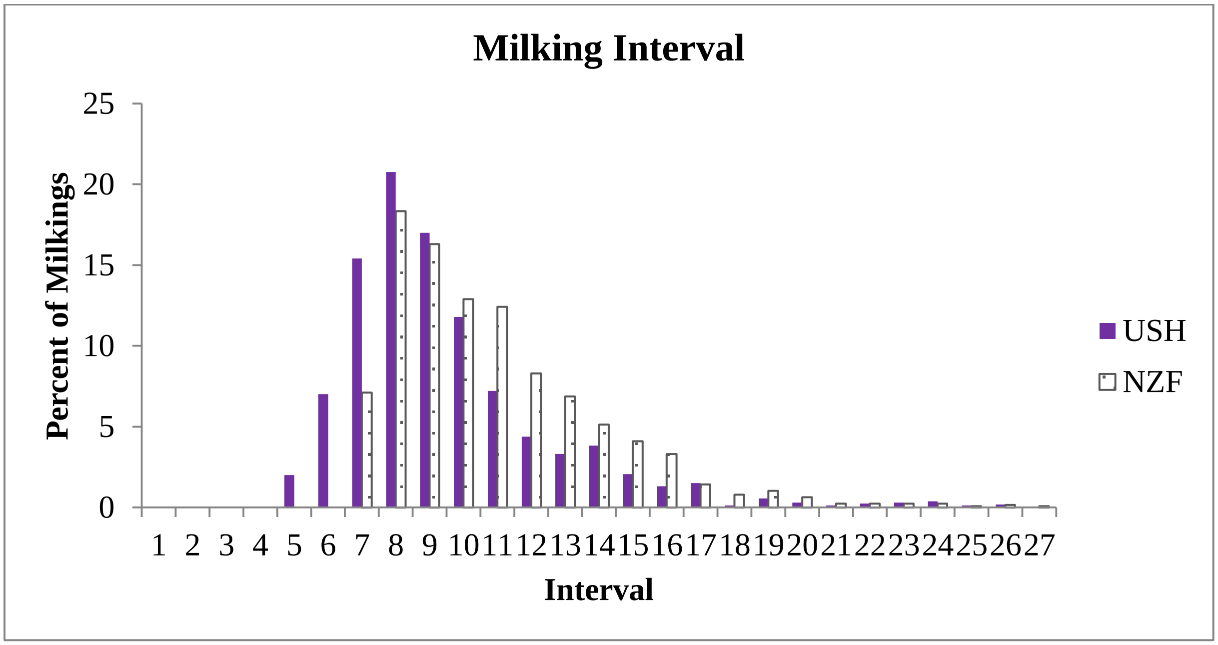

Figure 2.9 Milking interval of New Zealand Friesian (NZF) and United States Holstein (USH) dairy cows grazed at a high stocking rate (HSR: 2.89 cows/ha) or a low stocking rate (1.92 cows/ha) in a pasture-based automatic milking system. There was a significant stocking genotype x interval interaction (*P* = 0.05).

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CHAPTER 3

EFFECTS OF SUPPLEMENTATION OF A PARTIAL MIXED RATION ON THE FERMENTATION AND RUMEN ENVIRONMENT OF DAIRY COWS IN A PASTURE-BASED AND AUTOMATIC MILKING SYSTEM

ABSTRACT

Supplementing pasture-based diets of dairy cattle has the potential to create negative associative effects in the rumen, decreasing both the rate and extent of degradation of forages in the rumen. The objective of this study was to characterize the rumen environment and to determine the residual effect of feeding variable amounts of a total mixed ration on the *in situ* degradation of pastures and concentrates. Six ruminally cannulated Holstein cows (parity = 1.6 ± 0.49, DIM 148 ± 13; mean ± SD) were randomly assigned to one of two stocking rate groups; a low stocking rate (LSR) grazing system consisting of a diet containing grazed pasture plus concentrates, and a high stocking rate (HSR) grazing system receiving the same based diet as the LSR plus variable amounts of a partial mixed ration (PMR; 60% alfalfa grass haylage, 40% ground corn) adjusted for weekly changes in pasture availability. There was no significant difference ($P = 0.61$) in rumen pH between feeding systems. The *in situ* technique revealed no significant differences in the degradation rate of DM and NDF. Therefore, it is concluded that feeding variable weekly amounts of a PMR ration to fill deficits and weekly changes in forage availability in a pasture-based system did not substantially change the rumen environment or depress pasture degradation rates when PMR is fed at relatively low amounts.

Keywords: *in situ*, pasture-based, grazing, partial mixed ration.

INTRODUCTION

Supplementation of concentrates and forages in pasture-based diets has been extensively studied and reviewed (Phillips, 1988; Kolver and Muller, 1998; Reis and Combs, 2000; Bargo et al., 2002a, 2002b, 2003). However, only a few of these studies investigated the effects of feeding mixed rations on the rumen environment and forage degradation rates in grazing cattle (Bargo et al., 2002b).

Reis and Combs (2000) reported a decrease in the forage soluble fraction when supplementing 10 kg DM of concentrates. Similarly, Bargo et al. (2002b) found decreases in the disappearance of the potentially degradable fraction when supplementing with 15 kg DM of a partial mixed ration (PMR), indicating associative effects. However, both of these studies involved a large amount of supplementation and therefore may not be comparable to diets in which the ration consists of 60 to 70% pasture. A diet high in pasture, which is vulnerable to variable forage availability and quality and variable use of forage and concentrate supplements, may affect the rumen environment and thus pasture forage degradation. No studies exist to my knowledge examining this potential effect in a pasture-based dairy system.

This study aims to determine the effect of a variable PMR feeding strategy on the rumen environment in a pasture-based and automatic milking system (AMS). In this system, cows have the opportunity to make choices more individually and therefore may have more temporal (i.e. diurnal and day to day) and individual variation in feeding rates on both pasture forage and supplemental forage and concentrates, in contrast to a more controlled or forced feeding system. However, despite the individual feed choices involved in this particular system, fermentation patterns and feed degradation may be similar across animals due to the similarity of the diet the cows select. The objective this study was to determine if supplementation at high stocking rates caused associative effects that resulting in decreased rate or extent of disappearance of DM, CP, or NDF. I predicted that no differences in the ruminal environment will be detected between treatments.

MATERIALS AND METHODS

Animals, Experimental Design, and Treatments. Six ruminally cannulated US Holstein cows with average parity of 1.6 (± 0.49 SD) and average days in milk (DIM) of 148 (± 13) days were randomly assigned to one of two stocking rate (SR) treatment groups in a completely randomized design. The low stocking rate (LSR) treatment had 1.92 cows/ha and the high stocking rate (HSR) treatment had 2.89 cows/ha. Supplementation for HSR consisted of a partial mixed ration (PMR) of 60% legume-grass haylage and 40% ground corn. The PMR feeding was conducted as described in Chapter 2. Due to illness unrelated to the feeding treatments, one cow was removed from the HSR.

Pasture Layout, Barn, Feeds, and AMS settings. All details regarding pasture layout, barn, feeds and AMS settings are the same as in Chapter 2.

Rumen Fluid Samples. Rumen fluid samples were taken over a 48 h period during the *in situ* incubation trial, resulting in samples times of 0830, 1530, 1830, and 2030 h. Fluid samples were taken with a filtered syringe from different compartments of the rumen in order to get a representative sample. The pH was recorded with a pH meter immediately after rumen fluid was collected.

In situ Degradation. The *in situ* incubation technique (Orskov and McDonald, 1979) was used to determine the presence of associative effects in the rate and extent of degradation of pasture and concentrates in the rumen.

The material incubated in rumens of the cows in the LSR treatment diet included 4 ingredients: ground corn, concentrate based pellets, and masticated orchardgrass and ryegrass pasture. The HSR feeds were the same as in LSR, with the addition of a legume-grass haylage as the PMR feed mixed with grounded corn (60% haylage and 40% corn). Following Islas and Soto-Navarro (2011), masticate samples were collected from the 6 ruminally fistulated cows using the rumen evacuation method. Briefly, after a 2 h fasting the rumen content was completely evacuated and the digesta plus liquid was stored in large plastic buckets, weighed, and sealed with plastic cover. After this initial evacuation was completed, cows were allowed to graze on either Ryegrass or Orchardgrass pastures for 2 hours. Cows were not allowed to drink during the pasture grazing period. After grazing, cows were re-evacuated completely and masticated contents stored in large plastic buckets. Contents of the first evacuation were then returned into the evacuated rumen. The masticate samples were dried in a forced air oven at 60°C for 48 h and stored for use as incubation material in the *in situ* trial.

All feed ingredients used for incubations were chopped using a blender and then sieved through a 1.5 mm screen, therefore all incubated particles were less than 1.5 mm. Nitrogen free polyester bags (10 x 20 cm) with a 50 micron pore size (Ankom Technology, Macedon, NY) were used. Bags were filled with 5 g of dry feed material and sealed with a heat sealer (Model AIE-200, American International Electric Inc., Industry, CA). Bags were incubated for 2, 5, 12, 24, 36 and 48 h using duplicate bags for the 2, 5, 12, and 24 h incubation and triplicate bags for the 36 and 48 h incubation. A blank bag was included at each incubation hour to correct for changes in bag weight. All incubated bags were contained in a netted nylon bag closed to one end with a plastic zip tie. Bags were incubated in reverse order starting with the 48 h incubation. All bags were removed at the same time.

After incubation, bags were immediately soaked in cold water and hand rinsed once. Bags were then placed in a washing machine and were rinsed in cold water for 15 minutes. After rinsing, bags were placed in a forced air oven, dried for 48 hours at 60°C and stored. Crude protein and neutral detergent fiber were determined using same techniques described in Chapter 2 and the disappearance of dry matter, CP and NDF calculated.

The disappearance of dry matter and CP was analyzed with an exponential model following Orskov and McDonald (1979). The equation used was $p = a + b\ (1-e^{-ct})$; where p is the actual degradation over time (t), the parameter a is the intercept of the degradation curve at time zero and represents the soluble fraction, the parameter b represents the potentially degradable fraction relative to the rate constant of degradation indicated by the parameter c. With this model, the degraded fraction is a + b and the undegradable fraction is 100 - (a + b). If the value of a is positive then there is a component which is degraded instantaneously and or a component which is soluble enough to escape by soaking and washing; whether parameter a represents rapid degradation or washing losses can be determined with control bags (Orskov and McDonald, 1979). There were no control bags included in this study, therefore, parameter a included both rapid degradation and possible washing losses. When a negative value for a is obtained, an initiation period for degradation to start is required, this is referred to as lag time (Mertens and Loften, 1980).

The NDF results demonstrated a lag time in degradation and were therefore analyzed with a different exponential model following Mertens and Loften (1980). The equation used was $FR = P\ e^{-kd(t-L)} + U$, where FR is the amount of NDF remaining at incubation time t, P is the potentially digested fraction (100-U) at the fractional rate of degradation kd (%), U is fraction undigested at 48 h (%), L is the lag time (h) for NDF degradation, and t is time of incubation.

Laboratory Analysis. Crude protein and NDF of the incubated material and residue remaining after incubations were determined by same procedures described in Chapter 2.

