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Swedish University of Agricultural Sciences
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Abstract

Automatic milking systems (AMS) provide the opportunity for less manual labour and an increased milking frequency. But in order to reach an optimal milking frequency a well-functioning cow traffic is crucial. There are many factors affecting cow traffic but one factor that has not been studied thoroughly yet is the effect of different light intensities during the night, 22.00 h to 05.00 h. Therefore the aim of this study was to determine the effect of different light intensities during the night on number of selection gate passages (GP), milking frequency and milk yield. The study was conducted as a Latin square were three light intensities were applied: LOW (11 ± 3 lux), INT (33 ± 1 lux) and HIGH (74 ± 6 lux), in three different herds. There were in average 69 ± 4 primiparous cows and 133 ± 4 multiparous cows in each treatment. The dairy cows were housed in loose house barns with automatic milking and a Feed First™ cow traffic system. No effect of treatment was found on either number of selection GP per 24 hour and cow or on milking frequency. Only a slight decrease in selection GP per hour and cow during night time was observed when cows were exposed to treatment LOW, but the decreased activity did not affect milking frequency. The effect on milk yield was hard to determine due to disturbance during the experimental period but no differences in milk yield between treatments LOW and HIGH were found.

Sammanfattning

Automatiska mjölkningssystem kan medföra fördelar som mindre manuellt arbete och en ökad mjölkningsfrekvens. Men för att nå en optimal mjölkningsfrekvens krävs en väl fungerande kotrafik. Många faktorer påverkar kotrafiken men en faktor som inte har studerats är effekten av olika ljusintensiteter under natten, 22.00 h till 05.00 h. Syftet med studien var därför att studera effekten av olika ljusintensiteter under dygnets mörka timmar på antal passeringar genom selektionsgrinden, mjölkningsfrekvens och mjölkavkastning. Studien genomfördes som en Latin Square med tre ljusintensiteter under dygnets mörka timmar: LOW (11 ± 3 lux), INT (33 ± 1 lux) och HIGH (74 ± 6 lux), i tre olika besättningar. I genomsnitt inkluderades 69 ± 4 primiparous kor och 133 ± 4 multiparous kor per behandling. Mjölkkorna hölls i lösdrifter med robotmjölkning och ett Feed First™ kotrafikssystem. Ingen effekt av behandling hittades på antalet antal passeringar genom selektionsgrinden per 24 timmar och ko eller på mjölkningsfrekvensen. Endast en liten minskning i antal passeringar genom selektionsgrinden per timme och ko nattetid kunde observeras under behandlingen LOW men den minskade aktiviteten påverkade inte mjölkningsfrekvensen. Effekten av ljusintensitet på mjölkavkastningen var svår att avgöra eftersom korna var utsatta för störningar under försöksperioden men inga skillnader i mjölkavkastning mellan behandlingarna LOW och HIGH kunde påvisas.

Contents

Introduction

The automatic milking system (AMS) with robotic milking has been available for commercial use since 1992 and the number of herds with AMSs has increased rapidly in the last decades (Svennersten and Pettersson et al., 2008). AMSs provide the opportunity for less manual labour and an increased milking frequency which in turns could result in a greater milk yield (e.g. Rossing et al., 1997; Svennersten and Pettersson et al. 2008; Jacobs and Siegford, 2012). On the other hand, an AMS is big investments (de Koning and van de Vorst, 2002) and therefore it is important that the capacity of the robot is maximized (Castro et al. 2012). AMSs are in use for 24 hours and are based on voluntary visits to the milking unit several times a day (e.g. Džidić et al. 2001; Svennersten-Sjaunja and Pettersson et al., 2008; Jacobs and Siegford, 2012). To reach an optimal milking frequency without needing to fetch cows manually, well-functioning cow traffic is crucial (Svennersten-Sjaunja and Pettersson et al. 2008).

Cow traffic refers to the movement of the cows in the barn in order to perform activities, not only milking but also feeding and resting patterns. There are many factors affecting the cow traffic, for example cow traffic systems (free, forced or semi forced) (Forsberg, 2008; Svennersten-Sjaunja and Pettersson, 2008) management of feeding (Prescott et al., 1998; de Koning and van de Vorst, 2002; Rodenburg and Wheeler, 2002) social hierarchic (Forsberg, 2008) etc. One factor that has not been fully studied regarding cow traffic is how illumination during the dark period affects cow behaviour.

The physiological effect of light on dairy cows is on the other hand quiet well documented. Light intensity and the photoperiod, i.e. “the relative duration of light and dark that an organism experiences within a 24 hour period” have a physiological response on dairy cows which will affect growth, reproduction and lactation (Dahl et al., 2012). There are a number of studies that has confirmed that an extended photoperiod compared to a shorter photoperiod could result in an increased milk yield (Dahl and Petitclerc, 2003). In contrast, when studying dairy cows exposed to 24 hours of light compared to a natural photoperiod there was no effect on milk yield (Marcek and Swansson, 1984). There are also studies that have confirmed a hormonal response to changes in light intensity during the dark period (Muthuramalingam et al., 2006) which in turns could affect milk yield. The results from these studies could indicate that dairy cows need some hours of darkness to maintain the extended production that comes from an extended photoperiod.

When the AMS was introduced in Sweden farmers reported, according to Pettersson & Wiktorsson (2004), that when providing low light intensity during night time the number of visits to the milking unit was decreased compared to keeping the lights on for 24 hours. Though there is little scientific evidence that confirms this assumption.

Sufficient lighting for dairy cows in the AMS is important since studies shown that light have an impact on both the cows’ physiology and behaviour (e.g. Stanisiewski et al. 1988; Phillips et al., 2000; Pettersson and Wiktorsson 2004; Muthuramalingam et al. 2006). However, which light intensity that is suitable during the dark period is not yet fully studied. The aim of this study is therefore to determine how different illumination intensities during the dark period affects the number of gate passages, milking frequency and milk yield in automatic milking systems. Is the behaviour of the cow affected by different light intensities and is the response different in primiparous cows compared to multiparous cows. How can the illumination being managed in order to maximize the capacity of the milking unit and increase milk production?

Literature background

Cow traffic and milking frequency

Cow traffic refers to the movement of the cows in the barn where selection gates, if present, is guiding the cows (Jacobs and Siegford, 2012). A well- functioning cow traffic is fundamental in the AMS and includes both optimal visits to the milking unit and to the feeding area. Since visits to the feeding area and the milking unit are voluntary, the success of the system is dependent on active cows (Svennersten-Sjaunja and Pettersson, 2008). In order to get an even distribution of visit to the milking unit and maximize the capacity of the milking unit cows need to be active throughout the whole day (Forsberg, 2008).

A major advantage with the AMS is the potential of increased milking frequency without increased manual labour (Svennersten-Sjaunja and Pettersson, 2008). Studies have shown that milk production can be enhanced by a more frequent milking (Svennersten-Sjaunja and Pettersson, 2005; Wright et al., 2013). Hence the AMS also has the potential to increase daily milk yield. An optimal milking frequency is important to maximize the milk yield per MU. Handling time (cleaning of teats, attaching cups, etc.) during each milking session in an automatic milking unit is fixed. If the milk yield per milking session is to low the milk yield per minute is lowered i.e. more time spent on handling per litre of milk (de Koning et al., 2002). Therefore, the milking frequency should be high enough to stimulate milk production but not so high that it lowers the efficiency of the milking unit resulting in unproductive visits. Milking frequency should never be lower than two milking sessions a day although high yielding cows can be milked more frequently (Svennersten-Sjaunja and Pettersson, 2008), up to four times a day, before the visits becoming inefficient (Laurs et al., 2008). In practice, more than three milking sessions per day on a herd average of more is not realistic (Melin et al., 2005).

Since irregular milking's could result in decreased milk yield (Jacobs & Siegford. 2012) the variation in milking intervals is an important factor. Reviewed by Markey 2013, average milking interval is in between seven and nine hours but the variation within herd is considerable. Though, some variation in milking frequency throughout lactation is expected due to the decreased milk yield towards the end of lactation (Jacobs & Siegford. 2012).

