Validation of rumination measurement equipment and the role of rumination in dairy cow time budgets

by

Erika Lindgren

Institutionen för husdjurens utfodring och vård

Examensarbete 285
30hp E-nivå

Swedish University of Agricultural Sciences
Department of Animal Nutrition and Management

Uppsala 2009

Validation of rumination measurement equipment and the role of rumination in dairy cow time budgets

by

Erika Lindgren

Handledare: Per Peetz Nielsen

Institutionen för husdjurens utfodring och vård

Examensarbete 285
30hp E-nivå

Swedish University of Agricultural Sciences
Department of Animal Nutrition and Management

Uppsala 2009

Preface

This project was initiated and funded by Lantmännen. It was conducted as a Master's thesis in Animal Science at the Department of Animal Nutrition and Management, Swedish University of Agriculture Sciences (SLU).

I would like to acknowledge and thank the people who have assisted me in the process of this thesis:

My supervisor Per Peetz Nielsen (SLU) for all indispensable guidance and for his great patience. Rolf Spörndly (SLU) and Ingemar Olsson who has answered various questions which has arisen along the way. Christina Nyemad (Lantmännen) and Michael Murphy (Lantmännen) who initiated and formed the project. Dr. Doron Bar (SCR) and Dr. Massimiliano Intini (Milkline) for all information and technical assistance on RuminAct™. Lene Munksgaard (Foulum) who shared her time to tell me about her work with RuminAct™ which probably saved me a lot of time and puzzling. Tomas Rosman (Lantmännen) and Gunnar Pettersson (SLU) who retrieved data from the automatic recordings. Ulf Ohlson (SLU) for the valuable help on the statistical matters and the staff at Nötcenter Viken for their aid during my experiments. A special thanks to Björn Johansson (Lantmännen) who has been my sounding board and support throughout the whole process and assisted me with everything from painting cows to retrieving data. I would also like to show my appreciation to my partner Simon Nyström and my dear friends Ylva Freed and Marie Sjölin who all supported me and gave valuable feedback to my work.

Erika Lindgren, Uppsala 24-08-2009

TABLE OF CONTENTS

Sammanfattning

Automatisk idisslingsmätning kan användas som en hälsoindikator i mjölkbesättningar men även för forskningssyften. Målsättningen med denna studie var att validera den tekniska funktionaliteten av produkten RuminAct™, som med hjälp av akustik mäter idissling. Tidsbudgeten hos högproducerande kor studerades och eventuella skillnader i idisslingstid mellan 13 olika foderstater tolkades. Studien undersökte även vad som påverkar daglig idisslingstid samt idisslingseffektivitet.

Valideringen genomfördes med direktobservationer som jämfördes med de automatiskt registrerade idisslingstiderna. Totalt studerades 9 kor, i grupper om 3, under ca 4,5 timmar per grupp. Studien av kornas tidsbudget skedde likaså genom direktobservationer där 9 kor totalt observerades under ett dygn. Automatiskt registrerad data användes för att se vad som påverkar daglig idisslingstid samt idisslingseffektivitet.

RuminAct™ verkar vara ett användbart verktyg som möjliggör idisslingstid som en enkelt införskaffbar parameter för forskningssyften såväl som hälsoindikator i mjölkbesättningar. Denna studie visade att utrustningen endast underskattar idisslingstiden med 1,86 % i genomsnitt medan spridningen är desto större med en standardavvikelse på 6,57 %. Observationerna av tidsbudgeten visade att korna trots att de hålls i lösdrift, utfodras *ad lib.* och mjölkas 3 gånger per dag, troligtvis inte lider av tidsbrist eftersom de i tillräckligt stor utsträckning utförde sina beteendebehov och inga stereotypier observerades. Signifikanta skillnader i idisslingstid påvisades mellan foderstater men orsaken till dessa var svåra att fastställa, troligtvis till följd av problem med registreringen av foderintag och ättid. Hög mjölkmängd var positivt korrelerat till lång daglig idisslingstid och lång daglig idisslingstid var i sin tur positivt korrelerat till förlängd intercycle-period.

Abstract

Automatic rumination measuring can be applied as a health indicator in dairy farming but is also highly desirable for research purposes. This study aimed to validate the technical functionality of the product RuminAct™, which employ acoustics to monitor rumination duration. The time budget of high yielding cows was studied and possible differences in rumination time between 13 rations were interpreted. Further the study examined what affects daily rumination and rumination efficiency.

The validation was performed with direct observations that were compared to the automatically recorded rumination durations. 9 cows in total were studied, in groups of three, during approximately 4,5 h for each group. The time budget study was also conducted with direct observations and covered a total of 24 h and 9 cows. Automatically registered data was used to investigate which parameters affects daily rumination time and rumination efficiency.

RuminAct™ appears to be a useful tool that makes rumination time available as an easy obtained parameter for research purposes as well as health indicator for dairy farming. The present study showed that the equipment only underestimates rumination time with 1,86 % on average, although the standard deviation totalled 6,57 %. Observations of the time budget showed that the cows in this study probably are not suffering from any time

constraint since they seem able to perform their behavioural needs in sufficient amounts and no stereotypical behaviours were observed. Significant differences in rumination duration were found between rations although the causes of these variations were difficult to determine, probably due to problems with feed intake registrations. Prolonged daily rumination was positively correlated with higher milk yield and long daily rumination was also positively correlated with extended the inter-cycle periods.

Introduction

Rumination is an important constituent of the digestive function in ruminant animals (Murphy *et al.,* 1983) and one of the main functions is physical breakdown of coarse material to facilitate its passage from the rumen (Sjaastad *et al.,* 2003). Another role is to increase saliva production, which buffer the acids produced in the rumen during carbohydrate breakdown (Mertens, 1997). The rumen environment can consequently be kept stabile for the microbes to function properly. Rumination duration is mainly decided by the amount of feed ingested together with the ration composition (Nørgaard, 2003), mainly fibre content and particle size (Pearce, 1963). Excessive starch and easily fermented carbohydrates in relation to the content of effective fibre (the amount of fibre which stimulates rumination) results in a reduced chewing activity (Mertens, 1997). As a consequence, the saliva production is decreased and the ruminal pH is reduced. Low ruminal pH can result in altered fermentation patterns and create metabolic disturbances that affects cow health and production negatively. Health and production, together with animal behaviour are important to consider when discussing dairy cow welfare (Jensen, 1993).

Lindström and Redbo (2000) showed that oral manipulation of feed is a behavioural need in cattle, irrespective of rumen load. This indicates that a certain amount of rumination per day is important, not only to sustain a good production and health, but also to give cattle an outlet for their natural behaviour. Individuals that are constricted from performing their behavioural needs become frustrated and can develop stereotypies as *e.g.* tongue rolling or bar biting, which are considered as signs of reduced welfare (Redbo *et al.,* 1996). The time schedules of high yielding cows can be fairly tight and to sustain high production cows are required to eat a lot of feed but still needs time to perform other important behaviours (Munksgaard *et al.,* 2006) such as rumination.

To enable automatic recording of feeding behaviours, eating and rumination, has intrigued scientists for a long time. It is important to have great knowledge of chewing and rumination activities to completely understand the dietary factors affecting normal rumen functions (Kononoff *et al.,* 2002). Different sensors have been developed to automatically record jaw movements and one technique used is acoustic biotelemetry, which apply the sound of rumination as a parameter. The Italian company Milkline, whom market products for the dairy industry, have got a commercial product named RuminAct™, which utilizes a microphone-based system to measure rumination time (Milkline, 2007). Through a combination of activity measurements and rumination surveillance it is marketed as a good herd management tool for early detection of metabolic disorders, heat and calving.

Aims

The Swedish feed manufacturing company Lantmännen has purchased the RuminAct™, system for use in future feed trials. Since there is yet no independent scientific validation published on the equipment, Lantmännen requested a test of the product. The aim of the present study is to evaluate the technical functionality of RuminAct™ and to investigate, from a welfare perspective, how the high producing cows at Lantmännens research farm Nötcenter Viken, divides their time between important behaviours. The project also aims to interpret the results from possible differences in rumination time between 13 feed rations and explore which parameters affects daily rumination duration and rumination efficiency.

Literature review

Ruminant digestion

The ruminant obtain most of its energy from plant cell walls which are microbially degraded without presence of oxygen in the rumen (McDonald *et al.,* 2002). The end products of this fermentation primarily consist of short-chained volatile fatty acids (VFA), which mainly are acetic acid, propionic acid and butyric acid.

When cattle partake of feed, they do not chew very much but the processing of the feed is instead allocated to the rumination, where rumen content is formed as a bolus that is regurgitated and masticated a number of times (Sjaastad *et al.,* 2003). Coarse and stiff feed particles induce rumination through mechanical stimulation of nerve endings in the region of the esophageal opening. The re-mastication reduces particle size, which enables the particles to pass on through to the reticulo-omasal orifice. Furthermore particle shape, density and digestibility do also determine the retention time before passage on to the omasum (Sjaastad *et al.,* 2003). Comminution during eating and rumination also functions to increase particle surface/volume ratio, which enhances microbial fermentation (Poppi *et al.,* 1980). Chewing activities also stimulates secretion of saliva (Sjaastad *et al.,* 2003), which facilitates swallowing and possesses high concentrations of bicarbonate and phosphate buffers. The buffers aids in sustaining the ruminal pH at a level suitable for microbial activity which is approximately 5,5-6,5 (McDonald *et al.,* 2002).

In the rumen, the uppermost layer consists of gas produced particularly during fermentation of carbohydrates (Sjaastad *et al.,* 2003. Below the gas layer occurs a stratification of particles due to differences in density. Uppermost are partially degraded, long, fibrous materials floating on top of more fluid layers, creating a mat. As fermentation proceeds, the organic matter, which serves as fermentation substrates, is exhausted. Gas production then decreases and the particles loose their buoyancy owing to loss of entrapped gas. When particles are small and dense enough they gradually sink through the rumen mat to the ventral parts of the rumen. Large long particles sink more slowly than smaller particles with the same density. Small particles increase passage rate and dry matter (DM) intake while decreasing digestibility since the particles are subjected to fermentation during shorter time (Jaster & Murphy, 1983). In the middle and bottom zones of the rumen are mainly particles, which are finely dispersed and ready for transport to the reticulum (Sjaastad *et al.,* 2003). Contractions of the reticulum and rumen provide mixing of forestomach contents and a transfer of particles to the omasum. The contractions also facilitate regurgitation and aid in belching of gases. The digesta water content is mainly absorbed in the omasum prior to the abomasum transfer where enzymes continue the digestion.

Fibres and physical form of diet

Todays' high producing dairy cows are frequently fed diets with relatively large proportion of concentrates together with forage of high nutritional quality, to be able to supply the energy demanded for high milk production (Beauchemin *et al.,* 2003). This results in rations with limited fibre contents. Since fibre stimulate chewing activities, a low F:C (forage to concentrate) ratio in the diet decreases saliva production and provides a lower rumen pH (Mertens, 1997). A reduced ruminal pH can cause altered fermentation patterns where the fibre digestion is impaired and the acetate to propionate ratio decreases with reduced milk fat synthesis as outcome (VanSoest, 1963). Additional hazards with low F:C ratio is sub clinical or clinical acidosis, displaced abomasum, laminitis and fat-cow syndrome (NRC, 2001). Hence enough fibre and coarse materials in the rations are necessary to stimulate the saliva production and for the rumination reflexes to work properly (Sjaastad *et al.,* 2003). However, large fibre-inclusion in diets provides low energy density (Mertens, 1997) and the voluntary DM-intake is then reduced as a result of slower passage rate. With declining DM-intake follows descending milk production due to reduced energy intake.

Nutritionally fibre can be defined as "the slowly digestible or indigestible fraction of feeds that occupies space in the gastrointestinal tract of animals" (Mertens, 1997, p. 1463). One of the most common ways to describe fibre content in feeds is by NDF, which includes cellulose, hemicellulose and lignin. It is the only method that assesses total fibre and quantitatively determines differences between grasses and legumes, cool and warm season grasses, forages and concentrates. NRC (2001) states a minimum recommendation of NDF in the ration to 25-33 % of DM to maintain ruminal pH and milk fat percentage. However, NDF only describes the chemical characteristics but not the physical characteristics of fibre, like particle length (Woodford & Murphy, 1988), shape (Troelsen & Campbell, 1968), specific gravity (Des Bordes & Elch, 1984) specific fragility (Chai *et al.,* 1988) and rate of increase of functional specific gravity due to hydration and ion exchange (Hooper & Welch, 1985). Independently of composition or amount of NDF, the physical characteristics of fibres can influence the animal health, metabolism, ruminal fermentation and milk fat production (Mertens, 1997).