Statistical analysis. Evaluation for centrality and dispersion of the data conducted prior to the ANOVA analysis detected a consistent bias for one of the cows in the HSR treatment. After study completion, this cow was diagnosed by the veterinarian with an unexplained uterus illness not related to the feeding treatment and data from this cow were therefore removed from the final analysis.

Rumen evacuation data and *in situ* degradation parameters were analyzed by the method of least-squares ANOVA for a completely randomized design, using the Mixed Models procedure of SAS (Version 9.2, SAS Institute Inc.). The Kenward-Rogers method was used to estimate the degrees of freedom for comparing effects of stocking rates. Rumen evacuation data were analyzed with a model with stocking rate as the independent fixed effect. Repeated measures analysis was used to evaluate the effect of stocking rate on rumen degradation and pH obtained in the *in situ* trial. Time of incubation (or time of day equivalent) was the repeated measure and was modeled with a compound symmetry, autoregressive order 1 or unstructured covariance structure based on the lowest Akaike and Bayesian Information Criterion test (Little et al. 1996). In these analyses, individual cannulated cows were considered the experimental unit and entered in the model as a random effect.

RESULTS AND DISCUSSION

Rumen evacuations and pH. The rumen evacuations allowed me to describe rumen fill, retention time, and total clearance and to obtain unbiased masticated forage samples consumed by cows for *in situ* incubations. No differences were detected between the two feeding systems for any evacuation data collected (Table 3.1). However, absolute values for dry fill were numerically lower and values for retention time and clearance rate were numerically higher for HSR.

During the 48 hour *in situ* period, pH was not significantly different (P = 0.61) between HSR and LSR at all sampling hours, but pH differed significantly (P = 0.008) over the course of the day. Regardless of this difference, it is important to note that across all hours, pH was never below 5.50, a condition which may be considered an indicator of acidosis in a supplemented pasture-based system. However, the average pH for both treatments was slightly lower than the ranges described in other grazing trials using similar pastures. Bargo et al. (2003) reviewed recent literature describing pH values for grazing dairy cattle and reported average values of 6.10 (range: 5.75 to 6.29) for cows supplemented with 1.1 to 10 kg of concentrates. In this study, both LSR and HSR cows received concentrates at a rate of 1 kg of pellet per 6 kg of milk (average 4.5 and 4.6 ± 0.3 kg for HSR and LSR, respectively) plus a constant amount of 1 ± 0.2 kg of ground corn. The difference between treatments was the PMR (60 % forage, 40% ground corn) feeding at an average rate of 5 ± 0.1 kg/cow/day during the study (see Chapter 2 for more details). Thus, pH values recorded for HSR and LSR could be considered normal for supplemented grazing cattle based on Bargo et al. (2003). Furthermore, the additional feeding of approximately 2 kg of corn in the PMR mixture was not sufficient to cause a drop in rumen pH compared to LSR receiving no PMR.

There is not a well-established reference for average pH values in grazing dairy cows supplemented with PMR, particularly under commercial situations where PMR could be used to stabilize variations in feed intake patterns and rumen pH resulting from diurnal and temporal variations in pasture availability and consumption. Yet, feeding variable amounts of PMR over time may create residual effects in rumen pH and degradation. Bargo et al. (2002) found no significant differences in rumen pH between diets containing pasture plus concentrate (5.89) and pasture plus partial total mixed ration (5.88), values that are very similar to the average rumen pH values found in this study (5.98 and 5.89, for LSR and HSR, respectively). Evidently, the amount of PMR fed in HSR (representing an addition of 2 kg in the diet) was not enough to cause a constant decrease in pH over the course of the day and in detectable differences in pH between treatments.

In situ degradation. The *in situ* rumen degradation data for the supplements are shown in Table 3.2. Ground corn and pellets were incubated in both the HSR and LSR treatments, while the PMR containing pasture haylage and ground corn was incubated separately only in the HSR treatment. There were no detectable differences between the two stocking rate and feeding systems in all degradation parameters tested. Therefore, these data support the hypothesis that PMR supplementation does not affect degradation kinetics of concentrate supplements when low levels of PMR are used as a complementary feed resource in pasture-based systems. As expected, the rate of concentrate degradation was relatively high in this study (more than 16% per hour for ground corn). However, we recognize that inferences on the net efficiency of digestion of supplements are limited because neither the extent of concentrate degradation nor total tract digestion was measured in this study. It is possible that the efficient use of highly degradable concentrate supplements in pasture systems is limited by a very high rate of passage for supplements through the tract. In pasture dairy systems, the rumen of cows grazing high quality pasture of low DM and NDF content often suffers from low DM fill (fast turnover), with the absence of a stratified contents in the rumen and lack of stable mat, as compared to TMR feeding systems (Bargo et al. 2002b). This lack of structure in the rumen may prevent the efficient retention of small concentrate particles that may adhere to the ventral sac of the rumen and resist extensive degradation. Although not reported here, significant amounts of grain concentrate have been removed from the rumen ventral sac during full rumen evacuations, which suggests that the extent of degradation of concentrates was probably low. More controlled studies are needed to determine actual efficiencies of concentrate degradation and digestion in feeding systems using high quality pasture as the main feed resource.

As expected, the *in situ* technique revealed no significant differences in pasture degradation between feeding systems (Table 3.3). However, important numerical differences in most NDF degradation parameters (particularly lag time) were observed. It is possible that the 5 experimental cows used in the study did not provide enough statistical power to detect a significant difference between feeding systems.

The values for dry matter disappearance found in this study are comparable to other studies where a similar *in situ* technique was used. Hongerholt and Muller (1996) incubated freeze dried pastures samples dominated by orchardgrass and Kentucky bluegrass, ground through a 4-mm screen, and found values of 24.4%, 60.3%, and 6.7%/h for the soluble (a), potentially degradable (b), and the rate of degradation (c) of dry matter. Van Vuuren et al. (1992)

also used a similar procedure, freeze drying samples ground to 3 mm, to incubate ryegrass pasture and found degradation rates for dry matter of 40.8%, 53.1%, and 6.1%/h for the fractions a, b, and c, respectively.

Hongerhold and Muller (1996) recorded values of 19.0, 75.3, and 5.6%/h for the fractions a, b, and c for the CP degradation in orchardgrass based pastures. The values for CP for Orchardgrass may be more similar to Hoffman et al. (1993), in which a result of 46.1 to 51.5 % was found for the a fraction. However, in that study, sample processing was somewhat different and cows were on a silage based diet. Van Vuuren et al. (1992) found CP degradation values of 47.2%, 47.5%, and 9.2%/h for fractions a, b, and c This value for c was much higher than what was recorded in the current study. Differences in pasture maturity, botanical composition and pre-processing of plant material through mastication may explain differences between studies. Pasture dry matter and CP degradation are greatly influenced by plant maturity, creating important variations over the life cycle of plant species (Hoffman et al., 1993). Differences between the current study and the studies reported above may also occur because many of the studies reviewed were completed indoors on a TMR or silage based diet, as for example in Hongerhold and Muller (1996) and Hoffmann et al. (1993).

Figures 3.2 and 3.3 show the NDF degradation patterns of the two different pasture types. Although differences between the two stocking rate treatments were not statistically significant, more favorable fermentation conditions might have resulted in faster disappearance in the HSR treatment. This conclusion is based on the trends seen in the data for the *in situ* degradation of pasture, in which the degradation rate was 1 to 2 units higher for HSR vs. LSR (Table 3.3). The difference may be caused by differences in passage rates. If the passage rate in HSR cows was slower, possibly due to higher levels of indigestible NDF in the PMR, this may provide more time for microbial population growth and attachment, which would increase NDF degradation rates. Perhaps the PMR is creating synergistic effects on the rate of degradation of NDF by increasing particle retention times. However, without a significant difference in degradation rates this idea is difficult to support in this study.

The soluble fraction was similar in both orchardgrass and ryegrass based pastures (range 27 to 32 %), but the degradable fraction was about 10 units greater in ryegrass pastures. The lower NDF and higher concentration of NSC (not determined) in ryegrass compared to orchardgrass pastures (see table 2.2 of Chapter 2) may explain this difference.

Conclusion. The results from this study indicate that low levels of PMR supplementation of a pasture-based diet do not change rumen degradation rates or cause other negative associative effects in the rumen. Furthermore, when PMR is used to complement the deficit in availability of high quality pasture, it may have synergistic effects on the extent of concentrate digestion and NDF degradation. Overall, no significant differences were seen in measures of rumen degradation between stocking rate and feeding systems, but more controlled research is necessary to determine the actual occurrence of potential synergistic effects of PMR feeding.

APPENDIX

TABLES

Table 3.1. Effects of stocking rate and feeding system on rumen contents, estimated kinetic parameters and amount of masticates collected from orchardgrass and ryegrass based pastures.

Variable	LSR[1]	HSR[2]	SEM	*P* Value
Estimated Intake[3], kg	19.50	19.12	0.82	0.75
Wet Fill, kg	64.40	70.59	8.6	0.62
Dry Fill, kg	8.41	8.72	2.19	0.92
DM Content, %	12.90	12.00	1.80	0.72
Retention Time of DM[4], h	8.91	9.52	-	NA[6]
Clearance Rate of DM[5], %/h	0.11	0.11	-	NA

Masticates*	OG[7]	RG[8]	SEM	*P* Value
Masticate Wet Fill, kg	42.57	14.43	4.78	0.02
Masticate Dry Fill, kg	5.05	2.21	0.72	0.06
Pasture intake rate, kg/h	2.52	1.10	0.36	0.06

[1] Low stocking rate treatment. Received a pasture plus concentrate diet.

[2] High stocking rate treatment. Received a partial mixed ration supplementation in addition to pasture plus concentrate.

[3] Estimated Intake, derived from a parallel trial using fecal output estimates and 48 h digestibility using chromium oxide as external marker.

[4] Retention time was derived from estimated intake as [(DM intake/24h)/rumen DM content].

[5] Clearance Rate was derived from estimated intake as [rumen DM content/(DM intake/24h)

[6] NA, not applicable.

[7] Orchard grass, fescue, alfalfa, red clover and white clover pasture mixture.

[8] Ryegrass and white clover pasture mixture.

*Masticates were collected after the full evacuation of the rumen following a 2 h grazing session.

Table 3.2. Effects of stocking rate and feeding system treatment on *in situ* degradation parameters of concentrates and partial mixed ration

Parameter[1]	HSR[2]	LSR[3]	SEM	*P* Value
Ground Corn				
Dry Matter				
a	0.25	0.30	0.03	0.26
b	0.70	0.64	0.04	0.32
c, %/h	0.16	0.17	0.01	0.65
Crude Protein				
a	0.20	0.28	0.05	0.31
b	0.77	0.69	0.05	0.31
c, %/h	0.12	0.12	0.01	0.85
Pellet				
Dry Matter				
a	0.31	0.29	0.03	0.63
b	0.86	0.75	0.06	0.26
c, %/h	0.03	0.038	0.01	0.30
Crude protein				
a	0.27	0.09	0.09	0.22
b	0.71	0.81	0.05	0.19
c, %/h	0.05	0.11	0.04	0.30
Partial Mixed Ration				
Dry Matter				
a	0.34	-	0.02	NA[4]
b	0.42	-	0.01	NA
c,%/h	0.07	-	0.02	NA
Crude Protein				
a	0.58	-	0.03	NA
b	0.27	-	0.02	NA
c, %/h	0.1	-	0.04	NA
Neutral Detergent Fiber				
Lag	1.67	-	0.46	NA
P	0.39	-	0.08	NA
Kd/h	0.05	-	0.02	NA

[1] Parameters were a: soluble fraction, b and P: potentially degradable fraction, c and Kd: fractional rate constant of degradation, Lag, lag time of degradation.