There are a number of factors that have an effect on milking frequency, of which several can be controlled by herd management (Svennersten-Sjaunja and Pettersson, 2008). Cow traffic system (for example free, forced, selective or guided) has shown to have an impact on number of milking sessions per day (Forsberg, 2008; Svennersten-Sjaunja and Pettersson, 2008). Management of feeding; concentrates (Prescott et al., 1998; Rodenburg and Wheeler, 2002), roughage (de Koning and van de Vorst, 2002), and total mixed rations (Rodenburg and Wheeler, 2002) also has an impact on milking frequency. Regarding total mixed rations, both the number of feeding occasions and type of feed has shown to influence the number of milking sessions per day (Rodenburg and Wheeler, 2002). The cows' motivation to visit the milking unit varies between individuals. However, the motivation to be fed has been demonstrated to be stronger then the motivation to be milked (Prescott et al., 1998). Therefore the management of feeding concentrate during milking sessions have a great impact on milking frequency. Concentrate with a higher palatability compared to a lower palatability also resulted in increased milking frequency (Rodenburg and Wheeler, 2002).

In an AMS with selection gates it is possible to adjust milking permission settings, i.e. the minimum time between two milking sessions (Melin et al., 2005). Melin et al. (2005) reported that the milking frequency, feeding patterns and daily number of passages through selection gates were affected by these settings.

Diurnal patterns

Dairy cows are often kept in an environment very different from the environment of their wild ancestors (Kilgour 2012). Even so, their natural behaviour and diurnal rhythm will affect their behaviour when housed and therefore knowledge of this is important.

On pasture

Since the wild ancestor of dairy cattle is extinct, the best way to investigate the natural diurnal patterns of dairy cow behaviour is to study their behaviour on pasture (Kilgour 2012). In a review of 22 research articles considering diurnal behaviour patterns of dairy cows at pasture, Kilgour (2012) concluded that cattle spend most of their time (90% – 95%) either grazing, ruminating or resting. In general, grazing occupies most of the time and is often performed during daylight. Resting and ruminating, on the other hand, is more observed during night time.

Cattle show a distinct diurnal rhythm in response to daylight. Grazing, for example, peaks at sunset and sunrise (Kilgour 2012). Linnane et al. (2001) who presented corresponding results also concluded that grazing patterns are sensitive to a photo-effect. In the study, heifers in semi-feral conditions showed a seasonal response to day length and adapted their grazing pattern to season. The total grazing time was constant during most of the grazing season but when the day length decreased, night time grazing increased. There where little variation between animals and also between days.

Housed

The diurnal rhythm of cows housed indoors resembles the diurnal rhythm shown of cows on pasture (Harms et al., 2002; DeVries et al., 2003; Munksgaard et al., 2011). Munksgaard et al. (2011) compared two types of cow traffic systems in an AMS where cows were exposed to continuous lighting. They found that cows tended to spend less time feeding and more time lying overnight, regardless of which cow traffic system used. This corresponds to a study of dairy cows in a free-stall barn, where the highest presence of cows in the feeding alley occurred during daytime (06.00 h to 18.00 h) and the lowest presence during late evening and early morning hours (DeVries et al., 2003).

Jacobs and Siegford (2012) compared studies on milking frequency during night time (22.00 h to 07.00 h), and found that some studies showed a decrease in milking frequency during night time, however not all studies supported these findings. Harms et al. (2002) reported in a proceedings that the number of cows in the waiting area in front of the robot were lower at night time.

Light

Visible light is the spectrum of electromagnetic radiation that the human eye can perceive. Different wavelengths give different colors. The human range of the spectrum varies between individuals but is in general in between 400 nanometers (bluish lights) to about 700 nanometers (reddish light). Light intensity, or luminance, describes the flow of light on a surface and is measured in lux (lux = lumen / m^2). The distance to the light source and light armatures has a high impact light intensity measurements. In direct sun light the light intensity is approximately 100 000 lux but on a cloudy day the light intensity can be approximately 5000 lux. Below streetlights at night the light intensity is about 10 – 30 lux and moonlight only provides approximately 0.25 lux (Starby, 2006). It is important to point out that lux is how humans perception of brightness and presumably it differs from the perception of animals.

Visual perception of cattle

The visual perception of cattle differs from the visual perception of humans. Cattle do not have a concentrated retail vision but are believed to have a good distance vision (Heffner & Heffner, 1992). They have limited color vision and can distinguish red from blue or green lights but they show limited ability to differentiate green lights from blue lights (Phillips and Lomas, 2001). No published research concerning the night vision of cattle was found.

The effect of illumination management and intensity

Cows adapt not only their behaviour to the seasonal changes in photoperiod length (Linnane et al., 2001); there is also a physiological response (Dahl et al., 2012). Moreover, the intensity of the illumination also has an impact on both behaviour (Phillips et al., 2000; Pettersson and Wiktorsson 2004) and physiology (e.g. Stanisiewski et al. 1988; Muthuramalingam et al. 2006), although this subject has not been fully studied.

Behaviour

Phillips et al. (2000) showed that some level of light is needed to insure a natural walking behaviour as the dairy cows responded to lowered illumination intensity with an increased number of steps per second. The walking rate, meters per second, were increased when the floor provided good friction, if the floor was slippery the dairy cows compensated by taking shorter steps. It is discussed that the increased stepping- and/or walking rate were due a desire to return to their accommodations and to an increased stress when walking through the passageways in the dark. Based on these results, Phillips et al. (2000) recommend an optimal level of illumination for locomotion in passages during the dark period should be between 39 lux and 119 lux.

In a preference study by Phillips and Arab (1998) individually penned bullocks were given the opportunity to turn the lights on and off, selecting darkness or light. Behaviours of the animals and whether the light was on or off were recorded. The results showed that all behaviours were expressed under both light and dark conditions but there were a slight preference towards feeding during light. In total the bullocks spend 54 % in light, suggesting that it was a weak tendency towards bullocks preferring a lit environment.

Pettersson and Wiktorsson (2004) investigated whether dairy cows in an AMS preferred a lying area that where fully lit or lit with guiding lights only, during the dark period (23.00 h to 05.00

h). The lying area was divided in two, one with 200 lux and the other with 5 – 7 lux, and the cows were free to choose between the two compartments. No significant differences in distribution of cows during the dark period were found on herd level but there were a slight increase in numbers of occupied cubicles in the resting area with guiding lights only. Individual preferences, independent of ranking order, of lighter or darker resting areas could be observed. Furthermore, no significant effect of illumination on milking or feeding patterns were seen, even though the individual variation in milking interval was higher with guiding lights.

Reproduction, growth and production

The photoperiod length has a clear physiological response in reproduction, growth, lactation and health (Dahl et al., 2012). Studies have confirmed that during lactation long day photoperiod could result in an increased milk yield when compared to a short day photoperiod (Dahl and Petitclerc, 2003). This is probably due to a hormonal response to light intensity (Dahl and Petitclerc, 2003) combined with an increased dry matter intake (Dahl et al., 2000). Long day photoperiods with 16 – 18 hours of light are therefore recommend (Dahl et al., 2012). The question then arises what light intensity is preferable during the darker period to obtain the effect of an increased milk yield. Some studies (Muthuramalingam et. al 2006; Bal et. al., 2008) have investigated the effect of different illumination intensity during the dark period, however in most other studies the illumination intensity during the dark period is referred to as darkness, and not specified at lux level (e.g. Dahl et al., 1997; Miller et al., 1999).

In an epidemiological study of cows in tie-stalls in the northern hemisphere Reksen et al. (1999) found that milk yield at first artificial insemination and reproduction were positively correlated to the use of dim lights during night time . Unfortunately, it was not specified which lux level the study used for the dim light. However, Reksen et al. (1999) reasons that “the positive relationship between reproduction and dim illumination at night as seen in the present investigation was probably dependent on a low light intensity”.

Phillips and Schofield (1989) studied supplementary lighting with different illumination intensities in two experiments with dairy cows housed in open front cubicle sheds with sky lights. In experiment 1, cows were exposed to either supplementary light (mean 481 lux) or to a natural photoperiod with daylight as only light source. The study showed that cows exposed to supplementary lighting, e.g. a long photoperiod, increased their time spent in the feeding area (especially during the light supplementation) as well as time spent on some social activities. Lying time for cows exposed to the natural photoperiod was reduced. In experiment 1, supplementary light also resulted in both an increased dry matter intake and an increased milk yield. In experiment 2 the cows were exposed to natural daylight for approximately 8 h per 24 h and received supplementary lighting of 101 lux, 191 lux and 529 lux 10 h a day (16.00 h to 23.30 h and 05.30 h – 08.00 h) in a changeover design. On the contrary to experiment 1, no significant effect of treatment was seen on either dry matter intake or milk yield. These contradictory results are discussed to be due to the experimental designs.

