Relationships between feeding behaviour and feed intake in dairy cows during early lactation

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To

my wife, Fatemeh

my son, Pooya

my daughter, Jina

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LIST OF ABBREVIATIONS

ASAT	Aspartate aminotransferase
BHBA	β-hydroxy butyrate acid
BW	Body weight
CMD	Clinical metabolic disorders
DIM	Day in milk
DM	Dry matter
DMI	Dry matter intake
ECM	Energy corrected milk
g	grams
HM	Multiparous cows with above-average milk yield
HP	Primiparous cows with above-average milk yield
LDA	Left-displaced abomasum
LM	Lebendmasse
LN	Natural logarithm
LP	Primiparous cows with below-average milk yield
Min	Minute
NEFA	Non-esterified fatty acids
NEL	Net energy for lactation
P.P.	Postpartum
PROC GLM	Procedure General Linear Model
r	Correlation
R^2	Coefficient of determination
SCMD	Subclinical metabolic disorders
SD	Standard deviation
SEM	Standard error of means
TMR	Total mixed ration
TS	Trockensubstanz
WCMD	Without clinical metabolic disorders
WSCMD	Without subclinical metabolic disorders

ABSTRACT

The overall objective of this PhD thesis was to investigate the relationships between feeding behaviour, feed intake, milk production, and metabolic-related production diseases of dairy cows during early lactation. Data from 70 lactating German Holstein Friesian dairy cows (parity 1 to 7) were collected. The feeding behaviour monitoring was conducted by using an electronic feeding system, which was equipped with an electronic identification of each individual cow. In the first study of this dissertation, the feeding behaviour of dairy cows was analysed based on the individual visits, with a visit being defined as the time spent by an individual cow with her head in one of the troughs regardless of how the cow spent that time.

In the second and third studies, the visits were clustered in meals based on a "meal criterion", which was calculated by fitting a mixture of two normal distributions to the distributions of the natural logarithm (LN)-transformed lengths of the interval between visits. In these studies, the effects of parity, stage of lactation, and milk yield level on feeding behaviour and feed intake were investigated. The final study determined the effects of metabolic-related production diseases on feeding behaviour, feed intake, and milk production.

The results suggested that the meal is the more relevant unit than the individual visit for describing feeding behaviour. Parity, stage of lactation, and milk yield level had significant effects on feeding behaviour characteristics and feed intake. The high correlation between feeding behaviour such as meal duration and feed intake (meal size) suggests that measuring the time spent eating could be used to estimate the feed intake.

Metabolic-related production diseases had significant effects on feeding behaviour, feed intake, and milk production. The monitoring of feeding behaviour characteristics might be helpful to detect the cows' risk for metabolic-related production diseases at an early stage.

Key words: feeding behaviour, feed intake, dairy cow, early lactation

CHAPTER 1: Introduction

The transition period and early lactation, from 3 wk before to 8 wk after calving, is critically important to the health, production, and profitability of dairy cows (Drackley, 1999). Cows in transition period and early lactation include ca. 32% of all cows and 25%of the lactating cows, and produce ca. 37% of the overall milk yield in a herd. On the other hand, 80% of all cows ought to be pregnant during these periods. At the same time, more than 80% of all health disorders occur. During this time, the cow experiences a series of nutritional, physiological, and social changes, which make her more vulnerable to infectious and metabolic disorders (Goff and Horst, 1997). One of the major challenges faced by the cow at this time is obtaining sufficient energy to support the onset of lactation, especially given that feed intake tends to be suppressed around the time of calving (Drackley, 1999).

Engelhard (2005, cited by Kaufmann, 2005) studied the development of milk production and feed intake from 1996 to 2003 by using individual automatic feeder. He reported that the milk yield during the first month of lactation increased from 37.4 kg/d in 1996 to 42.2 kg/d in 2003. This 13% increase in milk yield stood in contrast to a mere 6% increase in feed intake (19.4 kg DM/d in 1996 to 20.5 kg DM/d in 2003). This lag between energy output from milk yield and energy input from feed intake led to a negative energy balance. The negative energy balance in early lactation may contribute to the onset of metabolic diseases and depression (Kronfeld, 1970).

Previous works have indicated that cows with lower feed intakes are more likely to be diagnosed with metabolic and infectious diseases during a transition period (Marquardt et al., 1977; Zamet et al., 1979). However, changes in feed intake must ultimately result from changes in feeding behaviour. Moreover, feeding behaviour has been shown to predict

morbidity in feedlot steers (Sowell et al., 1998; 1999); thus, it might be similarly useful for predicting diseases in transitional dairy cows.

Sensor-based monitoring p.p. might allow identifying sick cows at an early stage and providing supportive therapy in order to maintain dry matter intake during the transition period and early lactation.

Although feeding behaviour and feed intake have been studied, only a few studies have been conducted in early lactation, in which cows have a negative energy balance. Moreover, there is limited work on the effects of metabolic-related production diseases on feeding behaviour. Therefore, the overall objective of this PhD thesis was to investigate the relationships between feeding behaviour, feed intake, milk production, and metabolic-related production diseases of high-producing dairy cows during early lactation. This investigation was to give answers to the following questions:

1) What kind of feeding behaviour characteristic could be relevant to estimate feed intake?
2) Could feeding behaviour characteristics be used to predict the total feed intake?
3) Do parity, stage of lactation, and milk yield level have any effects on feeding behaviour and feed intake?
4) Do metabolic-related production diseases affect feeding behaviour characteristics, feed intake parameters, and milk production?

CHAPTER 2: Background

The transition period extends from the last 3 weeks of gestation through the first 3 weeks of lactation (Grummer, 1995; Drackley, 1999). The term *transition* is to underscore the important physiological, metabolic and nutritional changes occurring in this time frame. Figure 2.1 shows the transition period and some problems in this time and in early lactation. It constitutes a turning point in the productive cycle of the cow from one lactation to the next. Nutrition and management programmes during this phase directly affect the incidence of postpartum disorders, milk production and reproduction in the subsequent lactation.

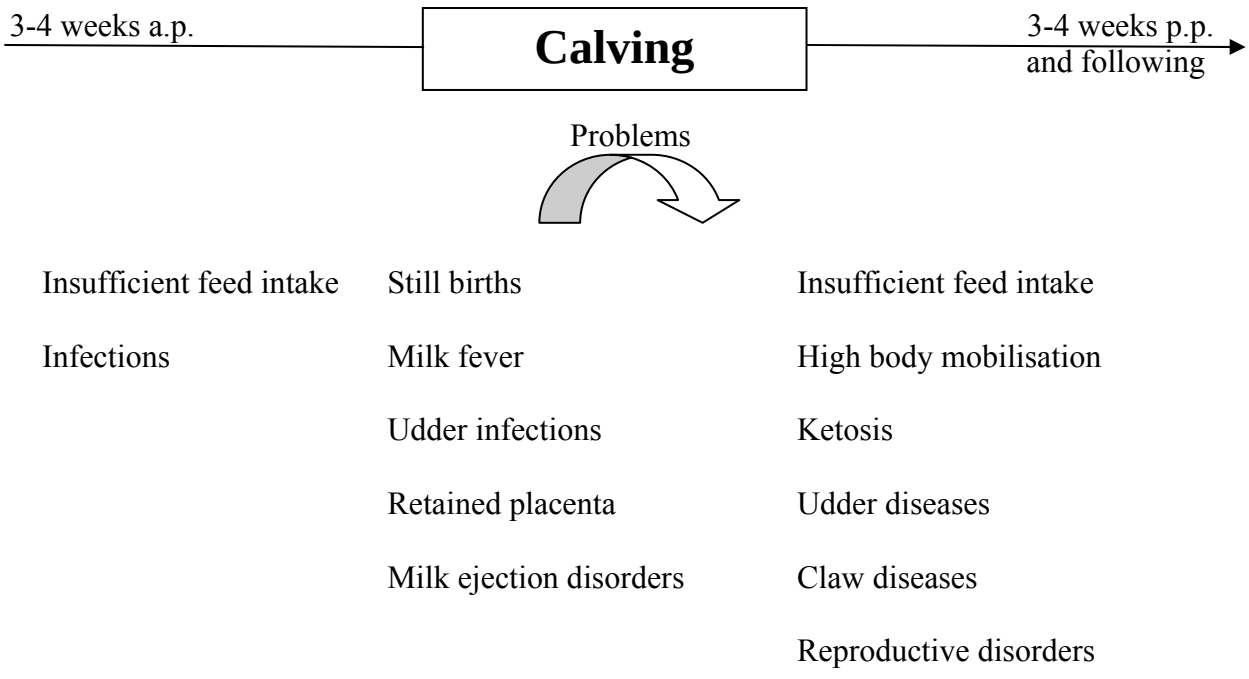


Figure 2.1 Problems in Transition Period.

Fleischer et al. (2001) studied the incidence rate of postpartum disorders in high-producing dairy cows. They found that these cows are at an increased risk for many diseases and disorders during early lactation (Table 2.1). Therefore, monitoring of animal behaviour during these periods might be very useful to detect cows at risk for health disorders.

Table 2.1 Lactational incidence risk[1] (LIR) and median DIM at diagnosis for various diseases after calving (Fleischer et al., 2001).

Disorder complex	LIR (%)	Median DIM at diagnosis (days p.p.)	Lactations
Retained placenta	8.9	1	2197
Metritis	23.6	24	2197
Ovarian cysts	11.7	61	2197
Mastitis	21.6	54	1598
Claw diseases	19.5	76	1267
Milk fever	7	1	2026
Ketosis	1.7	27	1734
Displaced abomasum	1.1	18	2026

[1]Lactational incidence risk = Number of affected lactations per 100 lactations at risk.

To understand the importance of feed intake and feeding behaviour in dairy cattle, this chapter provides a review of the scientific literature on feed intake with a particular emphasis on the physical and physiological regulation of feed intake, feeding behaviour, and physiological changes during the transition period.

2.1 Feed intake in transition period

The primary concern of all animals is the gathering of feed. All animals evolve as products of their dietary needs: the giraffe's neck, the lion's teeth, the cow's stomach, and suckling instinct in young mammals are all diet-oriented. An animal is not only what it eats, but it also is designed so that it can eat it (Albright, 1993).

Lactation generates a large increase in nutrient demands, especially in dairy cows which have been bred for high milk yields. Correlation between voluntary intake and milk yield varies between less 0.2 to 0.8, and intake is often more closely related to live weight than it is to milk yield (Forbes, 1995).

The composition of the feed is a complex activity that consists of a series of actions or behaviours. Initially, the animal must search for feed, be able to recognise a potential feed source and move towards it. Finally, it must initiate the behaviours associated with prehension and ingestion (McDonald et al., 2002).

Energy intake is a primary limitation on the milk yield of high-producing dairy cows as it is determined by the net energy content of the diet and dry matter intake (DMI). Factors affecting and regulating the feed intake of lactating dairy cows are numerous and complex and span cellular to macroenvironmental levels. Some can be controlled by humans and include animal factors (age, body condition, physiological stage, milk yield level, etc.), dietary factors (ingredient and nutrient composition of diet, physical and agronomic characteristics of feeds, etc.), managerial factors (production, feeding system, housing system, etc.), and climatic factors (temperature, humidity, wind). Therefore, the determination of factors affecting DMI and quantification of their effects are important for developing new feeding strategies during the prefresh transition period (Hayirli et al., 2002).

In their study, Hayiril et al. (2002) reported that the magnitude of DMI depression for heifer and cows was different as they approached parturition. DMI of cows gradually decreased from 2.06 to 1.36% of BW during the final 3 wk of gestation. The DMI of heifers remained more constant, at about 1.8 to 1.7% of BW from 3 to 1 wk before parturition, and then sharply decreased to 1.23% of BW during the final week of gestation. The greater extent of DMI depression during the prefresh transition period of cows compared with that of heifers suggests a greater decrease in energy balance, which may relate to their greater predisposition to postpartum health problems (Curtis et al., 1985).

Ingvartsen et al. (1992) determined a linear decrease of the dry matter intake about 1.5% (weekly) between the 26th and 3rd week a. p.. They established comparable values for the last 100 days of the gestation in a group of experimental animals that is started on the 168th day of the gestation with a high-energy ration (TMR; 11.6 MJ metabolisable energy / kg DM) fed ad lib. In the last three weeks of the gestation, DMI decreased in this group approximately from 13 to 9 kg of dry matter per day. In contrast, DMI did not decrease significantly in another group that was fed a low-energy ration (8.3 MJ metabolizable energy / kg DM). Raya (2006) investigated the feeding behaviour and feed intake of dairy cows from the 7th day a.p. to calving, and reported an average of 9.4 and 11.56 kg/d of DMI, 27.87 and 23.71 visits at the feeder per day, 113.94 and 113.47 min/d for eating time, and 80.39 and 106.38 gDM/min of feeding rate for primiparous and multiparous cows. Bertics et al. (1992) found a decrease of around 30% between the averages of the dry matter intake during day 21 and 17 a. p. and the DMI on the day of calving. Vasquez-Anon et al. (1994) registered a decline in dry matter intake of about 40% in the last two days before calving.

2.2 Regulation of feed intake

The maximal productive capacity of an animal will depend on its genetic potential and will vary over the animal's lifetime according to its age, physiological status (e.g., lactation, pregnancy), and to its environment's climate (Canale et al., 1990). Many theories exist as to what initiates and terminates a meal as well as controls the short-term feeding behaviour. Rumen fill and distension, rate of disappearance of feed from the rumen, concentrations of fermentation and products (total VFAs; acetate, propionate, butyrate, and NH_3) in the rumen, and/or blood and rumen osmolality are among the most plausible ones (Taweel et al., 2004). However, Mbanya et al. (1993), Van Soest (1994), Forbes (1995), and Chilibroste (1999) argue for the multifactorial control theory, which states that the initiation and termination of a meal seems more likely to be controlled by a combination of signals rather than a single signal.

Physical regulation

For ruminants, physical-mechanical control mechanisms are very important, that means, the feed intake is determined crucially also by the filling of the rumen. The filling of the rumen is controlled, on the one hand, by microbial fermentation and, on the other hand, by the passage of the feed. The microbial fermentation of feed is affected strongly by the quality of the feed (digestibility). Apart from the digestibility, the rate of passage depends on the cutting-up degree and structure of the feed (Gruber 2002).

Forage NDF content was more highly related with the DMI of forage by sheep compared to other chemical measures (Van Soest, 1965). Waldo (1986) suggested that NDF content is the best single chemical predictor of DMI by ruminants. Mertens (1994) used NDF as the only feed characteristic to predict the filling effect and energy content of diets, with the DMI positively correlated with the NDF concentration when energy limits intake, but negatively

correlated with the NDF concentration when filling limits intake. When distension in the reticulo-rumen limits DMI, decreasing forage particle size could result in increased DMI if the density of swallowed particles or the time available for rumination increases. Beauchemin et al. (1994) reported an interaction ($P < 0.01$) between the forage particle length (alfalfa silage chopped at 0.5 or 1.0 cm theoretical length of cut) and the percentage of forage in the diet (35 or 65%). In that experiment, DMI was reduced by nearly 3 kg/d when forage content was increased from 35 to 65% with diets containing the long-chopped alfalfa silage, but by less than 0.5 kg/d with diets containing the short-chopped forage. Dry matter intake by lactating cows feeding on diets containing grass silage was lower than the DMI of diets containing alfalfa silage, in spite of greater DMI and NDF digestibility for grass silage (Hoffman, 1988; Weiss and Shockey, 1991). It was found that physical and physiological factors regulating feed intake changed quantitatively with increasing digestibility of food. At low digestibility, the intake depended on physical capacity, rate of passage of undigested residue, and proportion of feed digested. At higher digestibility, the intake depended on metabolic size, productive energy, and digestibility (Conrad et al., 1964). Dry matter intake and FCM yield were positively related to NDF digestibility within a forage family, but negatively related across forage families (Oba and Allen, 1999). A possible explanation is that although NDF digestibilities were often higher for grasses compared to legumes, the filling effect of legumes was smaller because of greater particle fragility, which decreased the retention time in the reticulo-rumen and resulted in less distension and greater DMI (Allen, 2000). A low pH-level in rumen caused by highly fermentable feeds can decrease the rate of fibre digestion but increase the filling effect of the diet, which might raise distension in the reticulo-rumen (Allen and Mertens, 1988).

Physical regulation of DMI occurs when feed intake is limited by the time required for chewing or by distension within the gastrointestinal tract (Allen, 2000). Dietary factors that

increase eating time could result in decreased ruminating time, which raises the filling effect of the diet. The reticulo-rumen is generally regarded as the site from which distension most often regulates the DMI of ruminants (Allen, 1996; Forbes, 1995). Distension stimulates the stretch receptors in the muscle layer in the wall of the reticulo-rumen (Harding and Leek, 1972). Brain satiety centres likely integrate these and other stimuli to signal the end of a meal (Forbes, 1996). Because various signals to the brain satiety centres probably interact to trigger meal cessation, the response to distension in the reticulo-rumen might not be the same across cows and across physiological states within a cow (Allen, 2000). For each cow, the threshold of stimulation by reticulo-rumen fill that triggers meal cessation appears to be altered by absorbed nutrients and possibly hormonally (Mbanya et al., 1993). The extent to which DMI of lactating dairy cows is regulated by distension in the reticulo-rumen depends upon the animal's energy requirement and the filling effect of the diet (Allen, 2000). Allen (1996) reviewed experiments in which inert fill was added to the reticulo-rumen of lactating cows at approximately 25% of the pre-trial reticulo-rumen volume and concluded that the effects of the added fill on DMI were related to energy balance. Reductions in DMI with added inert fill were observed only when cows were in negative or slightly positive energy balance. The volume of rumen is increasingly limited during the pregnancy by the uterus and abdominal fat. The opinions on whether the reducing of the volume of rumen influences the feed intake vary. After parturition, the capacity of the rumen rises over two weeks; the feed intake, however, rises up to 10 weeks p.p., while the volume of rumen does not change any more (Forbes, 1986).

Osmolality of reticulo-rumen fluid is highly variable depending on the content of mineral salts and fermentability of organic matters in the diets. Increased osmolality is associated with various physiological responses that may affect satiety. Depression of feed intake by infusion of Na acetate into the reticulo-rumen was probably caused by its effect on osmolality, since the injection of the same amount of Na acetate into the jugular vein had no effect on DMI

(Baile and Mayer, 1969). Epithelial receptors in the reticulum and cranial sac of the rumen are stimulated by acids, alkali, and hypo and hyperosmotic solutions (Leek and Harding, 1975). Grovum (1995) suggested that the direct stimulation of receptors by hypertonicity of the fluid in the reticulo-rumen triggers satiety. The sensitivity of these epithelial receptors to butyrate is greater than propionate, and there is greater stimulation at a lower pH (Crichlow and Leek, 1980). This suggests that the degree of stimulation is related to the rate of absorption of volatile fatty acids (VFAs). The relative rate of VFAs absorption has been shown to be butyrate > propionate > acetate, and the rate of absorption is negatively related to the pH (Dijkstra et al., 1993).

The effects of hyperosmolality in the reticulo-rumen on meal termination are possibly mediated by the stimulation of osmoreceptors located elsewhere in the gastrointestinal tract or at locations reached by the circulatory system such as the liver or the brain (Allen, 2000). Extracellular volume is decreased during and after a meal because of the secretion of salvia during eating and an influx of plasma fluids into the reticulo-rumen because of a higher osmolality of the fluid in the reticulo-rumen compared to plasma (Warner and Stacy, 1968).

Feed intake by ruminants is decreased by dehydration. Dehydration is likely to stimulate vasopressin, which was injected intraperitoneally in goats, depressed DMI in a dose-dependent manner (Meyer et al., 1989). Although osmotic loads infused into the reticulo-rumen have consistently reduced meal size, there might be little effect on the daily feed intake, which is determined by both meal size and intermeal intervals (Allen, 2000). Infusion of NaCl into the reticulo-rumen of lactating cows at the onset of spontaneous meals decreased the meal size compared with no infusion, and the amount of intermeal intervals reduced, but DMI over the 12-h infusion period remained unaffected (Choi and Allen, 1999).

Although there are multiple mechanisms regulating DMI, physical regulation probably becomes a primary factor as the animal's energy requirement and the filling effect of diets increase (Allen, 2000).

Metabolic fuels

The primary fuels available to ruminants from consumed starch are propionate, acetate, butyrate, and sometimes lactate from fermentation, glucose from digestion in the small intestine, and lactate from glucose metabolism in intestinal tissues (Allen, 2000).

Senn et al. (1995) stated that energy content rather than feed volume is somehow registered during ingestion, and influences meal size. One possible mechanism for the proposed effect of the energy content on meal size is its influence on the prandial increase in rumen osmolality. The prandial increase in ruminal fluid osmolality is considered to be an important control mechanism of the meal size in ruminants (Carter et al., 1990), and during ingestion of energy-rich feeds ruminal fluid osmolality increases faster than during ingestion of energy-poor feeds (Bennink et al., 1978). Infusion of propionate into the mesenteric vein of steers reduced feed intake, but acetate infused at the similar rate did not (Elliot et al., 1985). Baile (1971) proposed the propionate receptor in the ruminal region of sheep and goats might function as the control mechanism of the feed intake. There is substantial evidence that absorbed propionate affects satiety. Anil and Forbes (1980) reported that infusion of propionate into the portal vein of sheep reduced their feed intake by over 80% compared with control, while infusion at the same rate into the jugular vein had no effect. Choi and Allen (1999) reported that propionate (as Na propionate or propionic acid) infusions into the reticulo-rumen of lactating dairy cows at the onset of spontaneous meals reduced meal length and meal size to a greater extent than equimolar amounts of infused NaCl or acetate (as Na acetate or acetic acid). This indicated that meal cessation was affected specifically by propionate over its effects on osmolality.

Grovum (1995) suggested that the effect of propionate infusion on the reduction in DMI is caused by an increased insulin secretion. This could explain the greater effects of propionate infusions compared to acetate infusions, and of portal infusions compared to jugular infusions

because: 1) propionate, but not acetate, increased plasma insulin of sheep (Manns and Boda, 1967); 2) insulin has been reported to decrease DMI in sheep (Foster et al., 1991); and 3) propionate concentrations at the pancreas would be higher than and more likely stimulate the insulin secretion when infused in the portal vein than when injected in the jugular vein (Allen, 2000).

Fatty acids, lactate, amino acids, and glycerol are fuels oxidised in ruminant and non-ruminant liver. However, while there is a net glucose uptake from the blood by the liver in non-ruminants, the uptake of glucose is negligible in natural ruminants (Stangassinger and Giesecke, 1986). Hexokinase is needed to activate glucose for metabolism, and while activity is high in a non-ruminant liver, it is very low in a ruminant liver. This is not surprising because the ruminant liver functions primarily as a glucose factory, producing glucose from precursors including propionate, lactate, amino acids, and glycerol. Propionate is the primary glucose precursor for ruminants but can also be oxidised and stimulate the oxidation of other fuels (Allen et al., 2005).