[2] High stocking rate treatment

[3] Low stocking rate treatment

[4] Not applicable because the comparison was limited by design.

Table 3.3. Effects of stocking rate treatment on *in situ* degradation of ryegrass and orchardgrass pastures

	Treatments			*P* Value
Parameter[1]	HSR[2]	LSR[3]	SEM	SR[4]
Ryegrass				
DM				
a	0.28	0.29	0.02	0.72
b	0.61	0.63	0.06	0.77
c, %/h	0.07	0.06	0.01	0.32
CP				
a	0.22	0.21	0.05	0.84
b	0.72	0.76	0.07	0.70
c, %/h	0.08	0.06	0.007	0.09
NDF				
Lag	2.06	2.79	0.37	0.23
P	0.21	0.13	0.16	0.71
kd/h	0.06	0.05	0.01	0.31
Orchardgrass				
DM				
a	0.31	0.34	0.03	0.47
b	0.57	0.54	0.03	0.45
c, %/h	0.08	0.07	0.02	0.51
CP				
a	0.31	0.35	0.03	0.34
b	0.64	0.62	0.03	0.61
c, %/h	0.08	0.06	0.01	0.23
NDF				
Lag	1.35	0.23	0.56	0.22
P	0.21	0.22	0.06	0.96
Kd, %/h	0.08	0.06	0.02	0.51

[1] Parameters were a: soluble fraction, b and P: potentially degradable fraction, c and Kd: fractional rate constant of degradation, Lag, lag time of degradation.

[2] High stocking rate treatment

[3] Low stocking rate treatment

[4] Stocking rate effect

FIGURES

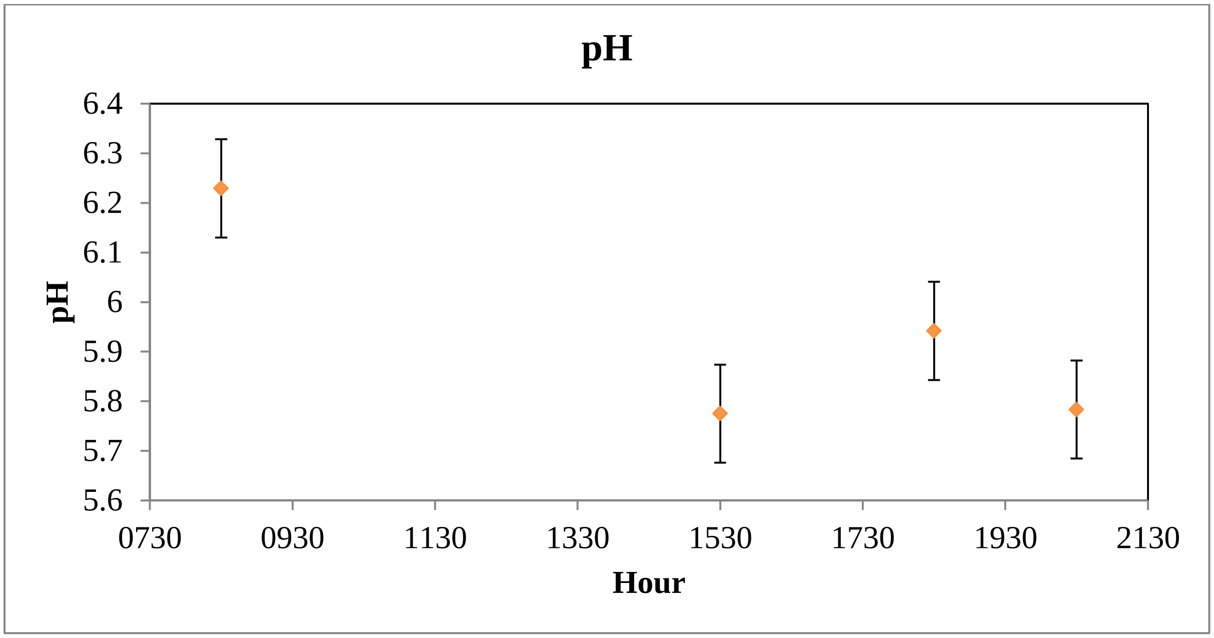

Figure 3.1 Rumen pH of dairy cows grazing temperate pasture in either a low stocking rate system supplemented with concentrates or a high stocking rate system supplemented with concentrates and partial mixed ration. There was no stocking rate and feeding system effect (*P* = 0.61), but significant differences were detected among hours of the day (*P* < 0.01). Bars denote standard errors of means (SEM= 0.09).

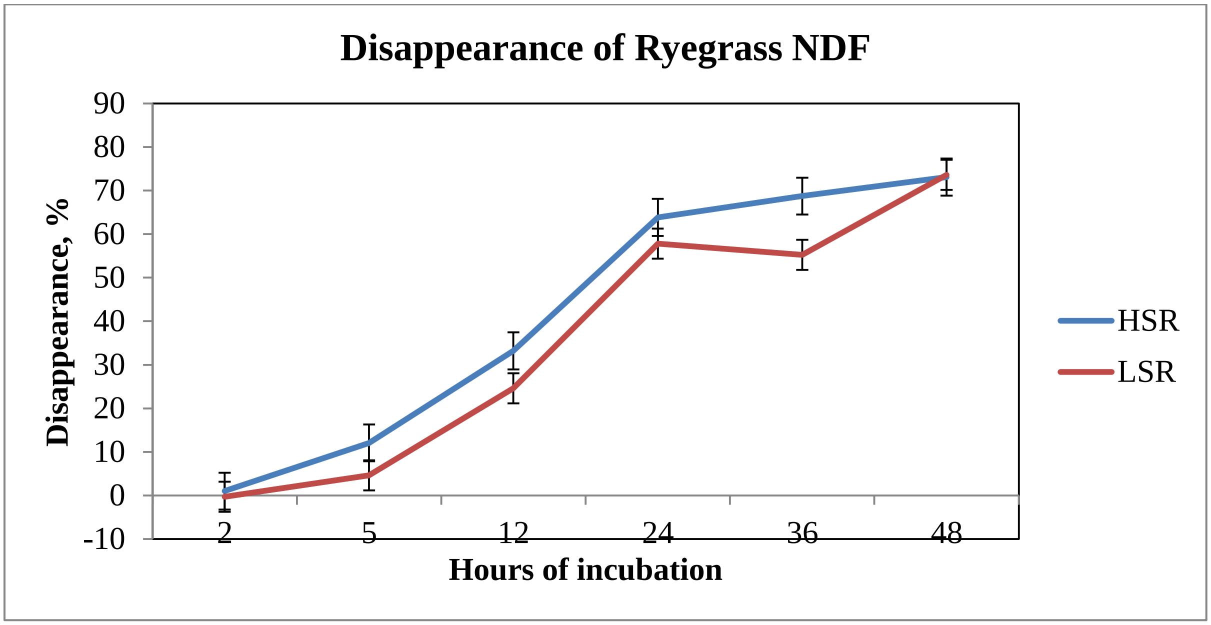

Figure 3.2. Disappearance of ryegrass NDF in dairy cows grazing temperate pasture in either a low stocking rate system supplemented with concentrates (LSR) or a high stocking rate system supplemented with concentrates and partial mixed ration (HSR). There was no stocking rate and feeding system effect (*P* = 0.45, SEM= 4.23).

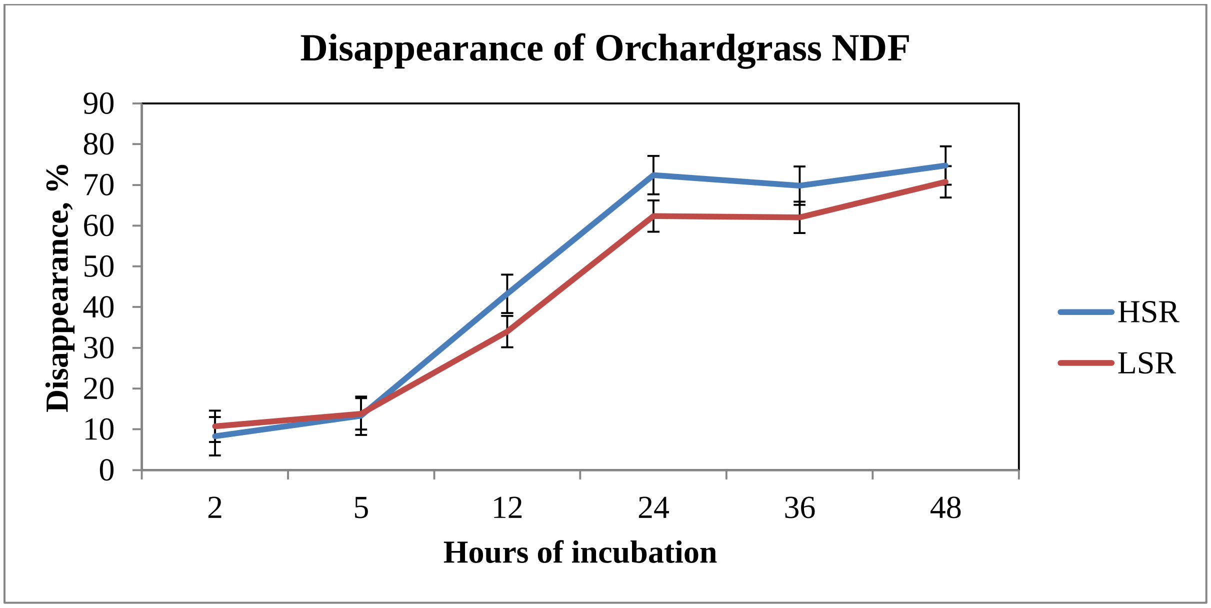

Figure 3.3. Disappearance of orchardgrass NDF in dairy cows grazing temperate pasture in either a low stocking rate system supplemented with concentrates (LSR) or a high stocking rate system supplemented with concentrates and partial mixed ration (HSR). There was no stocking rate and feeding system effect (*P* = 0.60, SEM= 4.71).