The physical features become important when trying to identify the lower limit of F:C ration when finely chopped forages or nonforage fibre sources are utilized. To determine the impact of physical characteristics of feeds Balch (1971) suggested total chewing time per kg DM as an index, which should take account for the variation in DM-intake but also the compensatory relationship that exists between eating and rumination (Bailey & Balch, 1961; Nørgaard, 1989). Mertens (1997) developed the peNDF (physically effective NDF), which defines the capability of feed to stimulate chewing activity and saliva production mainly through particle size. Poppi. *et al.,* (1985) showed that particles which remained on a 1,18 mm sieve passed the rumen more slowly than smaller particles. On the basis of this statement, Mertens (1997) proposed that particles >1,18 mm needs to be reduced to be able to pass out of the rumen and consequently they should stimulate chewing activity. This has also been confirmed in studies by Beauchemin and Yang

(2005). The peNDF content of a ration is determined by multiplying the physical effectiveness factor (pef) of the diet with its NDF content. The pef is determined either as the sum of the DM retained on the two sieves of the Penn State Particle Separator (Lammers *et al.,* 1996) or as the quantity of particles retained on a 1,18 mm sieve using a dry sieving technique (Mertens, 1997). Mertens (1997) stated a minimum content of peNDF to 22% in dairy cattle diets.

Rumination duration and patterns

Rumination has a basic circadian pattern and cattle normally spend about 8-9 hours a day ruminating (Welch, 1982). Alterations in the underlying circadian rhythm can possibly be due to feeding frequency and ration composition (Pearce, 1965), feeding time (Welch *et al.,* 1969), photoperiod (Gordon & McAllister, 1970) and housing system (Melin *et al.,* 2007). The rumination activity mainly occurs at night but also to some extent during the afternoon resting period (Gordon & McAllister, 1970; Woodford & Murphy, 1988). Chewing behaviour of eating and rumination express a sinusoidal pattern when cattle are fed *ad lib.* (Jaster & Murphy, 1983).

The total time spent chewing (eating and ruminating) depends to a large extent on feed quality and amount eaten (Metz, 1975, abstr.; Nørgaard, 2003). There exists a positive correlation between daily feed intake and daily rumination time (Metz, 1975, abstr.). Generally cattle ruminate for 25-80 minutes per kg roughage consumed (Sjaastad *et al.,* 2003) but the time spent ruminating per kg roughage depends both on the chemical and physical nature of the ration (Pearce, 1965). Beauchemin and Buchanan-Smith (1989), Beauchemin and Yang (2005), Beauchemin *et al., (*2003), Grant *et al.,* (1990a; 1990b) and Kononoff *et al., (*2003) reported ranges of chewing activities (Table 1) from lactating Holstein cows on total mixed ration (TMR) with differing forage particle sizes and NDF content, where all found that larger particles increased chewing activities. Welch and Smith (1969) estimated the correlation between rumination time and cell wall constituent to 0,94.

Table 1. Durations of chewing activities for dairy cows fed TMR. Modified after Beauchemin and Buchanan-Smith (1989), Beauchemin and Yang (2005), Beauchemin *et al., (*2003), Grant *et al.,* (1990a; 1990b) and Kononoff *et al., (*2003).

Chewing activity	Min/day	Min/kg DMI	Min/kg NDFI[2]	Min/kg peNDFI
Eating	185,1-350,0	7,1-14,7	23,4-48,2	121,4-142,3
Rumination	344,0-496,3	15,3-24,4	47,7-79,9	204,5-236,1
TC[1]	558,0-846,3	23,4-38,7	74,4-127,8	325,9-378,3

[1]TC= total chewing activity (min eating + min ruminating).
[2]NDFI = NDF-intake.

Welch and Smith (1972) found that increased indigestible fibre loads were not effective in stimulating increased rumination beyond the normal 8 or 9 hours per day. Therefore more efficient ruminators, that is to say animals that can ruminate more roughage during the fixed 8-9h/d, can consume larger amounts of roughage and produce more while fed a high roughage diet. Deswysen *et al.,* (1987) and Welch (1982) suggested that mastication efficiency could be measured as time spent chewing per unit of intake. Differences in chewing activity per kg DM has been found to differentiate between breed (Welch *et al.,* 1970), body size (Bae *et al.,* 1983; Welch, 1982), physiological state (Campling, 1966) and level of production (Coulon *et al.,* 1987, abstr.), suggesting that animals with a higher intake capacity need shorter time to eat and ruminate per unit of ingested feed (Coulon *et al.,* 1987, abstr.; Deswysen *et al.,* 1987). Harb and Campling (1985) also observed a significant negative relationship between voluntary hay intake and rumination duration/kg DM-intake, which further may support of Welsh and Smith (1972), that efficient ruminators can eat more roughage. Higher rumination efficiency may be due to decreased time between boluses, a larger number of chews per unit time, a lower proportion of pseudorumination[1] or more efficient regurgitation of large particles (De Boever *et al.,* 1990). Anatomical features like larger mouths, larger tooth surfaces, stronger jaw muscles or enhanced articulation of the jaw may also explain higher rumination efficiencies.

Most cattle ruminate for 10-17 periods (Albright, 1993) of 1/2-1 hour (Nørgaard, 2003) per 24 hours. During each period, approximately 30-60 boluses are produced (Nørgaard, 2003). Each cycle lasts for approximately 40 seconds and contains 30 to 60 chewings with a minor variation in number of chewings per minute. Between boluses, when one bolus is swallowed and another one is regurgitated, occurs the "inter-cycle period" (Figure 1). This lasts for approximately 4-8 seconds and during this time no chewing is performed. The jaw movements during rumination are generally very regular regarding frequency and magnitude, compared to eating jaw movements. A partial explanation to this is that rumination mainly occurs during lying and resting while eating typically takes place standing (Nørgaard, 2003; Ruckebusch & Bueno, 1978). The average chewing frequency per minute is also 5-20 % lower at rumination than during eating.

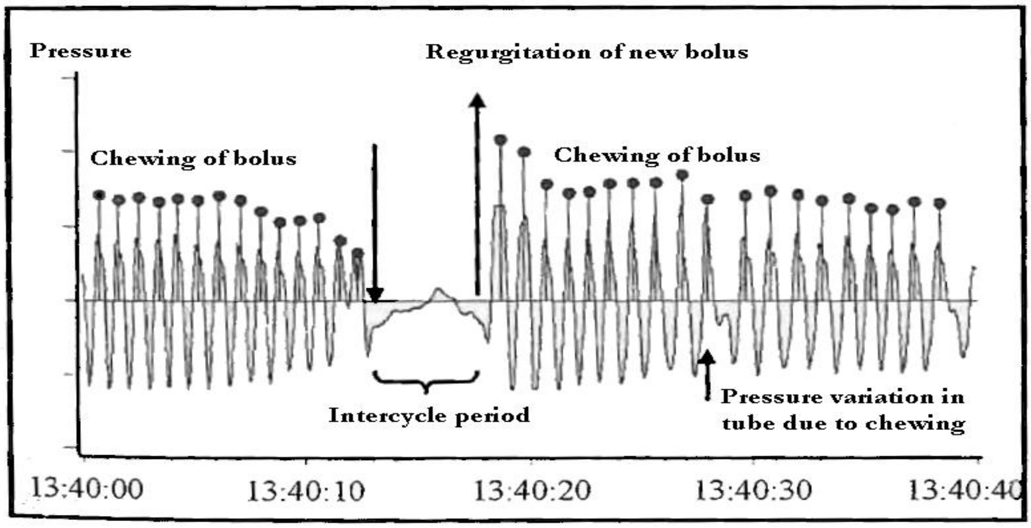

Figure 1. Description of a rumination cycle (modified after Nørgaard, P. 2003).

Dairy cow welfare

The welfare of an animal can primarily be related to its ability to cope with its external environment *e.g.* housing, weather, other animals as well as its internal environment such as nutritional status, specific pains and immunological responses (Broom, 1988; Philips,

[1]When the regurgitated material mainly consists of fluids only containing small quantities of solid particles (Deswysen & Ehrelin, 1981).

2002). To assess animal welfare, three aspects of the animal's state mainly needs to be considered: production, health and behaviour (Broom, 1988; Jensen, 1993; Rushen, 2001), however the evaluation should be based on a balancing of all three (Jensen, 1993). Jensen (1993) finds that production often is a quite simple variable to measure but provides the least information concerning welfare, since what we call production, *e.g.* growth or reproduction, are fundamental biological functions which are not affected very easily. Jensen (1993) further discusses health and physiological responses as important criteria's for the animal welfare, where a diseased or injured animal always can be considered to have a reduced welfare, although many diseases can be sub clinical and medical diagnoses are not always correctly made. Jensen (1993) also states that measurements of disturbed behaviours as stereotypies, cannibalism, excessive aggression and other behaviours connected to conflicts and frustration can provide clear signs of a reduced welfare, even though behavioural studies need to be interpreted carefully since every individual do not always react in the same way to certain stimulus. All animals do not *e.g.* possess the same inclination to develop stereotypies in frustrating environments. Also, animals that show stereotypic behaviours are not necessarily inadequately held, but can show reactions from previous experiences, which has induced development of the stereotypy (Mason, 1991).

Stereotypies usually evolve in aversive situations, often related to frustration, and in limiting monotonous environments but the motivational causes behind stereotypic behaviours are not completely clear (Redbo *et al.,* 1996). Their development and performance are however widely considered as symptoms of reduced welfare (Philips, 2002). Typical stereotyped oral behaviours related to feeding regime in cattle includes tongue-rolling, obsessive licking on objects and occasionally bar-biting (Redbo *et al.,* 1996). These behaviours consist of repeated rolling movements of the tongue, either inside or outside the mouth, or repetitive licking or biting movements directed towards interior. Restricted feeding and diets that provide short duration of feeding behaviours increases the risk of stereotypy development in cattle and also increases time spent performing the stereotypies (Redbo *et al.,* 1996; Redbo & Nordblad, 1997). Redbo (1992) also found that high-yielding cows show more stereotypies than low-producing cows. This may be due to a greater energy deficit in the high-producing cows.

Lindström and Redbo (2000) suggested that oral manipulation of feed is a behavioural need except for the purpose of saliva mixing and mechanical degradation of digesta. They tested 12 lactating fistulated cows with high or low rumen content against long or short duration of eating in a complete change over model (four treatments). The two treatments with short eating time had higher duration of stereotypic behaviours and behaviours related to feed searching than those with long eating time. They therefore concluded that "oral manipulation of feed is a behavioural need in cattle irrespective of rumen load". A behavioural need is an activity which the animal is motivated to perform no matter what the environment is like, or whether or not the physiological need which the behaviour serves are fulfilled (Jensen & Toates, 1993). Jensen and Toates (1993) states that a behavioural need can complete some or all of the following three criteria: 1) internal factors mainly control the behavioural patterns, 2) the motivation is gradually built up while the behaviour is not performed, 3) the behaviour itself is a reward to the animal.

Rumination is subjected to voluntary control and the animal will therefore cease to ruminate if it is disturbed *e.g.* at milking (Philips, 2002). Any occurrence which gives rise to pain, hunger, maternal anxiety or illness will also decrease rumination (Fraser, 1980).

During estrus a marked decline in rumination time can be observed as well as prior and after parturition. Significant overcrowding in barns is another cause to reduced rumination as well (Grant & Albright, 2001).

Cows can ruminate while standing but they preferably perform it lying down and commonly on the left-side side laterally to optimize positioning of the rumen (Albright, 1993; Ruckebusch & Bueno, 1978). Frequent rumination while standing might therefore indicate a reduced welfare (Albright & Arave, 1997). The ruminal behaviour is often associated with reduced alertness (Philips, 2002) and substantial self-stimulation along with the "inwardness" which appears during the process.

Time budget of high producing cows

The allocation of time to different behaviours over a 24-hour period can be referred to as a time budget. The time budget can be affected by management and housing system (Munksgaard *et al.,* 2005) as well as photoperiod (Philips, 2002). Other influencing factors, except from external, can be the state of the animal. For instance cows in late lactation has more lying time and spends less time eating (Chaplin & Munksgaard, 2001; Nielsen *et al.,* 2000)

Time shortage may be a problem in loose housing systems where walking between different resources and waiting for access to the milking parlour are inevitable activities (Munksgaard *et al.,* 2005). Low ranked cows may also have to spend additional time to get access to resources in crowded situations, for example in the waiting area in front of the robot in AMS (automatic milking systems) (Ketelaar de Lauwere *et al.,* 1996). Cows seem to distribute feeding and milking activities more evenly across a 24-h period in AMS than herds with conventional parlor milking (Wagner-Storch & Palmer, 2003).