In a study by Marcek and Swanson (1984) cows were subjected to either continuous lighting or a long day photoperiod (16 h of light and 8 h of darkness). The light intensity was 254 ± 9 lux during daytime and 132 ± 9 lux during night time. Even though no significant effect of treatment in response to milk yield was found, it was a trend towards producing less milk (kg per day) in cows and heifers exposed to continuous lighting, compared cows and heifers exposed to a long day photoperiod. This effect was greater for cows, which could be due the higher persistency of lactation in heifers in general. The persistency of lactation in the cows was increased during the long photoperiod treatment by 2%. Based on these results the authors suggest that continuous lighting may be detrimental to milk yield over time.

Studying the effect of continuous lighting on daily weight gain of heifers, Peters et al. (1980) showed that the average daily weight gain when exposed to continuous lighting was not significantly different from heifers exposed to natural photoperiod. On the other hand, the average daily weight gain for heifers exposed to a long photoperiod treatment (16 h light and 8 h dark) was significantly higher than both for heifers exposed to continuous lighting and for heifers exposed to a natural photoperiod. The dry matter intake was also significantly higher in the long photoperiod treatment compared to the other treatments. However, the feed to gain ratio was significantly lower for the long photoperiod treatment. These results indicate that 8 h of darkness stimulates feed intake, growth and feed conversion compared to 16 h of darkness or continues lighting.

Hormonal response

The hormonal response to light intensity and photoperiod length is one factor argued to be responsible for the photo-effect on milk yield though the physiological mechanisms are not fully understood (Dahl and Petitclerc, 2003). The secretion of endogenous melatonin is highly effected by light intensity which in turns might affect prolactin, growth hormone (GH), insulin-like growth factor-1 (IGF-1) (Dahl and Petitclerc, 2003).

Melatonin

One of the physiological responses of darkness, the absence of light, is an increased level of circulating melatonin (Stanisiewski et al. 1988). The melatonin production is inhibited when light hits the photoreceptors in the eye i.e. melatonin is only produced in the absence of light. The receptors send inhibition signals to the pineal gland where melatonin is synthesized. The functional role of a decreased melatonin secretion, as during light hours, is not fully established but melatonin affects the cardiac rhythm and also influences the secretion of other hormones (Dahl et al., 2000). The level of light needed to suppress melatonin secretion in cattle is under discussion, and it seems to be quite large differences between species. In Syrian hamsters only 1.08 lux was needed to suppress nocturnal melatonin (Brainard et al., 1982) while in humans 350 lux was needed to cause a significant suppression (McIntyre et al., 1989). Stanisiewski et al. (1988) confirmed that light inhibits secretion of melatonin in calves. Calves exposed to continuous lighting showed a reduction in the concentration of circulating melatonin.

Studies of the physiological response of light intensities between 40 and 60 lux during the dark period have shown diverse results. Muthuramalingam et al. (2006) showed that prepubertal heifers exposed to 50 lux had 50% less circulating plasma melatonin compared to heifers exposed to 0 lux. However, the suppression was not persistent throughout the entire dark period (8 h). Heifers exposed to 5 or 10 lux did not show any decrease in melatonin compared to heifers exposed to 0 lux. This suggests that 5 – 10 lux can be used as a level of illumination intensity during the darker period, without resulting in any physiological effect. In a study by Lawson and Kennedy (2001), light intensities above 50 lux tended to decrease the secretion of melatonin when compared to 0 lux. On the other hand, multiparous cows in a tie- stall barn exposed to 40 – 60 lux at night time did not show any decrease in melatonin when compared to 0 – 5 lux, according to Bal et al. (2008). Nor did the dry matter intake or milk yield differ between the two treatments.

Prolactin

Prolactin is one of many hormones involved in the lactogenesis. Prolactin is affected by photoperiod length, with increasing levels of circulating prolactin when the photoperiod is prolonged. Several studies have shown that circulating prolactin is decreasing when cows are exposed to a short photoperiod length, reviewed by Dahl et al. (2000). It has been widely discussed whether it is prolactin or some other hormone that is responsible for the galactopoietic effect of a long photoperiod (Dahl et al., 2000). Studies by Stanisiewski et al. (1988) demonstrated that the concentrations of circulating prolactin in calves exposed to continues lighting of approximately 525 lux were no different from the concentrations in calves exposed to a short photoperiod with 8 hours of light (approximately 525 lux) and 16 hours of darkness.

The correlation of melatonin and prolactin has been addressed in different studies but the outcome has not been consistent. Stanisiewski et al. (1988) found no correlations between daily concentration of circulating melatonin and daily concentration of circulating prolactin, although feeding of melatonin (meant to simulate short days) has shown to have an inhibiting effect on prolactin (Dahl et al., 2000).

GH and IGF-1

Growth hormone, or somatotropin, is a protein hormone synthesized and secreted by the anterior pituitary gland. Circulating GH increase milk yield in lactating cows (Bauman and Veron, 1993) and has been discussed as the hormone responsible for the galactopoietic effect achieved from a long photoperiod (Dahl et al., 2000). However, studies have failed to detect any differences in GH concentrations in dairy cows when exposed to different photoperiod lengths (reviewed by Dahl et al., 2000). IGF-1 on the other hand, has shown to fluctuate with photoperiodic treatments independent of GH, and might be responsible for the effect of a long photoperiod (Dahl et al., 2000). Muthuramalingam et al. (2006) showed that plasma melatonin and night plasma IGF-1 tended to be negatively correlated in prepubertal heifers. Since IGF-1 enhance growth and milk production (Sjaastad et al. 2010) these results could be interpreted as melatonin having a negative effect on productivity.

Material and methods

The field study followed a Latin square design and was conducted in three different Swedish dairy herds with AM systems (DeLaval, Tumba Sweden) in Sörmland and Uppland, Sweden (N65º; E15º). The study was conducted from October 2012 until March 2013. The experiment was approved by Uppsala local ethics committee, Uppsala county (210/12). It was carried out by subjecting the herds to different illumination intensity during the dark period, from 22.00 h to 05.00 h. The effects were measured on number of gate passages (GP) through the selection gates, number of visits to the milking unit and milk yield.

Preconditions

Both primiparous and multiparous cows of Swedish red and white breed and Swedish Holstein breed were included in the study. The cows produced in average 32 kg milk per day (Table 1) and had free access to roughage. Concentrates were provided both in concentrate feeding stations and in the milking unit during milking.

Table 1: Number of milking units, number of cows in the automatic milking system per milking unit, milk yield per cow and day and milking permission settings, expressed as herd means based on registrations from November 2012 to March 2013 (including all cows in each herd).

	Herd 1	Herd 2	Herd 3	All herds
No. of MU's*	2	2	1	1.7
No. of cows in the AMS** per MU*	54	63	66	61
Milk yield per cow and day (kg)	30	28	38	32
Milking permission settings*** (hours)	6.7	6.3	6.7	6.6

*MU = Milking unit
**Number of cows in the AMS = the average number of lactating in the automatic milking system cows milked by the MU* or MU's*.
*** Milking permission settings = Settings of minimum time between milking's at the MU*/MU's*, expressed in hours

The cows were kept in insulated loose house barns with AM (DeLaval, Tumba Sweden), and a Feed First™ cow traffic system. All herds had access to a free-stall area, a free-stall area with concentrate feeding stations, a feeding area whit a feeding table and a milking area (milking unit and waiting area in front of the milking unit) appendix A1, A2 and A3. The cows had free access the feeding area and entered through one way gates. When exiting the feeding area cows passed through a selection gate. At the selection gate the cows were directed either to the milking area or to the free-stall area with concentrate feeding stations, depending on time since last milking. If sorted to the milking area the cows where directed back to the feeding area after the visit to the milking unit. In a Feed First™ cow traffic system cows when leaving the free- stall area with concentrate feeding and entering the free-stall area have to pass through one way gates. This forces the cows to pass through the selection gate in order to get to the concentrate feeding stations and to the milking unit.

Herd 1 was illuminated with six rows of fluorescent lights, four rows in the lying area and two rows in the feeding area, evenly distributed over the barn. Herd 2 was lit with four rows of metal halogen lamps. Herd 3 was lit with three rows of metal halogen lamps and three rows of fluoresces lights. At all three farms an automatic timer controlled the lights and turned them on at 05.00 h and turned them off at 22.00 h which results in a dark period of 7 hour, henceforth referred to as night time. During daytime, 05.00 h to 22.00 h, the stables were lit to at least 158 lux, not including the supplementary from daylight. The illumination emanated from the feeding area and then lighted up the lying area making illumination intensity greatest in the feeding area and declining towards the lying area. The milking area was lit 24 hours a day.