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CHAPTER 4

EFFECTS OF STOCKING RATE AND PARTIAL MIXED RATION SUPPLEMENTATION ON FORAGE UTILIZATION AND OCCUPATION OF AUTOMATIC MILKING SYSTEMS IN A PASTURE-BASED SYSTEM

ABSTRACT

Integration of automatic milking system (AMS) into a Midwestern USA pasture-based system is a potential alternative low cost and labor efficient dairy system. However, guidelines of management in critical areas such as stocking rate, supplementation, and cow traffic are not yet well understood. The objective of this study was to determine the combined effects of stocking rate and feeding strategies on pasture utilization, milk yield, and interactions with the overall occupation and milking efficiency of an AMS. A total of 80 United States Holstein and 14 New Zealand Friesian cows divided into equal proportions in two herds balanced for parity (2.03 ± 0.1; mean ± SD), days in milk (227 ± 10 d; mean ± SD) were assigned to a low stocking rate treatment (LSR; 1.92 cows/ha) and a high stocking rate treatment (HSR; 2.89 cows/ha) implemented over 24 and 16 ha of temperate pasture, respectively. The feeding system for the LSR treatment included pasture plus addition of pellet (weighted average = 4.2 ± 0.3 kg/cow per d) fed at variable rates in the AMS at 1 kg per 6 kg of milk and ground corn (weighted average 1.0 ± 0.2 kg/cow per d) fed to individual cows at a fixed rate in automatic feeders. The same pasture and concentrate feeding systems plus the feeding of variable weekly amounts of a partial mixed ration (PMR; 60% forage, 40% concentrate) were used in the HSR treatment. The objective of the PMR feeding system was to adjust for deficits in pasture availability resulting as the difference between prescribed daily pasture consumption (SR x 14 kg DM/cow) and the average pasture growth rate in the HSR treatment. No significant differences in average daily pasture utilization were detected (alpha 0.05). Daily pasture utilization was 870.9 and 734.5± 70 kg DM/ha (mean ± SEM), respectively. Supplementation with PMR at low levels (average 4.86 ± 0.14 kg/cow per d) did not result in significant differences in herd milk production. However, daily milking distribution patterns by hour shifted ($P < 0.01$) as a consequence of PMR feeding in the HSR treatment. Results supported the prediction that proper PMR supplementation could be used as a tool to efficiently manage forage utilization in highly stocked pasture-based systems that are aiming to improve the AMS occupation and milkings.

Keywords: automatic milking systems, pasture-based dairy, stocking rate, partial mixed ration

INTRODUCTION

Pasture forage utilization is a main driver for profitability and represents a major management priority in a grazing dairy farm (Gronow et al., 2010). Past research showed that proper stocking rate (animals/area) management generally increases pasture utilization (Stockdale and King, 1980, MacDonald et al., 2008). Even defoliation, high stocking density grazing (animals/area/time), maintenance of proper plant residues and avoidance of lenient grazing leading to low quality forage are often cited as major benefits in properly stocked grazing dairy systems (Parsons and Chapman, 2000). Reduction of substitution rates of grazed pasture by supplements is another benefit in a properly stocked grazing system (Fales et al., 1995).

Concurrently, as the utilization of grazed pasture increases, milk production per area also increases, but milk production per cow often decreases (Stockdale and King, 1980; MacDonald et al., 2008). This decrease in milk production is the result of lower feed intake and conversion efficiencies (Little et al. 2011). To prevent the decrease in milk production per cow, managers often rely on supplements (Reis and Combs 2000, Bargo et al., 2002a, 2002b, 2003). However, improper supplementation with forages or concentrates could lead to a high substitution rate of pasture and low levels of pasture utilization (Baker and Leaver, 1986, Fales et al., 1995).

Proper stocking rate management could also affect the milking efficiency and the timing of occupation of automatic milking systems (AMS). Low density of animals per milking stall, uneven milking distribution or reduced milkings could be some of the potential undesirable effects in improperly stocked AMS grazing systems (Jago et al., 2007). However, no studies have confirmed these observations carefully.

The present study tested the effect of stocking rates and variable feeding of a partial mixed ration as a tool to manage forage utilization and milkings in an AMS grazing dairy system. The hypothesis was that timely adjustments in PMR feeding rates could be used to prevent undesirable decreases in pasture growth rate and forage utilization in a high stocking rate system and also aimed to improve the occupation for AMS milking.

MATERIALS AND METHODS

Animals, Experimental Design, and Treatments. Eighty United States Holstein and 14 New Zealand Friesian cows divided in equal proportion to two herds balance for parity (2.03 ± 0.1), days in milk (227 ± 10 days), were assigned to a low stocking rate (LSR; 1.92 cows/ha) or a high stocking rate treatment (HSR; 2.89 cows/ha) implemented over 24 and 16 ha of temperate pasture, respectively.

Two pasture systems were included in both stocking rate treatments: a high biodiversity pasture mixture (OG) including orchardgrass, tall fescue, alfalfa, white clover and red clover and a low biodiversity pasture mixture (RG) composed of white clover and perennial ryegrass. Both pasture mixtures were subdivided in paddocks of 1 ha for rotational grazing using a controlled traffic system (See Chapter 2 for more details). The LSR treatment had access to twenty four 1 hectare paddocks (See Chapter 2, Figure 2.2), sixteen paddocks containing OG pasture and the remaining 8 paddocks containing RG pasture. The HSR treatment had access to sixteen 1 ha paddocks, with half of the paddocks containing OG pasture and the other half containing RG pasture. Fresh pasture allocations were opened for grazing at 0500 h. The HSR treatment had access to one half of a paddock per day. A temporary fence was used to prevent cows from grazing the second half of the paddock. On the second day of grazing in the same paddock, the temporary fence was removed and cows accessed the second half of the paddock. The LSR system grazed 1 paddock per day. Rotational grazing of paddocks was based on approximate targets of 2400 and of 1600 ± 200 kg DM for pre-grazing and post-grazing pasture biomass, respectively. When necessary, pastures were grazed based on stage of maturity using the number of extended leaf per tiller in grasses and flower percentage in legumes.

The feeding system for the LSR treatment included grazed pasture plus addition of concentrate pellet (weighted average 4.2 ± 0.3 kg/head) feed in the AMS at a rate of 1 kg per 6 kg of milk and ground corn (weighted average 1.0 ± 0.2 kg/head) fed at a fixed rate in automatic feeders. The same pasture and concentrate feeding systems plus the feeding of a partial mixed ration (PMR; 60% pasture haylage, 40% concentrate) was used in the HSR. The objective of the PMR feeding in the HSR system was to adjust for deficits in pasture availability resulting from the difference between the prescribed pasture consumption (SR x pasture intake/head) and the average pasture growth rate in the system. The prescribed pasture consumption in the HSR treatment was 15 kg DM/head or approximately 36.4 Mcal of ME from grazed pasture (2.42 Mcal ME/kg DM).

Pasture Layout, Barn, Feeds, and AMS settings. All details regarding pasture and supplemental chemical composition, farm layout, milking barn design, traffic and AMS milking settings are reported in Chapter 2.

Pasture Measurements and Growth Rate Calculations. Indirect estimates of the pasture pre-grazing and post-grazing biomass in each grazed paddock were made with an electronic rising plate meter (RPM; F300, Farmworks, New Zealand), which calculates the average pasture biomass in a given paddock (y) as a function of the compressed pasture height (x) recorded in "click" units (1 click = 0.5 cm of compressed pasture height). Thirty "pluck" measurements of pre-grazing and post-grazing pasture were conducted alongside transects covering the entire area of a grazed paddock. The linear equation used to estimate pre-grazing and post-grazing biomass in OG pastures was $y = 92 x$. The linear equation used to estimate the pre-grazing and post-grazing biomass in RG pastures was $y = 78 x$. For the purpose of this study, the difference between the pre-grazing and post-grazing biomass or pasture harvested by animals was defined as forage utilization.

The pasture growth rate (PGR) was determined weekly with a rapid pasture meter (C-Dax, Farmworks, New Zealand). The PGR was the weekly difference in the average pasture cover of paddocks divided by7 d. The average PGR in the HSR systems was compared with the target PGR or PGR needed to determined amount of PMR feeding as indicated above. For example, the HSR farmlet stocked at 2.89 cows/ha and managed with a target pasture intake of 15 kg DM of pasture/cow required a PGR of 43.4 kg DM/ha/d. If the PGR determined weekly was lower than this required amount, the resulting deficit divided the stocking rate in the farmlet was defined as the amount of PMR to be fed. For example, if the PGR for the HSR was 30 kg/ha/d, the deficit between the PGR required (43.4 kg DM/ha/d) and the current PGR (30 kg DM/ha/d) divided 2.89 cows/ha was equal to the 4.62 kg DM/cow of PMR fed that week.

AMS Data Collection and Milk Samples. The AMS identified each cow by an assigned electronic collar ID and collected information on milk production, milking frequency, AMS visits, and amount of ground corn and pellet consumed.

Statistical Analysis. Pellet and corn intake, AMS and milk performance data were analyzed by method of least-squares ANOVA using the Mixed Models procedure of SAS (Version 9.2, SAS Institute Inc.). Dependent variables were analyzed with a model including the independent fixed factors stocking rate, week and the interaction stocking rate by week. The week effect was entered in the model as a repeated measure variable and the random using a compound symmetry, autoregressive order 1 or unstructured covariance structure based on the lowest Akaike and Bayesian Information Criterion test (Little et al. 1996). In this analysis individual cows were considered as the experimental unit for the animal-related variables and entered in the model as a random effect, as it is commonly used in whole farmlet grazing trials (Bargo et al. 2003). Pasture related data including pasture intake were analyzed similarly. In this analysis the individual 1 ha paddocks were used as the experimental unit and unit of replication. The model of analysis included the fixed effects stocking rate (farmlet), week and the treatment by week interaction. The individual paddock was considered as a random factor in the model. The selection for best fit of covariance structure was conducted as described above.

Nonparametric analysis of milking distributions during hours of the day and milking intervals were conducted with a Chi-squared test using the FREQUENCY procedure of SAS (Version 9.2, SAS Institute Inc.). This nonparametric method was preferred over a parametric procedure because the skewness of the data clearly departed from robust normal distributions. This analysis was used to determine the frequency of milkings at a particular hour of the day and the frequency of milkings at a particular interval. Filtered data were used for this analysis in order to exclude AMS milking failures and the 7 milkings following a given AMS milking failure, as these milking events may not be considered normal records (Bach and Busto, 2005).

Mean and standard deviation values were used to describe the performance of AMS in the two stocking rate systems. No analysis of variance was conducted on these variables, since only 1 AMS unit per stocking rate treatment was available in the study.

RESULTS

Pasture Measurements. Pasture measurements; pre-grazing biomass, post-grazing biomass, and pasture utilization (difference between pre-grazing and post-grazing biomass) were not different between stocking rate (SR) treatments, but there was a marginal tendency for higher post-grazing herbage mass residuals in LSR (Table 4.1). Higher grazing intensity and lower forage harvested per cow were detected in HSR (Table 4.1). Significant variation across weeks was found in the pre-grazing and post-grazing herbage mass of pasture for both treatments (Figure 4.1). This difference in biomass was likely explained by the changing environmental conditions and rainfall events occurring at the beginning of the study (data not shown). Favorable growing conditions developed shortly after the start of the study causing a sharp increase in pasture growth rate by week 3 of the study. Both SR treatments increased dramatically in pasture biomass; there was no detectable difference in pasture growth rate between treatments (Figure 4.2; $P > 0.05$).