The rate of ruminal starch digestion and passage vary greatly among grains fed to ruminants and depend upon the type of cereal grain, conservation method, and processing (NRC, 2001). Ruminal digestion kinetics determines the site and extent of nutrient digestion, which can greatly affect the type and pattern of fuels observed over time. While ruminal starch digestion results in the production of volatile fatty acids (VFAs), starch that escapes ruminal digestion can be degraded by enzymes in the duodenum. Although little glucose appears in the portal vein in ruminants, glucose is efficiently absorbed in the small intestine. Most glucose is metabolised to lactate by intestinal tissue (Reynolds et al., 2003). Therefore, diets with similar concentrations of starch can provide the animal with VFAs and lactate in different proportions, depending on the physical characteristics of the starch source (NRC, 2001). Cereal grains that are highly digestible in the rumen can depress the feed intake of lactating cows; the feed intake was depressed by nearly 3 kg DM/d (ca. 13%) when more fermentable

grains were substituted in the diets of lactating cows in several studies reported in the literature (Allen, 2000).

Oba and Allen (2003) demonstrated that a more rapidly fermented starch source reduced the meal size by 17%, causing an average 8% reduction in feed intake despite a 10% decrease in intermeal intervals. The more fermentable feeds nearly doubled the fractional rate of starch digestion in the rumen, increasing the contribution of VFAs, especially propionate, as fuels at the expense of lactate.

Besides inversing the amount of VFA produced, increasing ruminal starch fermentation also increases propionate as a proportion of the VFA absorbed. Depression of feed intake by propionate infusions has been documented extensively for ruminants (Allen, 2000). Intake depression by propionate is greater than by the other major fermentation acids (acetate and butyrate) when infused into the portal vein of sheep (Anil and Forbes, 1980), and infusion of propionate into the mesenteric vein of steers reduced their feed intake, whereas acetate infused at similar rates did not (Elliot et al., 1985).

Feed intake was reduced primarily through a linear reduction in meal size from 2.5 to 1.5 kg DM as propionate increased from 0% to 100% of infusate, a finding that indicates increased satiety (Allen and Bardford, 2007).

2.3 Feeding behaviour

Feeding is the predominant drive in dairy cattle, and consequently any attempt to predict cow response to a particular environment must accurately describe feeding response (Metz, 1985; Grant, 2006). Considerable research to date has focused on improving DMI of lactating dairy cows by changing the nutrient composition of feeds. However, the DMI of group-housed lactating dairy cows is also affected by the feeding behaviour of the cows, which is modulated by the environment, management practices, health, and social interactions (Grant and Albright, 2001; DeVries et al., 2005).

The analysis of feeding behaviour may help to explain the physiological mechanisms of feed intake regulation. This is also important for attempts to predict how to optimise feed intake in the cattle, especially during periods in which feed intake becomes a major limiting factor for production (e.g., in early lactation) (Senn et al., 1995). Feeding a TMR may be the optimal way to provide the balance of nutrients that ruminants need to maintain a stable and efficient microbial population. However, the availability of the feed over time and the distribution of intake over the course of the day contribute to the maintenance of a stable ruminal microbial population, which is important to reduce the risk of cows developing subacute ruminal acidosis (Nocek and Braund, 1985).

The time unit generally used in describing intake is the day, which has the advantage of being in synchrony with any diurnal patterns in feeding behaviour and with husbandry procedures, which usually show a 24-h cycle (Stamer et al., 1997). However, day might not be an appropriate time unit when the goal is to understand feeding behaviour. Most animals, and all domestic species, do not eat continuously throughout the day but eat in bouts. The study of short-term feeding behaviour has largely arisen from work that aimed to elucidate, in various species, the physiological mechanisms and controls that initiate and terminate eating bouts (Friggens et al., 1998).

The time spent eating, and the pattern of meals, can obviously have important effects on the total daily intake of dairy cattle (Grant and Albright, 2000). For that reason, a great deal of research in dairy nutrition and management has focused not only on changes in intake, but also on changes in feeding behaviour.

The majority of research on feeding behaviour has been completed with individually housed animals. In modern free-stall dairy operations, cows are group-housed. And this social environment can play a major role in the modulation of feeding behaviour (DeVries et al., 2006). In grazing systems, cattle often synchronise their behaviour so that many animals in the group feed, ruminate, and rest at the same time (Miller and Wood-Gush, 1991; Rook and Huckle, 1995). Curtis and Houpt (1983) reported that group-housed dairy cows housed indoors also synchronise their behaviour, particularly at feeding. They further explained that when cows are fed in groups, the act of one cow moving to the feed bunk stimulates others to feed. However, other researchers have also indicated that this synchronisation may be reduced when cattle are group-housed intensively indoors, possibly due to an increased competition for resources (O'Connel et al. 1989; Miller and Wood-Gush, 1991).

Cows are social animals and form social hierarchies. When visits to the feed bunk are grouped into meals, the number of meals correlates negatively with the social dominance of the cow so that dominant cows have fewer meals (Olofsson, 1999). When cows are kept in individual cubicles, free from the effects of social interaction, those with higher feed intakes take fewer meals during the day. Furthermore, meal size (quantity and length), but not meal number, is positively related to milk production (Dado and Allen, 1994).

In situations where competition is expected (e.g., with limited bunk space and feed), feeding behaviour is related to cow productivity (Friend and Polan, 1974; Friend et al., 1977). When a competition situation exists at the feed bunk, dominant cows typically spend more total time eating than cows of lower social rank, resulting in greater feed intake. Some level of

competition within a group of cows is inevitable; even under conditions of unlimited access to feed, cows interact in ways give some an advantage over others (Olofsson, 1999).

Competition at the feed bunk is highest when cows return from milking and when fresh feed is offered. At these times, dominant cows will demand priority for feeding. Thus, those cows that are less dominant may be limited in their access to the feed bunk at these times, forcing them to eat less, or at times where competition at the feed-bunk is reduced (DeVries et al., 2006). In group housing, eating behaviour of dairy cows during the day, eating time, or both vary with social dominance. During periods when many cows are eating (after milking and feeding), cows with a lower social rank may have to wait (Metz, 1983).

To understand how feeding behaviour is affected by various regulatory mechanisms, one must be able to quantify this behaviour. Therefore, a summary of the methodologies available for measuring the feeding behaviour of dairy cattle is provided.

2.4 Measuring of feeding behaviour

The typical characteristics of feeding behaviour are the number of visits at the feeders per day, visit duration, number of meals per day, meal duration, and daily eating time.

The development of computerised systems for recording the feed intake for a number of farm species, including cattle, has made it possible to increase significantly the amount of feeding behaviour information that is recorded automatically, which has led to various suggestions for the analyses and application of such data (Nielsen, 1999).

Feeding behaviour of lactating dairy cows fed ad libitum can be measured in many ways. Time-lapse photography (Vasilatos and Wangsness, 1980), closed-circuit television (Hedlund and Rolls, 1977), electronic recording or visual observation (Penning, 1983), hourly consumption patterns (Nocek and Braund, 1985), and automatic feeders with identification or automatic bitemeters (Delagarde et al., 1999) have all been used. Of these, only automatic

feeders with an identification system can handle and record data from a large number of cows in a free-stall housing situation for long periods (Shabi et al., 2005).

Average daily intake is, at least in a purely formal sense, the result of the average number of feeding bouts per day and the average size of those bouts. If the constraints that limit intake have their effect in time spans shorter than a day, the study of short-term feeding behaviour could improve the understanding and prediction of daily intake (Dado and Allen, 1993).

Animals typically divide their feeding time into a series of meals separated by non-feeding intervals (Forbes, 1995), and this is also the case with dairy cows (Tolkamp et al., 1998, 2000). However, identifying which intervals are between meals, versus shorter gaps within a meal, can be problematic. Different types of intervals may occur between visits to the feed alley. In some cases, the cow may simply lift her head for a few seconds. In others, she may withdraw from the alley for less than a minute or so when, for example, she is displaced by a dominant cow and must move to another location on the alley, or she may leave for several minutes when she visits the water trough elsewhere in the pen. Finally, in cases in which she goes to lie down in a stall, she may be away for an extended period of time (DeVries et al., 2003). Therefore, a proper definition of a meal is critical for the results of a feeding behaviour analysis. In studies of feeding behaviour, a meal criterion is usually defined. Baile (1975) has described three general criteria needed to define meals: minimum meal size, maximum time during which the minimum meal must be eaten, and the minimum intermeal interval during which no feed is eaten. Tolkamp et al. (2000) have suggested that the meal, rather than an individual feeding event, is a more biologically relevant unit describing animal feeding behaviour. The meal criterion has been defined as the longest non-feeding interval that is still considered an interval within a meal (Tolkamp et al., 1998; Yeates et al., 2001). Other authors have used definitions of meals that have either been arbitrary or based on the assumption that meals are randomly distributed in time, which has resulted in a wide range of meal criteria

having been used for cattle: 7 min (Dado and Allen, 1993); 10 min (Harms et al., 2002); 13 min (Morita et al., 1996); 20 min (Metz, 1975); and 60 min (Olofson, 2000).

Metz (1975) argued that because of a shortage of intervals of the length 20 to 60 min, the choice of meal criterion within this interval is expected to have a small effect on observed feeding patterns. Tolkamp et al. (1998) and Tolkamp and Kyriazakis (1999) developed a method for analysing feeding visits that was in accordance with satiety mechanisms. The concept of satiety predicts that the probability that a cow will initiate a meal is dependent on the time since the last meal (Metz, 1975). As the duration of non-feeding increases, hunger motivation will increase the likelihood of the start of a new meal (Simpson and Ludlow, 1986). Tolkamp et al. (1998) and Tolkamp and Kyriazakis (1999) described the occurrence of meals as the presence of clusters in data of feeding intervals. The intervals within each cluster were assumed to be log-normally distributed, and a mixture of two or three normal distributions was used as a model for the frequency distribution of natural logarithm-transformed feeding intervals. When two distributions were included in the model, the intervals were separated into one distribution with short intrameal intervals and another distribution with long intermeal intervals (Figure 2.2).

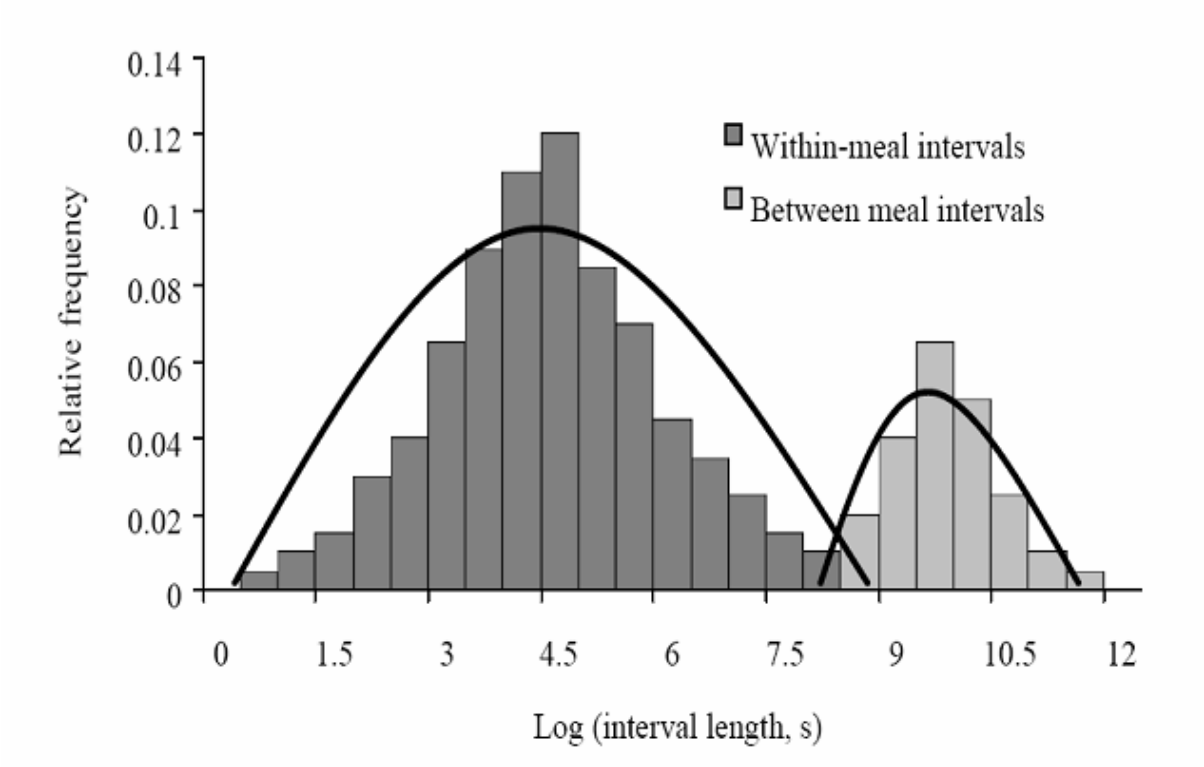


Figure 2.2 The frequency distribution of the log-transformed intervals fitted with a mixture of two normal distributions, effectively separating the within-meal intervals and the between-meal intervals. The meal criterion is the log interval at which the two curves intersect (adapted from DeVries, 2006).

The meal criterion, the longest interval between two feeding visits which do not separate two meals, was identified as the point where an interval is assigned to both distributions with equal probabilities.

The measurements used to describe feeding behaviour are those describing the time course of feed intake (Nielsen, 1999). The diagrammatical representation in Figure 2.3 seeks to highlight the fact that if all three apices of the triangle are known, then the three remaining parameters can be calculated (Friggens et al., 1998).

The measurements that are typically used include meal size, frequency, and duration (Senn et al., 1995; Nielsen, 1999). Meal frequency is calculated by counting the number of intervals per day that exceed the length of the meal criterion and adding one. Meal duration is calculated as the time from the beginning of the first feeding event until, but not including, an interval between events that exceeds the meal criterion. Meal size is the total amount of feed ingested during each meal (Nielsen, 1999).

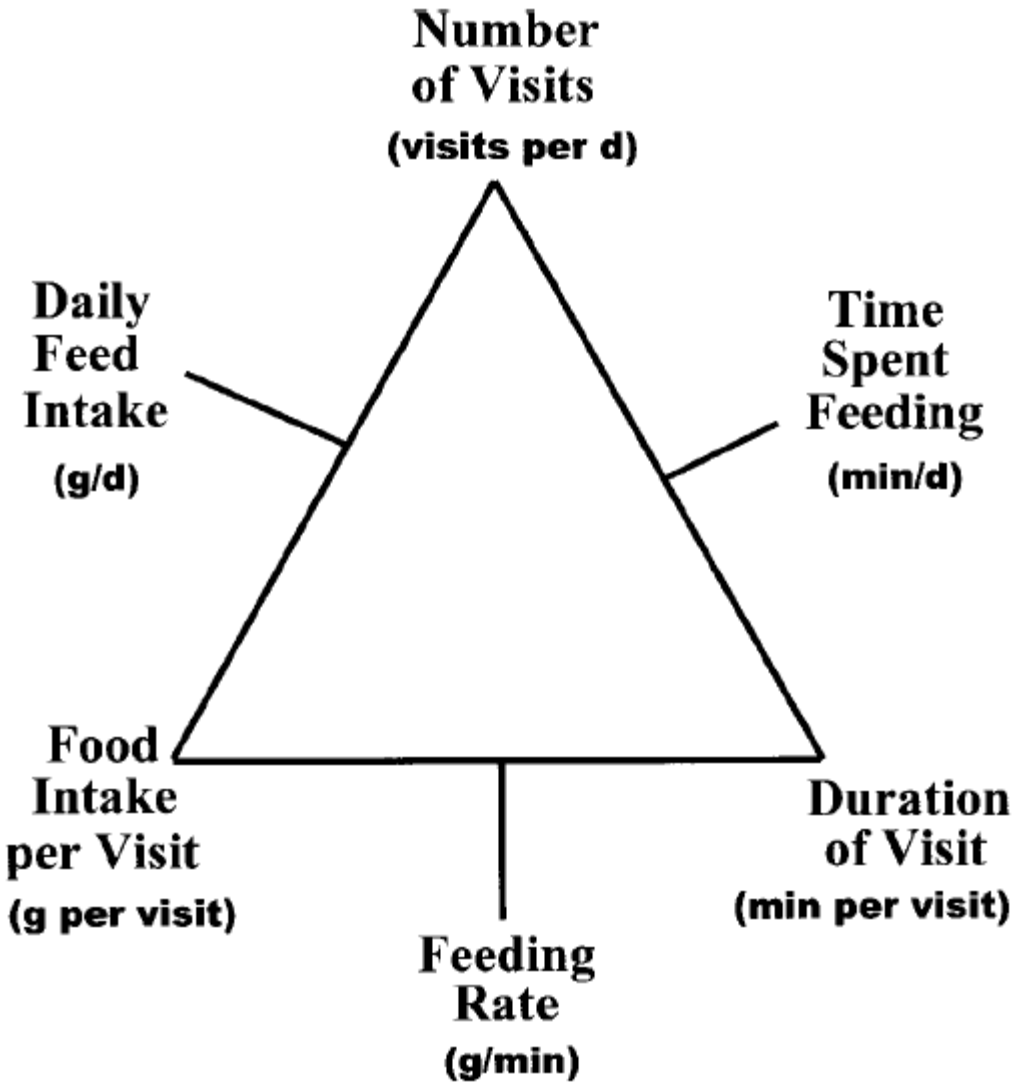


Figure 2.3 A representation of the arithmetical relationship between components of short-term feeding behaviour for data recorded on a visit basis. Primary measures are shown at the apices of the triangle. Derived measures, located at the midpoints of the triangle sides, can be calculated from the two primary measures, which are connected by that side (adapted from Friggens et al., 1998).

Some authors have argued that cow feeding events are clustered in meals (Tolkamp and Kyriazakis, 1999), which can be biologically identified (Tolkamp et al., 2000), and therefore should be used in the analysis of feeding behaviour. Unfortunately, there has been no research on the within cow repeatability of various characteristics of feeding behaviour especially

during early lactation. This is important since characteristics of feeding behaviour that are highly repeatable will be most sensitive for detecting treatment differences.

2.5 Physiological changes and metabolic disorders during transition period and early lactation

It was recognised that many of the metabolic disorders, which are afflicting cows during the periparturient period, are interrelated in their occurrence and are related to the diet fed during the prepartum period (Curtis et al., 1985). Curtis et al. (1985) determined that the increased energy content of the diet fed during the prepartum period was associated with a decreased incidence of displaced abomasums, and that the increased protein content of this diet was associated with a decreased incidence of retained placenta and ketosis.

The occurrence of health disorders during the transition period results in a loss in milk production during the time of illness and often for the entire lactation. For example, Rajala-Schultz et al. (1999) found that ketosis decreased the milk yield of cows in parity 4 or greater by 535 kg during a 305-d lactation. Wallace et al. (1996) studied the impact of health problems during the periparturient period on milk yield and reported that cows with any health disorders around calving produced 7.2 kg less milk per day during the first 20 d postpartum than did healthy cows.

Research has demonstrated a strong relationship between how much cows eat shortly after parturition and the incidence of metabolic problems. For example, Zamet et al. (1979) found that DMI for cows that experienced health problems were 18% lower prepartum and 20% lower postpartum than for healthy cows. Lean at al. (1994) reported that cows that developed clinical ketosis had lower DMI during the first 3 wk postpartum than either ketonemic or non-ketotic cows. In the study by Wallace et al. (1996), cows with any health disorder around parturition had decreased DMI during the first 20 d postpartum (13.9 vs. 17.8 kg/d).

Reduced feed intake prior to displaced abomasums in fatty liver cows is the key element in the observed changes in physiological parameters (Van Winden et al., 2003). A result of reduced feed intake is poor rumen fill. The poorly filled rumen enables the abomasum to shift to the left and finally the abomasum dislocates clinically (Van Winden et al., 2002). As another consequence of reduced feed intake blood concentrations of calcium and glucose, followed by a decreased blood insulin concentration (Herdt, 2000). Another effect of low glucose levels in ruminants is ketone body production, leading to a rise of blood BHBA concentrations (Herdt, 2000). In addition, a rise of ASAT activity in the blood has been assumed in order to deliver glycogenic amino acids as glucose precursors (Herdt, 2000).

Abomasal emptying and digestive flow are positively correlated with the amount of feed intake and the degree of rumen fill (Feng et al., 1993). Besides on the feed intake, motility of the abomasum depends on the tonicity of the vagal nerve, which in turn depends on afferent information of the autonomic system. A part of the autonomic system information is the concentration of glucose and insulin in the blood, as high concentrations of glucose and insulin increased the vagal tonicity, which in turn increased motility and gastric acid secretion under experimental conditions (Lam et al., 1997). Dirksen (1962) stated that besides the abomasal position in the abdomen and motility of the abomasum, at least a third condition for LDA development is necessary: gas production. A possible pathway for abomasal gas production is prolongation of fermentation in the abomasum (Van Winden et al., 2002). They reported that an increase of abomasal pH in postpartum cows, in which passage of VFA, produced in the rumen but not absorbed in the rumen or omasum, into the abomasum could have a pH-increasing role. The increase in pH enables the rumen bacterial flora to continue fermentation in the abomasum.

Cows that would develop displacement of the abomasum had generally a lower feed intake, lower milk production, decreased blood calcium levels, elevated blood ketone body and

NEFA concentrations, and high activity of ASAT compared to the other animals (Van Winden et al., 2003).

The sudden onset of milk synthesis in the mammary gland results in a tremendous demand for calcium. As a result, blood calcium concentrations can drop precipitously at calving, leading to milk fever (Drackley et al., 2005). Smaller decreases in blood calcium, called sub-clinical hypocalcemia, are believed to be contributing factors in disorders such as displaced abomasums and ketosis by decreasing smooth muscle function, which is critical for the normal function of the digestive tract (Goff and Horst, 1997). Hypocalcemia also leads to an increased secretion of cortisol, which is believed to be a factor in increased incidences of retained placenta (Goff, 1999). Until the ability of the digestive tract to absorb calcium can rise, calcium must be obtained by resorption from bone. Metabolic acidosis caused by a negative dietary cation-anion difference (DCAD) favours the mobilisation of calcium from bone, whereas high dietary potassium concentrations and positive DCAD suppress this process (Horst et al., 1997).

After calving, the initiation of milk synthesis and rapidly increasing milk production greatly increases the demands for glucose for the milk lactose synthesis, at a time when DMI has not reached its maximum (Drackley et al., 2005).

Because much of the dietary carbohydrate is fermented in the rumen, little glucose is absorbed directly from the digestive tract. Consequently, dairy cows rely extensively on hepatic gluconeogenesis to meet their systemic glucose requirements (Drackley, 2003). Propionate production from the low DMI during the early postpartum period is insufficient to synthesise the total amount of glucose needed (Drackley et al., 2001). Amino acids from the diet or from skeletal muscle breakdown as well as glycerol from mobilised body fat must provide most of the remaining glucose synthesis (Reynolds et al., 2003).