Experimental design

The study was preceded by a washout period where the cows were exposed to a continuous illumination of at least 158 lux 24 hours a day for 4 weeks. The experimental period consisted of three subsequent periods where three light intensities during the dark period were applied. The effect of light intensity was examined for the parameters number of gates passages (GP) through the selection gates, number of visits to the milking unit and milk yield. All treatments were represented at each period. Previous studies have shown that the physiological response to photoperiod length in dairy cows is significant after three to four weeks (Dahl and Petitclerc, 2003). Assuming that the response would be similar when altering the illumination intensity during the dark period, the periods were set to approximately five weeks. The herds were randomly assigned to the order in which they were exposed to the treatments.

In order to avoid any disturbance from cows being too close to parturition or drying off, only registrations from lactating cows more than 21 days in milk (DIM) and less than 275 DIM throughout each treatment were included in the analysis. Cows included where present throughout the whole treatment, but not necessarily present at more than one treatment. There were in average 203 ± 6 cows at each treatment that matched these criteria, 69 ± 4 primiparous cows and 133 ± 4 multiparous cows, presented as means ± standard deviation (SD). The cows were on average 150 ± 8 DIM and at their 2.2 ± 0.1 parity.

The first 12 days of each treatment was considered as an adaption period and these days were not included in the analyses. When excluding the adaption period, each treatment extended for 21 – 22 days except for period 4, treatment INT at Herd 1, which extended for 16 days. This was due to disturbances from maintenance work in the barn.

Registrations

The light intensity was measured with a lux meter (ST 1300) with a light sensor of a filtered silicon photodiode, the measurement accuracy was ± 5%. Light intensity where measured at cow eye level, approximately 1.5 m off the ground, at 20 (Herd 3), 36 (Herd 1) and 44 (Herd 2) measurement points evenly distribute across the feeding and lying area. The mean values of light intensity for the feeding area and lying area combined were calculated per herd and treatment. To calculate the mean light intensity value for each treatment, the mean values from each herd and treatments were combined. The light intensities at each treatment, presented as mean ± SD of means, were; LOW (11 ± 3 lux), intermediate, INT, (33 ± 1 lux) and HIGH (74 ± 6 lux). Light intensities were altered using dim lights (Herd 3) or by disconnecting armatures (Herd 1 and Herd 2). In order to avoid any influence from daylight all measurements were made after sunset and before sunrise. Selection GP, visits to the milking unit and milk yields were registered automatically by the milking unit management program (DelPro Software 3.7 and 3.5, and VMS management Software 2009).

Data handling

One 24 hour period started 05.00 h and ended 04.59 h the following morning. The 24 hour period was then divided in daytime and night time. The registrations were defined as daytime registrations if they occurred between 05.00 h and 22.00 h and night time registrations if they occurred between 22.00 h and 05.00 h following day. Data were divided in registrations from primiparous cows (cow in first lactation) and multiparous cows (cows in second lactation or more). A registration at the selection gate was defined as one selection gate passage; a registration at the milking unit was defined as a visit to the milking unit only if resulting in a milk yield registration. Average number of visits to the milking unit per 24 hours and cow was defined as milking frequency. Means for each treatment and herd were calculated for the variables;

number of selection GP per hour and cow, milking frequency and milk yield per 24 hours and cow.

In order to study the distribution of the selection GP and visits to the milking unit over the 24 hour period, mean values for selection GP per hour and cow and for number of visits to the milking unit per hour and cow was calculated for daytime and night time respectively. The means per hour and cow at night time were subtracted from the means per hour and cow at daytime (diff selection GP and diff MF).

Statistical analyzes

The effects of treatment were tested on the variables selection GP per 24 hours and cow; selection GP per hour and cow at daytime and at night time; milking frequency; visits to the milking unit per hour and cow at daytime and at night time; diff selection GP; diff MF and milk yield per 24 hours and cow using mean values for each treatment and herd in the PROC GLM procedure of SAS (v. 9.3, SAS Institute, Inc., Cary, NC) according to following model:

$$Y = \text{treatment} + \text{period} + \text{herd}$$

A Student's t-test was conducted to test for general differences in means across all treatments. The variables tested were: number selection GP for primiparous cows and multiparous cows; the number of selection GP at daytime compared to the number of selection GP at night time; the number of visits to the milking unit at daytime compared to number of visits to the milking unit at night time and the milk yield per 24 hours and cow for primiparous cows compared to multiparous cows.

Results

The effect of herd was significant on selection GP and visits to the milking unit, and overall significant for milk yield. The effect of period was only significant on selection GP per hour and cow during daytime, the difference between selection GP per hour and cow at daytime and selection GP per hour and cow at night time, and number of visits to the milking unit per hour and cow at daytime.

Selection gate passages

In average cows passed through the selection gates 13.2 ± 3.1times per 24 hours and cow (means ± SD). In general, primiparous cows had significantly more selection GP per 24 hours and cow, 14.1 ± 2.9, compared to multiparous cows ,12.6 ± 3.2 passages per 24 hours and cow ($P = 0.003$). Though there were no significant effect of treatment on the number of selection GP per 24 h and cow (Figure 1).

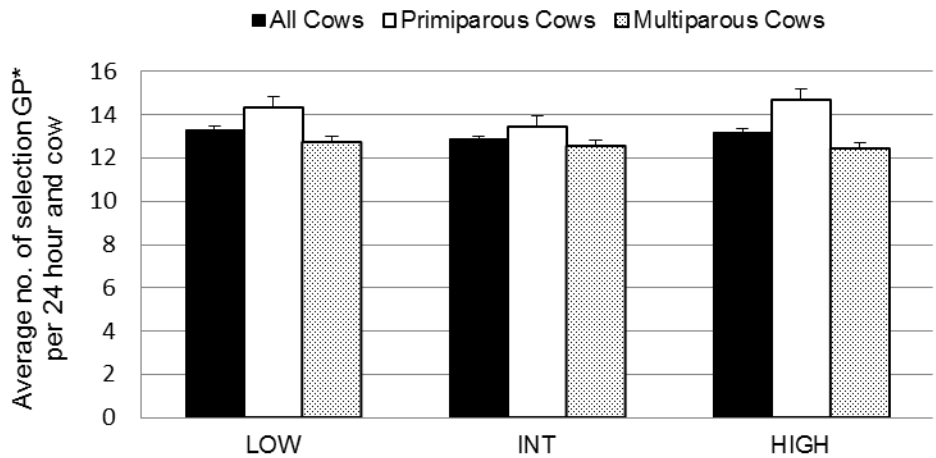


Figure 1: The average number of selection gate passages* per 24 hours and cow for each treatment, LOW, INT and HIGH. Solid bars ■ represent all cows, open bars □ represent primiparous cows and stippled bars ⚃ represent multiparous cows. Standard error of means is indicated by the error bars.
*GP = Gate passages.

When comparing selection GP per hour and cow during night time and daytime, a student's t-test showed that the cows had in general more selection GP per hour and cow during daytime than during night time (P = 0.018), regardless of parity. When studying the effect of treatment, a significant decrease in selection GP at night time at the LOW treatment compared to HIGH treatment were found (P = 0.036) (Figure 2). When analyzing multiparous and primiparous cows separately no differences were found.