The ration composition, especially energy density, strongly affects the eating time since it takes approximately 3-4 minutes for a cow to consume one kg of concentrate while one kg of hay takes about 30 minutes (Philips, 2002). Increases in milk yield produces increased energy demands (Munksgaard *et al.,* 2006). Depending on the diet composition, the increased energy intake of high yielding cows requires increased eating time as well, which leaves the cow less time for other important activities. In studies by Dado and Allen (1993, 1994) high producing cows obtained a higher DM-intake, consumed larger meals more quickly, ruminated longer and more efficiently, and drank more water than lower producing, primiparous cows.

Lying is an important behaviour for cattle and constitutes approximately 50% of their daily time budget (Metz, 1985). Increased standing is often seen as a sign of discomfort or dissatisfaction (Albright, 1987) and severely restricted lying time seriously impairs the welfare (Metz, 1985). The number and sizes of lying places, bedding material and the partitions are important factors that influence lying time (Wierenga & Hopster, 1990). Studies of cows in different housing systems and in different lactation stages shows that cows normally spend 12-14 hours a day lying (Albright, 1993; Fregonesi & Leaver, 2001; Munksgaard *et al.,* 2005; Wierenga & Hopster, 1990) and Munksgaard *et al.,* (2006) suggested 10 h per day as a minimum requirement for dairy cows to lie down. It has been shown that dairy cows on diets with low energy density has increased eating time while lying time tends to decrease compared to cows on high energy rations (Munksgaard & Herskin, 2001). This negative correlation between eating time and lying time does however decrease in higher producing cows (Personal communication. L. Munksgaard, 2009-03-16). Munksgaard *et al.,* (2005) studied the relative priorities between lying, eating and social behaviour in dairy cows. The experiment was performed by depriving the cows of the three behaviours for 9 or 12 hours per day compared to a control treatment. They found that the proportion of time spent lying increased while the proportions of time spent eating and social interaction were similar to the control group of non-constrained cows. Their conclusion was that lying had the highest priority while the cows were able to partly compensate for lost eating time by increasing the eating rate. There was little time allocated to social contact, however it was still defended quite strongly. Even though the cows sped up their eating they did not fully compensate for the constrained eating time. Consequently, the cows are willing to sacrifice some feed intake to maintain lying time.

Changes in the time budget may indicate adaptation to specific environments and do not necessarily mean a reduced welfare (Munksgaard *et al.,* 2005). Yet, if high priority behaviours are put under constraint, this may have negative consequences. When animals are subjected to time shortage, they would be expected to distribute more time to behaviours important to them, while less time would be assigned to non-essential behaviours (Houston & McFarland, 1980). However, information of the relative priorities between behaviours is limited (Munksgaard *et al.,* 2005).

Rumination measurement techniques

To fully understand the dietary factors affecting normal rumen function, it is essential to have a comprehensive knowledge of chewing and rumination activities (Kononoff *et al.,* 2002). Scientists have been interested in an automatic non-invasive method of measuring ingestive behaviours for a long time. As an option to visual observations, several sensors have been developed to monitor the jaw movements of grazing ruminants. *E.g.* jaw and mercury switches (Stobbs & Cowper, 1972), accelerometers and displacement transducers (Chambers *et al.,* 1981), jaw balloons and pressure transducers (Derrick *et al.,* 1993; Ruckebusch & Bueno, 1978), and systems developed for stall-fed animals (Beauchemin *et al.,* 1989; Beauchemin & Iwaasa, 1993; Girard & Labonte, 1993, abstr.; Luginbuhl *et al.,* 1987).

Penning (1983) developed a stretchable noseband, which acted as a transducer and created electrical signals in proportion to the jaw movements. A computer program that could discriminate between grazing, idling and rumination activities as well as a total jaw movement count, then analyzed the data set. The post processing algorithm was further developed (Penning, 1984) to use characteristics of the waveforms to distinguish between chews and bites during grazing as well as recognizing rumination chews. The previous analogue recording of the signals to cassette were replaced by Rutter *et al.,* (1997) with a microcomputer-based system that digitally recordes jaw actions. The recordings could then be analyzed by a special software on a PC (Rutter, 2000). The system described is available commercially as the IGER Behavior Recorder and Graze jaw movement analysis software (Ungar & Rutter, 2006).

Alkon *et al.,* (1989) suggested acoustic biotelemetry for studying animal behaviour because of the affluent information contained in sound records. The sound recording with radio transmission from a microphone to a remote recording device also gathers information without interfering with grazing behaviour (Laca *et al.,* 1992). During grazing trials Laca *et al.,* (1992) used an inward facing microphone, mounted on the forehead of grazing steers, to monitor jaw movements. There was no doubt that this method detected all jaw movements, which performed a bite or a chew. The ripping sound of a bite and the grinding sound of a chew were also clearly distinguishable. The acoustic technique was then considered by Laca *et al.,* (1992) as more reliable than direct visual observation for counting bites. Ungar and Rutter (2006) compared acoustic monitoring to the IGER Behaviour recorder and found that the error rate, where the method classified the wrong chewing beaviour (visual observation as control), was 1 and 22 % respectively. An important advantage compared to other techniques is that acoustic measurement detects the chew-bites (Laca *et al.,* 1994). This is when forage already in the mouth is chewed and fresh herbage is severed, all in one single jaw movement. The chew-bites may make up for a high proportion of the jaw movements in grazing cattle (Ungar *et al.,* 2006).

There are evident individual differences in chewing activities between individuals due to the variation of sex, body weight (BW), physiological state and age (De Boever *et al.,* 1990). This does not necessarily produce differences in chewing sound per unit DM-intake according to Galli *et al.,* (2006). Galli *et al.,* (2006) also reported that uncontrolled sources of variation, like different chewing force, size and structure of the individuals teeth as well as head shape, may make it necessary with a calibration of each individuals recording equipment.

The analysis of grazing sound records has not yet been automatized but there is a potential to do so (Ungar & Rutter, 2006). Clapham *et al.,* (2006) has developed some parameters for an automated algorithm to classify different sound data. Laca and WallisDeVries (2000) also suggested acoustic jaw measurements as a possible method for estimation of forage intake.

RuminAct™ is a commercially available product that measures rumen activity through the sound of regurgitation of boluses during rumination (Milkline, 2007). It is marketed as a management tool in large herds for an early detection of metabolic disorders, heat and calving, through a combination of rumination surveillance and activity measurements. The microphone is incorporated in a plastic gadget, which is attached to the left side dorsally on the head collar. To maintain the gadget, or "tag", in its right position, a lead weight is attached to the collar ventrally. The sounds are analyzed through a complex algorithm inside the tag (Personal communication. Doron Bar. 17 June 2009). Based on validation trials (Appendix 2) from the developer the tag is claimed to "detect rumen activity with 97% of accuracy through the following parameters (Milkline, 2007):

- Minutes of rumination in 2h intervals with a resolution of 2 minutes.
- Average interval between boluses in last 24h.
- Average interval between chewing actions in last 24h."

The tag is able to store the data for maximum 24h (Milkline, 2007). The information contained in the tag is unloaded via infrared (IR) communication to an antenna placed by the milking parlour or the water trough. From the antenna the information is automatically sent to a PC for use with the Milcon HM ™ software which analyzes the data.

A prototype of the product was developed by an Israelian dairy farmer and engineers at the dairy equipment developing company, SCR Engineers Ltd, Netanya, Israel, upgraded and designed it to a commercial product (Personal communication. Solomon *et al.,* 2009-03-09.). SCR has tested the product in a controlled trial with individual feeding at the dairy research barn ARO in Israel. They also tested it at the commercial farm, Klein dairy, during one year to collect data for analysis of rumination, routine and exceptional events. There is however no scientific reports published from these studies yet.

The RuminAct™ system has also to some extent been validated at the Danish research station KFC (Kvægbrugets Forsøgscenter) (Personal communication. L. Munksgaard, 2009-03-16). There the researchers found that the rumination time from the automatic recordings were underestimated on some individuals but not on other cows. Where underestimation was found it varied from a few % up to more than 50% within a 2 h period (Personal communication. L. Munksgaard, 2009-06-02). When the system was tested at four tied up cows the accuracy was much higher but still not reliable enough for use in research (Personal communication. L. Munksgaard, 2009-03-16). There are however more studies to be conducted at KFC before any conclusions are to be drawn.

Materials and method

Two separate behavioural studies were conducted at Lantmännens research farm Nötcenter Viken. One to validate the RuminAct™ system and one to analyze the time budgets of the high producing dairy cows at Nötcenter Viken. The present studies were approved by the Göteborgs Local Ethics Committee and in accordance with Swedish animal welfare regulations.

General

All cows used were held in loose housing system within a group of 48 cows (further referred to as the trial group) in total where everyone wore a RuminAct™ tag (Fig. 2) and a DeLaval ALPRO™-tag. They were fed *ad lib.* with TMR and milked in a rotary parlor approximately at 5.00, 13.00 and 21.00. All observations were performed directly and registered with a personal digital assistant (PDA) (PSION Workabout, Psion Teklogix, UK). To be able to recognize the observed cows, these were painted on the back with white or green colour. The observer was stationed at a ladder placed between two rows of cubicles where all cows could be spotted.

Figure 2. A correct positioning of the tag and the lead weight.

RuminAct™ validation

Three observations periods were performed, each on three cows at a time and a total of 9 animals were used. These 9 cows were either of Swedish Red and White (n=2) or Holstein breed (n=7) and produced 32,7 kg milk a day in average. Two of them (2649 and 2660) were primiparous while the rest were multiparous and in a range of 16-135 days in milk (DIM) (74,9 DIM in average).

The Milcon HM™ software measure rumination continuously but only displays rumination every second hour, on the hour. These registrations, however, might in reality have started several minutes prior to or past that time, since the tags have different internal time settings and are not synchronized. The cows were chosen and grouped in the different observation periods on the basis of their internal tag time setting that had to be obtained from a file called Msysprob.txt, in the software folders connected to the RuminAct™ system. This file contains data from the tags sent to the software (Personal communication. Doron Bar. 17 June 2009). To be able to survey all the tag information, the Msysprob file were run through a SAS program, which sorts the system data. Tags with similar internal time setting could be studied in the same period. Since the tags record rumination in two-hour blocks, each observation period were performed during two blocks, that is to say four hours added to the time discrepancies between tags, approximately 30 minutes. The behavioural observations were performed using instantaneously sampling method with two minutes interval during each period (Table 2). One observation period was interrupted thus three cows were only observed during one two-hour block.

Table 2. Descriptions of the registered behaviours.

Registration	Description
Lying rumination	The cow lies down with the whole body against the ground while chewing without consuming new feed
Standing rumination	The cow is standing up while chewing without consuming new feed
Lying	The cow lies down with the whole body against the ground
Standing	The cow is standing up
Good tag placement	The tag is placed between the top of the neck and the middle of the left side of the neck
Bad tag placement	The tag is either placed below the middle of the left side of the neck or on the right side of the neck

Time budget study

All cows present in the trial group were part of a feed experiment conducted by Lantmännen to examine the effect of different sources of water-soluble carbohydrates (WSC). This experiment contained 13 rations formulated using CPM dairy (2008) with treatment number 13 as a control treatment (Table 3). The ration compositions can be found in table 11 in appendix 1.

Table 3. Design of feed trial where A = Soluble fibre, B = Fermentable Starch and C = Sugars. Values -1, 0 and 1 denotes low level, medium level and high level, respectively. Hence, treatment 1 refers to low content of soluble fibre, low fermentable starch and medium sugars.

	Factor		
Treatment	**A**	**B**	**C**
1	-1	-1	0
2	1	-1	0
3	-1	1	0
4	1	1	0
5	-1	0	-1
6	1	0	-1
7	-1	0	1
8	1	0	1
9	0	-1	-1
10	0	1	-1
11	0	-1	1
12	0	1	1
13	0	0	0

Each period included 4 rations and lasted three weeks. All treatments were formulated to support a milk production of 40 kg. The 48 cows of the trial group were divided into 4 groups of 12 cows each, on the basis of days in milk (DIM), milk yield and milk protein and the groups were randomly allocated to the different rations (Table 4).

Table 4. The treatments' (T) allocation to groups during the four periods.

Period 1	**Period 2**	**Period 3**	**Period 4**
Group 5 / T4	Group 6 / T2	Group 7 / T5	Group 8 / T1
Group 6 / T8	Group 7 / T6	Group 8 / T9	Group 5 / T7
Group 7 / T3	Group 8 / T12	Group 5 / T11	Group 6 / T10
Group 8 / T13	Group 5 / T13	Group 6 / T13	Group 7 / T13

The time budget study was performed in the end of period 2. Three cows from three different groups (5, 6, 7) were observed. These 9 cows were either of Swedish Red and White (n=3) or Holstein breed (n=6) and produced more than 40 kg milk a day (average 44,7 kg). All were multiparous and in a range of 125-163 DIM (average 108,3 DIM). The observations covered a total of one 24-hour period and were performed both continuously and instantaneously every 10 minutes (Table 5 and 6). When cows were about to be milked the registration stopped as the first observation cow left the housing section and continued once the last observation cow returned from milking. Each milking lasted for approximately one hour so the total observed period was in reality 21 hours.