The total intake of energy by cows after calving usually is less than the energy requirement, even in healthy cows (Bell, 1995). The high ratio of growth hormone to insulin in the blood of

postpartal cows allows the mobilisation of long-chain fatty acids from adipose tissue triacylglycerol to attempt to make up the deficit between energy intake and requirements (Drackley et al., 2005).

Fatty acids released from adipose tissue circulate as nonesterified fatty acids (NEFA), which are a major source of energy to the cow during this period (Drackley, 1999). The concentration of NEFA in blood reflects the degree of adipose tissue triacylglycerol mobilisation (Pullen et al., 1989). Therefore, as negative energy balance increases, more NEFA are released from body fat, and the concentration of NEFA in blood increases. Stressors and poor nutritional management that cause decreases in voluntary DMI will result in large increases in NEFA immediately after calving (Drackley, 1999).

As the concentration of NEFA in blood increases around calving or in early lactation, more NEFA are taken up by the liver (Reynolds et al., 2003). In the liver, NEFA can be: 1) completely oxidised to carbon dioxide to provide energy from the liver, 2) partially to produce ketone bodies that are released into the blood and serve as fuels for other tissues, or 3) reconverted to triacylglycerol (Drackley, 1999).

Ruminants have an inherently low capacity for synthesis and secretion of very-low density lipoproteins (VLDL) to export triacylglycerols from the liver (Pullen et al., 1989), but a similar capacity to reconvert NEFA to triacylglycerols (Kleppe et al., 1988). Moreover, the hepatic tissue capacity to esterify NEFA to triacylglycerol is increased at the time of parturition (Grum et al., 1996). Consequently, cows fed typical diets during the dry period and peripartal period have an increased concentration of triacylglycerol in the liver 1 d after calving (Grum, et al., 1996).

If NEFA uptake by the liver becomes excessive, a fatty liver may develop (Bobe et al., 2004). Negative energy balance and carbohydrate insufficiency in the liver after calving also lead to an increased production of ketone bodies, which can result in clinical or sub-clinical ketosis (Herdt, 2000).

Negative energy balance, intense mobilisation of adipose triacylglycerols, and ketogenesis are highly associated with periparturient disorders and diseases (Bobe et al., 2004).

Increased concentration of NEFA before calving and BHBA after calving were strongly related to the development of displaced abomasums (LeBlance et al., 2005).

Litherland et al. (2003) reported that ad libitum feeding of high-energy diets during the dry period can increase the esterification capacity and decrease the oxidation capacity in liver tissue at 1 d postpartum, which would favour the deposition of triacylglycerols in liver.

Entry of NEFA into the mitochondria for β-oxidation to carbon dioxide or ketone bodies is controlled by the enzyme carnitine palmitoyltransferase (CPT-1) (Drackley et al., 2005). Activity of CPT-1 in ruminants is inhibited by malonyl-CoA, the product of acetyl-CoA carboxylase, and by methylmalonyl-CoA, which is produced during the metabolism of propionate (Knapp and Baldwin, 1990).

Maintaining an optimal liver function may be central to the ability of cows to make a smooth transition into heavy production (Drackley et al., 2005). Fat infiltration is a principal factor leading to the development of ketosis (Herdt, 2000). As the degree of fatty infiltration increases, normal functions of the liver are believed to be affected adversely (Bobe et al., 2004).

Fat infiltration impairs the ability of cultured liver cells to detoxify ammonia to urea (Strang et al., 1998). Ammonia decreases the ability of the liver to convert propionate to glucose (Overton et al., 1999), thus potentially linking fat accumulation to impaired gluconeogenesis in the liver (Drackley et al., 2001).

Although many studies (Grummer, 1995; Bell, 1995; Goff and Horst, 1997; Drackely, 1999; Ingvartsen et al., 2003; Jorritsma et al., 2003) have focused on the physiological changes during the transition period and early lactation, there is limited work on the relationship between feeding behaviour and these physiological changes.

2.6 Sensor-based monitoring of feeding behaviour and feed intake as well as metabolic-related production diseases

The development of remote data acquisition methods, choosing proper welfare indicators and elaboration of specific software, makes it possible to create automatic systems for monitoring the welfare and health status of cows. Sensor technology offers the opportunity to immediately indicate stress or the suspected presence of a livestock disease, and the ability to measure the production of milk and meat helps to optimise husbandry methods without any doubt (Groot Koerkam et al., 2007). These facts are a part of precision livestock farming in milk production on farm level. The monitoring of feeding behaviour and metabolic-related production diseases becomes more important in this field. The following examples explain the importance of sensor-based monitoring of animal behaviour.

The ability to measure accurately and easily and to predict the bite size and intake rate of grazing ruminants is key to many important management decisions in grazing systems (Ungar, 1996). The identification and classification of jaw movements is essential to a mechanistic understanding of the intake process (Ungar and Rutter, 2006).

Grazing ruminants perform jaw movements in order to gather herbage into the mouth and to chew it during ingestion and rumination. The timeline of jaw activity enables the duration and diurnal pattern of important aspects of animal behaviour to be inferred and is an important means of observing the mechanics of the grazing process. Rhythmic jaw activity is indicative of grazing or ruminating, whereas absence of activity is indicative of resting or travelling. One way of differentiating between grazing and ruminating is by distinguishing between biting and chewing jaw movements. Furthermore, if the sequence of jaw movements during grazing can be classified accurately, it is possible to estimate the biting rate and ingestive chewing requirements (Ungar and Rutter, 2006).

Penning (1983) constructed a nose band that acted as a transducer. The cyclical stretching and contraction of the nose band during jaw activity caused proportional changes in the electrical resistance of the transducer and the resulting analogue signal was recorded continuously on a cassette recorder carried by the animal. A further development of the post-processing algorithm (Penning et al., 1984) used features of the waveforms to identify rumination chews and to distinguish between chews and bites during grazing. The system of Penning et al. (1984) was developed further by replacing the analogue cassette recorder with a microcomputer-based system for the digital recording of jaw movements (Rutter et al., 1997).

Laca et al. (1994) found that biting and chewing actions could be more easily identified and counted by inspecting sound records rather than by direct observation, because of the existence of compound jaw movements that simultaneously involve forage manipulation and chewing. The sound record contains a wealth of information that can be gathered in a way that does not interfere with the grazing behaviour, and that may lend itself to automated analysis. Furthermore, an important advantage of the acoustic approach is that it allows accurate counts of chewing and biting events (Laca and WallisDeVries, 2000).

Sound records can be collected using radio transmission to a remote recording device (Laca et al., 1992) or direct recording to a small device carried on the animal (Matsui and Okubo, 1991).

An ambulatory data logger (named “Jaw recorder”), which simultaneously records the number of jaw movements and number of pauses between jaw movements longer than 3 s/min, has been developed and tested using cattle, sheep and goats (Matsui, 1994). The apparatus has a large data storage capacity, enabling it to record data every minute for a maximum of 22 days in one recording session. Grazing and rumination periods in the sheep and goats as well as cattle could be distinguished by a combination of jaw movements and pauses in the jaw movements longer than 3 s/min.

A storage telemetry system has been developed by Scheibe et al. (1998) that eliminates some of the disadvantages of direct telemetry and provides an opportunity for research-related and routine observation of free-ranging farm animals and wildlife. It can be used for automatic recording of different patterns of behaviour, such as activity and feeding. The system is made up of collars (ETHOREC) with sensors and electronic devices for behaviour recording, a central station (ETHOLINK) and software for data transmission and processing (ETHODAT) (Figure 2.4). All components of the ETHOREC recording device are integrated in the collar. The feeding and activity investigation using this system by Scheibe et al. (1998) has shown a significant correlation between ETHOREC measurements and field observations. Only 6 out of 20 correlations were less than 0.9.

Laca and WallisDeVries (2000) studied acoustic measurements of intake and grazing behaviour of cattle and concluded that the analysis of grazing sounds has the potential to overcome many of the problems associated with the measurement of grazing intake. A sound-based method would greatly simplify traditional grazing research, and could open new possibilities such as direct detection of spatial distribution of forage intake. They suggested that the recording system should be improved to allow precise measurements in environments where sounds are not controlled. The use of two or three microphones will improve the quality of the data and facilitate the discrimination between chews and bites. One microphone securely attached to a shaved patch on the forehead of the animal, will record chews, bites, and noise. A second microphone near but not in direct contact with the head, will record mostly bites and noise, and its signal can be subtracted from the previous one to obtain a clean record of chews. A third microphone could be installed on the back of the animal away from the head to record the noise to be subtracted from the other two signals (Laca and WallisDeVries, 2000).

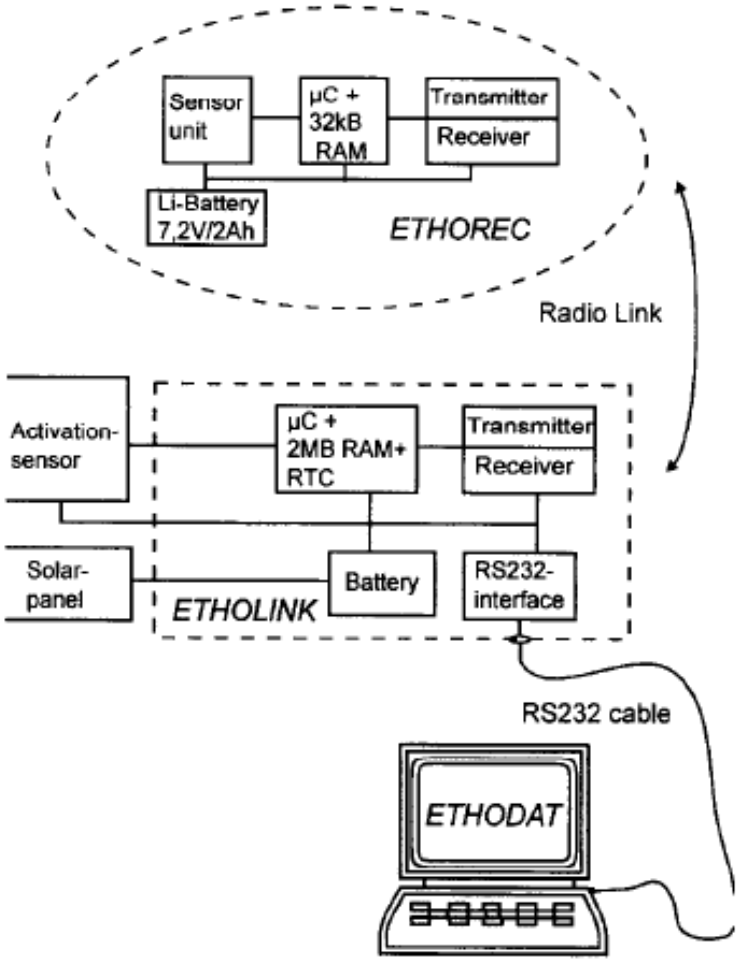


Figure 2.4 Functional block diagram of ETHOSYS. The ETHOREC registration device is designed as a collar. ETHOLINK is a self-contained central station. ETHODAT software can be used on a laptop or PC. ETHOLINK can communicate with up to 16 ETHORECs at a time (Scheibe et al., 1998).

CHAPTER 3: General material and methods

3.1 Animals, housing and feeding

Data were collected from a feeding experiment, which was performed in the Centre of Research for Animal Husbandry and Technology of Regional Office for Agriculture and Horticulture (Sachsen-Anhalt, Iden) from 10 July 2005 to 16 January 2006. For this study, data was collected from 70 lactating dairy cows: 23 cows in the first lactation, 17 cows in the second lactation, and 30 cows in the third-and-more-lactation (third to seventh lactation), with a body weight (BW) of 572 ± 42 (mean ± SD), 637 ± 38, and 716 ± 56 kg, respectively. Fifteen cows (in the first lactation) were crossbreds of German Holstein Friesian and Brown Swiss and 55 cows were purebred German Holstein Friesian. The cows were housed in a free-stall barn with special feeders. The ratio between cows and feeder was 2:1. Feeder units were equipped with electronic identification to identify cows and an electronic control to record the entry at the feeder. The animals could enter any feeder. Cows were fed ad lib. a TMR (based on the objectives of a feeding experiment) with an average of 6.99 MJ NEL/kgDM, 16.68% crude protein and 17.46% crude fiber (Table 2.1). Access to the feeder was continuous except during milking and between about 07:00 and 08:00 h, when food residues were removed from the bins and freshly mixed food was supplied. Chemical analyses of the ration were conducted weekly. Cows were milked three times daily (0400, 1200, and 2000) and the daily milk yield was recorded for each individual cow over the course of the study. Throughout the study, the animals had an average milk yield of 38.83 ± 7.96 (mean ± SD) kg/d with 3.93% ± 0.60 fat and 3.24% ± 0.26 protein.

3.2 Measurements and preparation of data

Individual analyses of feeding behaviour and feed intake were carried out by using an automatic feeder and electronic identification of individual cows. Each feeder was equipped with an access gate, which could be programmed to allow a specific cow to access a trough, and two infrared sensors that recorded the presence of a cow in the feeder (Figure 3.1).

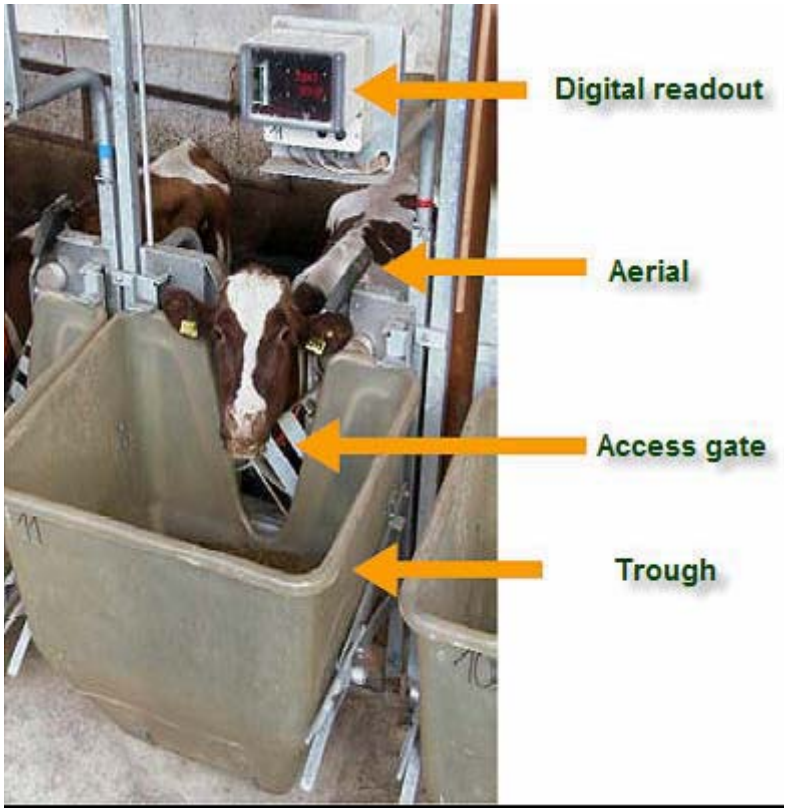


Figure 3.1 Automatic feeder

All experimental animals were fitted with a passive transponder, which was encased in a plastic container and attached to the bottom of the neck collar. The start and end time as well as the weight of the feeder at the start time and at the end time of each visit to the feeder were registered. A visit was defined as the time spent by an individual cow with her head in one of the troughs. Intervals between visits were calculated for each cow from the end time of a visit and the start time of the next. The automatic feeders measured intervals between visits to the feeder with the precision of 1 s. To determine if a visit was part of the previous meal, part of the next meal or formed a meal itself, meal criteria were calculated. Visits were thus clustered into meals. Individual meal criteria were calculated for each cow and a pooled criterion was calculated using the intervals from all cows for the entire experimental period. Meal criteria were calculated based on methods established by Tolkamp et al. (1998) and DeVries et al. (2003) by fitting a mixture of two normal distributions to the distributions of natural logarithm (LN)-transformed lengths of intervals between visits. Maximum likelihood estimation was used to fit these mixture distributions. In this study, the first distribution showed the intervals within a meal and the second one represented those between meals (Figure 3.2).

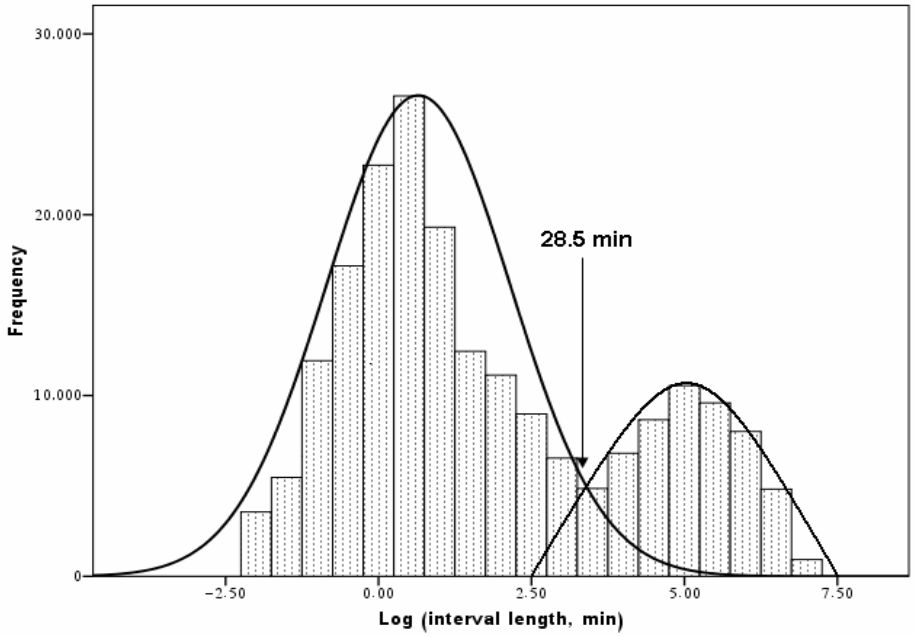
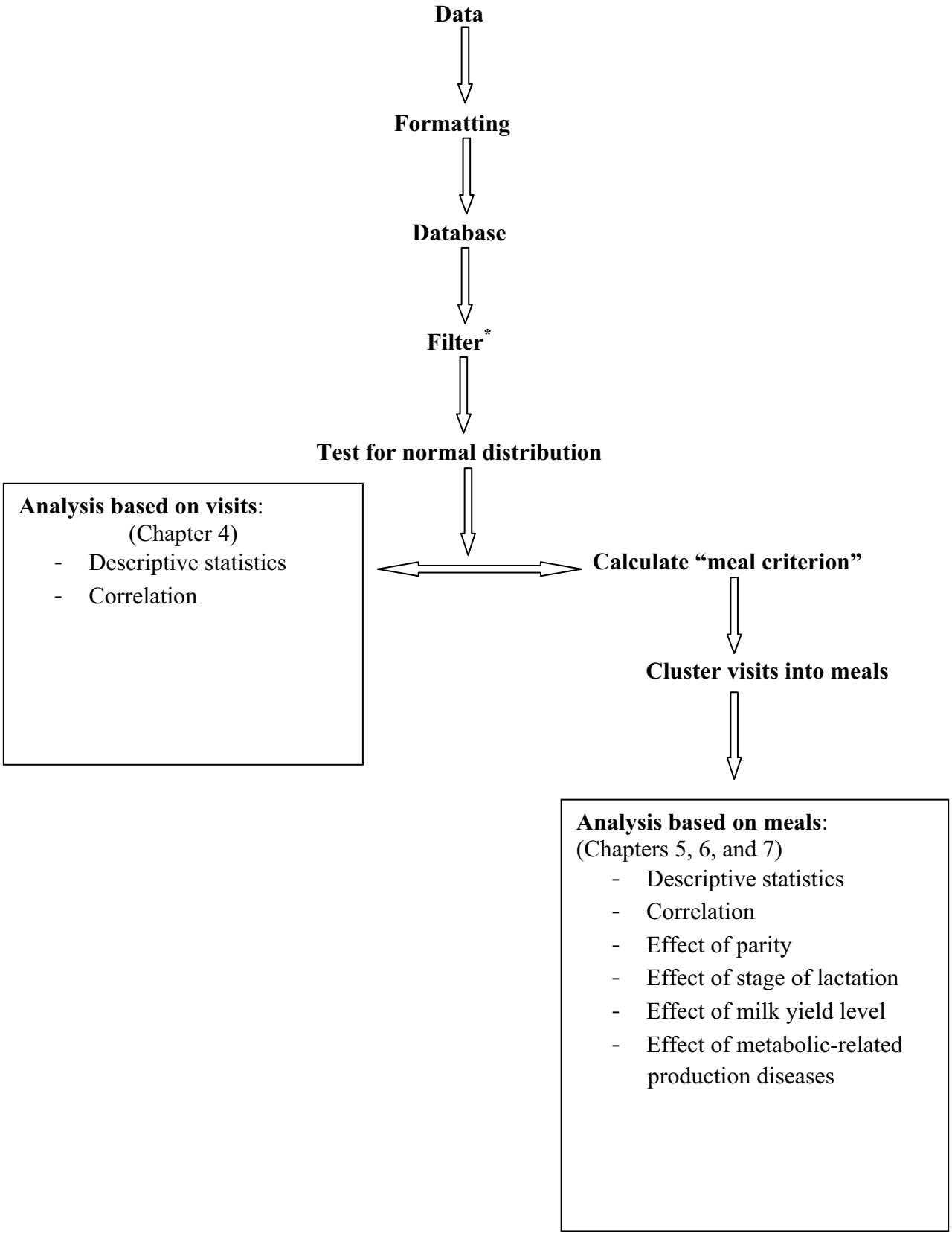


Figure 3.2 Frequency distribution of interval length between visits to feeder. Frequencies were divided by class width (0.5 log-units)

The meal criterion was determined as the point at which the distribution curve of inter-meal intervals intersected the distribution curve of intra-meal intervals. Based on the meal criteria, the meal frequency (meals/d) was calculated by counting the number of intervals per day that exceeded the length of the meal criterion, and adding one. The meal duration (min/meal) was calculated as the time from the beginning of the first feeding event, but not including an interval between events that exceeded the meal criterion. Daily mealtime (min/d) was simply the sum of the meal durations in a day. Meal size (kg/meal) is the total amount of feed ingested during each meal. Daily DMI (kg/d) was simply the sum of the meal sizes in a day. To determine if the use of a meal criterion based on the pooled data is appropriate for future calculations of meal-based measures, the daily estimates of feeding behaviour characteristics (meal frequency, daily mealtime) based on the individual meal criteria were regressed within cow onto those based on the pooled criterion. Figure 3.3 shows the process of data preparation.



*Data were filtered for possible errors. Errors were generated by reason of differences in time of the computers which were connected to the feeders. The error rate was less than 1%.

Figure 3.3 Process of preparation of data.

3.3 Laboratory and metabolic status analyses

The laboratory analyses of blood samples and metabolic status were conducted by Staufenbiel (2007). To define sub-clinical metabolic-related production diseases, the reference values in Table 3.1 were used. All disease events were diagnosed by a veterinarian and documented in a computer-based herd management system.