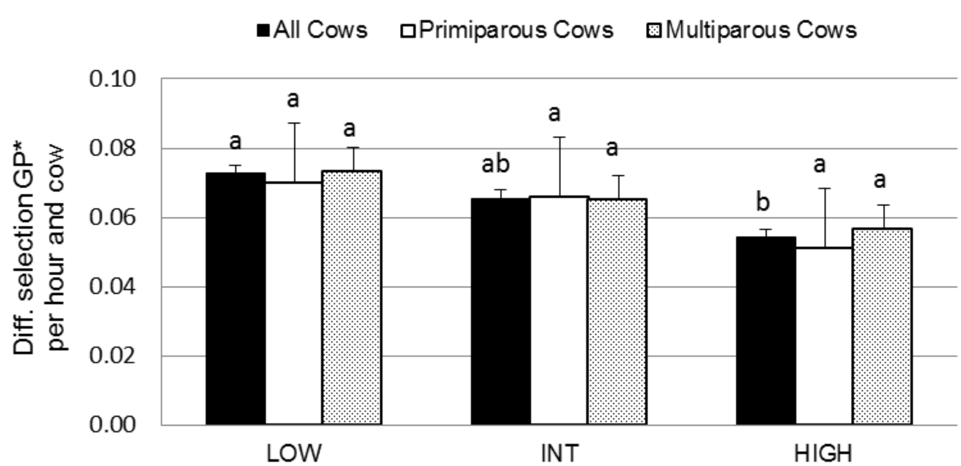


Figure 2: Shows the difference between the average number of selection gate passages per hour and cow at daytime and average number of selection gate passages per hour and cow at night time, for each treatment, LOW, INT and HIGH. Solid bars ■ represent all cows, open bars □ primiparous cows and stippled bars ⚃ multiparous cows. Standard error of means is indicated by the error bars. Bars with different letters represent a difference at P < 0. 05.
*Diff. selection GP = the difference between selection gate passages at daytime and selection gate passages at night time.

Visits to the milking unit

The average milking frequency during the experimental period was; for all cows 2.6, primiparous cows 2.5, and multiparous cows 2.7. There were no differences in the number of visits to the milking unit per hour and cow at daytime compared to number of visits to the milking unit per hour and cow at night time (P > 0.5). Also milking frequency was not affected by treatment, neither when all cows were included in the model nor when including primiparous or multiparous separately. Furthermore, no differences were found in number of visits to the milking unit per hour and cow between daytime and night time.

Milk yield

During the experimental period, cows produced in average 35 kg per 24 hours and cow. Multiparous cows produced significantly more milk: 37 kg per 24 hours and cow, than primiparous cows: 30 kg per 24 hours and cow (P < 0.001).

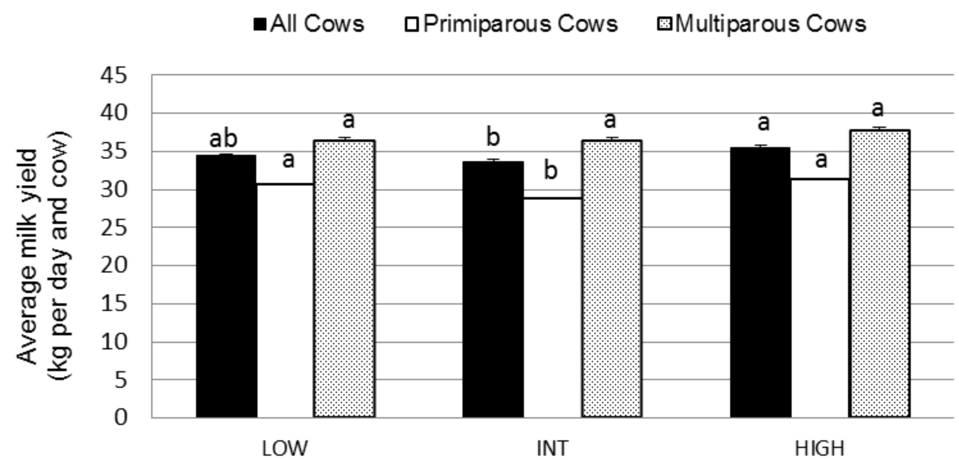


Figure 3: Average milk yield (kg) per 24 hours and cow for each treatment. Solid bars ■ represent all cows, open bars □ primiparous cows and stippled bars ⊡ multiparous cows. Standard error of means is indicated by the error bars. Bars with different letters represent a difference at P < 0. 05

When studying the effect of treatment (Figure 3) on all cows, treatment INT had a significantly lower milk yield per 24 hours and cow, 33.6 kg, than treatment HIGH, 35.5 kg (P = 0.049). When studying primiparous cows separately, the milk yield per 24 hours and cow were significantly lower at treatment INT, 28.8 kg, compared to both treatment LOW, 30.7 kg (P = 0.014) and treatment HIGH, 31.3 kg (P = 0.007). No effect of treatment was found on the milk yield per 24 hours and cow of multiparous cows.

Discussion

Small effects of treatment were found on number selection GP and no effect on visits to the milking unit. There were some effects on milk yield which can be explained by disturbance during the experiment, se below. Since there were overall significant effects of herd and some significance from of period it is to be considered as valid factors to include in the model.

There was no effect of treatment on the average number of selection GP per 24 hour and cow suggesting the activity of the cows throughout 24 hours is not inhibited by a light intensity of 11 lux or higher at night. Though, overall there was less selection GP per hour and cow during night time compared to daytime (Figure 2 and appendix B) indicating that cows are less active during the night regardless of light intensity. This corresponds with Harms et al. (2002), DeVries et al. (2003) and Munksgaard et al. (2011) who all found a slight decrease of activity (cows in the waiting area, time spent feeding, number of cows in the feeding alley) during late evening and early mornings. The bias of using selection GP as a measurement of activity can be discussed since there are no registrations of the activities taking place in between selection GP. But since there are numerous registrations, in average 203 ± 6 per treatment, in the present study selection GP is considered as a fair indication on the activity of the cows.

The distribution of selection GP throughout 24 hours is presented as the difference between selection GP per hour and cow at daytime compared to night time. The difference was significantly higher at the LOW treatment compared to the HIGH treatment indicating that the cows are less active during night if the illumination is lowered to 11 lux compared to a illumination is 74 lux (Figure 2, appendix B). There are light intensity recommendations of 39 lux to119 lux for locomotion in passages during the dark period (Phillips et al., 2000) and since 11 lux is below that recommendation this could explain the decreased activity at 11 lux. It is possible that the cows are slightly more discouraged moving around in the barn in low light intensities compared to higher light intensities. Though it is worth noticing that even though the differences were significant, both in the present study and in Phillips et al. (2000), the actual differences were in both cases very small.

As discussed, previous studies have not been unanimous considering the diurnal patterns of milking frequency (Jacobs and Siegford, 2012). Overall the present study could not present any differences concerning the number of visits to the milking unit during daytime compared to number of visits at night time. Even though the number of selection GP per hour and cow during night time deceased compared to selection GP per hour and cow during daytime when exposed to a lowered light intensity, no effect on number of visits to the milking unit was found. This indicates that even though there was a slight decrease in activity during night time when exposed to a lowered light intensity, the decrease was not enough to affect milking frequency.

The milk yield in kg per day and cow were in general not affected by treatment except for treatment INT which showed a lower milk yield compared to treatment HIGH and LOW when studying primiparous cows separately. No differences were found between treatments LOW and HIGH. Since no effect of treatment was found on multiparous cows the difference is derived from the primiparous cows. The lowered milk yield could be due to the construction work that took place during the INT treatment in Herd 2. Even though the actual construction period is removed from the analysis there might be a lingering effect on milk yield. The farmer reported that the cows were fetched manually for milking at a much higher frequency during the construction period than normal because there was a lot of noise emanated from the milking area. Being milked in attachment to that noisy construction area could be considered as a stressor and since cows that are exposed to stress may experience disturbance in milk let down (Sutherland et al. 2012) hence production losses (Bruckmaier 2005), this could explain the lowered milk yield at treatment INT. Since multiparous cows in general are more calm and docile (Dickson et al., 1970; Tőzsér et al., 2003) than primiparous cows it could explain why the effect is found on the primiparous cows only. Nonetheless, present study cannot disambiguate whether the lowered milk yield at 34 lux was due to the construction work or an effect of treatment therefore the effect of lowered light intensities during night on milk yield needs further investigation.

There are also other aspects to discuss concerning the results of milk yield in the present study. First of all, physiological traits like milk yield is affected by many factors not included in the model. Also, as discussed in Phillips and Schofeild (1989), a change over design is not recommended since it takes some time for physiological adaption to photoperiod length and illumination intensity. Even though the first 12 days in each treatment was considered a wash-out period and excluded from the analyses it might not be enough. Previous studies have shown that physiological responses to photoperiod length in dairy cows are significant after three to four weeks (Dahl and Petitclerc, 2003). In the present study each treatment lasted for approximately 5 weeks. If the response of light intensity resembles the response of photoperiod length this would mean that if there were any effects of treatment on milk yield, the effects may not have been significant until the last week of the treatment period. But, if only the last week of each treatment would have been analysed there would not have been enough registrations to present a normal distribution. However, if the different light intensities used in this study have had a greater impact on milk yield, it would probably have been showed by at least a tendency for altered yield between treatments LOW and HIGH. The effect of light intensity on behaviour on the other hand, might have a more direct impact since light has a direct impact on cow vision and therefore the effects should be significant after a shorter period of time.