Cow performance. Most cow performance variables were affected by a stocking rate by week interaction (Table 4.2). Milk production in HSR increased consistently across weeks of the study, whereas milk production in LSR achieved a maximum plateau by week 4 of the study (Figure 4.5). Other milk production related variables followed similar variations. Preparation time (time for teat cleaning plus teat cup attachment by the AMS) decreased as the study progressed, most likely due to the change in udder conformation as a consequence of higher milk production. On average, the preparation time was 36 s faster for the HSR treatment (Table 4.2). Milking frequency (MF) remained around 2.2 milkings/d in the HSR treatment, but in the LSR treatment MF decreased at a faster rate to less than 2 milkings/d by week 5 of the study (Figure 4.6). Better pasture quality and availability may have reduced the motivation of cows to return to the barn for milking in the LSR treatment, since no PMR was fed in this treatment as compared to the HSR treatment. Thus, PMR feeding in the HSR treatment may have resulted in a more steady motivation for cows to visit the AMS and to milk at more regular intervals. As MF decreased, milking interval increased over the course of the study, explained by a significant stocking rate treatment by week interaction (Table 4.2).

Weight increase was significantly higher in the HSR treatment ($P < 0.0037$), but did not show a significant SR x week interaction (Table 4.2). Refusals conducted by the AMS were significantly higher in the HSR treatment (Table 4.2), which may be explained by the higher motivation by cows to visit the AMS when PMR was fed in the milking barn.

No differences in pellet and ground corn supplement intake were detected between stocking rates or across weeks (Figure 4.3 and 4.4). Total intake was lower from week 1 to 3 in both stocking rate treatments, but total intake was higher in the LSR treatment by week 4 (Figure 4.3 and 4.4).

AMS milking distribution and performance. The PMR feeding in the HSR treatment affected the diurnal pattern of milkings at the AMS (Figure 4.8). Frequency of milkings was low from 0200 to 0500 h and from 2200 to 2300 h in both stocking rate treatments. Throughout daylight hours cows exhibited two differential milking cycles, one in the morning (0500 to 1200 h) and one during the afternoon and evening hours (1500 to 2100 h), probably related to environmental factors (i.e., temperatures), differential PMR feeding and diurnal patterns of grazing. The PMR feeding at 0500 h increased the frequency of milkings from 0500 to 0900 h in the HSR treatment. Conversely, the morning peak for AMS milkings in the LSR treatment occurred between 0700 and 1200 h. Comparative descriptions of the AMS performance of the two treatments are presented in Table 4.3. Underutilization of the AMS resulted from the low number of cows used in the study. On average, both SR treatments had a 52% effective occupation for milking; leaving a significant percent of free time that could be used for milkings if the SR of the AMS (cows/AMS) increased. Total milk yield, total milkings, and refusals means were numerically similar for both SR treatments. The numbers of fetched cows in each treatment were similar, but the frequency of fetched cows was about 10 times lower during the PM hours (Table 4.3).

DISCUSSION

Pasture measurements. The pre-grazing and post-grazing pasture measurements were not affected by dynamic supplementation (Table 4.1 and Figure 4.1). The pre-grazing biomass changed by week, due to environmental factors, yet the post-grazing biomass was maintained in both SR systems as a consequence of the grazing management guidelines applied. There was a tendency for a lower post-grazing biomass in the HSR treatment, which accompanied a higher grazing intensity. This difference was probably due to the higher stocking density for grazing in HSR, as the same numbers of cows were allocated to half of the daily grazed area used in LSR. As expected no differences in forage growth rate and daily forage utilization per area were detected between treatments, despite the predicted significant difference in the daily amount of pasture harvested (i.e., intake) per cow. This result was remarkable because grazing management guidelines were strategically designed to maintain desirable post-grazing residuals, regardless of stocking rate. The goal was to implement a grazing guideline that favored pasture growth rate, in order to achieve a high level of forage utilization per area regardless of the stocking rate system. The results demonstrate that PMR feeding based on detectable changes in pasture growth rate could be used as a tool to manage forage utilization in dairy grazing systems aiming to increase overall milk production from increases in stocking rate. Forage utilization is the main driver of profitability in pasture-based dairies (Gronow et al., 2010) and the major factor determining the level of economic risk in pasture-based feeding systems (Little et al., 2011).

It is generally known that within rational ranges, increased stocking rates generally increase pasture utilization (MacDonald et al., 2008). The increase in pasture utilization is generally due to the avoidance of lenient uneven grazing and maintenance of desirable grazed residuals stimulating high quality regrowth. However, as it has been seen previously, high stocking rates may eventually cause overgrazing, when stocking rate exceeds the carrying capacity of the pasture system. Overgrazing of pasture decreases plant community resilience and causes degradation; and can lead to an early cessation of the grazing season (MacDonald et al., 2008). Generally the increase in forage utilization with higher SR results in an increase in a decrease in milk production per cow (MacDonald et al, 2008). This was not the case in this study, as milk production per cow was not significantly different between stocking rate systems, although there was also no difference in pasture harvested per area.

It also is commonly observed that supplementation, particularly with forage, increases substitution rates (Bargo et al., 2003), which decreases pasture intake and may decrease pasture utilization if adjustments in stocking rate are not made. However, if substitution is managed, as it was proposed with the dynamic use of supplemental PMR, it can serve as an important grazing management tool. In this study, substitution created by PMR feeding was used to ensure the maintenance of an approximate residual of 1200 kg DM/ha in the HSR treatment. Therefore, supplementation amounts were evaluated weekly to cover only the deficit in pasture growth. The PMR was not designed to increase total intake or energy consumption in this study, but was designed to promote pasture regrowth and subsequent pasture utilization.

The concept of dynamic supplementation in a pasture-based feeding system was also used by Farina et al. (2011). In that study, the equation, pasture growth rate/stocking rate was also used to determine the amount of feed available per cow from pasture. The difference of target intake and the actual feed available determined the amount of feed needed from supplements. The current study included the same approach, determining the pasture growth rate (PGR) and estimating the amount of PMR fed based on the deficit in PGR. Farina et al. (2011), using the concepts of dynamic supplementation, also did not find any differences in pasture utilization when farmlets of high and low stocking rates were compared.

Intake and Feed. Pasture intake shown in Table 4.1 was derived from differences between the pre-grazing and post-grazing biomass as estimated by the rising plate meter. Therefore, inferences on pasture intake are subject to inaccuracies associated with this indirect method to estimate herbage mass. As expected with the study design, pasture intake rates were significantly higher in LSR (15.9 kg DM/cow/day) than HSR (9.8 kg DM/cow/day). Intakes for corn and pellets were not significantly different. Interestingly, RPM estimates of pasture consumption in LSR (15.9 kg DM/cow per d) and total forage consumption (14.66 kg DM/cow/d; resulting from the combination of pasture intake (9.8 kg DM/cow/d) and average PMR fed (4.86 kg DM day)) in the HSR treatment was very close to the 16.7 and 15.8 kg DM/cow per d of total forage intake derived from weighted averages (average adjusted by the proportion of United States Holstein and New Zealand Friesian cows in farmlets) of forage consumption estimated with the use of Chromium Oxide in Chapter 2. This similarity between methods suggests the possibility to obtain accurate estimations of pasture intake from the use of a RPM. This information is highly valuable for commercial pasture-based systems, where the lack of accurate methodologies to estimate pasture consumption often preclude proper feeding management.

AMS use and efficiency. The following paragraph briefly describes findings on MY and MF; a more detailed discussion for with mid-lactation cows can be found in Chapter 2. Table 4.2 shows the milk performance of the two herds managed with either LSR or HSR feeding systems. As shown by a significant stocking rate treatment x week interaction, milk production increased more steadily in HSR as a consequence of PMR feeding. The use of the AMS appeared to be affected more by changes in environmental conditions and pasture availability than by qualitative and quantitative differences between the stocking rate treatments. Both MF and refusals shifted during the study as the motivation to graze abundant high quality pasture increased across the study, particularly in LSR. Supplementation of PMR may have created a stronger motivation for cows to visit the AMS at a regular basis regardless of the detected changes in pasture growth and availability. Ketelaar-de Lauwere (2000) found similar results and concluded that at lower sward heights cows paid more total visits (milkings plus refusals) to the AMS. As MF decreases, the milking interval increased, and averaged 14.06 and 13.12 h for LSR and HSR. The average interval length was quite high, but included the entire herd and did not exclude cows in late lactation with lower milk production. These results also show that feeding a PMR in the barn did not affect MY or MF compared to the pasture plus concentrate feeding system used in LSR. These findings suggest that a pasture-based AMS could maintain acceptable MF and MP without providing extra forage supplementation in the milking barn.

Because treatments in this study were not replicated in more than 1 AMS unit, only means and standard deviations of AMS performance were collected and computed. The AMS performance was numerically similar between the two stocking rate systems, reflecting the lack of effects on milk performance variables recorded on individual cows. On average, AMS units milked cows in approximately 50% of the time as a consequence of under stocking. The average percent of time spent milking, often referred as occupation time, was 51.2 and 52.7% for LSR and HSR, respectively. The target occupation of an AMS is recommended to be 85% (Andre et al., 2010) because it is the maximum amount of time that the AMS has available for milking if a reasonable amount of extra time is left for maintenance, repairs and cleaning, or to increase milking opportunities for timid cows and/or naive first lactation cows in transition. However, during this study, the AMS was underutilized due to the small herd size (47 cows/AMS).

The distribution of milkings shifted over the course of the day between the two stocking rate treatments, but as discussed above, AMS occupation and total milk production were not affected. Cows in HSR visited the AMS earlier in the morning compared to the cows in the LSR. The increase in early milking frequency was likely explained by the daily feeding of PMR at 0500. Thus, feed manipulations in the milking barn could be used to entice higher frequency of AMS visitations at particular times of the day. Splitting the feeding of a PMR in the milking barn as opposed to feeding a PMR in the pasture to reduce cow traveling efforts may have the potential to increase efficiency in the AMS occupation through improvements in the distribution of milkings across the day.

Conclusion. As used in this study, dynamic supplementation with low levels of PMR in a highly stocked pasture-based feeding system did not affect pasture growth rate, forage utilization, MY, MF or overall occupation of an underutilized AMS stall (low number of cows/AMS). Dynamic supplementation allowed for the maintenance of proper pasture residuals, thereby improving condition for fast pasture regrowth. Supplementing with a PMR did not result in a marginal response in milk production per cow or per AMS stall, except when pasture availability was low. Feeding a PMR in the barn influenced cow traffic through the system and the frequency of milkings at certain hours of the day, indicating that PMR feeding could be used to improve the distribution of milkings in the AMS.

APPENDIX

TABLES

Table 4.1. Pasture, grazing management, feed intake, milk performance and feed conversion in a low stocking rate and high stocking rate pasture-based feeding system.

	Treatments			P <
Pasture Management Variable	LSR[1]	HSR[2]	SEM	SR[3]
Pre-grazing herbage mass, kg DM/ha	1930	1952	125	0.89
Post-grazing herbage mass, kg DM/ha	1211	1058	66	0.08
Grazing intensity, %	36	43	1.7	< 0.01
Forage consumed, kg DM/cow/day	15.90	9.8	1.1	< 0.01
Forage utilization, Kg DM/ha/day	734	871	70	0.13
Total milk production*, kg/d	20.85	22.41	1.11	0.33
Total intake*, kg/d	19.12	19.50	0.82	0.75
FCE*, kg milk/kg feed	1.12	1.12	0.06	0.97

[1] Low stocking rate treatment

[2] High stocking rate treatment

[3] Stocking rate effect

*Values from Chapter 2 (mid-lactation cows), intake determined by indirect marker method with chromium oxide

Table 4.2 Cow performance in automatic milking systems managed with a low stocking rate or high stocking rate pasture-based feeding system.