Table 3.1 The reference values of blood parameters (Staufenbiel, 2005; 2007)

Parameters	Reference value
Glucose (mmol/l)	2.2 - 3.3
Calcium (mmol/l)	2.25 - 2.8
Cholesterol (mmol/l)	2.6 - 5.0
NEFA (µmol/l)	< 400
ASAT (µmol/l)	< 105
BHBA (µmol/l)	< 1000
Urea (mmol/l)	3.5 - 5.0
Glutamate dehydrogenase (U/l)	< 25

3.4 Statistical analyses

The individual animal was considered the observational unit in all analyses. All data were analysed using PROC GLM in SAS (SAS Institute, 2003). In chapter 4, data were analysed

based on individual visits to the feeder without calculating the meal criterion. In chapter 4, 5, and 6, visits were clustered in meals. For each animal, the meal frequency (meal/d), meal duration (min/meal), meal size (kg/meal), daily mealtime (min/d), daily DMI (kg/d), and feeding rate (gDM/min) was calculated. To test for any effects of parity, stage of lactation, and milk yield level on the feeding behaviour characteristics and feed intake parameters, we used the following linear models:

1) $Y_{ij} = \mu + PA_i + PE_j + PA_i*PE_j + e_{ij,}$
2) $Y_{ij} = \mu + P_i + M_j + P_i*M_j + e_{ij}$
3) $Y_{ij} = \mu + HD_i + e_i$

where,

Y_{ij} = observation of the variable of interest,

μ = overall mean,

PA_i = effect of parity i (i = 1, 2, and 3),

PE_j = effect of period j (j = 1, 2, and 3),

PA_i*PE_j = interaction between parity i and period j,

P_i = effect of parity i (i = 1, primiparous and 2, multiparous),

M_j = effect of milk yield level (j = 1, low milk yield and 2, high milk yield),

P_i*M_j = interaction between parity i and milk yield level j,

HD_i = effect of health disorders i ((i = 1, with health disorders and 2, without health disorders),

e_{ij} = error term.

Correlations between feeding behaviour characteristics and feed intake were calculated using the regression procedure of SAS (SAS Institute, 2003).

Chapter 4

Untersuchungen zum Fressverhalten hochleistender Milchkühen in der Frühlaktation

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Zusammenfassung

Die Untersuchungen analysierten das Futteraufnahmeverhalten von Kühen in der Frühlaktation. Das Ziel bestand darin, die Beziehungen zwischen Merkmalen des Fressverhaltens und dem Futterverzehr zu ermitteln. Die Informationen über die Futteraufnahme der einzelnen Milchkuh sind insbesondere in der Frühlaktation für das Herdenmanagement besonders wertvoll. Allerdings gibt es dafür unter praktischen Bedingungen nicht die technischen Voraussetzungen. Deshalb sind die Beziehungen zwischen Parametern des Fressverhaltens, die mit praxisrelevanten Sensortechniken erfasst werden können, und der Futteraufnahme von besonderem Interesse.

Für den Versuch standen 70 hochleistende Milchkühe (23 in der 1. Laktation, 47 ab der 2. bis 7. Laktation) mit einer durchschnittlichen Jahresleistung von 12000 kg Milch zur Verfügung. Mittels Wiegetrögen und elektronischer Tierkennung wurden für jeden einzelnen Besuch einer jeden Kuh Anfangs- und Endzeit sowie die verzehrte Futtermenge registriert. Der Versuchszeitraum erstreckte sich vom 7. bis zum 105. Laktationstag. In dieser Zeit wurden 222.231 Messungen an den Fressplätzen aufgezeichnet und der Auswertung zugeführt. Für die Parameter Anzahl der Besuche je Tag, durchschnittliche Dauer der Besuche je Tag, tägliche Gesamtfressdauer sowie tägliche Futteraufnahme errechneten sich folgende Werte (Mittelwert ± SD): 32,07 ± 12,86 Besuche, 6,97 ± 2,64 Minuten, 201,42 ± 59,23 Minuten sowie 21,58 ± 4,19 kg Trockensubstanz. Dabei war festzustellen, dass die tägliche Gesamtfresszeit in enger Beziehung stand zur Anzahl der Besuche und zum längsten Besuch/Tag. Demgegenüber wurde offensichtlich, dass zwischen den Parametern „Gesamtfresszeit“ und „Aufnahme an Trockensubstanz“ praktisch keine Beziehungen bestehen.

(**Key words**: Milchkuh, Fressverhalten, Futteraufnahme, Frühlaktation)

4.1 Einführung

Die Fressdauer kann ebenso wie das Muster des Fressverhaltens einen wichtigen Einfluss auf die tägliche Gesamtfutteraufnahme von Milchkühen ausüben (GRANT and ALBRIGHT, 2000). Deshalb wurden seit einiger Zeit sowohl in Forschungsarbeiten zur Milchviehernährung als auch zum Einzeltier- und Herdenmanagement die Untersuchungen nicht nur auf den Verlauf der Futteraufnahme, sondern auch auf Veränderungen und Schwankungen in den Fress- und Futteraufnahmebedingungen fokussiert (DEVRIES et al., 2003).

Die Entwicklung zuverlässig arbeitender Systeme zur computergesteuerten Erfassung der Futteraufnahme von Milchkühen führte zu einem signifikanten Anstieg von automatisch erfassten Messdaten und gab Anlass, derartig gewonnene Informationen auf verschiedenste Art auszuwertenden und zu interpretieren sowie in die Überwachung und Steuerung von Fütterungssystemen zu implizieren (DEVRIES et al., 2003; NIELSEN, 1998). MELIN et al. (2005) wiesen darauf hin, dass laktierende Milchkühe durch die Zusammensetzung der Ration und durch die Umweltbedingungen im Fressbereich in ihrem Fressverhalten und der Futteraufnahme beeinflusst werden können. Neben anderen Einflussfaktoren des Managements und der Haltungsbedingungen stellten URTON et al. (2005) fest, dass Kühe, bei denen Anzeichen einer Metritis auftrat, eine um durchschnittlich 22 Minuten kürzere tägliche Fressdauer realisierten. Die Zielstellung der vorliegenden Untersuchungen war, das Muster des Fressverhaltens laktierender Kühe in der Frühlaktation anhand mehrerer automatisch messbarer Parameter zu erfassen. Gleichzeitig sollten die Beziehungen zwischen Fressverhalten und Futteraufnahme analysiert werden, um daraus mögliche sensorgestützte Managementtools abzuleiten.

4.2 Material und Methoden

4.2.1 Tiere, Haltung und Fütterung

Die Versuche sind in einem Experimentierstall des Zentrums für Tierhaltung und Technik der Landesanstalt für Landwirtschaft und Gartenbau des Landes Sachsen-Anhalt, Iden durchgeführt worden. Dabei handelt es sich um einen Liegeboxenlaufstall, der mit Wiegetrögen ausgestattet ist. Das Tier-Fressplatz-Verhältnis betrug 2:1.

Für die Untersuchungen standen 70 Milchkühe, davon 55 Tiere der Rasse Deutsche Holstein und 15 Kreuzungstiere (F1) Brown Swiss – Deutsche Holstein (nur 1. Laktation) zur Verfügung. 23 Tiere befanden sich in der 1. Laktation und 47 verteilten sich auf die 2. bis 7. Laktation. Die Datenanalyse umfasste den Zeitraum zwischen dem 7. und 105. Laktationstag. Die Kühe kalbten in der Zeit zwischen dem 3. Juli und dem 7. Oktober 2005. Die Tiere wurden dreimal täglich (4.00 Uhr, 12.00 Uhr und 20.00 Uhr gemolken. Die Futtervorlage erfolgte einmal pro Tag in Form einer totalen Mischration(TMR). Das Futterangebot erlaubte eine ad libitum – Aufnahme. Die TMR wies einen durchschnittlichen Energiegehalt von 6,99 MJ NEL/kg TS auf, der Rohproteingehalt betrug im Versuchszeitraum durchschnittlich 16,68 % und der Rohfasergehalt 17.46 %. Die Tröge wurden täglich vor der Fütterung von Futterresten gereinigt.

Eine chemisch-analytische Untersuchung der Ration ist wöchentlich durchgeführt worden. Das Experiment erstreckte sich über den Zeitraum vom 10. Juli 2005 bis 16. Januar 2006. Dabei wurden die Daten bei allen Kühen vom 7. bis 105. Laktationstag aufgezeichnet. Über den gesamten Versuchszeitraum erreichte der durchschnittliche tägliche Milchertrag aller im Versuch stehenden Kühe 38,83 ± 7,96 kg mit einem Fettgehalt von 3,93 ± 0,60 % und einem Eiweißgehalt von 3,24 ± 0,26 %.

4.2.2 Messmethodik

Die individuelle Analyse des Futteraufnahmeverhaltens und der aufgenommenen Futtermengen wurde an Einzelfressplätzen mit Hilfe von Wiegetrögen und einer elektronischen Tiererkennung realisiert. Jeder Einzelfressplatz mit Wiegetrog verfügte über ein programmierbares Zugangstor für die Zugangskontrolle der Kühe zum entsprechenden Futtertrog sowie zwei Infrarotsensoren zur Aufzeichnung der Aufenthaltsdauer des Tieres am Fressplatz. Die elektronische Tiererkennung erfolgte mit einem Ohr-Responder. Auf dieser Grundlage konnte für jeden Besuch die Anfangs- und Endzeiten sowie die verzehrten Futtermengen je Tier erfasst werden. Mit Hilfe dieser primären Messdaten war es möglich, die Fresshäufigkeit, die Dauer der einzelnen Fressplatzbesuche, die Gesamtfressdauer je Tag sowie die Futteraufnahme zu berechnen. Dabei muss berücksichtigt werden, dass – wenn die Tiere kurzzeitig den Kopf hinter das Fressgitter zurücknehmen – das Ende eines Besuches signalisiert wird. Wenn dann die Kuh die Futteraufnahme fortsetzt, wird dies als ein neuer Besuch registriert. So kann insbesondere bei unruhigen Tieren eine größere Zahl von Besuchen auftreten.

4.2.3 Statistische Analyse

Die Analysen konzentrierten sich auf das Einzeltier. Die täglich erfassten bzw. errechneten Parameter wurden dem entsprechenden Laktationstag jeder Kuh zugeordnet. Es handelte sich dabei um die Besuchshäufigkeit, die Dauer der einzelnen Besuche, die Futteraufnahme je Besuch, die Fressintensität und daraus abgeleitet die Gesamtfressdauer und Gesamtfutteraufnahme je Tag. Aus den täglichen Werten wurden die Durchschnittswerte je Laktationswoche und für den gesamten Versuchszeitraum vom 7. bis 105. Laktationstag

berechnet. Neben den Mittelwerten für die Stichprobe wurden die Standartabweichung sowie Minimum und Maximum ermittelt. Die Beziehungen zwischen einzelnen Parametern wurden mit Hilfe von Korrelationsanalysen (Pearson) berechnet. Für die Datenanalyse wurde das Statistik – Programm SPSS Base 14.0 verwendet. Die in dieser Publikation vorgestellten Teilergebnisse beziehen sich auf die gesamte Stichprobe, die für die Untersuchungen zur Verfügung stand. Eine weitere Differenzierung nach Nummer der Laktation und Genotyp ist folgenden Arbeiten vorbehalten.

4.3 Ergebnisse

Die Auswertungen des Fressverhaltens und der Trockensubstanzaufnahme über den gesamten Zeitraum vom 7. bis 105. Laktationstag ergab, dass die Tiere durchschnittlich 32,07 mal pro Tag den Fressbereich aufsuchten, die Dauer eines jeden Besuches betrug im Durchschnitt 6,79 Minuten. Daraus errechnete sich eine mittlere Gesamtfressdauer von 201,42 Minuten je Tag. Die tägliche Trockenmasseaufnahme erreichte einen durchschnittlichen Wert von 21,58 kg (Tabelle 4.1).

Tabelle 4.1 Kennzahlen des Fressverhaltens und der Trockenmasseaufnahme von Milchkühen für den Zeitraum vom 7. bis 105. Laktationstag
Characteristics of feeding behaviour and dry matter intake of dairy cows from 7th to 105th day of lactation

Parameter	Mittelwert	SD	Maximum	Minimum
Anzahl an Besuchen[1]	32,07	12,86	115,00	6,00
Besuchsdauer[2] (Min./Besuch)	6,79	2,63	25,81	1,28
Gesamtfressdauer[3] (Min./Tag)	201,42	59,23	501,55	41,73
Trockenmasseaufnahme (kg/Tag)	21,58	4,20	42,65	6,79

[1]Anzahl aller Besuche am Fressplatz (mit und ohne Futteraufnahme) je Tag und Kuh
[2]Zeitdifferenz zwischen Start- und Endzeit des Fressplatzbesuchs (Min.)
[3]Summe der Dauer aller Fressplatzbesuche (Min.) je Tag und Kuh

Alle Parameter weisen eine erhebliche Variation auf. So erreichten die Minimumwerte für die Anzahl der Besuche, die durchschnittliche Besuchsdauer je Fressplatzbesuch sowie die tägliche Gesamtfresszeit ca. 25 % der entsprechenden Mittelwerte, während die Maxima die Mittelwerte um mehr als das Dreifache überstiegen. Die niedrigsten Werte für die tägliche Trockensubstanzaufnahme lagen bei ca. einem Drittel des Mittelwertes und als maximale Futteraufnahme konnten mit mehr als 42 kg Trockensubstanz das Doppelte des Mittelwertes registriert werden.

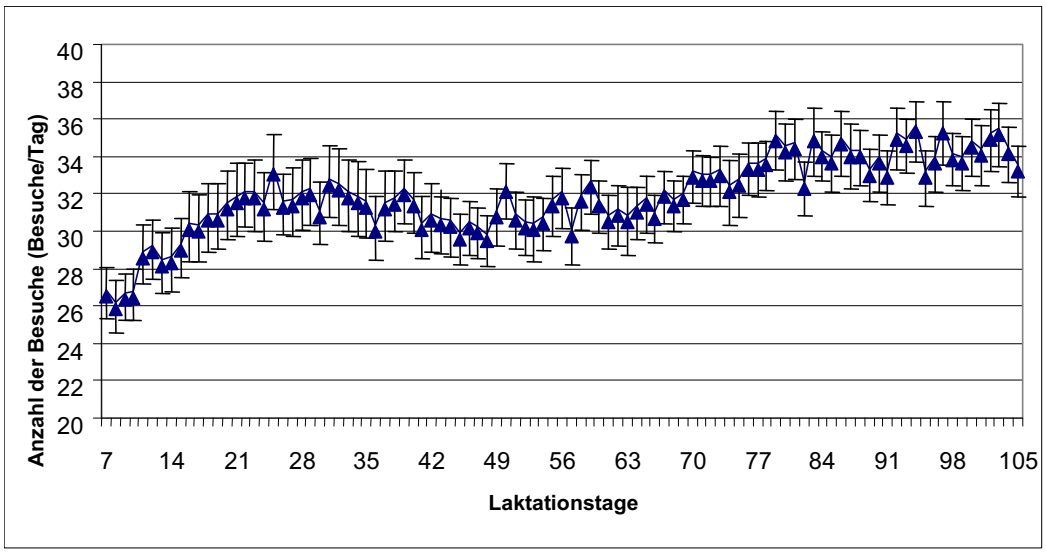

Abb. 4.1 Anzahl Fressplatzbesuche (Mittelwerte und Standarfehler) je Kuh u. Tag vom 7. Bis 105. Laktationstag.
Number of visits at feeders (mean and standard errors) per cow and day from 7th to 105th day of lactation

Wie sich die Entwicklung des Fressverhaltens und der Futteraufnahme im Verlauf der Frühlaktation entwickelte, wird in den folgenden Abbildungen dargestellt. Über die Anzahl der täglichen Fressplatzbesuche gibt Abbildung 4.1 Auskunft.

Während der ersten vier Wochen der Laktation ist ein Anstieg von durchschnittlich täglich 26 auf 31 Besuche festzustellen. Zwischen der 5. bis 10. Laktationswoche sind es stabil durchschnittlich etwa 31 Fressplatzbesuche. Nach der 10. Woche steigt die Häufigkeit der Besuche je Tag auf 35 an.

Bezüglich der durchschnittlichen täglichen Gesamtfressdauer war in den ersten vier Wochen ein beträchtlicher Anstieg von ca. 130 auf 180 Min./Tag zu registrieren. Ab der 5. Laktationswoche flachte die Entwicklung ab und erreichte nach 10 Laktationswochen 210 Min./Tag. Von der 11. bis 15. Laktationswoche erhöhte sich die tägliche Fressdauer um weitere 20 Min. auf 230 Min./Tag (Abb. 4.2).

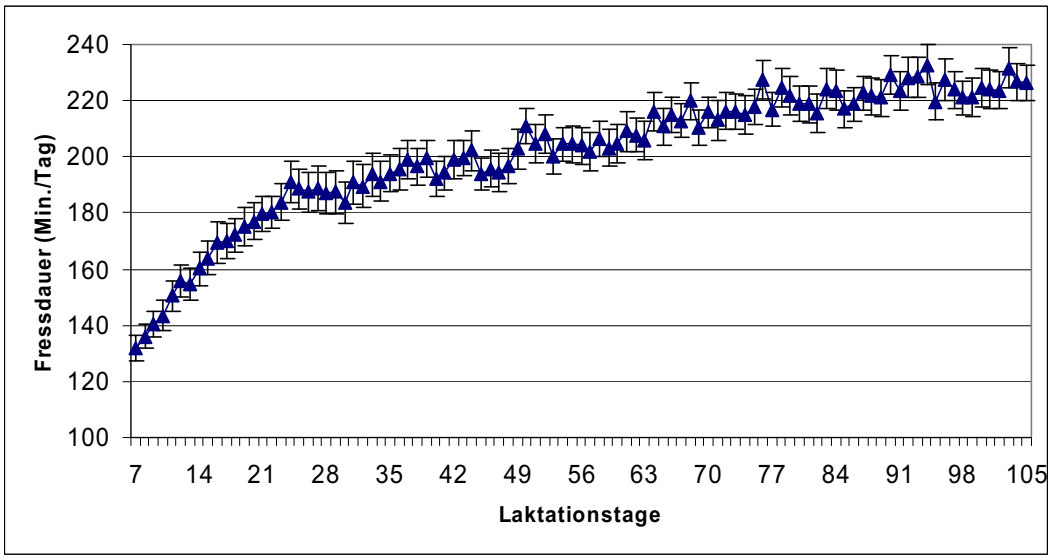

Abb. 4.2 Gesamtfresszeit(Mittelwerte u. Standartfehler) je Kuh u. Tag vom 7. bis 105. Laktationstag
Total feeding duration(means and standard errors) per cow and day from 7th to 105th day of lactation

Die Auswertung der durchschnittlichen Dauer eines Besuchs am Fressplatz ergab,dass durchschnittlichen Wert von 5,3 Minuten/Besuch zu Beginn der zweiten Laktationswoche bis zur sechsten Laktationswoche auf 7,3 Minuten/Besuch anstieg und dieses Niveau bis zur 11. Laktationswoche hielt. Anschließend war ein leichter Rückgang auf 7 Minuten zu verzeichnen- diese Dauer je Besuch war dann bis zum 105. Laktationstag stabil. (Abbildung 4.3).

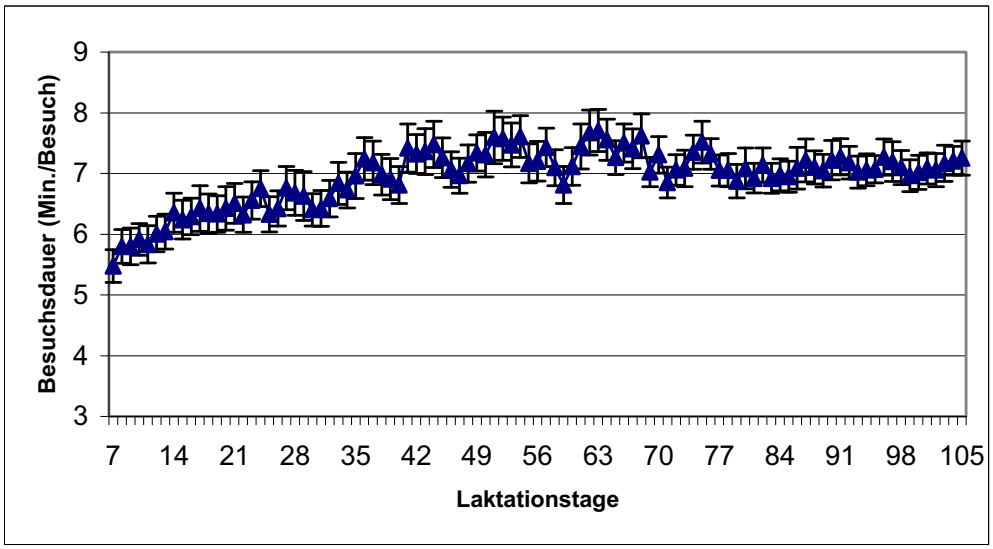

Abb. 4.3 Durchschnittliche Dauer der Fressplatzbesuche (Mittelwerte u. Standartfehler) je Kuh u. Tag vom 7. bis 105. Laktationstag
Average duration of visits at feeders (means and standard errors) per cow and day from 7th to 105th day of lactation

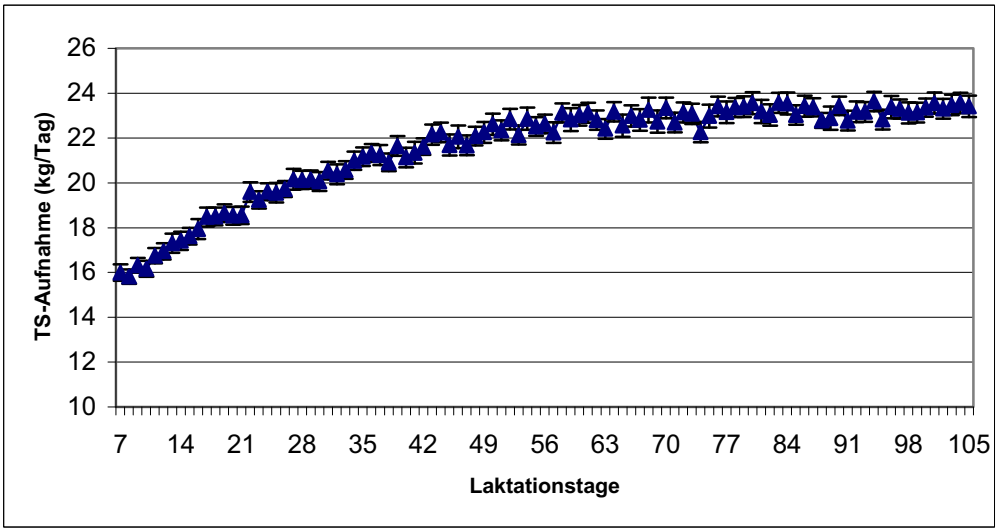

Abb. 4.4 Trockenmasseaufnahme je Kuh u. Tag (Mittelwerte und Standartfehler)vom 7. bis 105. Laktationstag
Dry matter intake per cow and day (means and standard errors) from 7th to 105th day of lactation

Die Entwicklung der durchschnittlichen täglichen Trockensubstanzaufnahme in der Frühlaktation ist der Abbildung 4.4 zu entnehmen.