Table 5. Descriptions of behaviours registered instantaneously every 10 minutes.

Behaviour	Description
Eating	The cow is standing in a feed stall and consumes new feed
Lying rumination	The cow lies down with the whole body against the ground while chewing without consuming new feed
Standing rumination	The cow is standing up while chewing without consuming new feed
Lying	The cow lies down with the whole body against the ground without ruminating
Standing	The cow is standing up in a stall or alley without eating or ruminating

Table 6. Descriptions of behaviours registered continuously.

Behaviour	Description
Tongue rolling	The cow rolls the tongue inside or outside the mouth
Teat sucking	The cow is sucking on another individuals' teats
Lick/bite on interior	The cow is licking or biting on the barn interior
Lick/bite another individual	The cow is licking or biting on another individuals body

Daily rumination and inter-cycle time

Feed consumption and eating time were measured during the entire feed trial through mangers placed on a scale in each feed stall (Biocontrol A/S, BC 40, Norway) where each individual cow is only allowed to consume feed from mangers containing the assigned ration. The cow is recognized by the transponder identification system ALPRO™ from DeLaval and accesses the feed through an air-pressure regulated gate that opens if the cow has allowance to eat there. The Biocontrol is connected to the data system Viken Data which gatherers all information automatically registered at Nötcenter Viken. Daily milk yield was also obtained from Viken Data. The RuminAct™ system recorded daily rumination as well as average seconds between boluses for all cows in the trial group during the entire feed trial. NDF-intake and peNDF-intake was calculated based on the DM-intake obtained from the Biocontrol and the content of NDF and peNDF in the different rations (Appendix 1, table 11.)

Statistical analysis

All data obtained from the PDA was transferred to a PC as text files and corrections of inaccurate registrations were made. The text files were then imported to SAS, Version 9.1 (2004) and all observations were calculated as frequencies during the observation period.

The observations of rumination from the validation experiment were used to generate a percentage of rumination/2h period (OR) for each individual. The rumination duration obtained from the Msysprob-file was also converted to rumination percentage/2h (RMR) for every cow. All data were then subjected to the mixed model procedure of SAS (Proc Mixed; SAS 9.1). The model included cow number and method, where method contained the two levels of OR and RMR. Cow number was considered a random effect. Effects were declared significant at $P < 0.05$. A Pearson correlation coefficient was calculated between OR and RMR and also between the observations of bad tag placement and the difference between the two methods.

The time budget observations were summarized and duration in minutes/day of each behaviour were calculated and means of the observed group were estimated. To confirm the observations of the 24-hour period, data from the ALPRO™ activity meter were compared to the behaviours observed. A Pearson correlation coefficient between total lying time (lying rumination+ lying) and the total activity was estimated using the CORR procedure of SAS (SAS, 9.1).

To examine which parameters affected the daily rumination time, all data from RuminAct™ and Viken Data during the four trial periods were analyzed by the first order autoregressive covariance structure (AR(1)) and the MIXED procedure of SAS, Version 9.1 (2004). The model used in SAS was:

Daily rumination= DM-intake + NDF-intake + peNDF-intake + eating time + milk yield + ration + after effect

As repeated effect the model included 'cow', and the repeated effect was regarded as an autoregressive correlation structure assuming that correlation decreases with duration between observations. Cow, ration and after effect were class variables while the remaining were numerical. Effects were declared significant at $P < 0.05$. Before this model was chosen, the effects of interaction were examined. These interactions were non significant and consequently not included in the model. For each treatment, means for the whole group were calculated for all numerical variables. A pairwise comparison between rations was also performed.

The feed intake data was corrected for deviant figures depending on the predicted dry matter intake (pDMI). The pDMI was based on 5,7 kg DM for maintenance and 0,43 kg DM/kg milk produced. The registered dry matter intake was allowed to exceed the pDMI with 35% and be below 35% of pDMI, otherwise the registration was removed. This resulted in a reduction of observations from 2882 to 1501. Registrations where daily rumination was 0 were also removed but this only caused a few removals.

From the Msysprob-file, an average of seconds between boluses during 2h-periods can also be obtained. This was utilized as a parameter of rumination efficiency during a few days each feed trial period. To examine which parameter that affects the average inter-cycle time, all data from RuminAct™ and Viken Data during the four trial periods were again analyzed by the first order autoregressive covariance structure (AR(1)) and the MIXED procedure of SAS, Version 9.1 (2004). The model used in SAS was:

Inter-cycle time = daily rumination + rumination time/kg DM intake + DM-intake + NDF-intake + peNDF-intake + eating time + milk yield + ration

As repeated effect the model included 'cow', and the repeated effect was regarded as an autoregressive correlation structure assuming that correlation decreases with duration between observations. Cow and ration were class variables while the remaining were numerical. Effects were declared significant at $P < 0.05$. Before this model was chosen, the effects of interaction were examined. These interactions were non significant and consequently not included in the model. A Pearson correlation coefficient was also estimated between rumination time/kg DM-intake and DM-intake to see if rumination speed was affected by voluntary DM-intake.

Results

RuminAct™ validation

The comparison between the direct observations and the automatically recorded data from RuminAct™ are displayed in figure 3 and in table 7. Table 7 also includes the difference between methods calculated as the automatically registered rumination time minus the duration observed. The analysis of variance showed no significant effect of method to survey rumination time (P = 0,69) but the standard deviation of difference between methods was 6,57 %. There existed no correlation between bad tag placement and the difference between methods (r = -0,18, ns).

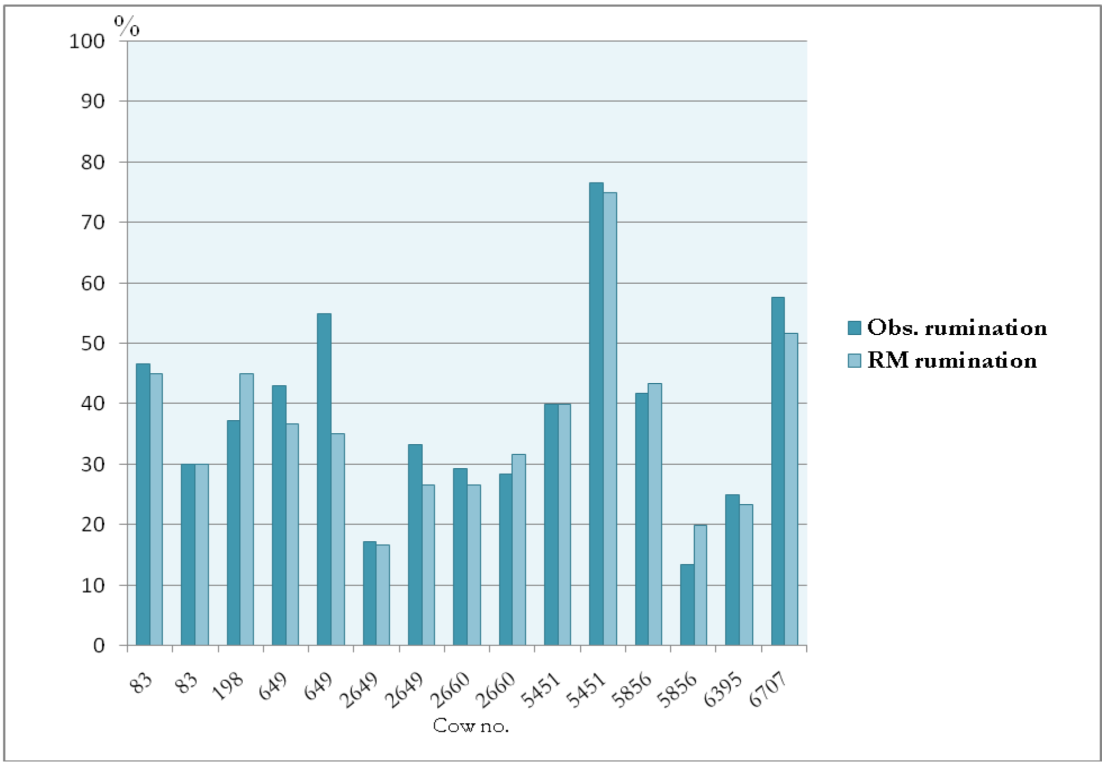

Figure 3. The direct observed (Obs.) rumination durations and rumination times from RuminAct™ (RM). All figures expressed as % of 2-hour block.

Table 7. The direct observed (Obs.) rumination durations, rumination times from RuminAct™ (RM), the difference between the two methods and the observations during which the tag was displaced. All figures expressed as % of 2-hour block.

Cow no.	Obs. idissling	RM idissling	Difference	Bad tag placement
83	46,67	45,00	-1,67	0,00
83	30,00	30,00	0,00	0,00
198	37,25	45,00	7,75	0,00
649	43,10	36,67	-6,44	5,17
649	55,00	35,00	-20,00	0,00
2649	17,24	16,67	-0,57	17,24
2649	33,33	26,67	-6,67	33,33
2660	29,31	26,67	-2,64	29,31
2660	28,33	31,67	3,33	0,00
5451	40,00	40,00	0,00	0,00
5451	76,67	75,00	-1,67	0,00
5856	41,67	43,33	1,67	0,00
5856	13,33	20,00	6,67	0,00
6395	25,00	23,33	-1,67	0,00
6707	57,69	51,67	-6,03	0,00
Average	38,31	36,44	-1,86	5,67
n	15	15	15	15
Stdev	16,37	14,68	6,57	11,38

[1]Number of observations

Time budget study

The observed durations of different behaviours during 21 hours are presented in figure 4. In table 8, minutes' performing each behaviour is displayed as well, together with percentage rumination while standing and total chewing activity. There were no observations made from the continuous registration of stereotypic behaviours.

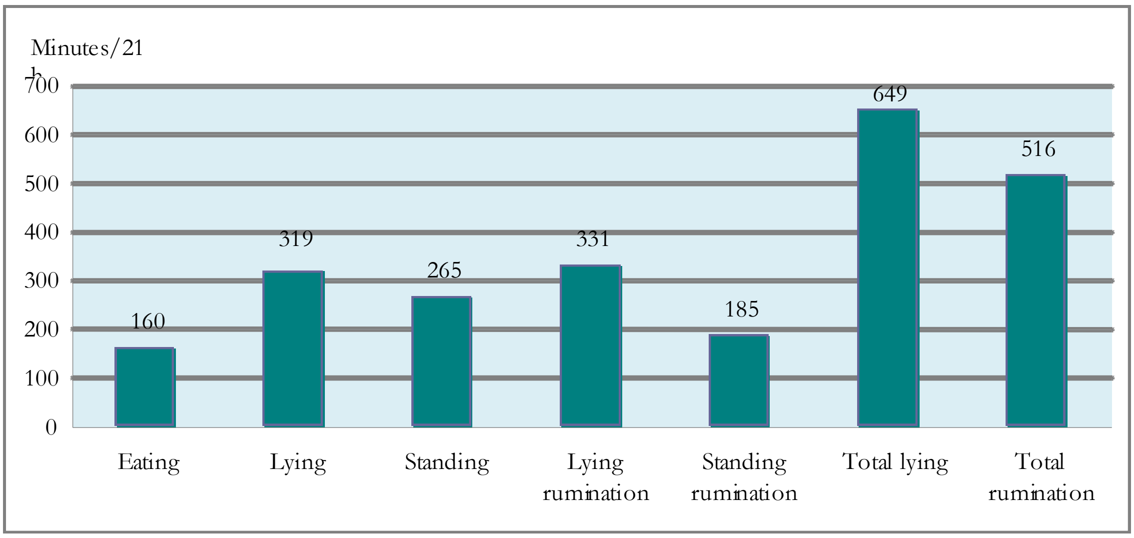

Figure 4. Minutes performing each behaviour per 21-hour (1260 minutes) period as averages of all cows.

Table 8. Durations (minutes/21h) of behaviours from each observed cow and the percentage of standing rumination to total rumination.