In present study only registrations from lactating cows more than 21 days in milk (DIM) and less than 275 DIM throughout each treatment were included in the analysis. Excluding cows in early lactation minimizes the risk of cows not being well adapted to the AMS which could otherwise be considered a bias. Previous studies have shown that 14 days is sufficient adaption time for primiparous cows (Melin et al., 2005). Also it is likely that cows close to drying off will change their behaviour due to alterations in management e.g. fewer visits to the MU per day as a result of a lowered milk yield and less amount of concentrate.

The AMS and feed first cow traffic is designed to guide the cow towards the optimal milking frequency which in itself could be considered as a bias. Variations in milking frequency are regulated by the system making treatment effects less pronounced. As an example primiparous cows had more selection GP then multiparous cows but the milking frequency was not affected by the increased activity.

In the present there are many factors not included in the analysis, such as feeding routines, feeds and management. It is likely that these factors will have a greater impact on milk yield than light intensity and will also have an impact on behaviour. Of course the type feeds and amount of feeds that a cow is provided will affect milk yield. Studies have also shown that number of times feed can have an impact on cow traffic (Rodenburg and Wheeler, 2002). In present study the types of feeds were similar but the exact ingredients and nutritional value is not known neither is the exact number of feedings. Though, the feeding routines were similar in all three herds. Management of cows that has long milking interval will also affect cow traffic. The routines of fetching cows with long intervals were not included in the study and it has been shown that there is a large variation in routines between herds (Rodenburg & House, 2007). If cows were fetched more or less frequently during different treatments in present study this could conceal treatment effects and the effects might be underrated or overrated. Though there were no such reports form the farmers.

There are advantages of implementing a lowered light intensity during night time. First of all, it could result in a decreased cost of illumination since the electricity consumption in most cases is decreased and also the lights would be needed to be replaced less frequently. In comparison, if the illumination intensity at Herd 2 is set to 11 lux during 7 hours, the electricity consumption would be approximately 62000 kWh per year compared to 70000 kWh per year if the illumination intensity is set to 74 lux, a difference of 8000 kWh per year. The percentage of the energy consumption deriving from the illumination varies between herds and countries. When studying four dairy herds in Sweden (Hörndahl and Nueman, 2012), 20% of the electricity consumption could be derived from illumination, but when studying three Irish herd the electricity consumption deriving from illumination were much lower (Upton et al., 2010). Nonetheless it could be economically beneficial.

Second of all, previous studies have indicated that continuous lighting can be detrimental to feed intake, weight gain (Peters et al., 1980) and milk yield (Marcek and Swanson, 1984). Though, it is somewhat unclear how continuous lighting is defined. In Peters et al. (1980) the light intensity during night time was 132 lux and in Marcek and Swanson, (1984) the intensity is not defined. Treatment HIGH had a light intensity of 74 lux which could be considered as continuous lighting. Also, Reksen et al. (1999) found positive effects of dim lights, light intensity not defined, on milk yield and reproduction supporting the theory that a lower light intensity during night time could be beneficial.

Future research on different light intensities for dairy cows should continue focus on the effects of lowered intensity during the dark period since previous studies have focused on the effects of different light intensities and photoperiod length for the light period. Furthermore, the effects of continuous lighting needs to be further looked into before determining if it is a suitable practice in commercial dairy production.

Conclusion

A lowered light intensity to 11 lux during the darker period for dairy cows in AMS did not affect the cow traffic in forms of selection GP per 24 hour and cow and milking frequency. Only a slight decrease in selection GP per hour and cow during night time when exposed to approximately 11 lux were observed but the decrease in selection GP did not affect milking frequency. The effect on milk yield was hard to determine due to disturbance during the experiment but no differences in milk yield between light intensities 11 lux and 74 lux were found.

References

Bal, M .A., Penner, G. B., Oba, M. and Kennedy, A. D. 2008. Effects of dim light at night on milk yield, milk composition and endocrine profile of lactating dairy cows. Canadian journal of animal science. 88, 609-612.

Bauman, D. E. and Vernon, R. G. 1993. Effects of exogenous bovine somatotropin on lactation. Annual review nutrition 13, 437–461.

Brainard, G. C., Richardson, B. A., Petterborg, L. J. and Reiter, R. J. 1982. The effect of different light intensities on pineal melatonin content. Brain research 233, 75-81.

Bruckmaier, R. M. 2005. Normal and disturbed milk ejection in dairy cows. Domestic animal endocrinology 29, 268-273.

Castro, A., Pereira, J. M., Amiama, C. and Bueno, J. 2012. Estimating efficiency in automatic milking systems. Journal of dairy science 95, 929-936.

Dahl, G. E., Elsasser, T.T., Capuco, A. V., Erdman, R. A. and Peters, R. R. 1997. Effects of a long daily photoperiod on milk yield and circulating concentrations of insulin-like growth factor-1. Journal of dairy science 80, 2784-2789.

Dahl, G. E., Buchanan, B. A., and Tucker, H. A. 2000. Photoperiodic effects on dairy cattle: A review. Journal of dairy science 83, 885–893.

Dahl, G.E., and Peticlerc, D. 2003. Management of photoperiod in dairy herd for improved production and health. Journal of animal science 3, 11-17.

Dahl, G. E., Tao, S. and Thompson, I. M. 2012. Lactation biology symposium: Effects of photoperiod on mammary gland development and lactation. Journal of animal science 90, 755-760.

De Koning, K., van de Vorst, Y. & Meijering, A. 2002. Automatic milking experience and development in Europe. In: McLean, J., Sinclair, M. & West, B. Proceedings from the first North American conference on robotic milking, Toronto, Canada, March 20-22 2002. I-1-I-11.

De Koning, K. and van de Vorst, Y. 2002. Automatic milking - changes and chances. Proceedings from the British mastitis conference, Institute for animal health /milk development council, Brockworth, Gloucester, England, 2002-10-09. p 68-80.

DeVries, T. J., von Keyserlingk, M. A. G. and Beauchemin, K. A. 2003. Short communication: Diurnal feeding pattern of lactation. Journal of dairy science 86, 4079-4082.

Dickson, D. P., Barr, G. R., Johnson, L. P. and Wieckert, D. A. 1970. Social dominance and temperament of Holstein cows. Journal of dairy science 53, 904 – 907.

Džidić, A., Halachmi, I. and Lukač Havranek, J. 2001. Prediction of milking robot utilization. Agriculturae onspectus scientificus 3, 137-143.

Forsberg, A. M. 2008. Factors affecting cow behaviour in a barn equipped with an automatic milking system. Licentiate thesis. Uppsala: Swedish university of agricultural science.

Grant, R. J and Albright, J. L. 2001. Effect of animal grouping on feeding behavior and intake of dairy cattle. Journal of dairy science 84 (E. Suppl.), E156-E163.

Harms, J., Wendl, G. & Schön, H. 2002. Influence of cow traffic on milking and animal behaviour in a robotic milking system. In: McLean, J., Sinclair, M. & West, B. Proceedings from the first North American conference on robotic milking, Toronto, Canada, March 20-22 2002. II-8-II-14.

Heffner, R. S. & Heffner, H. E. 1992. Visual factors in sound localisation in mammals. Journal of comparative neurology 317, 219-232.

Hörndahl, T. and Neuman, L. 2012. Energiförbrukning i jordbrukets driftsbyggnader – En kartläggning av 16 gårdar 2005-2006 kompletterat med mätningar på två gårdar 2010-2012. Alnarp: Sveriges lantbruksuniversitet. (Lantbruk, trädgård, jordbruk, Rapportserie 2012:19) Avalible at: http://pub.epsilon.slu.se/9105/11/horndahl_et_al_121001.pdf (2013-10-15)

Jacobs, J. A. and Siegford, J. M. 2012. Invited review: The impact of automatic milking systems on dairy cow management, behavior, health and welfare. Journal of dairy science 95, 2227-2247.

Kilgour, R. J. 2012. In pursuit of “normal”: A review of the behavior of cattle at pasture. Applied animal behavior science 138, 1-11.

Laurs, A., Priekulis, J., Zujs, V. and Saliņš, A. 2008. Milking frequency in milking robots with feed first cow traffic. Engineering for rural development 29, 275-278.