	Treatments			*P* Value		
Variable	LSR[1]	HSR[2]	SEM	SR[3]	W[4]	SR x W[5]
Milk, kg/day	20.67	21.56	1.47	0.67	<.0001	<0.01
Weight Change, kg	0.98	2.00	0.24	<0.01	<.0001	0.11
Milking Frequency/d	2.01	2.17	0.08	0.17	<.0001	0.03
Milking Interval, h	14.06	13.12	0.62	0.29	<.0001	0.02
Refusals/d	0.89	1.28	0.11	0.01	<.0001	0.07
Box Time, min	15.14	15.57	0.76	0.69	0.0005	0.08
Milk Time, min	11.99	12.04	0.69	0.96	<.0001	0.01
Prep Time, min	3.13	3.49	0.13	0.06	<.0001	0.03

[1] Low stocking rate treatment

[2] High stocking rate treatment

[3] Stocking rate effect

[4] Week effect

[5] Stocking rate by week interaction

Table 4.3 AMS performance in a low stocking rate and high stocking rate pasture-based feeding system

Variable	LSR[1]	HSR[2]	SD[3]
Number of Cows	46.27	45.05	2.86
Total Milk, kg	1036.07	1084.57	97.49
Percent Milking Time	51.24	52.73	3.66
Percent Free Time	41.91	40.41	4.01
Total Milkings	96.82	103.48	9.29
Refusals	43.00	61.93	42.35
Fetch[4] cows am	11.06	10.34	4.57
Fetch[5] cows pm	1.21	1.21	2.23

[1] Low stocking rate treatment

[2] High stocking rate treatment

[3] Standard deviation

[4] Cows with milking interval over 12 h at 0500 h

[5] Cows with milking interval over 12 h at 1500 h

FIGURES

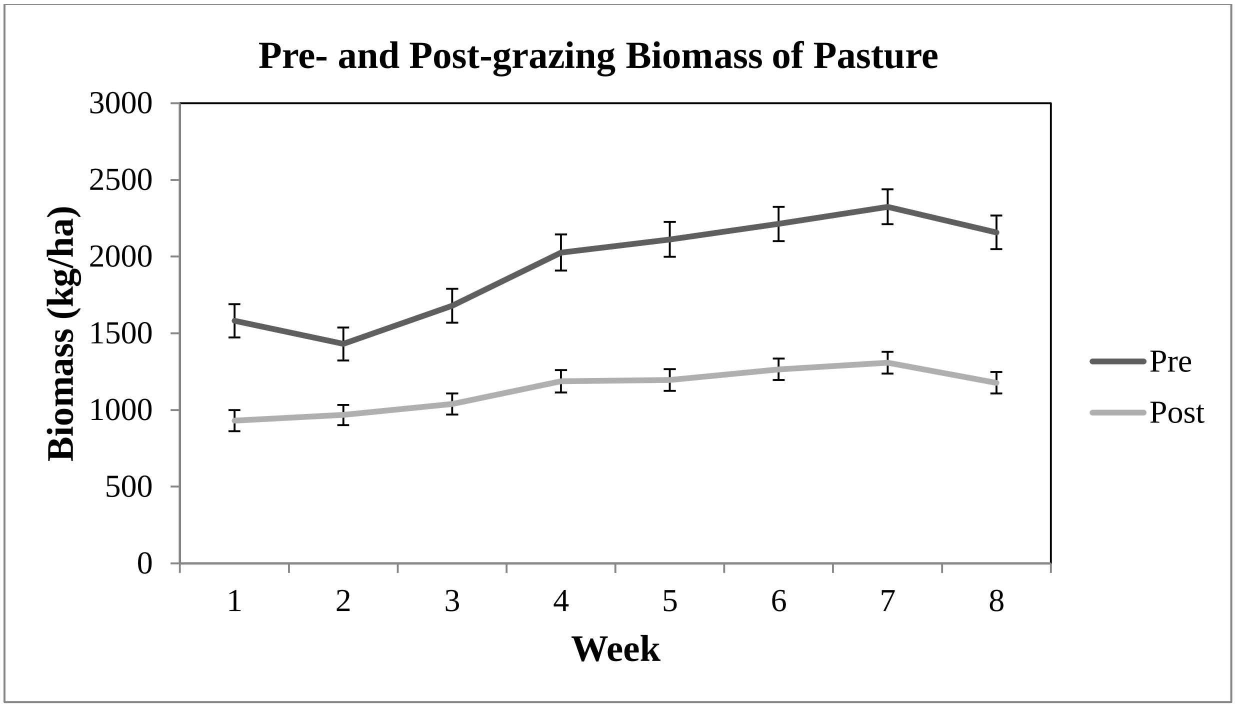

Figure 4.1 Pre-grazing (Pre) and post-grazing (Post) pasture biomass for high stocking rate and low stocking rate pasture-based feeding systems. There was no difference in pre-grazing and post-grazing biomass between stocking rate treatments, but pasture pre-grazing and post-grazing biomass differed across weeks of the study ($P < 0.0001$). Bars denote the standard error of means (SEM = 117.44 and 72.97 for pre-grazing and post-grazing biomass, respectively)

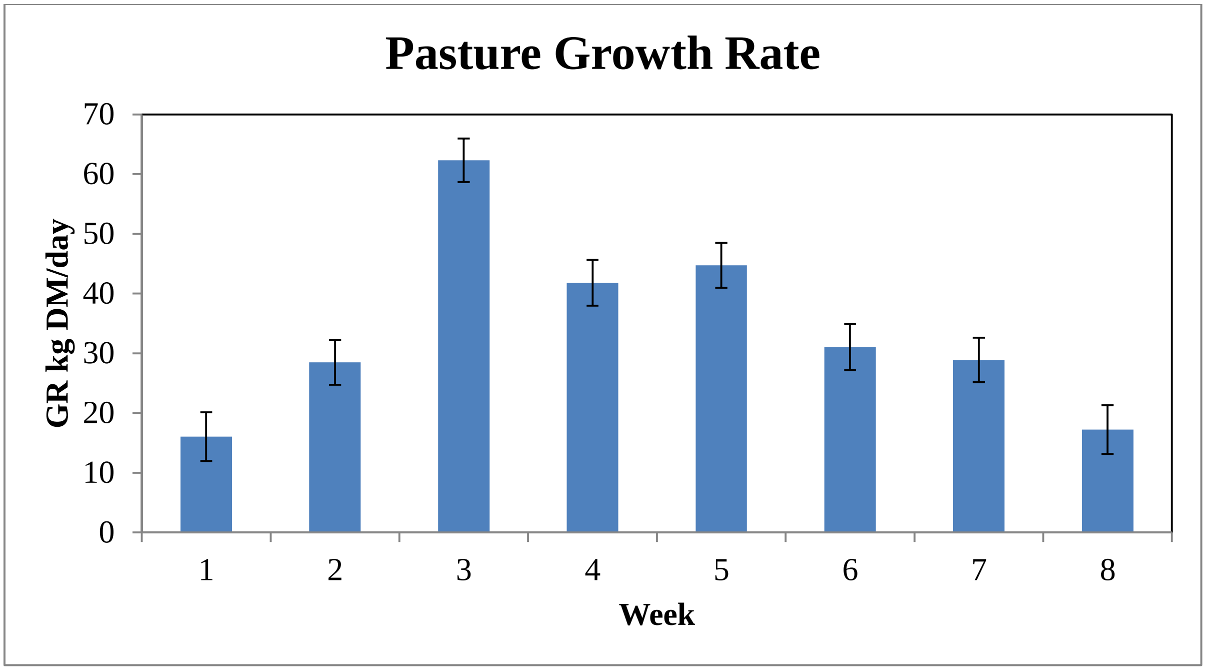

Figure 4.2 Pasture growth rate (GR) means both for high stocking rate and low stocking rate pasture-based feeding systems. There was no significant difference between stocking rate treatments, but growth rate did differed across weeks of the study ($P < 0.0001$). Bars denote the means and error bars are the standard errors of the means (SEM = 4.1)

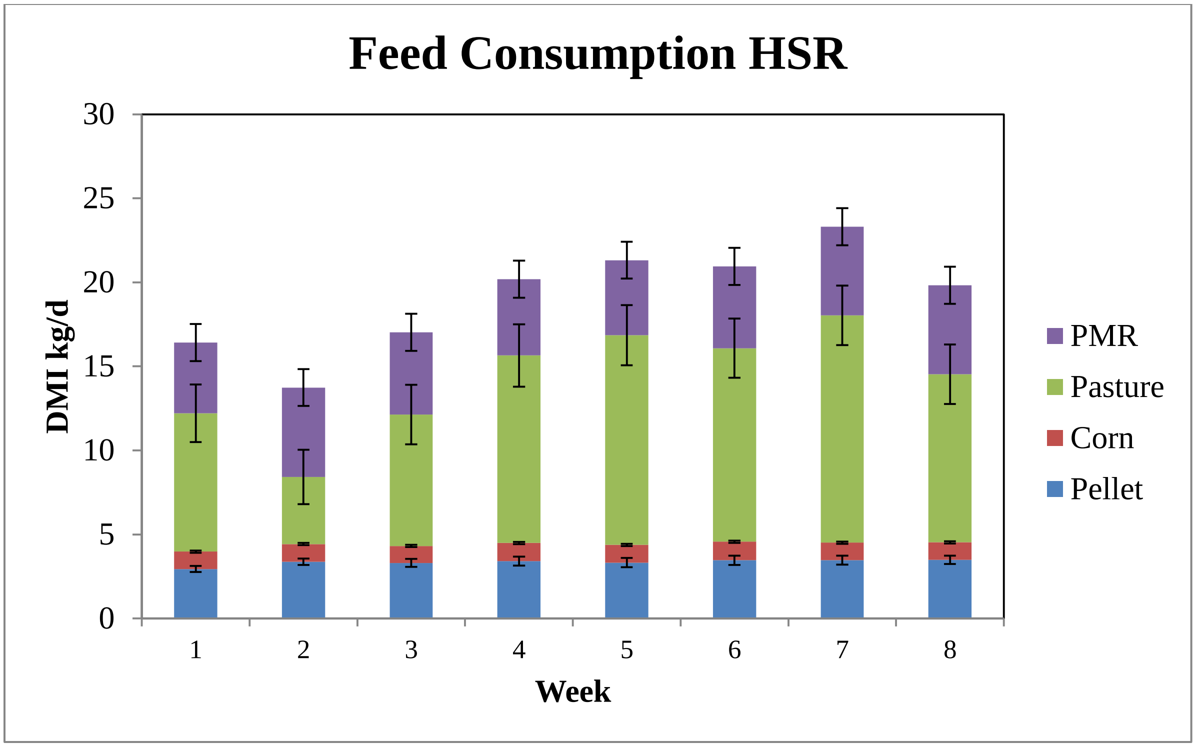

Figure 4.3 Consumption of different feedstuffs in the high stocking rate treatment (HSR) in a pasture-based feeding system. Bars denote the standard error of means.