Cow no.	Eating	Lying	Standing	Lying rumination	Standing rumination	Total chewing	Total lying	Total rumination	% rumination while standing
484	102,7	364,0	280,0	308,0	205,3	616,0	672,0	513,3	40,0
533	139,0	250,1	370,6	120,4	379,9	639,3	370,6	500,3	75,9
1455	220,7	312,7	239,1	413,9	73,6	708,2	726,6	487,4	15,1
1835	132,6	540,0	75,8	502,1	9,5	644,2	1042,1	511,6	1,9
2453	213,1	259,4	268,7	389,1	129,7	731,9	648,5	518,8	25,0
5381	112,0	336,0	326,7	373,3	112,0	597,3	709,3	485,3	23,1
5451	168,0	252,0	224,0	429,3	124,4	784,0	681,3	616,0	20,2
5550	159,9	310,3	291,5	131,6	366,7	658,2	441,9	498,4	73,6
5856	196,0	242,7	308,0	308,0	205,3	709,3	550,7	513,3	40,0
Average	**160,4**	**318,6**	**264,9**	**330,6**	**185,4**	**676,5**	**649,2**	**516,1**	**35,9**
n[1]	**9**	**9**	**9**	**9**	**9**	**9**	**9**	**9**	**9**
Stdev	**42,8**	**93,5**	**83,6**	**130,4**	**125,9**	**60,6**	**192,3**	**39,3**	**25,4**

[1]Number of observations

When total activity, obtained from the ALPRO™ activity meter, was related to the direct observed total lying time through the CORR procedure, a negative correlation (r = -0,50) was found that was significant (P<0,05).

Daily rumination and inter-cycle time

Means and standard deviations of the automatically measured variables for all rations are presented in table 9, except for daily rumination where least square means (LSMeans) and standard errors (STDerr) are shown instead. The mixed model procedure showed that daily rumination was significantly affected by eating time, milk production, ration and after effect. Further, the inter-cycle time was significantly affected by daily rumination, eating time and rumination time/kg DM-intake. P-values and parameter estimates for variables analyzed are shown in table 10. The CORR procedure showed that there existed a significant (P<0,0001) negative correlation (r= -0,70) between rumination time/kg DM-intake and DM-intake.

Table 9. Variable means and standard deviations (within brackets) of all trial cows for each ration except for daily rumination where LSMeans and STDerr (within brackets), extracted from the statistical test, are shown. Daily rumination obtained from RuminAct™, eating and DM-intake from Biocontrol, milk yield from Alpro™, total chewing, NDF-intake and peNDF-intake are calculated values.

Ration no.	Daily rumination (min)	Eating (min)	Total chewing (min)	DM intake (kg)	NDF intake (kg)	peNDF intake (kg)	Milk yield (kg)
1	432,6 (33,2) [1]	136,6 (50,6)	569,2 (126,6)	21,7 (5,1)	7,8 (1,9)	6,1 (1,5)	39,8 (6,5)
2	450,6 (32,4) [1]	194,4 (53,5)	645,0 (129,7)	22,2 (4,3)	7,9 (1,5)	6,1 (1,2)	38,5 (6,4)
3	367,3 (45,5) [1]	169,4 (51,0)	536,7 (85,0)	24,4 (4,7)	8,2 (1,6)	6,7 (1,3)	42,8 (7,2)
4	464,1 (45,6) [1]	165,7 (55,2)	629,8 (133,1)	22,2 (4,7)	7,2 (1,5)	5,3 (1,1)	38,0 (7,2)
5	379,9 (35,9) [1]	144,8 (39,5)	524,7 (101,8)	23,1 (4,8)	8,7 (1,8)	6,1 (1,3)	39,7 (6,2)
6	474,3 (57,3) [1]	167,6 (46,1)	641,9 (123,3)	22,2 (4,3)	7,8 (1,5)	5,8 (1,1)	37,7 (7,0)
7	392,8 (54,1) [1]	119,8 (27,2)	512,6 (116,3)	22,0 (5,0)	7,5 (1,7)	5,7 (1,3)	35,0 (5,7)
8	423,3 (44,7) [1]	131,9 (43,4)	555,2 (111,7)	21,8 (5,6)	7,2 (1,9)	5,6 (1,4)	37,4 (7,8)
9	424,4 (58,0) [1]	161,2 (42,3)	585,6 (113,6)	26,9 (4,9)	9,4 (1,7)	6,3 (1,2)	38,7 (6,8)
10	480,6 (52,6) [1]	149,4 (48,6)	630,0 (74,8)	25,4 (5,6)	8,4 (1,8)	5,8 (1,3)	39,4 (5,3)
11	581,2 (49,3) [1]	154,5 (50,7)	735,7 (88,5)	27,4 (5,9)	9,5 (2,1)	6,1 (1,3)	40,4 (6,1)
12	633,7 (50,8) [1]	180,3 (52,3)	814,0 (88,3)	23,4 (4,7)	7,7 (1,5)	6,1 (1,2)	40,9 (6,7)
13	571,2 (44,7) [1]	148,7 (56,0)	719,9 (97,3)	22,5 (5,3)	8,0 (1,9)	5,9 (1,4)	37,1 (5,1)
Total means	**467,4 (81,7)**	**158,5 (52,4)**	**623,1 (119,1)**	**23,4 (5,3)**	**8,1 (1,8)**	**6,0 (1,3)**	**39,1 (6,8)**
n[2]	**13**	**13**	**13**	**13**	**13**	**13**	**13**

[1]LSMeans and STDerr (within brackets).
[2]Number of observations

Table 10. P-values for each variable obtained by mixed model analysis of daily rumination and inter-cycle time with parameter estimates for all quantitative variables (within brackets).

	Daily rumination (min)	**Eating (min)**	**Rumination time/kg DM-intake**	**DM intake (kg)**	**NDF intake (kg)**	**peNDF intake (kg)**	**Milk yield (kg)**	**Ration**	**After effect**
Daily rumination	x	0,001 (0,20)	x	0,76 (-2,74)	0,957 (1,43)	0,793 (5,11)	<0,0001 (1,73)	<0,0001	0,0184
Inter-cycle time	<0,0001 (0,006)	0,0005 (0,005)	0,023 (-0,049)	0,555 (-0,12)	0,626 (0,31)	0,713 (-0,17)	0,385 (-0,010)	0,098	x

Results with least square means of daily rumination and the pairwise comparison between rations is shown in figure 5. Ration number 11 and 12 produced the longest rumination durations while ration number 3 and 5 gave the shortest times.

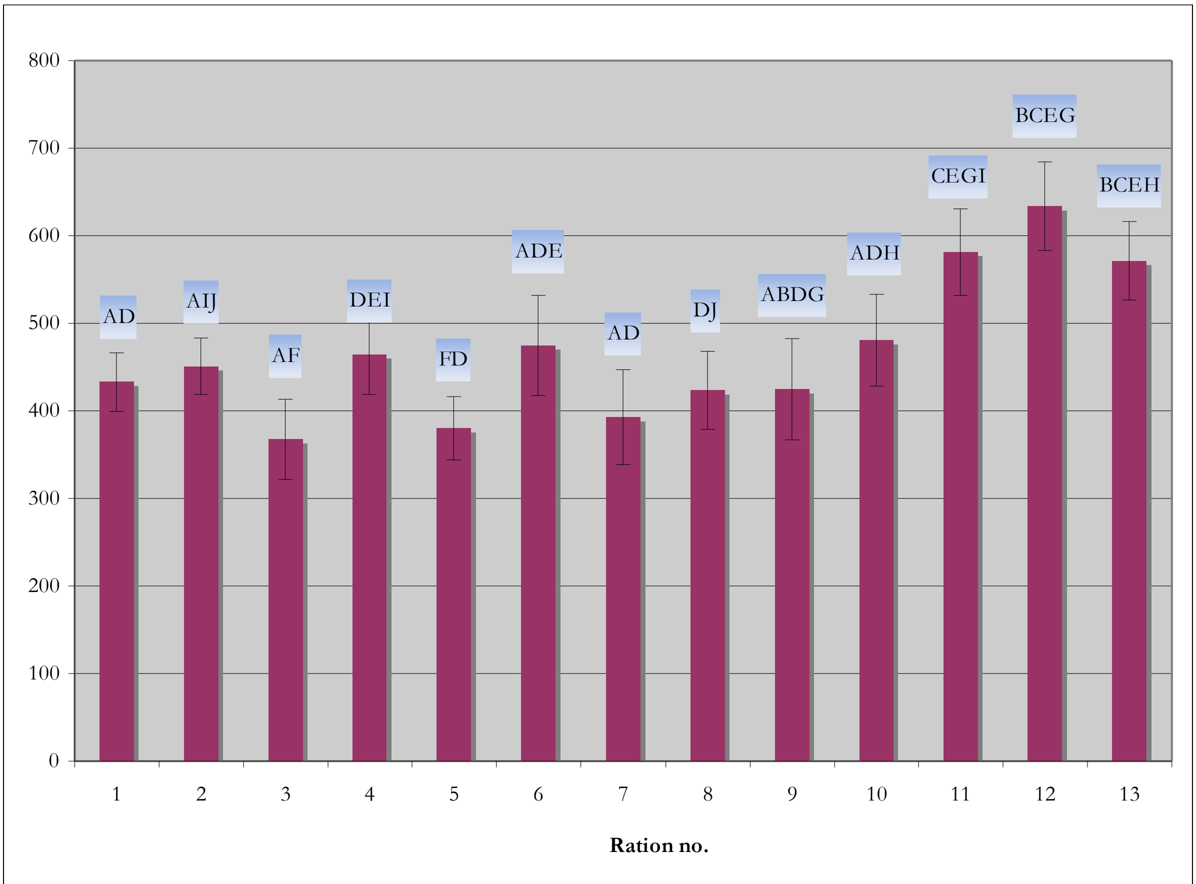

Figure 5. Least square means and standard error of rumination duration (min/day) for each ration. Piles with no common letter show a significant difference between rumination duration.

Discussion

RuminAct™ validation

Since no significant effects of method recording rumination duration could be shown, the hypothesis that the RuminAct™ data does agree with the observed rumination cannot be rejected. This does not necessarily mean that there are no differences, only that differences could not be proved. The average difference between the two methods recording rumination (OR-RM) was -1,86 %, which implies that the tags, on average, underestimates rumination to a very small extent. At farm level, an underestimation of rumination is favourable to an overestimation since the purpose for the farmer is to find rumination drops. Then the farmer might have to check the cow once too much rather than missing out on a dip in the rumination.

It would be tempting to say that the RuminAct™ system is completely reliable since the mean difference between methods only totalled -1,86 %. However, the standard deviation was more than three times larger than the mean (6,57), which implies somewhat larger deviations than the mean narrates. Further, one of the tags (Cow no. 649) showed a marked divergence from the observed time of rumination where the tag underestimated the duration between 6 to 20 %-units. None of the deviations could be related to the tag placement since there did not exist any correlation between bad tag placement and the difference between recording methods. Surrounding noise would most likely have caused an over estimation rather than the opposite. Possibly there was something temporarily disturbing the tag, and observations during a longer period could have shown less divergence from the observed durations. It could also be that a minor amount of tags produced are not working properly and should be replaced. This study did however only cover 9 tags.

To further validate the accuracy of the system, a larger quantity of tags should be tested throughout longer periods. Then a more complete picture of the extent of potentially dysfunctional tags could be received. It would however be very time consuming and for experiments with large samples, some unreliable tags might not mean substantial bias. One technique, to reduce the number of tags to visually observe, could be to place two tags on one cow and then perform direct observations only on the ones where disparity have occurred. The difficulty with this method is to get both tags positioned well enough for accurate recording. It should nonetheless be viable, since the tags do not seem that dependent on the exact positioning recommended by the developer. Another important part should be to validate the same tag on different cows to see that each tag can manage different individuals.

From a practical perspective, the RuminAct™ system was easy to handle and the software was rather user friendly. There was some exertion to join the tags correctly to the collars but once there, most of them stayed well in place. Tags with observed bad placement during the experiment were not optimally attached from the beginning. Consequently the lead weight attached to the collar seems to fulfil its purpose, although one problem arose. On a substantial amount of collars, the lead weight placed the ALPRO™-tag in a horizontal position, which made several cows unidentifiable at the reader by the rotary parlor. This might cause a problem in experiments where information on milk yield is important and farmers utilizing the ALPRO™-system will most likely face problems when one system is disturbing the other. A redesign of the shape of the lead weight would probably be necessary to solve this drawback.

Even though RuminAct™ is intended for farmers, it can become a valuable tool for scientists, since it is easy to handle compared to other similar equipment, which demands complex switch and wire harnesses. Further, if it in the future also could record and analyze other chewing sounds than that of rumination (prehensive bites, chewing and chew-bites), the potential to estimate voluntary feed intake (VFI) may become possible. This would be very valuable during grazing season, when farmers have little knowledge on how to complement feed the cows. For research purposes of grazing behaviour and in studies where voluntary feed intake is of great importance, an algorithm to analyze all chewing sounds would make RuminAct™ even more useful. The developer has indicated that a second generation of RuminAct™ will detect other chewing sounds than rumination alone, but no more information regarding this was made clear.