Lawson, T. J. and Kennedy, A. D. 2001. Inhibition of nighttime melatonin secretion in cattle: Threshold light intensity for dairy heifers. Canadian journal of animal science 81, 153-156.

Linnane, M. I., Brereton, A. J. and Giller, P. S. 2001. Seasonal changes in circadian grazing patterns of Kerry cows (Bos Taurus) in semi-feral conditions in Killarney national park, Co. Kerry, Ireland. Applied animal behaviour science 71, 277-292.

Marcek, J. M., and L. V. Swansson. 1984. Effect of photoperiod on milk production and prolactin of Holstein dairy cows. Journal of animal science 67, 2380-2388.

Markey, C. 2013. Effect of cow traffic system on cow performance and AMS capacity. Swedish university of agriculture. Faculty of veterinarian medicine and animal science. Department of clinical sciences.

McIntyre, I. M., Norman, T. R., Burrows, G. D. and Armstrong, S. M. 1989. Human melatonin suppression by light is intensity dependent. Journal of pineal research, 6, 149-56.

Melin, M., Svennersten-Sjaunja, K. and Wiktorsson, H. 2005. Feeding patterns and performance of cows in controlled cow traffic in automatic milking systems. Journal of dairy science 88, 3913-3922.

Miller, A. R. E., Stanisiewski, E. P., Erdman, R. A., Douglass, L. W. and Dahl, G. E. 1999. Effects of long photoperiod and bovine somatotropin (Trobest®) on milk yield in cows. Journal of dairy science 82, 1716-1722.

Munksgaard, L., Rushen, J., de Passillé, A. M. and Krohn, C. C. 2011. Forced versus free traffic in an automated milking system. Livestock science 138, 244-250.

Muthuramalingam, P., Kennedy, A. D. and Berry, R. J. 2006. Plasma melatonin and insulin-like growth factor-1 responses to dim light at night in dairy heifers. Journal of pineal research 40, 225–229.

Peters, R. R., Chapin, L. T., Emery, R. S. and Tucker, H. A. 1980. Growth and hormonal response of heifers to various photoperiods. Journal of animal science 51, 1148-1153.

Pettersson, G. and Wiktorsson, H. 2004. Illumination or guiding lights during night hours in the resting area in AM- barns. Page 468-473in Proceedings international symposium, Automatic milking – A better understanding. Wageningen academic publishers, Wageningen, the Netherlands.

Phillips, C. J. C. and Schofield, S. A. 1989. The effect of supplementary light on the production and behavior of dairy cows. Animal production 48, 293-303.

Phillips, C. J. C. and Arab, T. M. 1998. The preference of individually-penned cattle to conduct certain behaviours in the light or the dark. Applied animal behaviour science 58, 183–187.

Phillips, C. J. C., Morris, I. D., Lomas, C. A. and Lockwood, S. J. 2000. The locomotion of dairy cows in passageways with different light intensities. Animal welfare 9, 421-431.

Phillips, C. J. C. & Lomas C. A. 2001. The perception of color by cattle and its influence on behavior. Journal of dairy science, 84(4): 807-813.

Prescott, N. B., Mottram, T. T. & Webster, A. J. F. 1998. Relative motivations of dairy cows to be milked or fed in a Y-maze and an automatic milking system. Applied animal behaviour science 57, 23-33.

Reksen, O., Tverdal, A., Landsverk, K., Kommisrud, E., Bøe, K. E. and Ropstad, E. 1999. Effects of photointensity and photoperiod on milk yield and reproductive performance of Norwegian red cattle. Journal of dairy science 82, 810-816.

Rodenburg, J. & Wheeler, B. 2002. Strategies for incorporating robotic milking in North American herd management. In: McLean, J., Sinclair, M. & West, B. Proceedings from the first North American conference on robotic milking, Toronto, Canada, March 20-22 2002. III-18-III-32.

Rodenburg, J. & House, H. K. (2007). Field observations on barnlayout and design for robotic milking of dairy cows. In: Proceedings from the sixth intl. Dairy housing conference, Minneapolis, Minnesota, June 17-18 2007.

Rossing, W., Hogewerf, A. H., Ipema, A. H., Ketelaar-de Lauwere, C. C. and de Koning, C. J. A. M. 1997. Robotic milking in dairy farming. Netherlands journal of agriculture science 45, 15-31.

Sjaastad, O. V., Sand, O. and Hove, K. 2010. Physiology of domestic animals. 2 ed. Oslo: Scandinavian veterinary press

Stanisiewski, E. P., Chapin, L. T., Ames, N. K., Zinn, S. A. and Tucker, H. A. 1988. Melatonin and prolactin concentrations in blood of cattle exposed to 8, 16 or 24 hours of daily light. Journal of animal science 66, 727–734.

Starby, L. 2006. En bok om belysning. Ljuskultur. Stockholm

Sutherland, M. A., Rogers, A. R. and Verkerk, G. A. 2012. The effect of temperament and responsiveness towards humans on the behavior, physiology and milk production of multi-parous dairy cows in a familiar and novel milking environment. Physiology and behavior 107; 329-337.

Svennersten-Sjaunja, K. M. and Pettersson, G. 2005. Effect of milking frequency on lactation persistent in an automatic milking system. Page 156 in EAAP-56th Annual Meeting, Uppsala. Book of abstracts No.11. Wageningen academic publishers, Wageningen, the Netherlands.

Svennersten-Sjaunja, K. M. and Pettersson, G. 2008. Pros and cons of automatic milking in Europe. Journal of animal science 86, 37 – 46.

Tőzsér, J., Maros, K., Szentléleki, A., Zándoki, R., Nikodémusz, E., Balázs, F., Bailo, A. and Alföldi, L. 2003. Evaluation of temperament in cows of different age and bulls of different colour variety. Czech journal of animal science 8, 344 – 348.

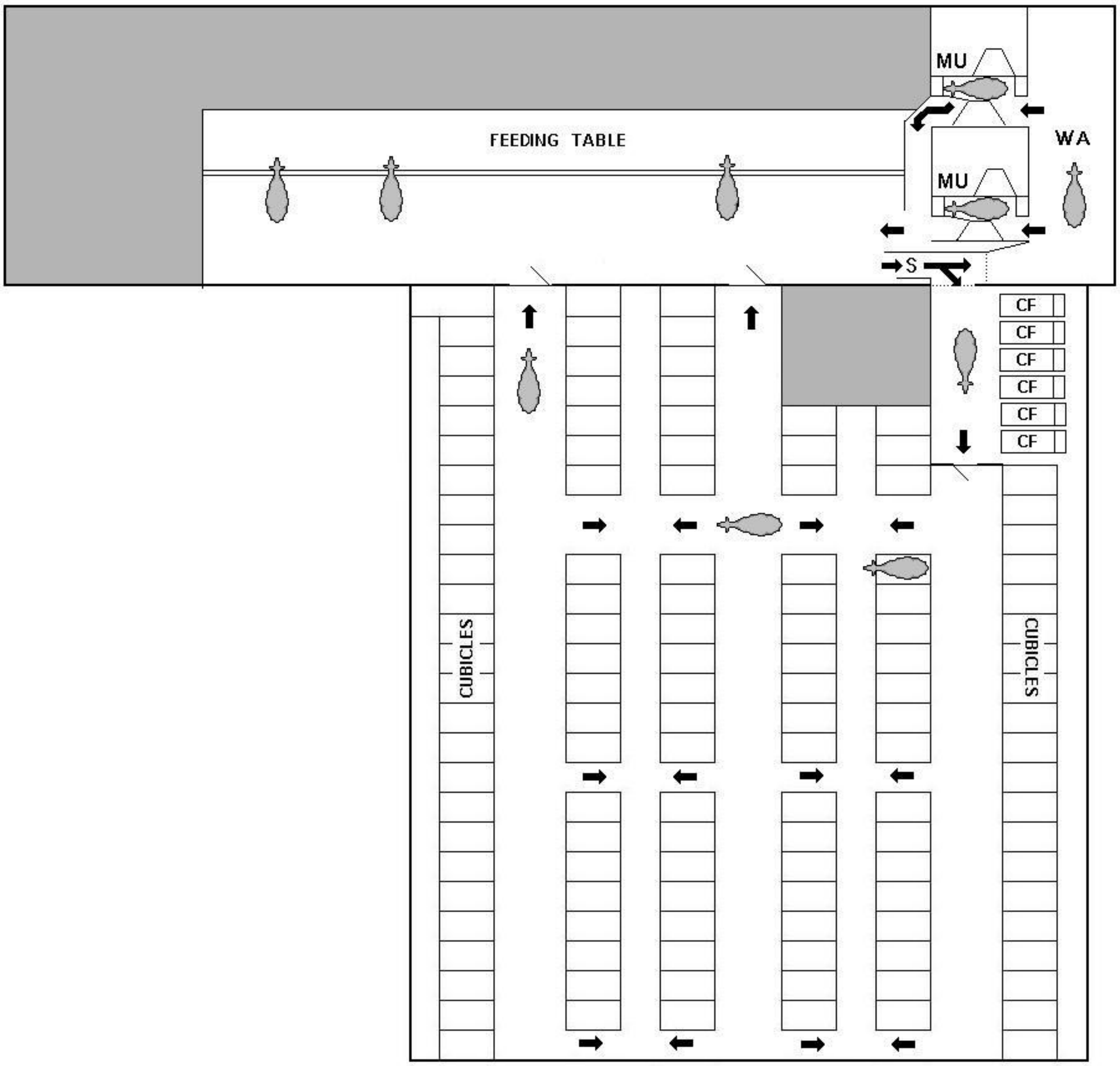
Upton, J., Murphy, M., French, P. and Dillon, P. 2010. Dairy farm energy consumption. Teagasc National Dairy Conference 2010, (ss. 87- 97) Charleville and Mullingar, Ireland, 17 – 18 November. Available at: http://www.teagasc.ie/advisory/farm_management/buildings/facilities_fittings_services/LightingOfAnimalHousing/DairyFarmEnergyCoonsumption.pdf (2013-10-15)