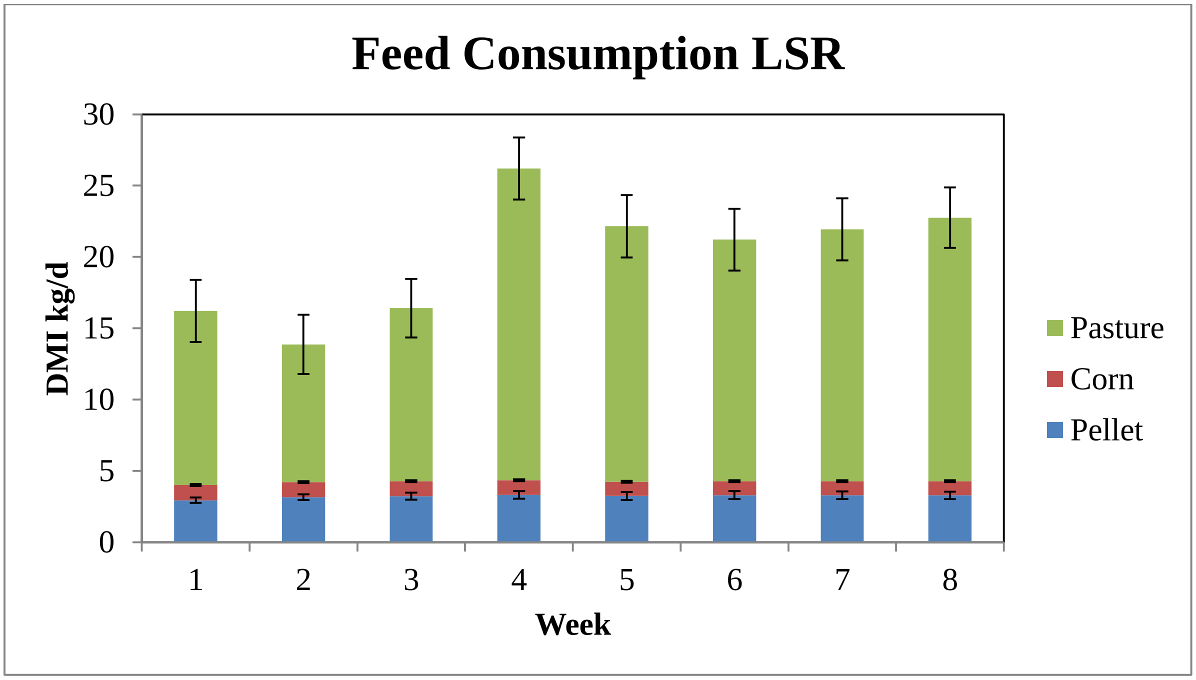

Figure 4.4 Consumption of different feedstuffs in a low stocking rate treatment in a pasture-based feeding system. Bars denote the standard error of means.

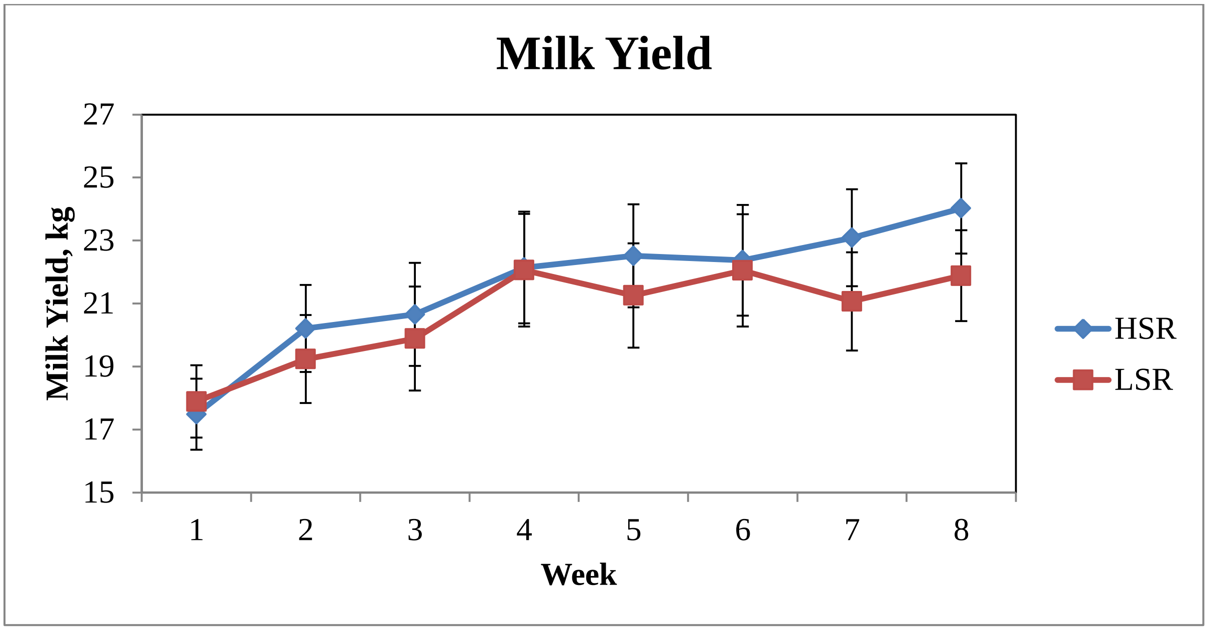

Figure 4.5 Milk yield for high stocking rate (HSR) and low stocking rate (LSR) pasture-based feeding systems. There was no significant difference in milk yield between stocking rate treatments, but milk yield differed across weeks of the study (P < 0.0008). Bars denote the standard error of means (SEM = 1.79)

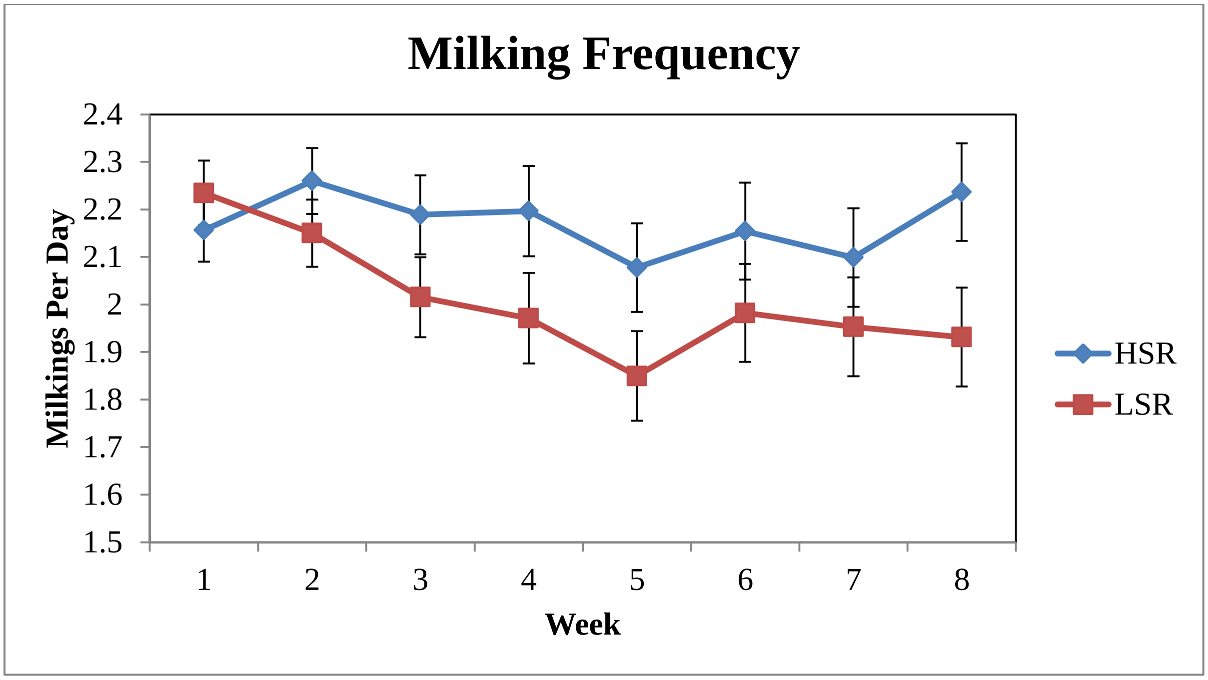

Figure 4.6 Milking frequency for high stocking rate (HSR) and low stocking rate (LSR) pasture-based feeding systems. There was no significant difference in milking frequency between stocking rate treatments, but milking frequency differed across weeks of the study (P < 0.03). Bars denote the standard error of means (SEM = 0.1)

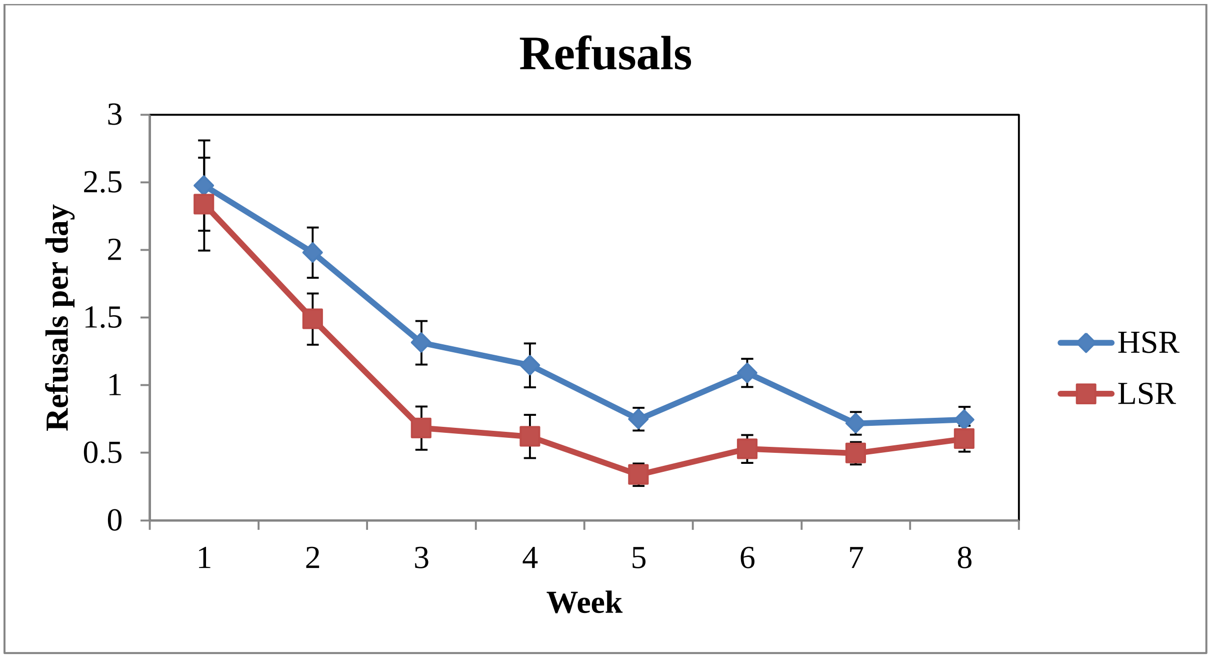

Figure 4.7 Milking refusals for high stocking rate (HSR) and low stocking rate (LSR) pasture-based feeding systems. There was a significant difference in milking refusals between stocking rate treatments (*P* = 0.01). Milking refusals also differed across weeks of the study (P < 0.0001). Bars denote the standard error of means (SEM = 0.11).