Time budget study

The observation cows did not appear to differ in their behaviour from the rest of the animals placed in the trial group throughout the observation periods, and consequently appeared as a representative sample of the whole group. The observed cows lie down 649 minutes a day in average, which is above the stated minimum recommendation of 10h (600 min) (Munksgaard *et al.,* 2006). Some individuals, cow no. 533, 5550 and 5856, did however spend only 370,6 min, 441,9 min and 550,7 min respectively lying down. This seems somewhat short, but might be an underestimation due to the fact that the 24-hour study was split over several days. It can also be a consequence of low social rank since it is well known that low-ranked individuals spend extra time waiting in passageways for space to become available and they can also frequently use cubicles standing to hide from dominant animals' (Wierenga & Metz, 1986; Potter & Broom, 1987). Galindo and Broom (2000) pointed out that the general cubicle:ratio recommendations of 1:1 does not mean that every cow in a group has a lying place assured and is able to lie for as long as it wants. They suggested that farmers always should keep a number of spare cubicles as alternative for those cows reluctant to use certain cubicles or those that are displaced more often from specific areas.

Since no observations were performed during milking, the behaviours are expressed as minutes/21-hour period. Hence, the durations of standing, standing rumination and total rumination are in reality longer. As a result, the percentage of standing rumination is probably also somewhat larger than the calculated 35,9 %. There are no maximum recommendations of standing rumination found in the literature but in view of the fact that total lying time are within normal ranges, the percentage of standing rumination might not be of substantial matters.

Cows managed in similar ways as the observation cows, with loose housing systems and TMR, have been reported to ruminate 344,0-496,3 minutes a day (see table 1.) while the observed cows in the present study ruminated 516,1 minutes a day. This rather high figure might also be a result of the scattered 24-hour study. The automatic recordings from the whole trial group during the entire trial period showed an average daily rumination of 489,7 minutes which is more likely to represent the reality since the fibre content of the fed diets were fairly low.

The observed cows ate in average 160,4 minutes a day while the automatic registrations of eating duration totalled 158,5 min in average of the trial group. Neither of these figures is fully consistent with earlier published ranges of 185,1-350,0 minutes a day (see table 1.). The short eating duration might be related to the substitutional relationship between eating and rumination, where the short eating time is compensated by a longer rumination (Bailey & Balch, 1961; Nørgaard, 1989). The total chewing activity of the observed cows were 676,5 min and 648,1 min for the trial group, which is well within the earlier found ranges of 558,0-846,3 min a day (see table 1.).

Perhaps a less disjointed 24-hour study could have shown a more representative picture of the time budget, but then more observers would have been required, with the potential risk of in between observer bias as a result. As an attempt to validate the 24-hour study, each observation period were compared to the corresponding hours from the ALPRO™ activity data. A significant negative correlation (r = -0,50) was found between the activity data and the observed total lying time, which implies that the more activity performed, the less time spent lying.

Despite high production, three milkings a day and loose housing system, the cows at Nötcenter Viken seem able to perform their behavioural needs, which is probably why no observations of stereotypic behaviours were made. Yet one behaviour, not included in the etogram, was frequently noticed among both the observed cows as well as the rest of the trial group. The behaviour was "leaning" and it is described as when the cow presses the forehead or the muzzle on another cow or fixtures of the stall (Munksgaard & Simonsen, 1996). It is considered an abnormal behaviour where increased frequencies have been observed in connection with reduced lying time in overcrowded loose housing (Wierenga, 1983) and cows subjected to intensive daily handling (Munksgaard, 1986). Munksgaard and Simonsen (1996) suggested that leaning could be a symptom of behavioural conflict when cows want to lie down but are constrained or in pain (Personal communication. L. Munksgaard, 2009-06-02). At Nötcenter Viken the cubicle:cow ration was 1:1 at the time of the observation period. Hence there was no evident overcrowding and as noted earlier, the requirement of lying was fulfilled for most of the cows. However, cow no. 533 was seen leaning and she was also one of the cows with short lying duration. On the contrary, leaning was observed in two other cows of the observation group, no. 484 and no. 2453, and none of them had lying durations below 10 h. Further it should be noted that a number of cows seemed to suffer from claw problems and staggered with arched backs. Perhaps the observed leaning could be a symptom of behavioural conflict when the cow wants to lie down but finds it difficult due to lameness. A more comprehensive study of claw health scoring and patterns of lying down and getting up behaviours might possibly give clarity to this matter.

Daily rumination and inter-cycle time

The large proportion of unrealistic registrations from feed intake is probably due to troubles with the Biocontrol feeding stations. There were some feed wastes outside the mangers but that does not explain the unrealistically high intakes. However, numerous cows have been noticed to displace and steal feed from other individuals who are already identified by the ALPRO™. Hence the feed intake and eating times are registered for the wrong animals. Cows that steal from others ought then to have a much less feed intake and eating duration registered, while robbed cows appear to have consumed more feed during longer time than in reality. An additional problem is that a large proportion of cows manage to eat from mangers they are not assigned to, simply by pressing their head and neck on the air-pressure gate until it relents. When this occurs, no feed intake is registered for that cow. Apart from missing intake registering, this causes problems in studies of the effect from different rations, since the cow then mixes dissimilar diets.

With such a considerable amount of data removed (from 2882 to 1501 observations) due to the unrealistic registrations of feed intake, the validity of the remaining figures is questionable. The lack of expected relationships discussed below implies that the data may not be reliable.

Given that high feed intake provides a lot of material to digest, rumination time and daily feed intake is positively correlated (Metz, 1975, abstr.). In the present study this relationship could not be shown. Probably this is due to the problems with feed intake registrations. However, milk production showed a significant effect ($P = <0,0001$) on daily rumination where increased milk yield prolonged the rumination time (1 kg increase in milk production required an increased rumination of 1,73 min). Since high DM-intake provides more energy, the milk yield increases with higher DM-intake. Consequently the DM-intake shows an indirect effect on daily rumination through milk yield in this case. There existed a significant negative correlation ($r = -0,70$) between rumination time/kg DM-intake and DM-intake, which implies that the cow ruminates less at higher DM-intakes. This could be an approach for the cow to release time for other high priority activities despite its need for a high DM-intake.

The daily rumination was significantly affected by eating time ($P=0.001$) and the analysis of variance showed that increased eating time resulted in longer duration of rumination (1 minute prolonged eating time extended rumination duration by 0,2 min), which contradicts the stated substitutional relationship between eating and rumination found by Bailey and Balch (1961) and Nørgaard (1989). This can be due to that long eating time resulted in higher dry matter intake that prolonged the rumination, but can also be a cause of the trouble with the large proportion of faulty data.

Beauchemin and Yang (2005) found peNDF to be a reliable indicator of chewing activity. In the present study neither peNDF-intake nor NDF-intake could be related to the daily rumination duration. Because both parameters are calculated values based on DM-intake, the non-significant effect of both peNDF-intake and NDF-intake are probably due to the non-existing effect of DM-intake. Another explanation can be that the content of NDF and peNDF did not vary enough between rations to produce different rumination durations. The intention when formulating the diets meant for the feed trial was to investigate the effects of different WSC sources, which is why the remainder of the nutrient composition was assembled as similar as possible.

The registering of average time between boluses is something the developer has not put any real effort in validating (Personal communication. Doron Bar. 17 June 2009). The present study did not aim to do so either, due to lack of time and the extent of the project. However, since the data was recorded anyway, the parameter inter-cycle time was analyzed to see what affected it, given that a shorter interval between boluses could be a sign of more efficient rumination (De Boever *et al.,* 1990). The analysis of variance showed significant effect of daily rumination, eating time and rumination time/kg DM-intake. Increased daily rumination prolonged the inter-cycle period (parameter estimate = 0,006), which suggests that with long total daily rumination, the speed does not need to be that high. However, long eating duration also prolonged the inter-cycle time (parameter estimate = 0,005), which was not expected since long eating time reduces the time left for other activities in the total time budget, yet eating duration, as mentioned before, was probably not correctly measured. Increased rumination time/kg DM-intake reduced the inter-cycle period (parameter estimate = -0,049). This result contradicts itself since increased rumination time/kg DM-intake implies slower rumination. With slower rumination, a longer inter-cycle period would be expected. It could be that the registration of average time between boluses is not accurate but again, the registrations of DM-intake were not reliable. Another possible explanation is that the cow controls the rumination rate in other ways, for example by decreasing chewing rate.

For future validation of the inter-cycle time registration function, direct observations of the cows should be performed, since the swallowing and regurgitating of boluses is quite easy noticeable. However, for validation purposes, the knowledge of how to access the Msysprob-file and the SAS-program that sorts system data is essential. This is important due to the fact that the Milcon HM™ software only displays rumination durations and average time interval between boluses every second hour, on the hour. These registrations, however, might in reality have started several minutes prior to or past that time, since the tags have different internal time settings and are not synchronized. The Msysprob-file and the SAS-program are not available when buying RuminAct™ but was, after personal correspondence, sent from the developer.

By calculating least square means of daily rumination duration for each ration, number 11 and 12 turned out to produce the longest rumination times (581,2 min and 633,7 min respectively), while number 3 and 5 gave the shortest (367,3 min and 379,9 min respectively). If comparing forage inclusion, NDF-content, % NDF provided from forage, as well as peNDF-content (Appendix 1, table 11) in ration number 3, 5, 11 and 12 it would be expected to find high values in ration number 11 and 12 and low amounts in 3 and 5, because high figures of these four parameters are unambiguously associated with chewing stimulation (NRC, 2001; Mertens, 1997; Beauchemin & Yang, 2005). However, the content of forage, peNDF and % NDF provided from forage in ration number 11 falls below the total mean of all rations (46,83%, 22,14% and 25,44% respectively). Only the NDF-content exceeds the total mean which is 34,45%. Further does ration number 3 and 5 exceed the total means, except for NDF-content where ration 3 falls below. Looking at average intake of DM, NDF and peNDF does not bring any clarity to the matter either. Ration number 3 and 11 exceeded the total mean of DM-intake (23,4 kg) while 5 averaged right below and 12 equalled. For NDF-intake, ration number 3, 5 and 11 exceeded the total mean (8,1 kg) and 12 fell below. Further looking at peNDF intake, all rations (3, 5, 11, 12) exceeded the total mean (6,0 kg). It is difficult to see any common feature between these rations that can explain the long and short durations of rumination. Again, this might be a cause of the intake registrations that were quite unreliable. Another possible explanation to the lack of connections between these diets might be that the physical effectiveness factor was not experimentally determined but came from tabulated values in CPM dairy. Hence, basing the physical effectiveness factor on the actual particle length might have shown another picture.

To enable reliable studies of chewing activity and the effect of different diets at Nötcenter Viken, the complications with the feeding stations requires a solution. The gate pistons will probably have to be replaced by stronger ones, so that cows can only eat from the assigned ration, without possibilities to force the gates to open. To enhance the feed intake measurements and eating time registrations, cows should be hindered to steal from each other by displacing other cows. Shortening the duration from which the air pressure gait shuts might rectify this.

Conclusions

RuminAct™ might become a valuable tool for both farmers and researchers in the future since it surveys rumination duration with good accuracy and is comparatively easy to manage. The present study showed that the tags underestimate rumination time with only 1,86 % on average, compared to direct observations, yet standard deviation totalled 6,57 %. The product could gain from additional validation as certain tags might show larger deviations from actual durations and also because this study only covered 9 tags.

The time budget study showed that the trial cows at Nötcenter Viken seems to handle the loose housing system with TMR and milkings in rotary parlour three times a day, very well. They did not seem to suffer from time constraint, yet one abnormal behaviour was observed, leaning, which could be due to behavioural conflict caused by for example foot pain.

Prolonged daily rumination was positively correlated with higher milk yield and long daily rumination was also positively correlated with extended the inter-cycle periods. The rumination duration did differ significantly between some rations although any clear causes to this are lacking, probably due to troubles with feed intake registrations.

References

Albright, J.L. 1987. Dairy Animal Welfare: Current and Needed Research. *Journal of Dairy Science 70,* 2711-2731.

Albright, J.L. 1993. Feeding Behaviour of Dairy Cattle. *Journal of Dairy Science 76,* 485-498.

Albright, J.L., Arave, C.W. 1997. *The Behaviour of Cattle,* pp. 100-126. Cambridge: CABI.

Alkon, P.U. 1989. Towards an acoustic biotelemetry system for animal behavior studies. *Journal of Wildlife Management 53,* 658-662.

Bae, D.H., Welch, J.G., Gilman, B.E. 1983. Mastication and Rumination in Relation to Body Size of Cattle. *Journal of Dairy Science 66,* 2137-2141.

Bailey, C.B., Balch, C.C. 1961. The digestion of hay administered to cows through rumen fistulas. *The British Journal of Nutrition 15,* 183-188.