Wright, J. B., Wall, E. H., and McFadden, T. B. 2013. Effects of increased milking frequency during early lactation on milk yield and udder health of primiparous Holstein heifers. Journal of animal science 91, 195–202.

Appendix A1

Appendix A1 illustrates the barn layout in Herd 1 (not according to accurate scale). Grey areas were not accessible to the cows.

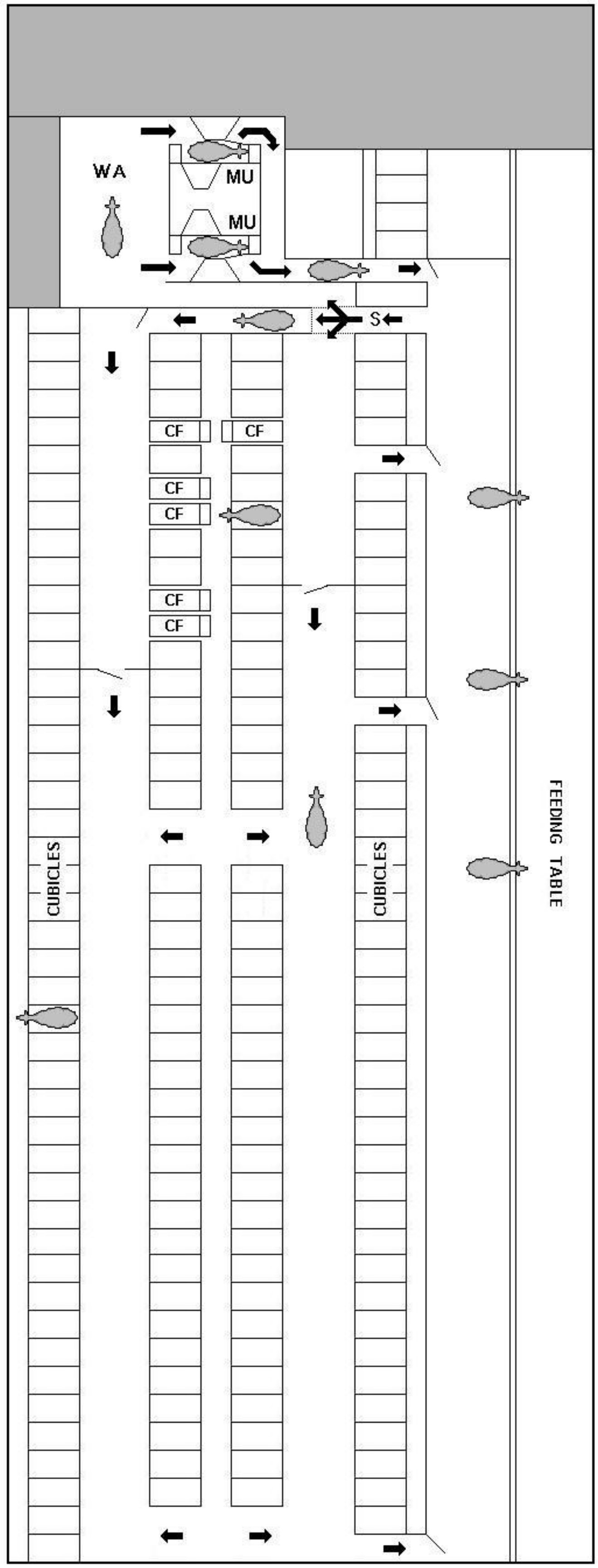
MU: Milking unit
CF: Concentrate feeding station
S: Selection gate
WA: Waiting area



Appendix A2

Appendix A2 illustrates the barn layout in Herd 2 (not according to accurate scale). Grey areas were not accessible to the cows.

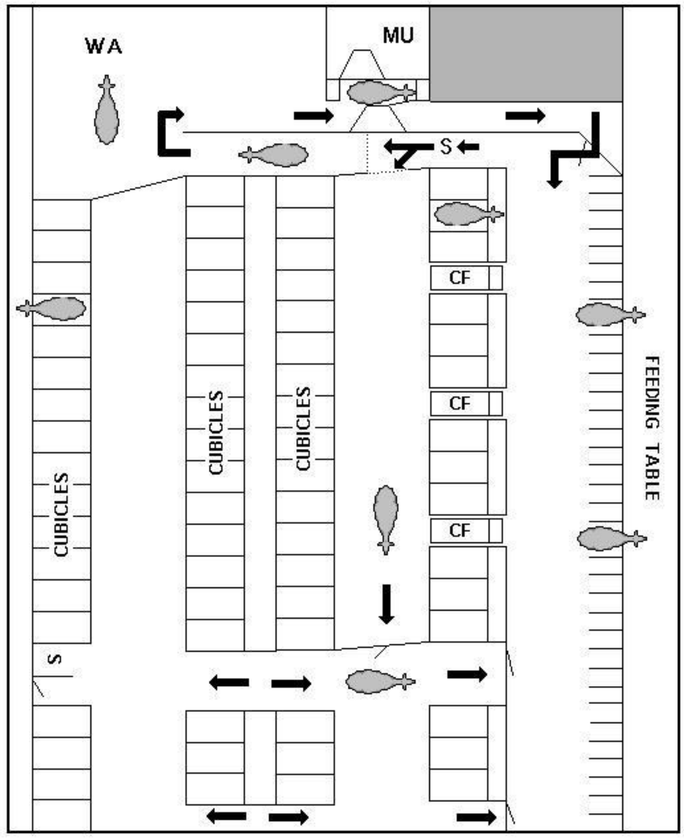
MU: Milking unit
CF: Concentrate feeding station
S: Selection gate
WA: Waiting area



Appendix A3

Appendix A3 illustrates the barn layout in Herd 3 (not according to accurate scale). Grey areas were not accessible to the cows.

MU: Milking unit
CF: Concentrate feeding station
S: Selection gate
WA: Waiting area



Appendix B

Appendix B shows a table that prsents the average number of selection gate passages per hour and cow at daytime and at nighttime, also the difference of average number of selection gate passages per hour and cow between daytime and nigh time, for all treatments and with all cows included.

	LOW	INT	HIGH	Total Average	SE**	P-value
Selection GP* per hour and cow at daytime	0.577	0.557	0.566	0.567^{E}	0.006	0.243
Selection GP* per hour and cow at nighttime	0.504	0.491	0.512	0.502^{F}	0.004	0.135
Difference	0.073^{A}	0.065^{AB}	0.054^{B}	0.064	0.003	0.069

*GP = Gate passages
**SE, standard error, and P-value is based on the different treatments not including Total Average
A, B Mean values within a row with different letters represents a difference (P < 0. 05)
E, F Mean values within a column with different letters represents a difference (P < 0. 01)

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