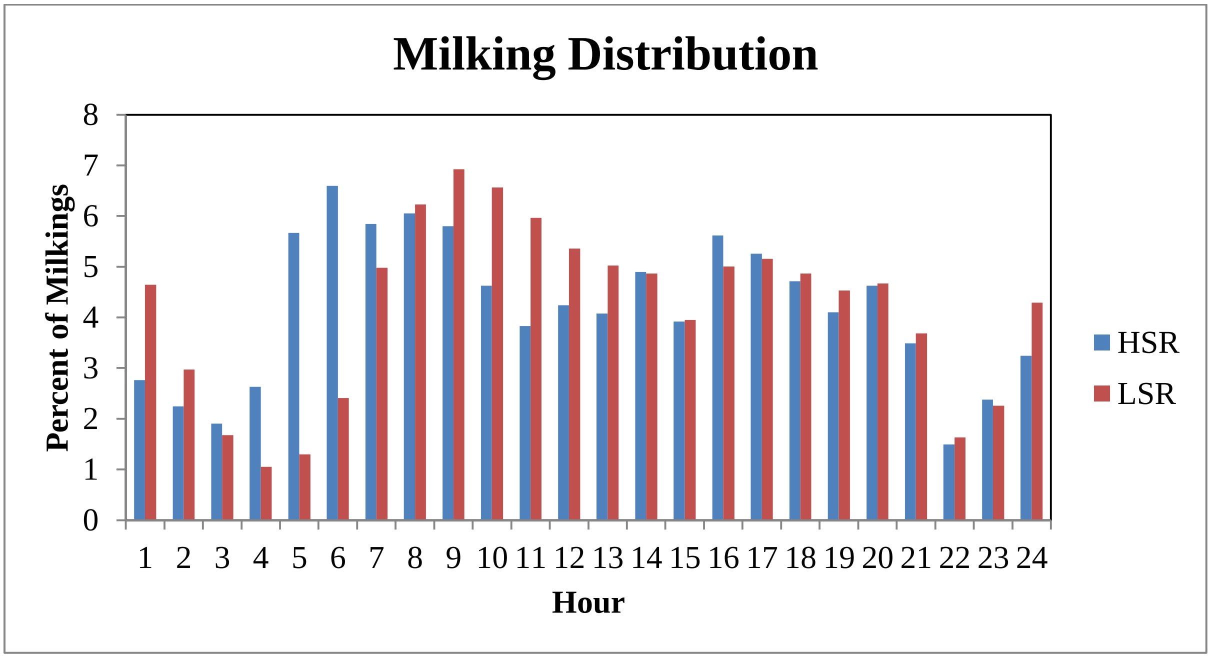

Figure 4.8 Milking distribution for high stocking rate (HSR) and low stocking rate (LSR) pasture-based feeding systems. There was a significant difference in milking distribution between stocking rate treatments (P < 0.0001).

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CHAPTER 5

GENERAL CONCLUSIONS AND FUTURE RESEARCH

There is growing interest in integrating automatic milking systems (AMS) and pasture-based dairying. However, guidelines outlining the proper management of these systems are scarce. Our objective was to help fill the information gaps regarding the operation and efficiency of a pasture-based dairy with AMS using free traffic flow and voluntary grazing with contrasting stocking rates, supplementation strategies and cow genotypes.

All chapters of this thesis focused on two typical pasture-based feeding systems of the Midwestern United States. This thesis compared a low stocking rate (LSR, 1.92 cows/ha) system and a high stocking rate (HSR, 2.89 cow/ha) system fed partial mixed ration (PMR). This thesis also compared the performance of two genotypes of dairy cows (New Zealand Friesian, NZF; United States Holstein, USH) often used in Midwestern pasture-based dairy systems.

Our study showed that the increase in stocking rate from 1.92 to 2.89 cow/ha with dynamic supplementation was a potential strategy to increase milk production per area and use of the AMS. Dynamic feeding of PMR in the HSR system was used to balance the supply-demand of forages based on expected changes in pasture growth rate (PGR). Supplementing only the deficit in PGR helped maintain desirable grazing residuals without sacrificing pasture utilization. This study showed that managing pasture residuals with dynamic PMR supplementation did not affect PGR, which makes it a desirable option for dairies that want to increase stocking rate and milk production per cow and/or per area without sacrificing forage utilization. This feeding practice could be relevant for the proper integration of AMS in small pasture-based dairy farms and may introduce greater flexibility to manage AMS occupancy and stocking rate (cows/AMS stall) without sacrificing forage utilization. Future research could focus on further increases in stocking rate and supplementation in order to increase milk production per area, while also increasing milk production per cow.

Chapter 2 showed that a rising plate meter (RPM) gave an accurate measurement of pasture intake. The RPM was used to record pre- and post- grazing biomasses, which in turn were used to estimate pasture intake per cow. An estimate of pasture dry matter intake (DMI) was determined by an external marker technique using chromium oxide. When the estimated forage consumption by the external marker chromium oxide was compared to the RPM, the values were very close (HSR: 10.18 ± 0.61 and 9.8 ± 1.10 kg DM; LSR: 14.8 ± 0.66 and 15.9 ± 1.10 kg DM; for chromium oxide pasture intake estimates and RPM pasture intake estimates, respectively). This indicates that the RPM is a valuable tool for determining pasture DMI, which is affordable and could be used in any grazing dairy.

Chapter 2 also highlighted the importance of dairy cow genotype in pasture-based systems. Our study showed that USH had a greater genetic potential for milk production (MP; 27.9 ± 0.8 and 15.3 ± 1.3 kg for USH and NZF, respectively) accompanied by a greater level of feed intake (22.3 ± 0.8 and 16.3 ± 0.8 kg DM for USH and NZF, respectively). The USH genotype outperformed NZF cows in both HSR and LSR treatments, however a genotype by time interaction suggested important differences between genotypes as pasture availability changed in the study. At study onset, pasture biomass was low and NZF were nearly at their maximum milk production. These results indicated that when pasture biomass per cow is limited, either by environmental conditions, as in this case, or by SR in a very high SR system, NZF may be the preferred genotype. Conversely, when pasture availability per cow was high, USH had higher milk production, regardless of SR. This indicates both that USH performs better when pasture availability is high and that HSR did not restrict intake. Further research could continue to examine practical genotype by environment interactions that aid farmers in genotype selection, based on the production system they choose.

It was observed in other studies that supplementation creates a higher marginal response in cows of higher genetic merit. In this study, a PMR supplement with a similar quality to pasture was used. The purpose of the PMR was to adjust for the deficit in PGR and therefore did not result in significantly greater milk production. However, if a supplement higher in energy was used, a significant marginal response in milk production may have been detected. Increasing supplementation in the form of high energy concentrates may be a good option for this system because the AMS and Cosmix feeders allow for supplementation of individual cows, perhaps determined by genotype, stage of lactation, or parity. Using this technology for precision feeding (i.e., feeding based on milk production level, genotype, or stage of lactation) may help increase milk production per cow and, in turn, feed conversion efficiency (FCE).

Feed conversion efficiency in pasture-based systems may be improved by refining pasture management practices. Supplementation and stocking rate can affect FCE due to low pasture availability per cow in high stocking rate systems. However, our study showed that with dynamic PMR supplementation, there is no significant difference in intake or milk yield, preventing a decrease in FCE across stocking rates (1.12 ± 0.06 for both LSR and HSR). Our study also showed that FCE was affected by genotype (1.00 ± 0.06 and 1.24 ± 0.06, for NZF and USH, respectively). Assuming feed intake is not severely limited cows of greater genetic merit should achieve higher FCE, since they have a higher marginal response to concentrates and greater genetic potential for high milk production. Further research is required to better understand the relationships between stocking rates, supplementation, and FCE in order to increase the efficiency of pasture based systems.

Although supplementation may have potential to improve FCE in a pasture-based feeding system, it may also affect the rumen environment and forage degradation in the rumen. The study reported in Chapter 3 showed that low levels of PMR (40% ground corn, 60% haylage) supplementation did not depress rumen pH or reduce degradation rates of pasture DM, CP, or NDF. In this study there were potential indications that the PMR helped to slow the rate of passage. This may have been due to greater levels of indigestible NDF in the haylage, slowing passage rate and increasing the extent degradation and possibly creating a more favorable environment for rumen microbes increasing the rate of degradation. Validation of these indications should be researched in the future in order to continue to increase the utilization of nutrients in a pasture based diet.

Although there may be some benefits to increasing supplementation, the effects of supplementation on barn traffic and AMS must also be considered. Chapters 2 and 4 both included important information on AMS utilization. Results in both chapters demonstrated that dynamic supplementation did not increase milking frequency (MF). This indicates that additional supplementation (other than in the AMS) was not required to achieve moderate frequency of visitations. However, results in Chapter 2 did show, that as the grazing season extended into the fall mid-lactation cows were less willing to visit the AMS, in which, feeding a PMR may be an extra motivation to return to the barn. Understanding how feeding affects traffic flow to the AMS is vital to running an efficient system and further research could aid in determining the effects of other these feeding strategies on AMS occupation.

Although the PMR in the HSR did not significantly increase milking frequency (2.3 ± 0.07 and 2.5 ± 0.07 for LSR and HSR, respectively), there was a shift in distributions of milking across the day causing HSR to increasing their number of milking visitations around the time of PMR feeding (0500 h). The effect of the PMR on milking distribution is important because it may be a possible tool used to increase milkings at times of the day when visitations are low. It also is interesting to note the differences in visitations between genotypes, as seen in Chapter 2. It is possible that a combination of genotypes may utilize the AMS better than one genotype; not just considering the distribution of milkings but the differences in milking interval.

The NZF group had longer milking intervals which may allow for more flexibility in the time of milkings for those cows, allowing USH cows with shorter milking intervals a priority for milking. This combination of cows with different milk production and expected milking intervals may allow for more efficient utilization of the AMS and also increase milk production for cows of greater genetic merit, without affecting milk production in lower genetic merit cows. More research is required to understand the effects of milking interval on milk production and how to manipulate milking interval in this system to potentially increase milk production and system efficiency.

Overall, the results of this research show that dynamic PMR supplementation maintains milk production in both NZF and USH and helps optimize pasture utilization. The PMR used in dynamic supplementation is a suitable substitute for pasture and did not cause negative associative effects at the rate provided, but also did not significantly increase milk production. In conclusion, dynamic PMR supplementation is a viable tool for pasture-based AMS dairy farms because it does not affect the rumen environment, and may improve the efficiency of AMS utilization by offering opportunities to improve AMS stocking rate (cow/AMS) and occupancy, without sacrificing pasture utilization.