Zu Beginn der zweiten Laktationswoche betrug der Futterverzehr durchschnittlich 15,5 kg TS/Tier und Tag. Bis Ende der vierten Laktationswoche war ein deutlicher stetiger Anstieg

auf ca. 20 kg TS/Tier und Tag zu beobachten, was eine Erhöhung des täglichen Futterverzehrs von 1,5 kg TS pro Woche bedeutet. Zwischen der 5. und 10. Laktationswoche verlangsamte sich die Progression der täglichen Futteraufnahme; diese erreichte in der 10. Laktationswoche ein Niveau von 23,5 kg TS /Tier und Tag. Dieser Wert wurde bis zum 105. Laktationstag stabil eingehalten.

Zur Bewertung der Beziehungen von Parametern des Fressverhaltens und der Futteraufnahme wurden Korrelationen berechnet. Unter Berücksichtigung der Veränderungen im Verlauf der Laktation, wie sie aus den vorangegangen Abbildungen sichtbar wurden, erfolgte die Berechnung der Beziehungen zwischen verschiedenen Parametern wochenweise. An je zwei Beispielen werden zum einen Korrelationen zwischen Parametern des Fressverhaltens und zum anderen zwischen ausgewählten Parametern des Fressverhaltens und der realisierten Futteraufnahme dargestellt. In Abbildung 4.5 sind die Beziehungen zwischen der täglichen Anzahl an Fressplatzbesuchen und der Gesamtfressdauer pro Tag dargestellt.

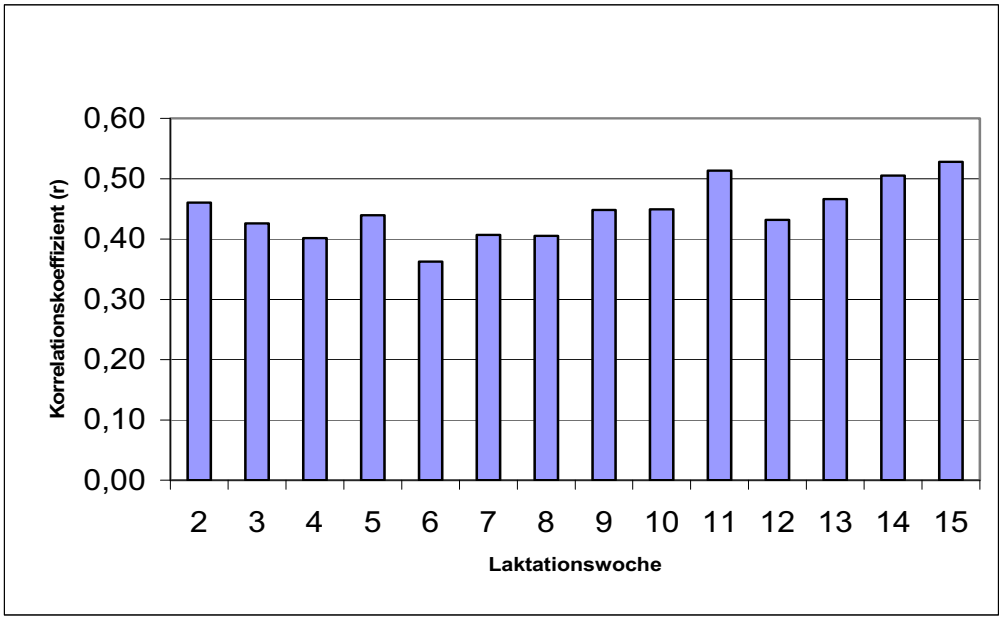

Abb. 4.5 Beziehungen zwischen der Anzahl von Fressplatzbesuchen und Gesamtfressdauer pro Tag im Zeitraum der 2. bis 15. Laktationswoche
Relationships between number of visits at feeders and total feeding duration per day from 2nd to 15th week of lactation

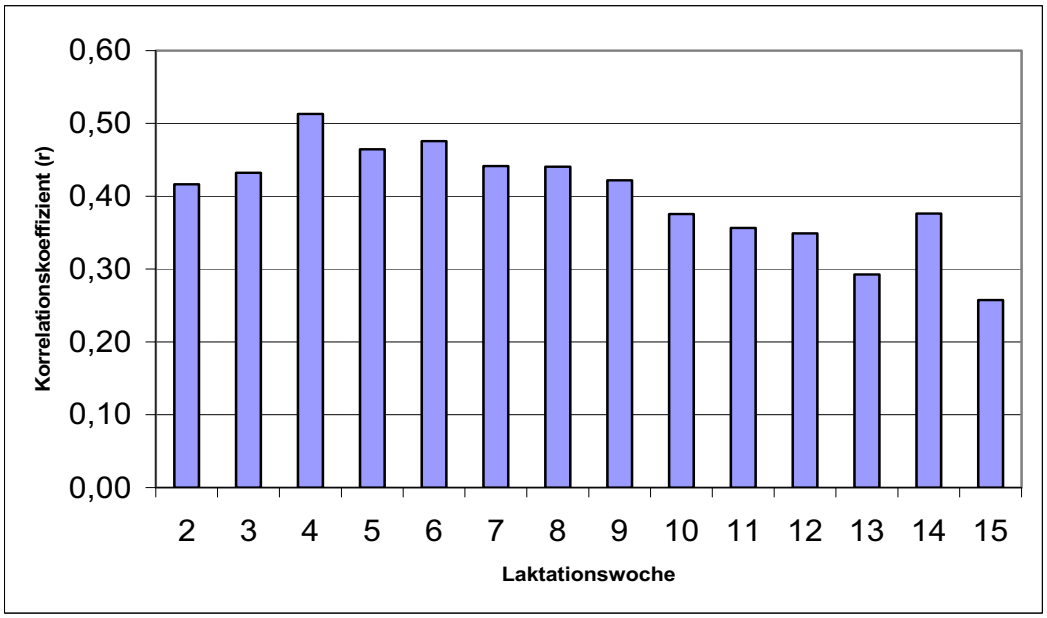

Abb. 4.6 Beziehungen zwischen der Dauer des längsten Fressplatzbesuchs und der Gesamtfressdauer pro Tag im Zeitraum der 2. bis 15. Laktationswoche
Relationships between duration of the longest visit and total feeding duration per day from 2nd to 15th week of lactation

Über die gesamte Zeit der Frühlaktation betrachtet ergeben sich für die einzelnen Wochen Korrelationskoeffizienten mit Werten zwischen 0,4 und 0,52 ($p<0,01$).

Die Betrachtung der Beziehungen eines Teilereignisses zu dem relevanten Gesamtverhalten wird am Beispiel des Verhältnisses von der Dauer des längsten Fressplatzbesuches zur Gesamtfresszeit pro Tag dargestellt (Abbildung 4.6).

Die engsten, statistisch zu sichernden Beziehungen zwischen den beiden Parametern ergaben sich für den Bereich zwischen 2. bis 9. Laktationswoche ($r = 0,42 – 0,51$).

Die Abbildung 4.7 veranschaulicht die Beziehungen zwischen der Gesamtfressdauer pro Tag und der täglichen Trockensubstanzaufnahme.

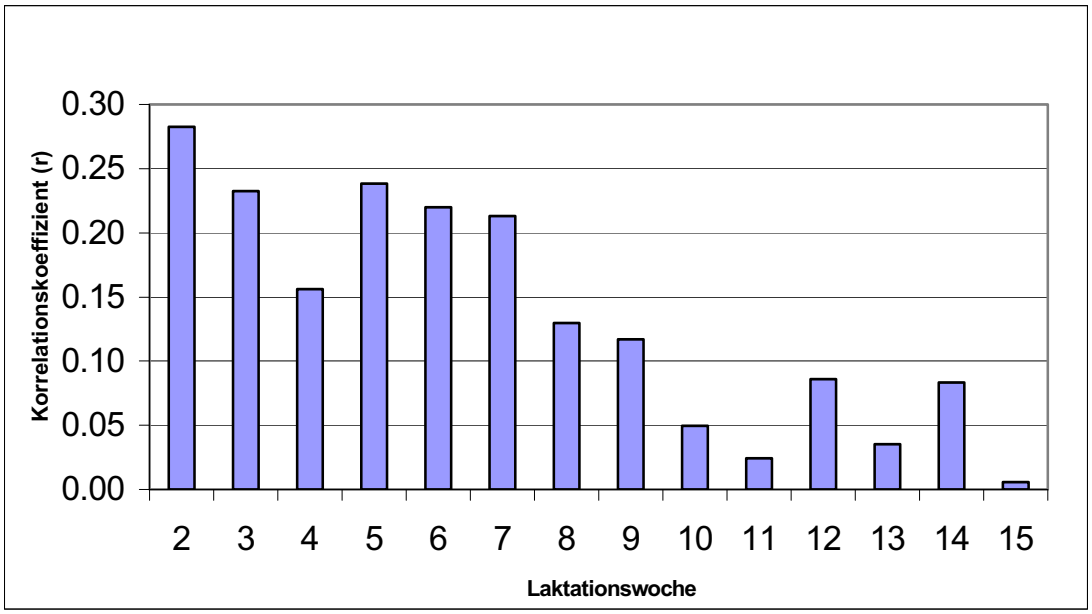

Abb. 4.7 Beziehungen zwischen der Gesamtfressdauer und der Trockenmasseaufnahme pro Tag im Zeitraum der 2. bis 15. Laktationswoche
Relationships between total feeding duration and dry matter intake per day from 2nd to 15th week of lactation

Die Korrelationen liegen auf einem relativ niedrigen Niveau - es wurden Werte zwischen $r = 0,27 – 0,02$ errechnet.

Ein ähnliches Bild ergibt sich, wenn die Beziehung zwischen der durchschnittlichen Dauer der Fressplatzbesuche und der täglichen Futteraufnahme berechnet wird (Abbildung 4.8).

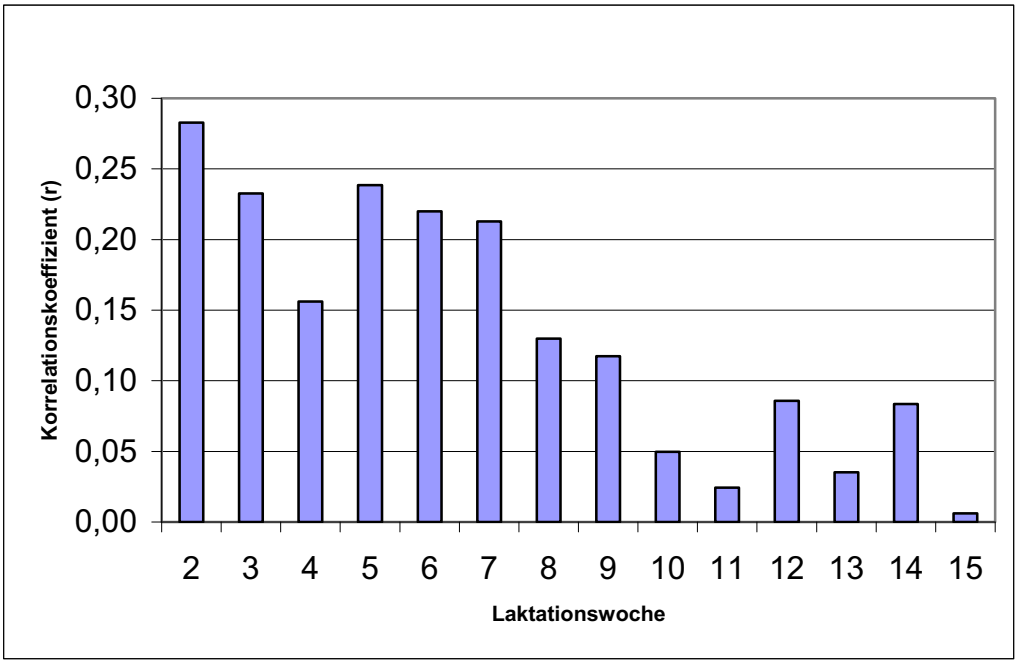

Abb. 4.8 Beziehungen zwischen der durchschnittlichen Dauer der Fressplatzbesuche und der durchschnittlichen Trockenmasseaufnahme pro Tag im Zeitraum der 2. bis 15. Laktationswoche
Relationships between average of duration of visits at feeders and average of dry matter intake per day from 2nd to 15th week of lactation

Eine Gesamtübersicht über Parameter des Fressverhaltens und der Futteraufnahme von der zweiten bis 15. Laktationswoche, bezogen auf die einzelnen Laktationswochen, ist in Tabelle 4.2 zusammengestellt.

Es ist festzustellen, dass die durchschnittliche tägliche Anzahl der Fressplatzbesuche je Kuh von 28 in der zweiten auf 35 Besuche in der 15. Laktationswoche anstieg. Gleichzeitig erhöhte sich die durchschnittliche Dauer je Fressplatzbesuch von 5,96 Minuten in der zweiten auf 7,11 Minuten in der 15. Laktationswoche. Daraus resultierte eine durchschnittliche tägliche Gesamtfressdauer von 148,68 Minuten in der zweiten sowie 225,48 Minuten in der 15. Laktationswoche. Die durchschnittliche tägliche Trockensubstanzaufnahme je Kuh stieg im gleichen Zeitraum von 16,67 kg auf 23,22 kg an.

Tabelle 4.2 Parameter des Fressverhaltens und der Trockensubstanzaufnahme in der Zeit von der 2. bis 15. Laktationswoche
Parameters of feeding behavior and dry matter intake in the period from 2nd to 15th week of lactation

Woche	Anzahl an Besuchen je Tag[1]		Besuchsdauer (Min/Besuch)[2]		tägliche Fressdauer (Min)[3]		Trockensubstanz-aufnahme	
	Mittel-wert	SD	Mittel-wert	SD	Mittel-wert	SD	Mittel-wert	SD
2	28	11.01	5.96	2.44	148.68	44.79	16.67	3.11
3	31	13.44	6.37	2.75	172.51	54.33	18.32	3.35
4	32	13.70	6.55	2.63	186.72	59.05	19.71	3.45
5	32	14.24	6.65	2.74	190.10	61.98	20.55	3.46
6	31	12.96	7.12	2.87	196.54	55.59	21.32	3.51
7	30	12.02	7.23	2.72	197.92	54.41	22.02	3.78
8	31	12.91	7.42	3.00	205.30	54.10	22.56	3.74
9	31	12.74	7.32	2.77	205.63	55.14	22.79	3.78
10	32	11.44	7.38	2.59	214.42	51.69	22.98	4.03
11	33	12.54	7.18	2.32	217.50	54.74	22.96	3.83
12	34	12.63	7.00	2.28	221.07	56.58	23.38	3.91
13	34	12.89	7.13	2.53	221.93	53.53	23.10	3.58
14	35	12.93	7.13	2.30	225.95	56.86	23.22	3.75
15	35	12.78	7.11	2.25	225.48	55.76	23.40	3.71

[1]Anzahl aller Besuche am Einzelfressplatz (mit und ohne Futteraufnahme) je Tag und Kuh
[2]Zeitdifferenz zwischen Start- und Endzeit des Fressplatzbesuchs (Min.)
[3]Summe der Dauer aller Fressplatzbesuche (Min.) je Tag und Kuh

4.4 Diskussion

In den vorliegenden Untersuchungen wurde eine durchschnittliche tägliche Fressdauer von 201,42 Min./Tag (7. – 105. Laktationstag) ermittelt. Von ähnlichen Werten wird auch in Arbeiten von VASILATOS u. WANGSNESS (1980), TOLKAMP et al. (2000) sowie SHABI et al. (2005) berichtet. Detaillierte Auswertungen von TOLKAMP et al. (2000) führten zu der Feststellung, dass bei laktierenden Kühen während des Übergangs von der Früh - zur mittleren Laktation die tägliche Fressdauer ansteigt und einen Durchschnittswert von 225,1 Min./Tag erreicht. VASILATOS u. WANGSNESS (1980) fanden einen Anstieg der täglichen

Fressdauer in der Frühlaktation, wobei im weiteren Verlauf ein Maximum von 253 Min./Tag erreicht wurde. SHABI et al. (2005) konnten demgegenüber in der mittleren Laktation lediglich eine tägliche Gesamtfressdauer von durchschnittlich 170 Min. messen. Wesentlich höher liegen die Angaben von BEAUCHEMIN u. BUCHANAN-SMITH (1989), die für Kühe ab der zweiten Laktation im mittleren Laktationsstadium von einer durchschnittlichen Fressdauer von 237 Min. berichten, wobei eine durchschnittliche tägliche Futteraufnahme von 18 kg Trockensubstanz/Tag erreicht wurde. Die Ergebnisse der eigenen Untersuchungen bestätigen die Ergebnisse von DEVRIES et al. (2003). Dabei wurde ein ähnlich deutliches Ansteigen der Fressdauer vom Laktationsbeginn bis zur 15. Laktationswoche beschrieben.

DADO u. ALLEN (1994) untersuchten die Variationen und die Beziehungen zwischen einer Reihe von Parametern der Futter- und Wasseraufnahme laktierender Milchkühe in der Frühlaktation (63±11 Laktationstage). Ihren Angaben zufolge erreichte die Aufenthaltsdauer am Fressplatz durchschnittlich 301 Min./Tag, die Futteraufnahme betrug 22,8 kg TS/Tier und Tag. Die Anzahl von Fressplatzbesuchen wird mit durchschnittlich 30 je Tag angegeben und übertrifft die Messwerte von 12 Besuchen je Tag, die SHABI et al. (2005) registriert hatten, sehr deutlich. Von nur 6 bis 7 Mahlzeiten je Tag berichteten TOLKAMP et al. (2000) sowie DEVRIES et al. (2003). Es besteht allerdings offenbar das Problem, dass die Angaben zur Anzahl der Besuche und zur durchschnittlichen Dauer je Fressplatzbesuch sehr stark in Abhängigkeit von der Definition des Messverfahrens und der mathematischen Bearbeitung der Messwerte im jeweiligen Experiment differieren. In den vorliegenden Untersuchungen wurden alle registrierten Besuche am Fressplatz zugrunde gelegt, ohne zwischen Besuchen mit oder ohne Futteraufnahme zu unterscheiden, und die Aufenthaltsdauer am Fressplatz umfasste die gesamte Zeitdauer zwischen Beginn und Ende der Zeitmessung am Fressplatztor. Ähnliche Vorgehensweisen lagen den Untersuchungen von TOLKAMP et al. (2000) zugrunde, die als Durchschnittswerte eine Futteraufnahme von 22,74 kg TS/Tag, 31,6

Besuchen/Tag sowie 5,2 Min. je Besuch ermittelten, was mit den eigenen Untersuchungen in guter Übereinstimmung stehen. Lediglich die über den Gesamtzeitraum ermittelte durchschnittliche Besuchdauer am Fressplatz (6,8 Min) weicht von den von TOLKAMP et al. (2000) gemessenen Werten ab.

Die Beziehung zwischen der Anzahl von Fressplatzbesuchen je Tag und der täglichen Fressdauer ist statistisch gesichert ($p < 0,01$) und scheint dahingehend nutzbar zu sein, durch die Aufzeichnung der Anzahl der Besuche am Fressplatz Voraussagen über die tägliche Gesamtfressdauer vornehmen zu können. Demgegenüber sind die Korrelationskoeffizienten zwischen der täglichen Gesamtfressdauer und der täglichen Trockensubstanzaufnahme so niedrig, dass sie kaum für sichere Vorhersagen einsetzbar sind. Für Vorhersagemodelle zum Fressverhalten in der Frühlakation scheint die Beobachtung von Bedeutung zu sein, dass bis zur 9. Laktationwoche eine significante Korrelation ($p < 0,01$) zwischen dem längsten Fressplatzbesuch am Tag und der täglichen Gesamtfressdauer vorzufinden ist. Ab dem dritten Laktationmonat verändern sich die Beziehungen zwischen den einzelnen gemessenen Parametern in unterschiedlicher Weise, so dass es sinnvoll erscheint, Vorhersagemodelle den verschiedenen vorrengig physiologisch bedingten Verhaltenweisen in der Futteraufnahme anzupassen und für noch zu definierende sich gegenseitig abgrenzende Laktationsabschnitte die Abhängigkeiten genauer zu definieren.

DADO u. ALLEN (1994) wiesen im Ergebnis ihrer Studien darauf hin, dass zahlreiche Variationen ihre Ursache im unterschiedlichen Produktionsniveau der Versuchstiere haben, aber auch in der chemischen Zusammensetzung und physikalischen Struktur der eingesetzten Rationen, in Management- une Umweltfaktoren und überdies auch in unterschiedlichen Definitionen der Versuchsparameter und der Messmethoden begründet sein können.

4.5 Schlussfolgerungen

Generell ist festzustellen, dass die das Futteraufnahmeverhalten charakterisierenden Parameter, die auf das Einzeltier bezogen gemessen und aufgezeichnet werden und zur Vorhersage der Futteraufnahme genutzt werden sollen, von sehr vielen Einzelbedingungen abhängig sind und in unterschiedlicher Weise im Laktationsverlauf von diversen Faktoren beeinflusst werden können. Dennoch scheint es möglich, Zusammenhänge zwischen verschiedenen messbaren Parametern auf Einzeltierebene herauszuarbeiten und für Vorhersagemodelle nutzbar zu machen. So ergaben sich aus den vorliegenden Untersuchungen diverse statitisch gesicherte Zusammenhänge zwischen den Parametern Anzahl der Fressplatzbesuche, Besuchdauer, tägliche Gesamtfressdauer sowie tägliche Trockensubstanzaufnahme. Diese Zusammenhänge variierten im Verlauf der Frühlaktation. Dabei war ein starkes Ansteigen der Werte aller genannten Parameter im Zeitraum der zweiten bis vierten Laktationwoche vorzufinden. Einzelne Parameter steigen in unterschiedliche Dauer der Fressplatzbesuche bereits ab 9. Laktationswoche eine stagnierende bzw. Rückläufige Tendenz. Abschließend ist dazu die auffassung zu vertreten, dass insbesondere die durchschnittliche Dauer der Fressplatzbesuche geeignet scheint, Rückschlüsse hinsichtlich der trockensubstanzaufnahme ziehen zu können. Dazu sind mathematische Modelle zu entwickeln, die auf der Ebene des Einzeltieres Veränderungen im zeitlichen Verlauf quantifizieren.