Balch, C.C. 1971. Proposal to use time spent chewing as an index of the extent to which diets for ruminants possess the physical property of fibrousness characteristic of roughages. *The British Journal of Nutrition 26,* 383-392.

Beauchemin, K.A., Buchanan-Smith, J.G. 1989. Effects of Dietary Neutral Detergent Fibre Concentration and Supplementary Long Hay on Chewing Activities and Milk Production of Dairy Cows. *Journal of Dairy Science 72,* 2288-2300.

Beauchemin, K.A., Iwaasa, A.D. 1993. Eating and ruminating activities of cattle fed alfalfa or orchardgrass harvested at two stages of maturity. *Canadian Journal of Animal Science 73,* 79-88.

Beauchemin, K.A., Yang, W.Z. 2005. Effects of Physically Effective Fibre on Intake, Chewing Activity, and Ruminal Acidosis for Dairy Cows Fed Diets Based on Corn Silage. *Journal of Dairy Science 88,* 2117-2129.

Beauchemin, K.A., Yang, W.Z., Rode, L.M. 2003. Effects of Particle Size of Alfalfa-Based Dairy Cow Diets on Chewing Activity, Ruminal Fermentation, and Milk Production. *Journal of Dairy Science 86,* 630-643.

Beauchemin, K.A., Zelin, S., Genner, D., Buchannan-Smith, J.G., 1989. An Automatic System for Quantification of Eating and Ruminating Activities of Dairy Cattle Housed in Stalls. *Journal of Dairy Science 72,* 2746-2759.

Broom, D.M. 1988. The Scientific Assessment of Animal Welfare. *Applied Animal Behaviour Science 20,* 5-19.

Campling, R.C. 1966. A preliminary study of the effect of pregnancy and of lactation on the voluntary intake of food by cows. *The British Journal of Nutrition 20,* 25-39.

Chai, K., Milligan, L.P., Mathison, G.W. 1988. Effect of muzzling on rumination in sheep. *Canadian Journal of Animal Science 68,* 387-397.

Chambers, A.R.M., Hodgson, J., Milne, J.A. 1981. The development and use of equipment for the automatic recording of ingestive behaviour in sheep and cattle. *Grass and Forage Science 36,* 97-105.

Chaplin, S., Munksgaard, L. 2001. Evaluation of a simple method for assessment of rising behaviour in tethered dairy cows. *Animal Science 72,* 191-197.

Clapham, W.M., Abaye, O., Fedders, J.M., Yarber, E. 2006. *Sound spectral analysis of grazing steers.* United States Department of Agriculture- Digital Documents Repository. Available at Internet http://hdl.handle.net/10113/11920 , viewed 2009-07-03.

Coulon, J.B., Doreau, M., Rémond, B., Journet, M. 1987. Evolution des activités alimentaires des vaches laitiéres en début de lactation et liaison avec les quantités d'aliments ingérées. *Reproduction, nutrition, développement 27,* 67-75. (Abstr.)

CPM dairy. 2008. Cornell-Penn-Miner. Version 3.0.10, USA.

Dado, R.G., Allen, M.S. 1993. Continuous Computer Acquisition of Feed and Water Intakes, Chewing, Reticular Motility, and Ruminal pH of Cattle. *Journal of Dairy Science 76,* 1589-1600.

Dado, R.G., Allen, M.S. 1994. Variation in and Relationships Among Feeding, Chewing, and Drinking Variables for Lactating Dairy Cows. *Journal of Dairy Science 77,* 132-144.

De Boever, J.L., Andries, J.I., De Brabander, D.L., Cottyn, B.G., Buysse, F.X. 1990. Chewing Activity of Ruminants as a Measure of Physical Structure -- A Review of Factors Affecting It. *Animal Feed Science and Technology 27*, 281-291.

Derrick, R.W., Moseley, G., Wilman, D. 1993. Intake, by sheep, and digestibility of chickweed, dandelion, dock, ribwort and spurrey, compared with perennial ryegrass. *Journal of Agricultural Science, Cambridge 120,* 51-61.

Des Bordes, C.K., Welch, J.G. 1984. Indigestible Particles Influence of Specific Gravity on Rumination and Passage of Indigestible Particles. *Journal of Animal Science 59,* 470-475.

Deswysen, A.G., Ehrlein, J.G. 1981. Silage intake, rumination and pseudo-rumination activity in sheep studied by radiography and jaw movement recordings. *The British journal of nutrition 46,* 327-335.

Deswysen, A.G., Ellis, W.C., Pond, K.R. 1987. Interrelationships among Voluntary Intake, Eating and Ruminating Behavior and Ruminal Motility of Heifers Fed Corn Silage. *Journal of Animal Science 64,* 835-841.

Fraser, A.F. 1980. *Farm Animal Behaviour 2nd edition,* pp. 164. London: Spottiswoode Ballantyne Ltd.

Fregonesi, J.A., Leaver, J.D. 2001. Behaviour, performance and health indicators of welfare for dairy cows housed in strawyard or cubicle systems. *Livestock Production Science 68,* 205-216.

Galindo, F., Broom, D.M. 2000. The relationships between social behaviourof dairy cows and the occurrence of lameness in three herds. *Research in Veterinary Science* ***69****,* 75–79.

Galli, J.R., Cangiano, C.A., Demment, M.W., Laca, E.A. 2006. Acoustic monitoring of chewing and intake of fresh and dry forages in steers. *Animal Feed Science and Technology 128,* 14–30.

Girard, V., Labonté, J. 1993. Dispositif d'enregistrement en continu du comportement alimentaire journalier et étude de la variabilité du comportement chez la vache laitière. *Ann Zootech 42,* 49-56. Abstr.

Gordon, J.G., McAllister, I.K. 1970. The circadian rhytm of rumination. *Journal of Agricultural Science, Cambridge 74,* 291-297.

Grant, R.J., Albright, J.L. 2001. Effect of Animal Grouping on Feeding Behaviour and Intake of Dairy Cattle. *Journal of Dairy Science 84 (E. Suppl.)*, E156-E163.

Grant, R.J., Colenbrander, V.F., Mertens, D.R. 1990a. Milk Fat Depression in Dairy Cows: Role of Particle Size of Alfalfa Hay. *Journal of Dairy Science 73,* 1823-1833.

Grant, R.J., Colenbrander, V.F., Mertens, D.R. 1990b. Milk Fat Depression in Dairy Cows: Role of Particle Size. *Journal of Dairy Science 73,* 1834-1842.

Harb, M.Y., Campling, R.C. 1985. Variation among pregnant, non-lactating dairy cows in eating and ruminating behaviour, digestibility and voluntary intake of hay. *Grass and Forage Science 40,* 109-111.

Hooper, A.P., Welch, J.G. 1985. Effects of Particle Size and Forage Composition on Functional Specific Gravity. *Journal of Dairy Science 68,* 1181-1188.

Houston, A.I., Macfarland, D.J. 1980. Behavioral resilience and its relation to demand functions. In: Staddon, J.E.R. (Ed.), *Limits to Action: The Allocation of Individual Behaviour,* pp. 177–203. New York: Academic Press.

Jaster, E.H., Murphy, M.R. 1983. Effects of Varying Particle Size of Forage on Digestion and Chewing Behavior of Dairy Heifers. *Journal of Dairy Science 66,* 802-810.

Jensen, P. 1993. *Djurens beteende och orsakerna till det,* pp. 144-153. Falköping: LTs förlag.

Jensen, P., Toates, F.M. 1993. Who needs 'behavioural needs'? Motivational aspects of the needs of animals. *Applied Animal Behaviour Science 37,* 161-181.

Ketelaar-de Lauwere, C.C., Devir, S., Metz, J.H.M. 1996. The influence of social hierarchy on the time budget of cows and their visits to an automatic milking system. *Applied Animal Behaviour Science 49,* 199-211.

Kononoff, P.J., Heinrichs, A.J., Lehman, H.A. 2002. The Effect of Corn Silage Particle Size on Eating Behavior, Chewing Activities, and Rumen Fermentation in Lactating Dairy Cows. *Journal of Dairy Science 86,* 3343-3353.

Kononoff, P.J., Lehman, H.A., Heinrichs, A.J. 2002. Technical Note—A Comparison of Methods Used to Measure Eating and Ruminating Activity in Confined Dairy Cattle. *Journal of Dairy Science 85,* 1801-1803.

Laca, E.A., Ungar, E.D., Demment, M.W. 1994. Mechanisms of handling time and intake rate of a large mammalian grazer. *Applied Animal Behaviour Science 39,* 3-19.

Laca, E.A., Ungar, E.D., Seligman, N.G., Ramey, M.R., Demment, M.W. 1992. An integrated mehodology for studying short-term grazing behaviour of cattle. *Grass and Forage Science 47,* 81-90.

Laca, E.A., WallisDeVries, M.F. 2000. Acoustic measurement of intake and grazing behaviour of cattle. *Grass and Forage Science 55*, 97-104.

Lammers, B.P., Buckmaster, D.R., Heinrichs, A.J. 1996. A Simple Method for the Analysis of Particle Sizes of Forage and Total Mixed Rations. *Journal of Dairy Science 79,* 922-928.

Lindström, T., Redbo, I. 2000. Effect of feeding duration and rumen filll on behaviour in dairy cows. *Applied Animal Behaviour Science 70,* 83-97.

Luginbuhl, J.M., Pond, K.R., Russ, J.C., Burns, J.C. 1987. A Simple Electronic Device and Computer Interface System for Monitoring Chewing Behavior of Stall-Fed Ruminant Animals. *Journal of Dairy Science 70,* 1307-131.

Mason, G.J. 1991. Stereotypies: a critical review. *Animal Behaviour 41,* 1015-1037.

McDonald, P. Edwards, R.A., Greenhalgh, J.F.D., Morgan, C.A. 2002. *Animal Nutrition 6th edition,* pp. 179-195. England: Pearson Education Ltd.

Melin, M., Pettersson, G., Svennersten-Sjaunja, K., Wiktorsson, H. 2007. The effects of restricted feed access and social rank on feeding behavior, ruminating and intake for cows managed in automated milking systems. *Applied Animal Behaviour Science 107,* 13–21.

Mertens, D.R. 1997. Creating a System for Meeting the Fibre Requirements of Dairy Cows. *Journal of Dairy Science 80*, 1463–1481.

Metz, J.H.M. 1975. Time patterns of feeding and rumination in domestic cattle. PhD dissertation, University of Wageningen, The Netherlands. Available at Internet: http://library.wur.nl/wda/abstracts/ab636.html , viewed 2009-03-27. (Abstr.)

Metz, J.H.M. 1985. The reaction of cows to a short-term deprivation of lying. *Applied Animal Behaviour Science 13,* 301-307.

Milkline. 2007. *RuminAct™ Detecting welfare.* Available at Internet: http://www.healthycow24.com/eng/ruminact/down/pdf/INFO_E_Ruminact_22-10-07.pdf , viewed 2009-01-28.

Munksgaard, L., Herskin, M.S. 2001. Does milking frequency and energy concentration of the diet affect time budgets of high yielding dairy cows?. In: Garner, J.P., Mench, J.A., Heekin, S.P. Proceedings of the 35th International Congress of the ISAE. pp. 190.

Munksgaard, L., Herskin, M.S., Løvendahl, P., Andersen, J.B. 2006. Chap. "Effects of nutrition on stress reactivity" in *Ruminant physiology.* Wagening Academic Publishers, The Netherlands. pp 511-525.

Munksgaard, L., Jensen, M.B., Pedersen, L.J., Hansen, S.W., Matthews, L. 2005. Quantifying behavioural priorities—effects of time constraints on behaviour of dairy cows, *Bos taurus*. *Applied Animal Behaviour Science 92,* 3-14.

Murphy, M.R., Baldwin, R.L., Ulyatt, M.J., Koong, L.J. 1983. A Quantitative Analysis of Rumination Patterns. *Journal of Dairy Science 56,* 1236-1240.

Nielsen, B.L., Veerkamp, R.F., Lawrence, A.B. 2000. Effects of genotype, feed type and lactational stage on the time budget of dairy cows. *Acta agriculturæ Scandinavica. Section A, Animal science 50,* 272-278.

NRC. National Research council. 2001. *Nutrient requirements of dairy cattle 7th edition*. Washington, D.C: National Academy Press. pp 34-40.

Nørgaard, P. 1989. The Influence of Physical Form of Ration on Chewing Activity and Rumen Motility in Lactating Cows. *Acta Agricultural Scandinavica 39,* 187-202.

Nørgaard, P. 2003. Optagelse af foder og drøvtygning. Chap. 6 in: Hvelpelund, T. and Nørgaard, P. *Kvægets enæring og fysiologi. Bind 1 Næringsstoomsætning og fodervurdering,* pp. 120-145. DJF Rapport, Husdyrbrug nr. 53.