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CHAPTER 5

Variations in the feeding behaviour of high-yielding dairy cows in relation to parity during early to peak lactation

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Abstract

The objective of this study was to compare the feeding behaviour of high-yielding dairy cows in relation to parity during early to peak lactation and to determine whether or not there was any relationship between variables describing their feeding behaviour and total feed intake. Information concerning feed intake of each individual dairy cow is especially valuable for the herd management, particularly in early lactation. However, technical requirements for implementation are rarely given. Therefore, relationships between feed intake and time-related feeding behaviour parameters are of special interest. Time-related parameters could be recorded on farm conditions adapted sensor technology. Seventy high-yielding lactating dairy cows in different parities (23 in the first lactation, 17 in the second lactation, and 30 in the third-and-more-lactation) with an average of 11000 kg milk yield per year were fed using automatic feeders from the 2nd to the 15th week of lactation. 222,231 recorded visits were analysed in three equal periods [period 1 = 7-39, period 2 = 40 – 72, and period 3 = 73 – 105 days in milk (DIM)] during early to peak lactation. Visits were clustered in meals based on the estimated meal criterion (28.5 min), which was calculated using a mixture distribution model by fitting the natural logarithm frequency distribution of the intervals between visits. Based on the meal criterion, our study yielded the following values for meal frequency, number of visits per meal, meal duration, meal size, daily mealtime, daily dry matter intake (DMI), and feeding rate over the course of the study were 7.61 ± 1.7 (mean ± SD) meals/d, 4.02 ± 1.68 visits/meal, 37.07 ± 13.77 min/meal, 2.96 ± 0.92 kg DM /meal, 272.18 ± 82.14 min/d, 21.46 ± 4.29 kg DM /d, and 85.56 ± 28.77 g DM/min, respectively. Younger cows had more meals per day, more number of visits per meal, longer daily mealtime but a smaller meal size, lower daily DMI, and lower feeding rate compared to older cows ($P < 0.001$). Meal duration and meal size were highly related to the number of visits at feeder per meal (R^2 =

0.55-0.63; P<0.001, R^2 = 0.25-0.39; P<0.001 respectively). In addition, meal size was highly related to meal duration (R^2 = 0.59-0.72; P<0.001). Results from this study, which analysed data based on meal criterion, showed a higher correlation between the selected parameters of feeding behaviour and feed intake compared with our previous study (Kaufmann et al., 2007), which analysed data based on individual visits on the feeder without calculating the meal criterion. The high correlation between meal duration and meal size could be used to estimate feed intake. This means that the measurement of short-term feeding behaviour such as meal duration could be utilised to estimate the feed intake. The meal duration may be analysed by using a transponder on the animal and an antenna in the feed alley.

(**Key words**: feeding behaviour, feed intake, parity, dairy cow)

5.1 Introduction

Feeding behaviour is an area of research which truly links nutritional and behavioural sciences. Information concerning the feed intake of each individual dairy cow is especially valuable for herd management. However, the technical equipment to measure the feed intake of each individual cow is expensive. Therefore, relationships between feeding behaviour parameters, which can be recorded on farm conditions adapted with sensor technology, and feed intake are of special interest. The average daily intake of cows is frequently considered to be the result of one or more constraints, especially during early lactation (Tolkamp et al., 2000). Average daily intake is, at least in a purely formal sense, the result of the average number of feeding bouts per day and the average size of those bouts. If limited intake is a result of time spans shorter than a day, then a study of short-term feeding behaviour could improve the understanding and prediction of daily intake (Dado and Allen, 1994; Forbes, 1985; Gill and Rommey, 1995). The feeding behaviour of most animals can be recorded as events that include bites or visits to a feeder (Nielsen, 1999). Tolkamp et al. (1998, 2000) and

DeVries et al. (2003) argued that dairy cows divide their feeding time into a series of meals separated by non-feeding intervals. These researchers developed a model to define the meal criterion by using the distribution of a large sample of intervals between visits to the feeders. The meal criterion is defined as the longest non-feeding interval that is still considered an interval within a meal.

Previous investigations of the effects of parity and stage of lactation on changes in feeding behaviour have been limited to cows during early lactation. DeVries et al. (2003) reported that cows were highly consistent in some characteristics of feeding behaviour. In our previous study (Kaufmann et al., 2007), we analysed all visits to a feeder without calculating meal criterion, and in this paper, we analysed the feeding behaviour and feed intake parameters after clustering the visits in meals based on the estimated meal criterion. The objective of the recent study was to compare the feeding behaviour and feed intake parameters of high-producing dairy cows in relation to their parity during early to peak lactation and to determine whether or not there was a relationship between these variables.

5.2 Materials and methods

5.2.1 Animal, housing and feeding

Data were collected from a feeding experiment, which was performed in the Centre of Research for Animal Husbandry and Technology of the Regional Office for Agriculture and Horticulture (Sachsen-Anhalt, Iden) from 10 July 2005 to 16 January 2006. For this study, data were collected from 70 lactating dairy cows: 23 cows in the first lactation, 17 cows in the second lactation, and 30 cows in the third-and-more-lactation (third to seventh lactation), with a body weight (BW) of 572 ± 42 (mean ± SD), 637 ± 38, and 716 ± 56 kg, respectively. Fifteen cows (in the first lactation) were crossbreds of German Holstein Friesian and Brown

Swiss, and 55 cows were purebred German Holstein Friesian. The cows were housed in a free-stall barn. The ratio between cows and feeder was 2:1. Feeder units were equipped with electronic identification of individual cows and an electronic control. The cows could enter any feeder. Cows were fed ad libitum a TMR (based on the objectives of a feeding experiment) with an average of 6.99 MJ NEL/kg DM, 16.68% crude protein and 17.46% crude fiber. The feeders were accessible throughout the day, except during milking and cleaning (0700 to 0800 h). Chemical analyses of the ration were conducted weekly. The cows were milked three times a day (0400, 1200, and 2000 h) and the daily milk yield was recorded for each individual cow over the course of the study. Throughout the study, the animals had an average milk yield of 38.83 ± 7.96 (mean ± SD) kg/d with 3.93% ± 0.60 fat and 3.24% ± 0.26 protein.

5.2.2 Measurements

Individual analyses of feeding behaviour and feed intake were carried out by using an automatic feeder and electronic identification of individual cows. Each feeder was equipped with an access gate, which could be programmed to allow a specific cow to access a trough, and two infrared sensors, which recorded the presence of a cow in the feeder. All experimental animals were fitted with a passive transponder, which was encased in a plastic ear tag and attached to the bottom of the collar. The time of the beginning and end of each visit was recorded. Additionally, the weight of the cow at the beginning and end of the visit was recorded. A visit was defined as the time spent by an individual cow with her head in one of the troughs, regardless of how the cow spent that time. Intervals between visits were calculated for each cow from the end of a visit to the beginning of the next. The minimum interval was 1 sec. To determine whether a visit was part of the previous meal, part of the next meal or formed a meal itself, meal criteria were calculated. Visits were grouped into meals.

Individual meal criteria were calculated for each cow and a pooled criterion was calculated using the intervals from all cows for the whole experimental period. Meal criteria were calculated based on methods from Tolkamp et al. (1998) and DeVries et al. (2003) by fitting a mixture of two normal distributions to the distributions of natural logarithm (Ln)-transformed lengths of intervals between visits. Maximum likelihood estimation was used to fit these mixture distributions. In the present study, the first distribution showed the intervals within one meal and the second one represented those between meals. The meal criterion was determined as the point at which the distribution curve of inter-meal intervals intersected the distribution curve of intra-meal intervals. Based on the meal criteria, meal frequency (meals/d) was calculated by counting the number of intervals per day that exceeded the length of the meal criterion and adding one. The meal duration (min/meal) was calculated as the time from the beginning of the first feeding event until an interval between events that exceeded the meal criterion – this interval was not included in the calculation. The daily mealtime (min/d) was simply the sum of the meal durations in a day. The meal size (kg/meal) was the total amount of feed ingested during each meal. The daily DMI (kg/d) was the sum of the meal sizes in a day. To determine if the use of a pooled meal criterion is appropriate for future calculations, we regressed the daily estimates of feeding behaviour characteristics by using the individual meal criteria onto those based on the pooled criterion.

5.2.3 Statistical analysis

The individual animal was considered as the observational unit in all analyses. All data were analysed using PROC GLM in SAS (SAS Institute, 2003). For each animal, meal frequency (meal/d), meal duration (min/meal), meal size (kg/meal), daily mealtime (min/d), daily DMI (kg/d), and feeding rate (gDM/min) was calculated. To test for effects of parity and stage of

lactation on feeding behaviour characteristics and feed intake parameters, we used a linear model:

$Y_{ij} = \mu + PA_i + PE_j + PA_i*PE_j + e_{ij,}$

where

Y_{ij} = observation of the interested variable

μ = overall mean

PA_i = effect of parity i (i = 1, 2, and 3)

PE_j = effect of period j (j = 1, 2, and 3)

PA_i*PE_j = interaction between parity i and period j

e_{ij} = error term.

Correlations between feeding behaviour characteristics and feed intake were calculated using the regression procedure of SAS (SAS Institute, 2003).

5.3 Results

Meal criteria were calculated for each cow over the course of the study and varied among cows from 13 min to 53 min with an average of 27.27 min (SD = 6.72). The meal criterion from pooled data (for all cows and over the course of the study) was 28.5 min (Figure 3.2). The correlation between pooled and individual estimates for meal frequency and daily mealtime is illustrated in Figure 5.1. The estimates of all parameters using both an individual criterion and a pooled criterion were very similar. Therefore, we used the pooled meal criterion in all subsequent analyses. Based on this meal criterion, we found an average meal frequency of 7.61 ± 1.7 (mean ± SD) meals/d, number of visits per meal of 4.02 ± 1.68 visits/meal, meal duration of 37.07 ± 13.77 min/meal, daily mealtime of 272.18 ± 82.14 min/d, meal size of 2.96 ± 0.92 kg/meal, daily DMI of 21.46 ± 4.29 kg/d, and feeding rate of 85.56 ± 28.77 g DM/min over the course of the study.

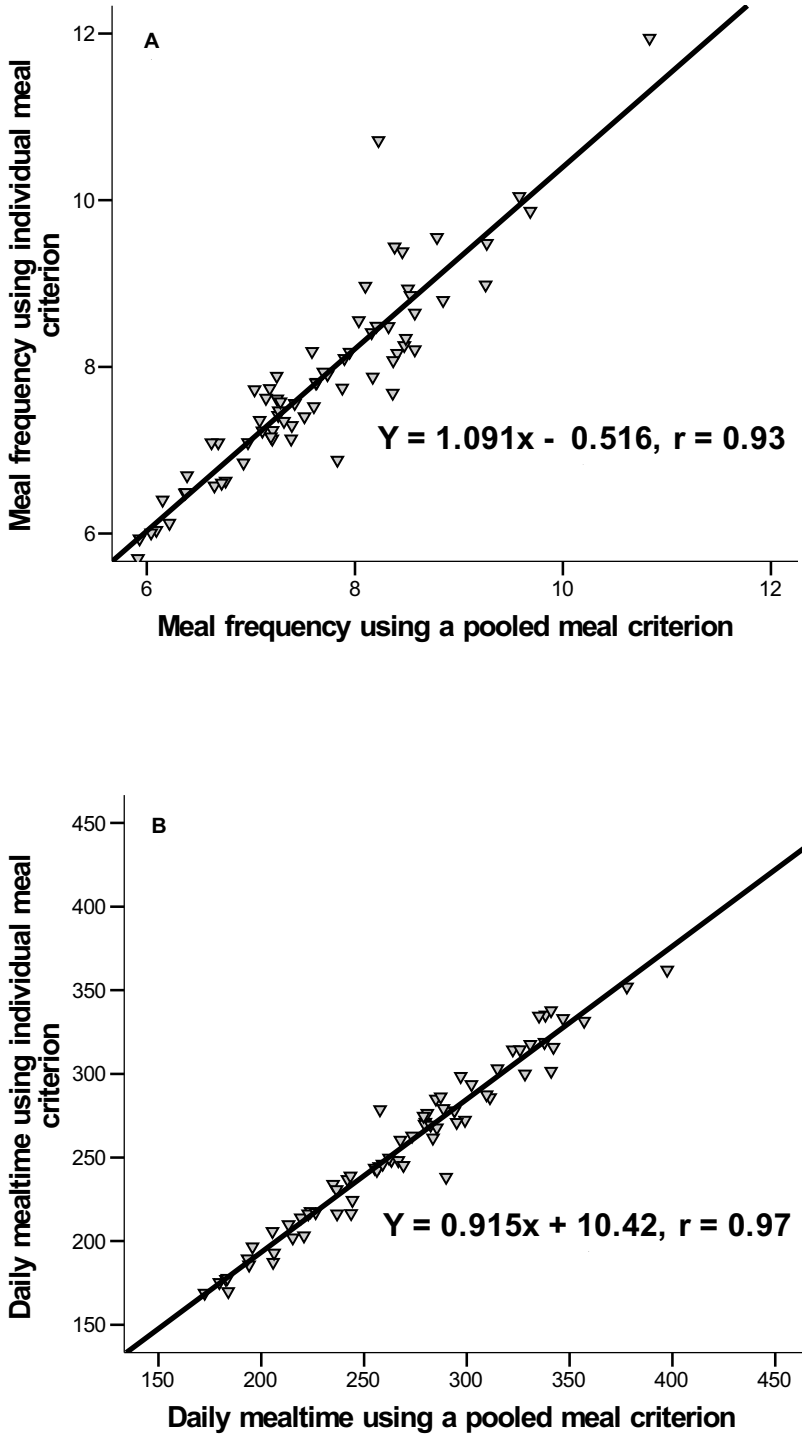

Figure 5.1 The relationship of meal frequency (A) and daily mealtime (B) calculated with a pooled meal criterion (28.5 min) and with individual meal criterion.

Table 5.1 Mean values of feeding behaviour characteristics and feed intake parameters of 70 lactating dairy cows in relation to their parities from Period[3] 1 to Period 3.

	1st lactation			2nd lactation			≥ 3rd lactation				P[1]<		
	Period 1	Period 2	Period 3	Period 1	Period 2	Period 3	Period 1	Period 2	Period 3	SEM[2]	Parity	Period	Interaction[3]
Meal frequency	8.89	8.50	7.90	7.61	7.66	7.22	7.34	6.95	6.83	0.07	***	***	***
Visits per meal	3.67	4.33	4.87	4.03	4.09	4.88	3.48	3.36	4.09	0.02	***	***	***
Meal duration (min/meal)	31.02	37.07	42.72	37.90	39.75	43.66	29.90	35.42	40.45	0.55	***	***	***
Daily mealtime (min/d)	270.30	303.93	325.39	278.91	295.30	305.12	213.77	239.29	264.06	3.14	***	***	***
Meal size (kg/meal)	1.89	2.33	2.64	2.73	3.15	3.23	3.83	3.60	3.85	0.03	***	***	***
Daily DMI (kg/d)	16.45	20.24	20.12	19.20	23.54	24.27	20.23	22.73	23.00	0.12	***	***	***
Feeding rate (gDM/min)	66.81	66.30	65.15	78.02	84.39	83.28	100.94	106.69	99.91	0.88	***	***	***

[1]*** = significant difference at level 0.001

[2]SEM = the standard error of means

[3]Period 1 = from 7 to 39, Period 2 = from 40 to 72, and Period 3 = from 73 to 105 d of lactation

The lactation stages were compared in terms of feeding behaviour characteristics and feed intake parameters (Table 5.1). Parity, period and interaction between parity and period had a significant effect on all feeding behaviour characteristics and feed intake parameters. Cows in the first lactation had more meals per day than cows in other parities ($P < 0.001$). The meal frequency was significantly decreased in all parities from period 1 to period 3. The number of visits per meal was significantly different between parities and increased during lactation. The mean of meal duration rose from period 1 to period 3 ($P < 0.001$). Cows in the first lactation spent an average of approximately 5 h per day (270 to 325 min) at the feeders whereas cows in the third-and-more-lactation spent only 4 h per day (214 to 264 min) at the feeders. Similar to meal duration, daily mealtime increased from period 1 to period 3 ($P < 0.001$). Cows in the first lactation had a smaller meal size than cows in the other parities ($P <0.001$). Younger cows (first lactation) had less daily DMI than older cows. Cows in the first lactation had a significant lower feeding rate than older cows.

Over the course of the study, the correlation between the number of visits per meal and the meal duration was significant ($r = 0.57$, $P < 0.01$). However, we found a low correlation between the number of visits per meal and the meal size ($r = 0.14$). The correlation between meal duration and meal size was significant ($r = 0.51$, $P < 0.01$). The coefficients of determination (R^2) between the number of visits per meal, meal duration and meal size as well as between meal duration and meal size over the time are shown in Figure 5.2.

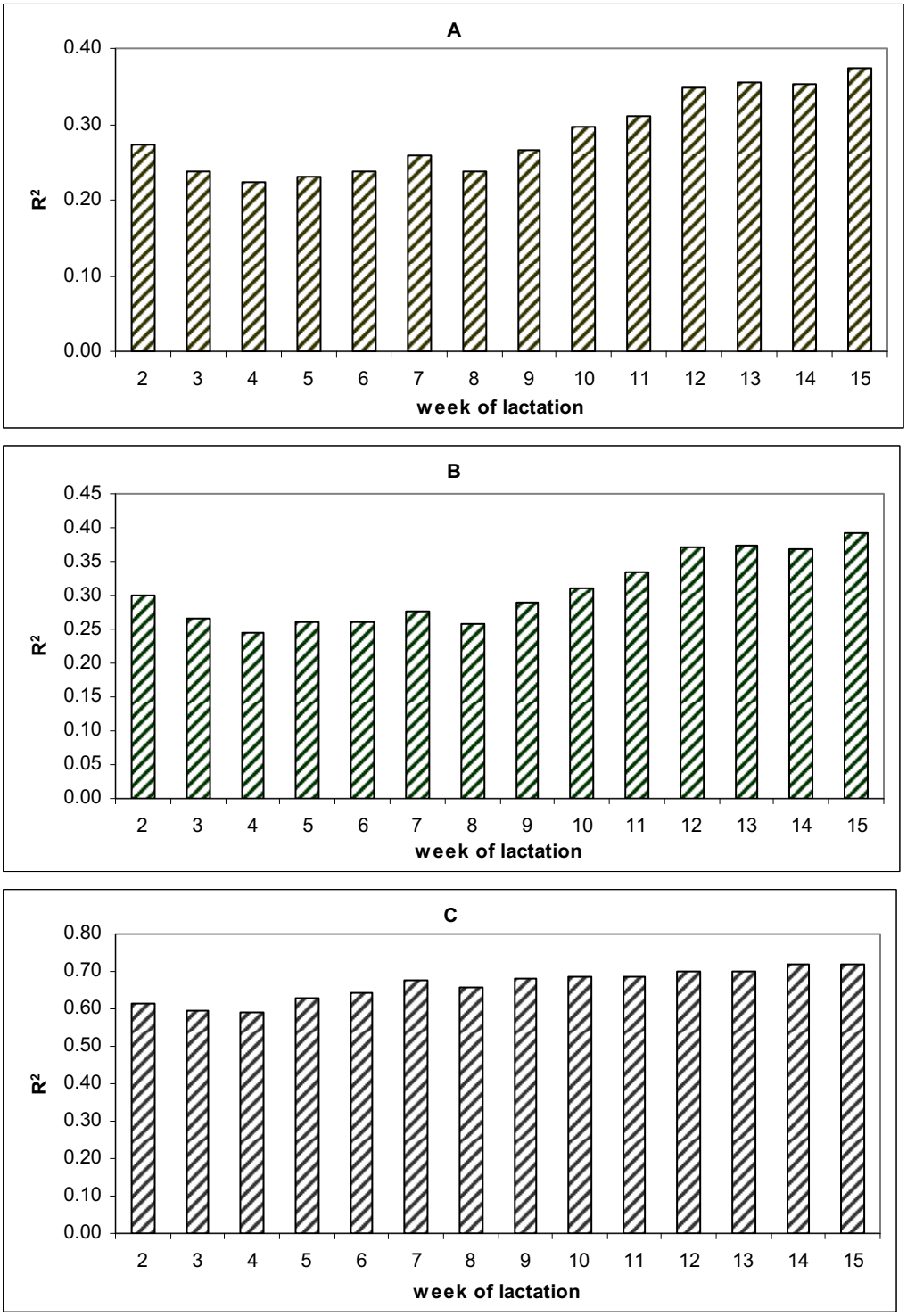

Figure 5.2 Coefficients of determination (R^2) for number of visits per meal and meal duration (A), number of visits per meal and meal size (B), and meal duration and meal size (C) during early to peak lactation.

Meal duration was significantly related to the number of visits per meal (R^2 = 0.55-0.63; P<0.001). The relationship between the number of visits per meal and meal size were found from R^2 = 0.25 to 0.39. Meal size during early lactation was highly related to meal duration. Coefficients of determination (R^2) between meal duration and meal size increased from 0.59 (P<0.001) in the first four weeks of lactation to 0.72 (P<0.001) in the 15th week of lactation.