Pearce, G.R. 1965. Rumination in sheep - II. The circadian pattern of rumination. *Australian journal of agricultural research 16,* 635-648.

Penning, P.D. 1983. A technique to record automatically some aspects of grazing and ruminating behaviour in sheep. *Grass and Forage Science 38,* 89-96.

Penning, P.D., Steel, G.L., Johnson R.H. 1984. Further development and use of an automatic recording system in sheep grazing studies. *Grass and Forage Science 39,* 345-351.

Philips, C. 2002. *Cattle Behaviour & Welfare 2nd edition*, ch 1, 10, 13, 14. Cornwall: Blackwell Science Ltd.

Poppi, D.P., Hendrickson, R.E., Minson, D.J.m1985. The relative resistance to escape of leaf and stem particles from the rumen of cattle and sheep. *Journal of Agricultural Science, Cambridge 105,* 9-14.

Poppi, D.P., Norton, B.W., Minson, D.J., Hendricksen, R.E. 1980. The validity of the critical size theory for particles leaving the rumen. *Journal of Agricultural Science, Cambridge 94,* 275-280.

Potter, M.J., Broom, D.M. 1987. The behaviour and welfare of cows in relation to cubicle house design. *Current Topics in Veterinary and Medical Animal Science 40*, 129-147.

Redbo, I. 1992. The influence of restraint on the occurrence of oral stereotypies in dairy cows. *Applied Animal Behaviour Science 35,* 115-123.

Redbo, I., Emanuelson, M., Lundberg, K., Oredsson, N. 1996. Feeding level and oral sterotypies in dairy cows. *Animal Science 62*, 199-206.

Redbo, I., Nordblad, A. 1997. Stereotypies in heifers are affected by feeding. *Applied Animal Behaviour Science 53*, 193-202.

Ruckebusch, Y., Bueno, L. 1978. An analysis of ingestive behaviour and activity of cattle under field conditions. *Applied Animal Ethology 4,* 301-313.

Rushen, J. 2001. Assessing the Welfare of Dairy Cattle. *Journal of Applied Animal Welfare Science 4*, 223-224.

Rutter, S.M. 2000. Graze: A program to analyze recordings of the jaw movements of ruminants. *Behavior Research Methods, Instruments, & Computers 32,* 86-92.

Rutter, S.M., Champion, R.A., Penning, P.D. 1997. An automatic system to record foraging behaviour in free-ranging ruminants. *Applied Animal Behaviour Science 54*, 185- 195.

SAS, 2004. SAS/STAT® User's Guide, Version 9.1, 1st Edition. SAS Institute Inc., Cary, NC.

Sjaastad, ØV. Hove, K., Sand, O. 2003. Physiology of Domestic Animals, pp. 507-527. Scandinavian Veterinary Press. Oslo.

Stobbs, T.H., Cowper, L.J. 1972. Automatic measurement of the jaw movements of dairy cows during grazing and rumination. *Tropical Grasslands 6,* 107–112.

Troelsen, J.E., Campbell, J.B. 1968. Voluntary consumption of forage by sheep and its relation to the size and shape of particles in the digestive tract. *Animal Production 10*, 289-298.

Ungar, E.D., Ravid, N., Zada, T., Ben-Moshe, E., Yonatan, R., Baram, H., Genizi, A. 2006. The implications of compound chew–bite jaw movements for bite rate in grazing cattle. *Applied Animal Behaviour Science 98,* 183–195.

Ungar, E.D., Rutter, S.M. 2006. Classifying cattle jaw movements: Comparing IGER Behaviour Recorder and acoustic techniques. *Applied Animal Behaviour Science 98*, 11–27.

VanSoest, P.J. 1963. Ruminant Fat Metabolism with Particular Reference to Factors Affecting Low Milk Fat and Feed Efficiency. A Review. *Journal of Dairy Science 46,* 204-216.

Wagner-Storch, A.M., Palmer, R.W. 2003. Feeding Behavior, Milking Behavior, and Milk Yields of Cows Milked in a Parlor Versus an Automatic Milking System. *Journal of Dairy Science 86,* 1494-1502.

Welch, J.G. 1982. Rumination, Particle Size and Passage from the Rumen. *Journal of Animal Science 54,* 885-894.

Welch, J.G., Smith, A.M. 1969. Forage Quality and Rumination Time in Cattle. *Journal of Dairy Science 53,* 797-800.

Welch, J.G., Smith, A.M. 1972. Milk Fat Depression and Rumination Stimulation. *Journal of Dairy Science 58,* 678-681.

Welch, J.G., Smith, A.M., Gibson, K.S. 1970. Rumination Time in Four Breeds of Dairy Cattle. *Journal of Dairy Science 53,* 89-91.

Wierenga, H.K. 1983. Chap. "The influence of the space for walking and lying in a cubicle system on the behaviour of dairy cattle" in*: Farm animal housing and welfare*. Seminar in the CEC programme of coordination of research on animal welfare (Aberdeen, July 28-30, 1982). pp. 171.

Wierenga, H.K., Hopster, H. 1990. The Significance of Cubicles for the Behaviour of Dairy Cows. *Applied Animal Behaviour Science 26,* 309-337.

Woodford, S.T., Murphy, M.R. 1988. Effect of Forage Physical Form on Chewing Activity, Dry Matter Intake, and Rumen Function of Dairy Cows in Early Lactation. *Journal of Dairy Science 71,* 674-686.

Personal communication

Bar, Doron. Dr.med.vet. PhDChief Scientist, SCR, Israel. E-mail 2009-06-17.

Munksgaard, Lene. Head of research unit, Department of Animal Health and Bioscience, Research Centre Foulum, Denmark. Lecture 2009-03-16.

Munksgaard, Lene. Head of research unit, Department of Animal Health and Bioscience, Research Centre Foulum, Denmark. E-mail 2009-06-02.

Solomon, R., Bar-Shalom, A., Klein, A., Adin, G., Bar, D., Miron, J. *Monitoring the changes in rumination of high producing Israeli dairy cows, equipped with "SCR Hi-Tag" system.* PowerPoint-presentation 2009-03-09.

Appendix 1.

Table 11. Nutrient composition of rations.

Ration no.	1	2	3	4	5	6	7	8	9	10	11	12	13	Average
DM[1]%	43	43	49	48	42	44	45	44	48	48	51	44	44	**w46**
Forage (% of DM)	55,80	52,06	55,06	41,25	50,83	45,83	50,83	48,70	36,31	38,96	34,64	51,40	47,08	**46,83**
Crude Protein (% of DM)	21,36	18,93	18,82	16,31	22,27	18,48	19,32	16,15	23,12	20,12	21,46	16,85	19,10	**19,41**
ME[2] (MJoule/kg DM)	10,65	10,84	11,05	11,37	10,91	11,26	11,17	11,25	11,42	11,14	10,95	11,37	11,09	**11,11**
NDF[3] (% of DM)	35,93	35,47	33,42	32,56	37,60	35,00	34,18	32,82	35,06	32,97	34,56	32,97	35,36	**34,45**
Forage NDF (% of DM)	26,10	24,59	26,68	19,75	23,99	21,63	23,84	23,23	16,63	18,66	16,22	24,55	21,89	**22,14**
peNDF[4] (% of DM)	28,36	27,41	27,31	23,76	26,26	25,87	25,83	25,57	23,43	22,82	22,18	25,93	26,02	**25,44**
Lignin (% of DM)	4,10	3,86	3,83	2,88	3,63	3,18	3,49	3,05	2,59	3,32	3,53	3,08	3,36	**3,38**
NFC[5] (% of DM)	33,99	37,86	39,06	43,93	32,53	38,80	38,17	43,00	34,23	39,87	37,29	43,02	37,89	**38,43**
Silage Acids (% of DM)	3,51	3,47	2,56	2,68	3,60	3,25	3,11	3,25	2,78	2,65	2,38	3,21	3,29	**3,06**
Sugar (% of DM)	6,64	6,47	5,97	6,05	4,04	3,95	9,19	9,02	4,34	4,42	9,58	8,70	6,16	**6,50**
Starch (% of DM)	12,13	11,17	19,77	18,58	14,13	14,86	14,47	14,24	12,30	18,97	11,32	18,06	14,51	**14,96**

[1]Dry matter

[2] Metabolizable energy

[3] Neutral Detergent Fiber

[4] Physically effective neutral detergent fier. Physical effectiveness factor from tabulated values in CPM dairy determined by dry sieving.

[5] Non fiber carbohydrate

Appendix 2.

Doron Bar, Dr.med.vet. PhD
Chief Scientist
28.11.08

Short summary of SCR HR-Tag validation trials

Eyal Klein[1], Eyal Brayer[2], and Danny Amram[2]
[1] Klein dairy, Beerotaim, Israel; [2] SCR Engineers, Israel

Material and methods:
Between 6 October 2005 and 10 January 2006 35 SCR HR-Tags were mounted on 35 Israeli Holstein dairy cows (32 milking cows and 3 dry cows) in three dairy farms. Two or three cows were simultaneously observed for a total of 140 hours at different times of the day. In each 5 minutes "window" the cow main activity (either eating, ruminating, or other) was noted. The blinking of the LED inside the tag* has been noted as constantly blinking, occasionally blinking, or turned off.
* the LED blinked in this production batch every 6 seconds when rumination was recorded; later batches are with longer intervals as to increase battery lifespan.

Results:

LED / Activity	Constantly blinking	occasionally blinking	turned off
Eating	**0 (0%)**	**58 (12%)**	**428 (88%)**
Ruminating	**467 (92%)**	**16 (3%)**	**25 (5%)**
Other	**5 (1%)**	**0**	**669 (99%)**

Dividing the occasionally blinking instances equally between negative and positive tag results, we calculated the following classic 2 by 2 table:

Rumination / Tag	Positive	Negative
Positive	**475**	**34**
Negative	**33**	**1126**

Therefore, the sensitivity of HR-Tag is 94%, the specificity 97%, positive predictive value 93%, and the negative predictive value 97%.

Conclusion: SCR HR-Tags recorded rumination with high sensitivity and specificity. Sensitivity was impaired mainly at the beginning of the rumination period, at loud surrounding noise (e.g. standing directly under a fan), or when there was no tight fit of the tag to the skin. Specificity was impaired mainly as interpreting rhythmic chewing activity or constant licking of a neighboring cow as rumination.

Nr	Titel och författare	År
275	Riskfaktorer för *Staphylococcus aureus* i mjölk och på has hos mjölkkor Risk factors for *Staphylococcus aureus* in milk and on hocks of dairy cows Karin Andersson	2009
276	Smältbarhet på ensilage och hö hos hästar i träning Digestibility of silage and hay for horses in training Sara Gunnarsson	2009
277	Buffalo Production in North Vietnam Wiveca Sveen	2009
278	Optimal group size for calves fed in transponder-controlled milk feeders Optimal gruppstorlek för kalvar som utfodras I transponderstyrda kalvammor Ida Eriksson	2009
279	Böklåda med torv på rastgårdsytan i ekologisk slaktsvinsproduktion - Effekter på beteende och emission av kväve (NH_3 och N_2O) 30 hp E-nivå Emma Selberg Nygren	2009
280	Use of market crop wastes as feed for livestock in urban/periurban areas of Kampala, Uganda 15 hp C-nivå Emma Selberg Nygren	2009
281	Capacity studies on DeLaval's sort gate DSG10 30 hp E-nivå Johanna Karlsson	2009
282	Metanproduktion hos mjölkkor utfodrade med hög andel grovfoder Methane emissions from dairy cows fed high levels of forage 30 hp E-nivå Rebecca Danielsson	2009
283	Minskade andelar kraftfoder i foderstaten under betesperioden - effekt på mjölkavkastning och betesbeteende hos mjölkkor Decreased concentrate levels in the diet during the grazing season – effects on milk yield and grazing behaviour of dairy cows 30 hp E-nivå Karin Alvåsen	2009
284	Farmars' perceptions and handling of livestock manure in urban/ peri-urban areas of Kampala, Uganda 15 hp C-nivå Karin Alvåsen	2009

I denna serie publiceras examensarbeten (motsvarande 15 eller 30 högskolepoäng) samt större enskilda arbeten (15-30 högskolepoäng) vid Institutionen för husdjurens utfodring och vård, Sveriges Lantbruksuniversitet. En förteckning över senast utgivna arbeten i denna serie återfinns sist i häftet. Dessa samt tidigare arbeten kan i mån av tillgång erhållas från institutionen.

DISTRIBUTION:
Sveriges Lantbruksuniversitet

Institutionen för husdjurens utfodring och vård
Box 7024
750 07 UPPSALA
Tel. 018-67 28 17