5.4 Discussion

Many researchers (Tolkamp et al., 1998; Friggens et al., 1998; DeVries et al., 2003) suggest that the use of meals rather than the visits is appropriate for certain types of analyses, particularly in relation to the short-term regulation of feed intake. This supports the results of the present study, in which data were analysed based on meal criterion and showed higher correlation between feeding behaviour, compared with the results of our previous study (Kaufmann et al., 2007), where individual visits at the feeders were analysed without calculating the meal criterion. In this study, the meal criteria were similar to meal criteria estimated by other authors. Tolkamp et al. (1998), Tolkamp and Kyriazakis (1999), and Yeates et al. (2001) found meal criteria ranging from 26.4 to 63.7 min; Yeats et al. (2001) calculated a meal criterion of 29 min; Tolkamp et al. (2000) estimated meal criteria ranging from 24 to 28 min for different groups of cows; DeVries et al. (2003) reported 27.7 min (8.4 to 52.5 min for individual animals) for the meal criterion from pooled data. DeVries et al. (2003) used the pooled meal criterion and found an average meal frequency of 7.3 ± 1.5 (mean ± SD) meals/d, meal duration of 47.1 ± 13.0 min/meal, and daily mealtime of 332.3 ± 69.2 min/d. Tolkamp et al. (2000) studied the short-term feeding behaviour of dairy cows from early to mid lactation and reported an average meal frequency of 6.1 meals/d, meal duration of 36.9 min/meal, and daily mealtime of 225.1 min/d. The values for meal frequency, meal duration, and daily mealtime found in the current study were similar to those reported by

DeVries et al. (2003) and Tolkamp et al. (2000). We based our calculation of the meal criterion on the same method described by these researchers. Dado and Allen (1994) found an average meal frequency of 11.9 meals/d, meal duration of 25.9 min/meal, and daily mealtime of 294 min/d. However, these results differ from our findings regarding meal frequency and meal duration. The variability between the results may be due to different methods of calculation, for example, Dado and Allen used 7.5 min as the meal criterion. The shorter meal criterion used by Dado and Allen (1994) led to a higher meal frequency but did not change the total daily mealtime (DeVries et al., 2003). Another possible explanation for these differences may include the difference in experimental conditions. Dado and Allen (1994) studied 12 cows on the 63 DIM for 10 days in a tie stall. There was substantial between-cow variation for all characteristics of feeding behaviour for all three time periods. DeVries et al. (2003) studied the effect of the stage of lactation [period 1: 35 ± 16, period 2, 57 ± 16, and period 3, 94 ± 16 (mean ± SD) DIM] on the feeding behaviour of dairy cows. They found significant differences in feeding behaviour between period 1 and period 2 but no differences between period 2 and 3. These findings are in agreement with our results, which showed significant changes in feeding behaviour and feed intake at three different time periods during early lactation. Studies of the feeding behaviour of dairy cows considering the number of lactation showed a great variation. Cows in the first lactation tended to have more meals per day and spent more time at the feeder but consumed less than cows in the third-and-more lactation. Older cows consumed more DM per min than younger cows. Only a few studies have compared the differences in feeding behaviour between parity groups. Dado and Allen (1994) found a significant difference in DMI between parity groups. Bowman et al. (2003) reported that primiparous cows spent more time eating and had a smaller meal size as well as lower DMI compared to multiparous cows. However, the number of meals per day was similar for both parity groups. This is confirmed by findings in this study, which showed that the duration of the daily mealtime of younger cows was increased but the daily DMI was lower

compared to older cows. Although the number of visits per meal was similar between cows in the first and second lactation, there was a significant difference between cows in the first lactation and cows in the third-and-more-lactation. Bowman et al. (2003) found a significant difference in daily time eating (347 vs. 323 min/d) and daily DMI (20.50 vs. 23.00 kg/d) but no difference in the number of meals per day (13.4 vs. 13.5) between primiparous and multiparous cows. Some differences between our results and findings of Bowman et al. (2003) may be partially caused by differences in the definition of visit and meal criterion. Bowman et al. (2003) defined a visit as eating activity greater than 30 s and more than 300g of feed being removed from the feeder, and also meals within close proximity had to be greater than 10 min apart to be considered separate and distinct meals. By contrast, in the current study, a visit was defined as the time spent by an individual cow with her head in one of the trough, regardless of how the cow spent that time. The visits which separated by intervals shorter than or equal 28.5 min were grouped into meals. Possible explanations for the different results for younger and older cows might be due to differences in rumen volume, and/or that older cows do eat quicker and ruminate for a longer period of time. This fact is also reported by other authors (Dado and Allen, 1994; Bowman et al., 2003). In addition, rumen capacity tends to be smaller for primiparous cows. The meal size may be limited by rumen volume. Behavioural studies suggest that different mechanisms may control individual meals and the total daily DMI of cows (Forbes, 1995; Dado and Allen, 1994; Bowman et al., 2003). Van Soest (1994) stated that there is a strong relationship between body weight and gastrointestinal capacity in herbivores. Body weight was reported to be the most important factor explaining variation in DMI of first lactating cows (Kertz et al., 1991). Our results regarding the feeding rate (66.09 vs. 81.90 and 102.52 g DM/min for cows in the first-, second-, and third-and-more-lactation, respectively) were similar to findings of Dado and Allen (1994) who reported that a feeding rate for multiparous cows was over 80 g of DM/min compared to 69.5 g of DM/min for primiparous cows. Bowman et al. (2003) found also an

average feeding rate of 71.9 g DM/min for multiparous cows and 59.4 g DM/min for primiparous cows. Some variation in results among studies may be due to different production levels, behaviour definition description, chemical composition and physical form of the diet, management, and environment (Dado and Allen, 1994; Forbes, 1995). Behaviour at the feeder is often affected by social dominance. Dominant cows tend to spend more time eating in a competitive situation than cows with a lower social rank, if feeder space is restricted (Alberight, 1993). In a competition situation, cows consume more feed but spend less time per day for feed intake (Olofsson, 1999). In the current study, the ratio of 2 cows per feeder might lead to a competitive situation, which can affect feeding behaviour characteristics. However, Jackson et al. (1991) found that up to a ratio of 3.5 cows per feeder there was no effect on daily intake.

The relationship between the individual behavioural characteristics indicated several changes in dairy cattle feeding behaviour during early lactation. A relationship between the number of visits per meal, meal duration ($P<0.001$) and meal size ($P<0.001$) can be used to predict daily mealtime and daily DMI by recording the number of visits per meal or day. Coefficients of determination between meal duration and meal size during early lactation were high (R^2 = 0.59-0.72; $P<0.001$). The close correlation between meal duration and meal size could be used to estimate feed intake.

5.5 Conclusion

Information concerning the feed intake of each individual dairy cow is especially valuable for herd management particularly during early lactation. Results from the current study, compared with our previous one (Kaufmann et al., 2007), demonstrated that the identification of a biologically relevant meal criterion for the feeding behaviour of lactating dairy cows is necessary to evaluate visits at the feeders. Based on this procedure, we found high coefficients

of correlations between parameters of feeding behaviour and feed intake. For example, the high correlation between short-term feeding behaviour such as meal duration and meal size could be used to estimate feed intake.

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CHAPTER 6

Relationship between feeding behaviour and feed intake of dairy cows depending on their parity and milk yield

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Abstract

To investigate the relationship between the parameters of feeding behaviour and feed intake, 70 lactating dairy cows (23 primiparous and 47 multiparous) were monitored from the 2nd to 15th week of lactation. Data were collected by using an automatic feeder and electronic identification of individual cows from 10 July 2005 to 16 January 2006. The resulting data of the cows in primiparous and multiparous condition were categorised into groups based on the mean of their milk yield over the first 15 weeks of lactation: primiparous cows with below-average milk yield (LP) and above-average milk yield (HP) with an average of 28.44 and 34.31 kg energy-corrected milk (ECM) per day, respectively, and multiparous cows with below-average milk-yield (LM) and above-average milk-yield (HM) with an average of 38.70 and 44.49 kg ECM per day, respectively. The parameters of feeding behaviour were calculated based on the estimated meal criterion from pooled data. Parity, level of milk yield, and interaction between parity and level of milk yield had significant effects on the feeding behaviour (meal frequency and daily mealtime) and feed intake parameters (meal size and daily DMI). There was no significant difference in meal duration either between primiparous and multiparous cows or between LP and HP. However, a significant difference between LM and HM was observed. Cows in HM had shorter feeding times but a larger meal size, higher DMI, and feeding rate. Moreover, these cows displayed a stronger correlation between meal duration, daily mealtime and daily feed intake ($r = 0.37$ and 0.50, $P<0.001$, respectively) than any other cow or group of cows of the study. Meal duration, daily mealtime, meal size and daily DMI increased on average about 32%, 20%, 35%, and 22% respectively, considering all milk-yield groups from the 2nd to 15th week of lactation.

(**Key words**: feeding behaviour, feed intake, parity, milk yield, dairy cows)

Abbreviation key: LP and **HP =** low and high milk yield in primiparous cows, respectively, **LM** and **HM** = low and high milk yield in multiparous cows, respectively, **PP** = post partum, **DIM** = day in milk, **ECM** = energy-corrected milk.

6.1 Introduction

A high feed intake of dairy cows is essential to maintain high milk production, particularly during early lactation, and to keep the cows in good condition. Considerable research to date has focused on improving the DMI of lactating dairy cows by changing the nutrient composition of feeds. However, the DMI of group-housed lactating dairy cows is also affected by the feeding behaviour of the cows, which is modulated by the environment, management practices, health, and social interactions (Grant and Albright, 2001; DeVries et al., 2005). Previous studies have demonstrated that milk production is related highly and positively to feed intake (Dado and Allen, 1994; Shabi et al., 2005; Kononoff et al., 2006). Chase (1993) indicated that the first step in developing a nutrition programme for high-producing herds is to design a feeding system that allows cows to achieve and maintain high DMI. Grant and Albright (2000) stated that the time spent eating, and the pattern of meals, can obviously have important effects on the daily feed intake of dairy cows. The development of computerised systems for recording the feed intake of dairy cattle has made it possible to increase information on feeding behaviour (Nielsen, 1999). The analysis of feeding behaviour has been found to be appropriate when studying the regulation of feed intake on a short-term basis (Dürst et al., 1993; Forbes, 1985; Tolkamp et al., 2000). Kertz et al. (1991) revealed that older cows ate faster than primiparous cows during the first 5 weeks p.p.

The identification of behavioural differences between high-producing cows and low-producing cows is also of significant value. Such information may help to describe the mechanism involved in high intake and production. To the best of our knowledge, there are no studies addressing the effect of cows' yield level regarding their milk yield on feeding behaviour and feed intake, particularly in early lactation. Therefore, the purpose of this study was to investigate the feeding behaviour characteristics and feed intake parameters as well as their relationships regarding lactating dairy cows depending on their parity and their level of milk yield.

6.2 Material and methods

6.2.1 Animals, housing, and feeding

Data were collected during a feeding experiment between 10 July 2005 and 16 January 2006. The experiment took place in the Centre of Research for Animal Husbandry and Technology of the Regional Office for Agriculture and Horticulture (Sachsen-Anhalt, Iden). Seventy high-producing dairy cows [23 primiparous and 47 multiparous with 572 ± 42 and 687 ± 63 kg of BW (mean ± SD), respectively] were studied for this experiment. The cows were housed in a free-stall barn. The ratio between cows and feeder was 2:1. The feeder units were equipped with electronic identification of individual cows and an electronic control. The cows could enter any feeder. The study was conducted between the 7th and 105th day of lactation. Cows were fed a TMR (based on the objectives of a feeding experiment) consisting of 24% corn silage, 31% grass silage, 5% grass and alfalfa hay, and 40% concentrate on a DM basis. The ration contained an average of 6.99 MJ NEL/kg, 16.68% CP and 17.46% CF, and was fed once a day between 06.00 and 08.00 a.m. ad libitum. The cows were milked three times a day

(04.00 a.m., 12.00 p.m., and 08.00 p.m.) and the individual milk yields were recorded throughout the study. Both the content of the milk (fat, protein, and lactose) and the chemical composition of the feedstuffs were analysed weekly.

6.2.2 Measurement

Individual primary measurements, including number of visits and visit duration to the feeder, interval between visits as well as individual feed consumption at each visit were monitored continuously throughout the study by means of a computerised monitoring system described in our previous studies (Kaufmann et al., 2007; Azizi et al., submitted). To determine whether a visit was part of the previous meal, part of the next meal or formed a meal itself, a meal criterion was calculated. Our estimation of the meal criterion was based on a method developed by Tolkamp et al. (1998) and DeVries et al. (2003). For our pooled data (for all animals and over the course of study), the meal criterion was 28.5 min on average. A more detailed description can be found in our previous paper (Azizi et al., submitted). To explain briefly, the meal criterion was calculated by fitting a combination of two normal distributions to the distributions of log-transformed lengths of the intervals between visits. Maximum likelihood estimation was used to fit these combined distributions. In the present study, the first distribution showed the intervals within meals and the second one represented those between meals. The meal criterion was determined as the point at which the distribution curve of inter-meal intervals intersected the distribution curve of intra-meal intervals. Based on this meal criterion, the visits were clustered into meals. Then, meal frequency, meal duration, and daily mealtime were calculated. The meal frequency (meals/d) was calculated by counting the number of intervals per day that exceeded the length of the meal criterion and adding one.

The meal duration (min/meal) was calculated as the time from the beginning of the first feeding event until, but not including, an interval between events that exceeded the meal criterion.

The daily mealtime (min/d) was simply the sum of the meal durations in a day. The feed intake (meal size and daily DMI) was calculated based on dry matter (DM). The feeding rate was calculated as total daily DMI divided by total daily mealtime. ECM was calculated according to the following formula (Tyrell and Reid, 1965):

ECM (kg/d) = [(41.63 * milk fat (%) + 24.13 * milk protein (%) + 21.60 * milk-lactose (%) – 11.72)* milk yield (kg/d)] /340

6.2.3 Statistical Analyses

Analyses were carried out on the individual animal as the observational unit using PROC GLM in SAS (SAS Institute, 2003). Data of cows in primiparous and multiparous condition were categorised into groups based on the mean of their milk yield over the first 15 weeks of lactation: primiparous cows with below-average milk yield (LP) and above-average milk yield (HP) with an average of 28.44 and 34.31 kg ECM per day, respectively, and multiparous cows with below-average milk yield (LM) and above-average milk yield (HM) with an average of 38.70 and 44.49 kg ECM per day, respectively. To test for effects of parity and milk yield level on feeding behaviour characteristics and feed intake parameters, we used a linear model:

$Y_{ij} = \mu + P_i + M_j + P_i*M_j + e_{ij,}$

where

Y_{ij} = observation of the variable of interest

μ = overall mean

P_i = effect of parity i (i = 1, primiparous to 2, multiparous)

M_j = effect of milk yield level j (j = 1, low to 2, high milk yield)

P_i*M_j = interaction between parity i and milk yield level j

e_{ij} = error term

Correlations between feeding behaviour and feed intake parameters were calculated using PROC CORR in SAS (SAS Institute, 2003).

Changes of each parameter for all groups of cows within three equal time periods (Period 1 = 7-39, Period 2 = 40-72, and Period 3 = 73-105 d of lactation) over the course of the study are shown by box plots, which represent the median, interquartile range, and extreme cases of individual variables.

6.3 Results

Parity, milk yield level, and interaction between parity and milk yield level had significant effects on all characteristics of feeding behaviour and feed intake except meal duration (Table 6.1). The meal frequency of multiparous cows was lower than of primiparous cows (P<0.001). Cows with a high milk yield had fewer meals per day than cows with a low milk yield (P < 0.001). No significant difference in meal duration between primiparous and multiparous cows was found (P = 0.63). However, the differences between milk yield groups (P < 0.001) as well as the interaction between parity and milk yield level were significant (P < 0.001). Over the time of the study, the daily mealtime of primiparous cows increased by about 40 min compared to multiparous cows (P < 0.001). The daily mealtime of cows with a high milk yield level compared to cows with a low milk yield level (P < 0.001). Multiparous cows ate one kg DM per meal more than primiparous cows. In addition, the differences in meal size between milk yield groups were significant (P <0.001). Cows in HM ate approximately 1.2 kg DM per meal more than cows in LP (3.42 vs. 2.24, P<0.001). The daily DMI of multiparous

cows increased by 4.21 kg compared to primiparous cows (P<0.001). Cows in HM ate ca. 5 kg DM per day more than cows in LP (23.44 vs. 18.28, P<0.001). The feeding rate of multiparous cows was about 30 g DM/min higher than that of primiparous cows (95.06 vs. 66.09, P<0.001).

Table 6.1 Mean values (± SE) feeding behaviour characteristics, feed intake and energy corrected milk yield of lactating dairy cows.

	Primiparous		Multiparous		P-Value		
	LP[1]	HP	LM	HM	Parity	Milk-yield	Interaction[2]
Cows, no.	13	10	24	23			
ECM[3]	28.44 ± 0.16	34.31 ± 0.18	38.70 ± 0.12	44.49 ± 0.12	0.000	0.000	0.746
Meal frequency per day	8.50 ± 0.04	8.35 ± 0.05	7.34 ± 0.03	7.07 ± 0.03	0.000	0.000	0.105
Meal duration (min/meal)	36.97 ± 0.38	36.87 ± 0.44	38.48 ± 0.28	35.72 ± 0.29	0.629	0.000	0.000
Daily Mealtime (min/d)	300.85 ± 2.20	298.60 ± 2.51	271.97 ± 1.62	244.62 ± 1.66	0.000	0.000	0.000
Meal size (kg/meal)	2.24 ± 0.02	2.35 ± 0.03	3.15 ± 0.02	3.42 ± 0.02	0.000	0.000	0.000
Daily DMI (kg/d)	18.28 ± 0.11	19.08 ± 0.12	22.27 ± 0.12	23.44 ± 0.08	0.000	0.000	0.054
Feeding rate (gDM/min)	64.67 ± 0.69	67.92 ± 0.79	88.34 ± 0.51	102.07 ± 0.52	0.000	0.000	0.000

[1]LP = cows in primiparous with low milk-yield; HP = cows in primiparous with high milk-yield; LM = cows in multiparous with low milk-yield; HM = cows in multiparous with high milk-yield.

[2]Interaction = Interaction between Parity and Milk-yield.

[3]ECM = Energy-corrected milk (kg/d).

The correlations between feeding behaviour characteristics and daily DMI for all cows and cows in each milk yield group are shown in Table 6.2.

Table 6.2 The correlation between feeding behaviour characteristics and daily DMI of lactating dairy cows with different parity and milk yield level.

		Daily DMI (kg/d)				
Measure		All cows	LP[1]	HP	LM	HM
n[2]		6930	1287	990	2376	2277
Meal frequency in day	r	-0.089	0.029	0.099	0.124	0.115
	P	0.001	0.297	0.02	0.001	0.001
Meal duration (min/meal)	r	0.239	0.222	0.287	0.205	0.365
	P	0.001	0.001	0.001	0.001	0.001
Daily mealtime (min/d)	r	0.179	0.314	0.361	0.287	0.496
	P	0.001	0.001	0.001	0.001	0.001
Meal size (kg/meal)	r	0.699	0.528	0.638	0.536	0.618
	P	0.001	0.001	0.001	0.001	0.001

[1]LP = cows in primiparous with low milk yield; HP = cows in primiparous with high milk yield; LM = cows in multiparous with low milk yield; HM = cows in multiparous with high milk yield

[2]n = Total number of observations.

The correlations between meal frequency and daily DMI were low. The correlation between meal duration and daily DMI was higher in both higher yielding groups than in LP and LM (r = 0.37 and 0.29 vs. 0.21 and 0.22, respectively). Similar to meal duration, the daily mealtime related significantly with the daily DMI in all milk yield groups (in the range of 0.29 to 0.50). The correlation between meal size and daily DMI was also closer in both higher yielding groups than that in LP and LM (r = 0.64 and 0.62 vs. 0.53 and 0.54, respectively).

The trend of changed feeding behaviour and feed intake parameters over the course of the study for each milk yield group is shown in Figures 6.1 and 6.2. Depending on the milk yield level, in all three periods, the primiparous cows had a higher meal frequency than the multiparous cows. Meal duration constantly increased by about 32% for all milk yield groups over the course of study. There was an increase in daily mealtime of about 50 min (from 30 to 53 min) for cows in all milk yield groups during early lactation.

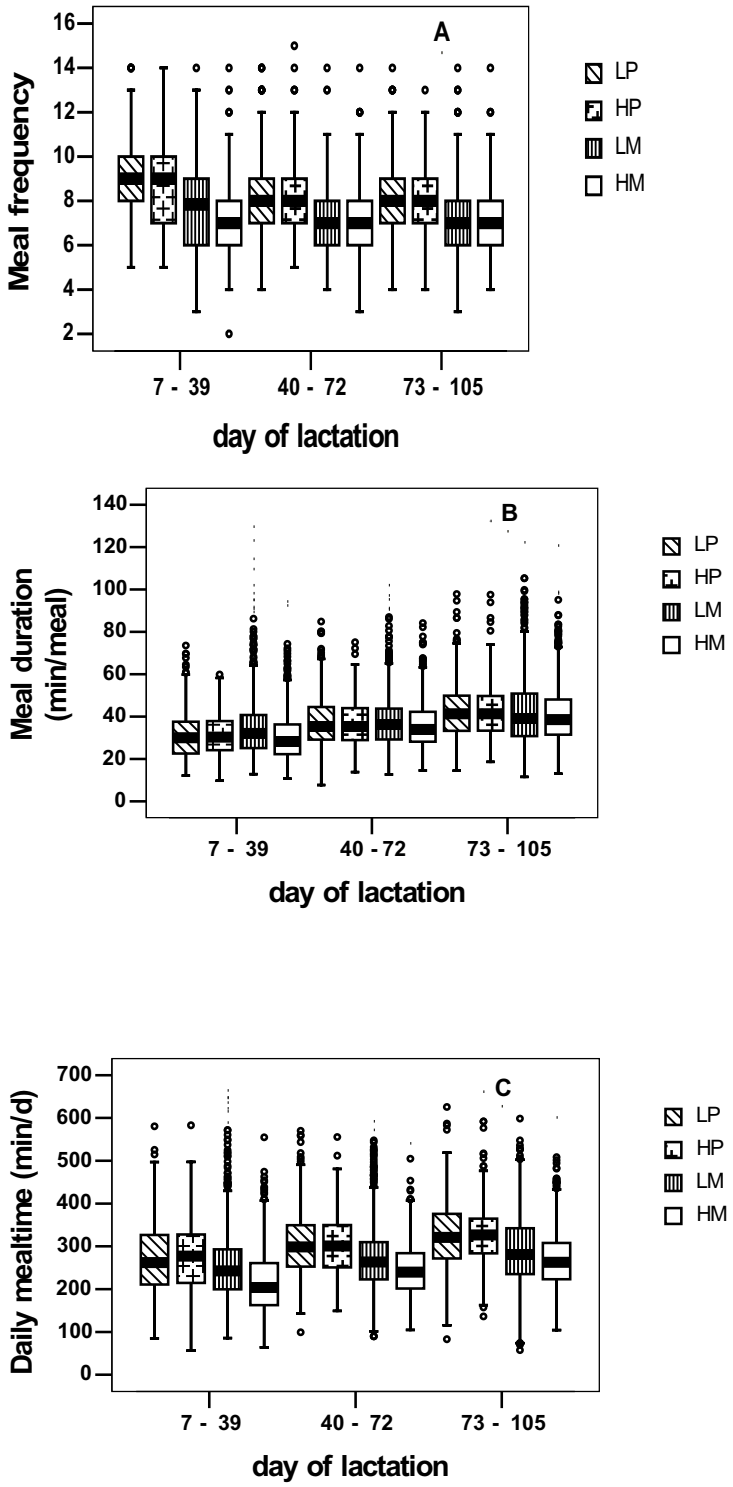

Figure 6.1 The effect of parity and milk-yield level on meal frequency (A), meal duration (B), and daily mealtime (C) based on days of lactation. LP = cows in primiparous with low milk-yield; HP = cows in primiparous with high milk-yield; LM = cows in multiparous with low milk-yield; HM = cows in multiparous with high milk-yield. Boxplots represent the median, interquartile range, and extreme cases of individual variables.

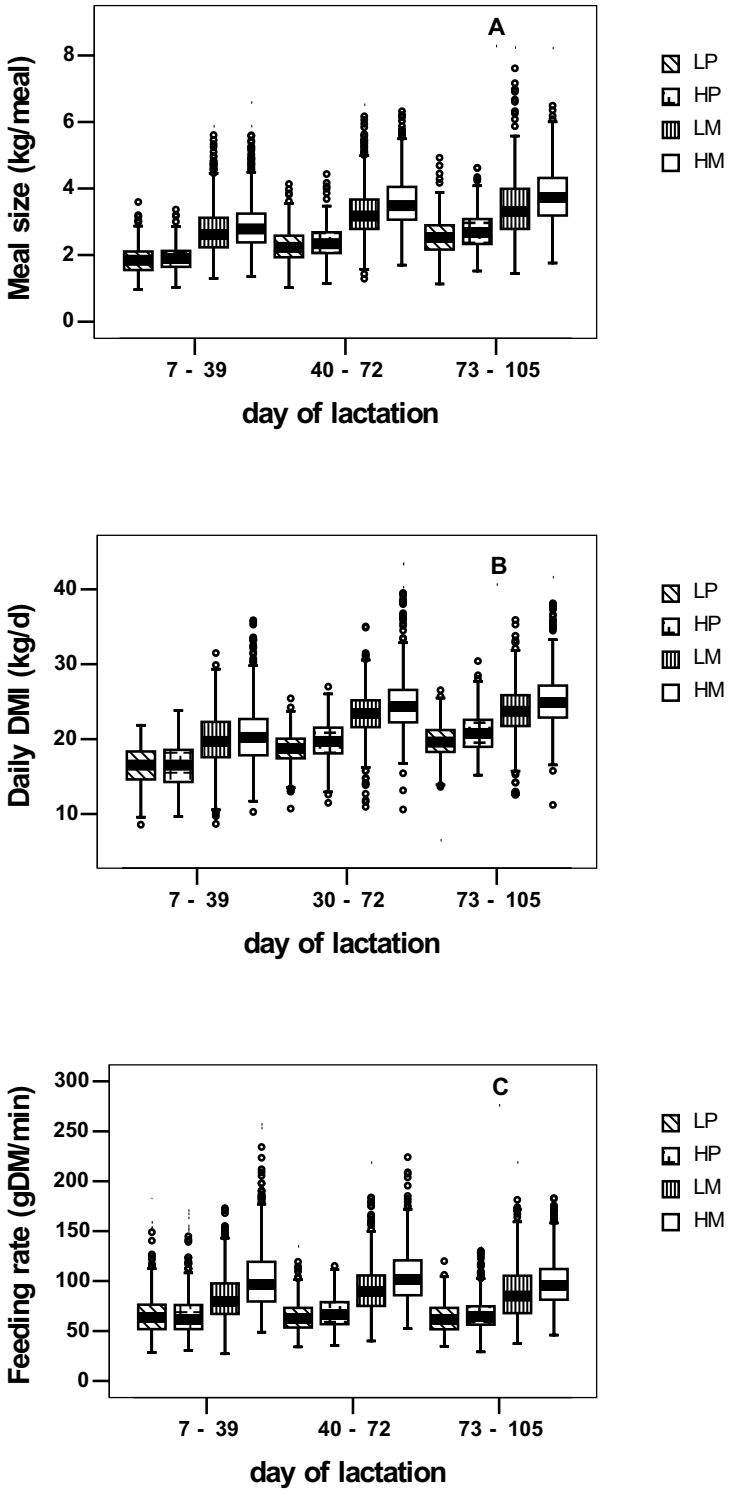

Figure 6.2 The effect of parity and milk-yield level on meal size (A), daily DMI (B), and feeding rate (C) based on days of lactation. . LP = cows in primiparous with low milk-yield; HP = cows in primiparous with high milk-yield; LM = cows in multiparous with low milk-yield; HM = cows in multiparous with high milk-yield. Boxplots represent the median, interquartile range, and extreme cases of individual variables.

The daily mealtime of cows in LP, HP, LM, and HM increased from 270, 268, 256, and 217 min/d (Period 1) to 325, 324, 287, and 270 min/d (period 3), respectively. The meal size constantly increased for all milk yield groups, that is, from 1.84, 1.93, 2.72, and 2.87 kg/meal (period 1) to 2.57, 2.74, 3.45, and 3.80 kg/meal (period 3), respectively, for cows in LP, HP, LM, and HM. A rise in daily DMI of about 20% for all milk yield groups was observed during early lactation. Thus, the mean of daily DMI by cows in LP, HP, LM, and HM increased from 16.43, 16.49, 19.87, and 20.46 kg (period 1) to 19.68, 20.94, 23.55, and 25.20 kg (period 3), respectively. The feeding rate remained on the same level in all milk yield groups over all three periods.

6.4 Discussion

The hypothesis of this study was that cows have different feeding behaviour characteristics depending on their parities and productivity. Daily DMI is the product of the number of meals per day and the average meal size. Daily mealtime is also the product of the number of meals per day and the average meal duration. However, the data in Table 1 show that the product of meal frequency and meal size as well as of meal frequency and meal duration is larger than the daily DMI and the daily mealtime. This difference is not the result of miscalculations or rounding errors, but it is a phenomenon commonly observed in these types of studies (Friggens et al., 1998; Tolkamp et al., 2000). Because meal frequency and meal size as well as meal frequency and meal duration are related in a nonlinear manner, the product of their means will differ from the means of their product (i.e., the mean of the daily DMI or daily mealtime). The means of feeding behaviour characteristics and feed intake parameters obtained in the current study were within the range of results which had been reported by other researchers (Dado and Allen, 1994; Tolkamp et al., 2000; DeVries et al., 2003). However, the results were partly different from those reported by Miron et al. (2004) and

Morita et al. (1996). Miron et al. stated an average of 14 meals per day, 15.9 min/meal for meal duration, and 223 min/d for eating duration (daily mealtime); and Morita et al. found an average of 18.9 min/meal for meal duration, 4.0 kg/meal for meal size, and 0.249 kg/min for eating speed (feeding rate). Therefore, a possible explanation may be the differences in the definition of meal criteria. Miron et al. (2004) used an arbitrary definition of meal, which was defined as a visit to a trough that lasted at least 1 min while eating at least 0.2 kg of food; Morita et al. (1996) calculated an average of 13 min as meal criterion. The longer meal criterion used in our recent study compared with these meal criteria translated into a lower meal frequency (Tolkamp et al., 2000; DeVries et al., 2003).

To investigate the feeding behaviour and feed intake between primiparous and multiparous cows, Dado and Allen (1994) studied 6 primiparous and 6 multiparous cows during early lactation and reported an average of 11.3 and 10.8 eating bouts per day (meal frequency) with a bout length of 25.9 and 31.1 min (meal duration). The meal size was 1.8 and 2.5 kg, and the daily eating time added up to 284 and 314 min with a daily DMI of 20 and 24.8 kg for primiparous and multiparous cows, respectively. Our results showed also a reduced meal frequency by 10%, a 40% bigger meal size, and a 22% higher daily DMI in multiparous cows compared with primiparous cows.

Only a few studies have examined the variation in feeding behaviour and feed intake among lactating dairy cows depending on their level of milk yield. Dado and Allen (1994) found in a multivariate data acquisition system, measuring continuous feed and water intake as well as chewing behaviour, that cows with higher yields achieved greater DMI by increasing meal size while spending less time eating. These findings are in agreement with the results of our study, which showed that cows with a higher milk yield consumed more daily DMI and spent less time eating per day than cows with a lower milk yield. Cows in the HM group spent 20% less time eating than the cows in the LP group. They also ate 53% more per meal and 28% more dry matter per day than the cows in the LP group. These differences attributed to

differences in body weight are thought to be due to increased rumen fill of primiparous cows (Dado and Allen, 1994) and may be due to differences in energy demands for lactation. Forbes (1996) stated that DMI is controlled by numerous interacting factors including physical factors in the feed that limit the intake as well as the absorption of nutrients which result from digestive processes. In our study, cows were fed with a TMR consisting of 60% roughage and 40% concentrate. This high-roughage TMR is assumed to affect the feeding behaviour and feed intake parameters, particularly in high-producing dairy cows. The effect of a diet on feeding behaviour and feed intake was reported by Friggens et al. (1998). They found that cows fed with a high-concentrate TMR had fewer but longer visits to the feeders and ate more feed per visit than did cows consuming a low-concentrate TMR.

The results showed higher correlations between feeding behaviour characteristics and feed intake (DMI) within milk yields groups than across all cows. These correlations were similar to those reported by Dado and Allen (1994) and Friggens et al. (1998). Dado and Allen (1994) found a correlation of 0.35 between eating bouts per day and daily DMI, 0.27 between eating bout length and DMI, 0.42 between daily eating time and DMI, and 0.58 between meal size and DMI. We found a stronger correlation between meal duration, daily mealtime, and daily DMI (r = 0.37and 0.50, respectively) in HP than Dado and Allen (1994). Highly positive correlations between meal duration, daily mealtime, and daily DMI indicated that these variables could probably be used to describe the feed intake. The comparison of the variation in meal duration and daily mealtime (35% and 26%, respectively), on the one hand, and the smaller variation of daily DMI (14%), on the other hand, shows that there is a great variation in feeding rates in cows.

The trend of feeding behaviour characteristics and feed intake parameters of cows in different milk yield groups differed over the course of the study. DeVries et al. (2003) analysed changes in feeding behaviour in three different time periods during early lactation (period 1, 35 ± 16 (mean ± SD), period 2, 57 ± 16, and period 3, 94 ± 16 DIM) and reported an increase

in meal duration and daily mealtime from period 1 to period 2, but no changes between period 2 and 3. The results of the current study, which was conducted approximately at the same DIM, were in agreement with these findings but partly differed from the results of Friggens et al. (1998). They found no significant effect of the stage of lactation on the number of visits at the feeder, visit duration, and feed intake per visit. These differences may have derived from differences in the methodology of the measurement of feeding behaviour characteristics, especially in the estimation of the meal criterion. DeVries et al. (2003), for example, used a criterion comparable to ours and that is why their calculated meal criterion differed from ours only by 0.8 min, while Friggens et al. (1998) presented their results in terms of visits rather than meals.

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CHAPTER 7

Relationships between metabolic-related production diseases and feeding behaviour characteristics as well as feed intake of dairy cows in early lactation

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Abstract

The early postpartum period is considered the major risk period for metabolic disorders. However, relatively little is known about the relationship between metabolic disorders and feeding behaviour parameters. The objectives of this study were to investigate the differences in feeding behaviour characteristics and feed intake parameters between cows with clinical metabolic disorders and healthy cows, and to determine whether feeding behaviour characteristics could be used to identify sub-clinical metabolic disorders in early lactation. Data on feeding behaviour characteristics, feed intake, and milk production of 47 German Holstein Frisian lactating multiparous dairy cows from the 7th to 105th day of lactation were collected. Seventeen cows with diagnosed clinical metabolic disorders (milk fever, ketosis, retained placenta, and displacement of the abomasum) were compared with healthy cows in days in milk (DIM) in the first week of lactation. Eight cows with out of normal reference values of blood parameters: nonestrified fatty acids (NEFA) >800 µmol/l, β-hydroxy butyrate acid (BHBA) >1000 µmol/l, and aspartate aminotransferas (ASAT) > 105 U/l, but without any clinical problems were compared with cows without clinical or sub-clinical disorders during the second and third week of lactation. Cows with clinical metabolic disorders (CMD) had a lower meal frequency, meal duration, daily mealtime, meal size, daily dry matter intake (DMI), energy-corrected milk (ECM), milk fat, milk protein, and milk lactose than cows without clinical metabolic disorders (WCMD) over the course of the study. Cows with sub-clinical metabolic disorders (SCMD) had also a lower meal duration, daily mealtime, meal size, and daily DMI than did cows without sub-clinical metabolic disorders (WSCMD) during the second and third week of lactation. There were no significant differences in meal frequency and ECM between SCMD and WSCMD cows.

(**Keywords**: Feeding behaviour, feed intake, clinical and sub-clinical metabolic disorders, dairy cows)

Abbreviation key: **CMD** = clinical metabolic disorders, **WCMD** = without clinical metabolic disorders, **SCMD** = sub-clinical metabolic disorders, **WSCMD** = without sub-clinical metabolic disorders, **DIM** = days in milk, **NEFA** = nonestrified fatty acids, **BHBA** = β-hydroxy butyrate acid, **ASAT** = aspartate aminotransferase

7.1 Introduction

The early postpartum period is considered the major risk period for metabolic disorders. The majority of metabolic disorders are related to either energy balance or mineral balance (Spain and Scheer, 2004). In early lactation, dietary intake is unable to meet the demands of a high milk production. The cow therefore enters a period of negative energy balance (NEB), which leads to the mobilisation of body reserves to balance the deficit between food energy intake and milk energy production (Bauman and Currie, 1980; Bell, 1995). The process of mobilisation seems to affect the well-being of the cow, and other biological pathways are compromised as intake energy is directed toward production. Most of the metabolic disorders of dairy cows such as milk fever, ketosis, retained placenta, and displacement of the abomasum occur within the first two weeks of lactation (Goff and Horst, 1997). As negative energy balance increases, more nonesterified fatty acids (NEFA) are released from body fat and the concentration of NEFA in the blood increases (Drackley et al., 2005). If the NEFA uptake by the liver becomes excessive, a fatty liver may develop (Bobe et al., 2004). Negative energy balance and carbohydrate insufficiency in the liver after calving also lead to an increased production of ketone bodies (Drackley, 1999). Negative energy balance, intense mobilisation of body fats, and ketogenesis are strongly associated with peripaturient disorders (Jorristma et al., 2003; Bobe et al., 2004). The degree of fatty acid mobilisation, as indicated by plasma NEFA concentrations, has been positively related to the incidence of postpartum metabolic disorders (Grummer, 1993; Dyke et al., 1995). Geishauser et al. (2000) stated that

betahydroxy butyrate and ASAT activity in the blood are associated with negative energy balance in postpartum cows.

Veterinary examination is the best way to detect diseases, but such exams are relatively infrequent on most dairy farms and many cases of disease may go unnoticed. In addition, frequent administration of tests to a big herd can be costly and time consuming (Urton et al., 2005). Many dairy producers use changes in milk production as well as urine and milk tests to monitor the health of their animals, but milk production responds poorly to the recognition of sub-clinical disorders (Urton et al., 2005). For example, Rajala-Schultz (1999) reported a higher milk yield from cows that developed milk fever than from healthy cows. New technology has been developed that allows the monitoring of the feeding behaviour of dairy cows. Therefore, a practical method to identify sub-clinical metabolic disorders during early lactation would be especially useful.

To our knowledge, relatively little is known about the relationship between metabolic disorders and feeding behaviour parameters. Recently, Urton et al. (2005) and Huzzey et al. (2007) used feeding behaviour characteristics to identify dairy cows at risk for metritis. Therefore, the first objective in this study was to investigate the differences in feeding behaviour characteristics and feed intake parameters between cows with clinical metabolic disorders and healthy cows. The second aim was to determine whether feeding behaviour characteristics could be used to identify sub-clinical metabolic disorders in early lactation.

7.2 Materials and methods

7.2.1 Animals, feeding, and housing

The experiment was performed in the Centre of Research for Animal Husbandry and Technology of the Regional Office for Agriculture and Horticulture (Sachsen-Anhalt, Iden)

from 10 July 2005 to 16 January 2006. Data from 70 lactating German Holstein Friesian dairy cows (parity = 1 to 7) were collected. For this special investigation, only the 47 multiparous cows were selected. The cows were kept in a free-stall barn and monitored by using an electronic feeding system from the 7th to 105th day of lactation. The ratio between cows and feeder was 2:1. The feeding system was equipped with an electronic identification of the individual cows and an electronic control and recording of their entry at the feeder. Cows were fed a TMR consisting of 24% corn silage, 31% grass silage, 5% grass and alfalfa hay, and 40% protein and mineral supplement on a DM basis. The ration contained an average of 6.99 MJ NEL/kg, 16.68% CP, and 14.80% CF, and was fed once daily between 0600 and 0800 h ad lib. The cows were milked three times daily (at 0400, 1200, and 2000 h) and their individual milk yields were recorded throughout the study. The contents of fat, protein, and lactose in the milk as well as the chemical composition of the feedstuffs were analysed weekly.

7.2.2 Measurement

Individual analyses of feeding behaviour and feed intake were carried out by using an automatic feeder and electronic identification of the individual cows. Each feeder was equipped with an access gate that could be programmed to allow a specific cow to access a feed bin, and two infrared sensors that recorded the presence of a cow in the feeder. All experimental animals were fitted with a passive transponder encased in a plastic ear tag and attached to the bottom of the neck collar. By these means, the start and end time as well as the feed intake were registered for every visit to the feeder. A visit was defined as the time spent by an individual cow with her head in one of the feed bins, regardless of how the cow spent that time.

7.2.3 Sampling procedure and laboratory analyses

Ten ml of blood were collected from the coccygeal vein into an evacuated sterile tube without anticoagulant. Samples were allowed to clot and kept chilled until serum was harvested; then, an aliquot was stored at -20 °C within 5 h of collection. Blood samples were collected on d -20 and -7 (antipartum) and as well as on d 1, 7, 14, 28, and 56 postpartum. Serum biochemistry analyses (concentrations of β-hydroxy butyrate acid (BHBA), NEFA, cholesterol, glucose, bilirubin, insulin, leptin, glutamate dehydrogenase, ASAT activity, urea, calcium, and phosphorus) were conducted at the Animal Health Laboratory with a Hitachi 911 auto-analyser.

After inducing cows to urinate by stroking the escutcheon, a free-flow urine sample was collected and a drop applied to a ketone (acetone and acetoacetate) test tablet, which was scored as positive or negative after a change of colour from white to purple was observed within 30 s.

All disease events were recorded based on the schedule of the farm. In the current study, from the recorded data, four metabolic-related production diseases were defined. The case definition for displacement of the abomasum was diagnosed by a veterinarian of a left or right side displacement of the abomasum based on auscultation of a characteristic tympanic resonance ("ping") during percussion on the left or right side, which was generally confirmed during subsequent surgical correction. The case definition for retained placenta was diagnosed by the farmer upon failure to pass the foetal membrane within 24 h after calving. The case definition for milk fever was diagnosed by the farmer or veterinarian upon stage hypocalcaemia parturient paresis, cow down. The case definition for ketosis was diagnosed by a veterinarian of primary clinical ketosis based on presenting a complaint of inappetence

and/or decreased milk production in cows, of the presence of a positive urine or milk ketone test, and absence of displaced abomasum or other primary disease.

7.2.4 Statistical analyses

Analyses were conducted using SAS (SAS Institute, 2003) on the individual animal as the observational unit. For each variable, all data were confirmed to be distributed normally prior to any analysis. To estimate the meal criterion (the minimum time between visits to consider the next visit at the feed bin as part of a new meal), we used the method of Tolkamp et al. (1998) and DeVries et al. (2003), as explained in our previous study (Azizi et al., submitted). In brief, visit intervals were natural logarithm (LN)-transformed. The frequencies of LN of the visit intervals had two normal distributions: the first was within meals and the second between meals. The meal criterion was estimated as the interval length where the two normal distributions intersected, which was 28.5 minutes from our pooled data. Based on this meal criterion, the visits were clustered into meals. Meal frequency (meal/d) was calculated by counting the number of intervals per day that exceeded the length of the meal criterion and adding 1. The number of visits per meal was calculated by counting the number of visits within a meal. Meal duration (min/meal) was calculated as the time from the beginning of the first feed, but not including an interval between events that exceeded the meal criterion. Meal size (kg/meal) is the total amount of feed ingested during each meal. Daily mealtime and daily DMI were calculated from meal durations and meal sizes per day, respectively. Feed intake (meal size and daily DMI) was calculated based on dry matter (DM). Feeding behaviour characteristics and feed intake parameters between cows with clinical metabolic-related production diseases (retained placenta, milk fever, ketosis, and displacement of the abomasums) and healthy cows were compared by *t*-tests. In addition, feeding behaviour characteristics and feed intake parameters of cows without any clinical problems but

abnormal blood parameters (NEFA, BHBA, and ASAT activity) were compared with those of healthy cows by means of a *t*-test.

7.3 Results

Out of 47 multiparous cows, 17 developed clinical metabolic-related production diseases (retained placenta, milk fever, ketosis, and displacement of the abomasum) in the first week postpartum. The parameters of these 17 cows were compared with those of 18 cows without any problems. Table 7.1 shows the feeding behaviour characteristics, feed intake parameters, and milk production for CMD and WCMD cows during the first 21 day of lactation. The differences in feeding behaviour, feed intake, and milk production parameters can also be seen in Figures 1 to 7. Besides the differences contributed by clinical metabolic disorders, these figures show the trends over the course of study.

Table 7.1 Means of feeding behaviour, feed intake, and milk production variables for cows with clinical metabolic disorders (CMD) and without clinical metabolic disorders (WCMD) during the first 21 day of lactation.

	CMD	WCMD	SEM[1]	P-Value
Cows, no.	17	18		
Meal frequency	7.39	7.63	0.14	0.086
Meal duration (min/meal)	29.02	32.39	1.06	0.002
Daily mealtime (min/d)	210.78	236.8	6.79	0.000
Meal size (kg/meal)	2.35	2.7	0.053	0.000
Daily DMI (kg/d)	16.9	19.98	0.27	0.000
Feeding rate (gDM/min)	86.08	92.85	2.52	0.008
ECM[2] (kg/d)	36.84	41.31	0.64	0.000
Milk fat (%)	4.45	4.31	0.063	0.026
Milk protein (%)	3.22	3.42	0.021	0.000
Milk lactose (%)	4.72	4.81	0.015	0.000

[1]SEM = the standard error of means
[2]ECM = energy-corrected milk

The meal frequency per day between CMD and WCMD cows was significantly different (7.06 vs. 7.22, P <0.01), whereas the difference in the mean number of visits per meal was not significant (P >0.60). The trend in meal frequency shows a strong difference between CMD and WCMD cows over the course of the study except from the 4th to the 6th and the 14th wk of lactation (Figure 7.1). The mean of meal duration (min/meal) for CMD cows was significantly shorter than that for WCMD cows (37.63 vs. 40.37, P <0.01) during the first 21 d of lactation.

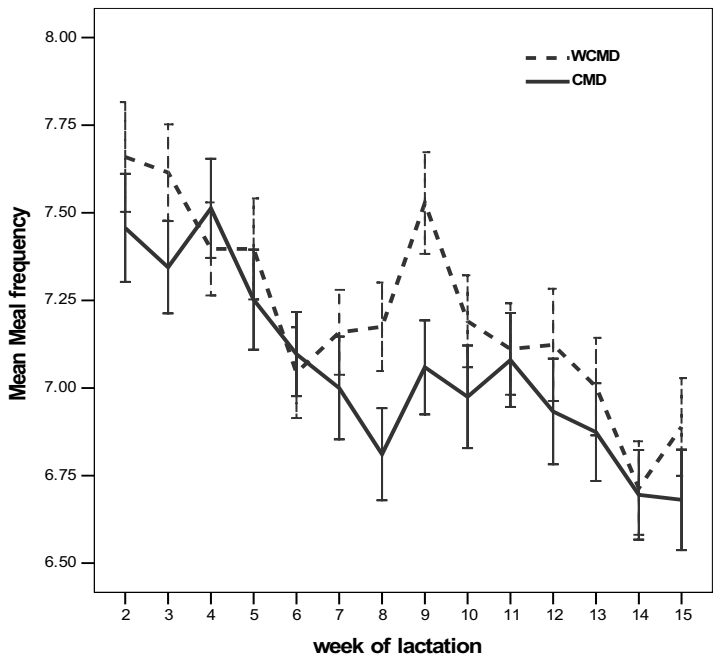

Figure 7.1 Means of meal frequency for cows with clinical metabolic disorders (CMD) and healthy cows (WCMD) from 2nd to 15th week of lactation. Bars represent the standard error of means.

The difference in meal duration increased until the 6th wk. From the 7th to 10th wk, it decreased and then increased again (Figure 7.2). The healthy cows spent about 26 min longer at daily mealtime than cows with clinical metabolic disorders ($P < 0.01$).

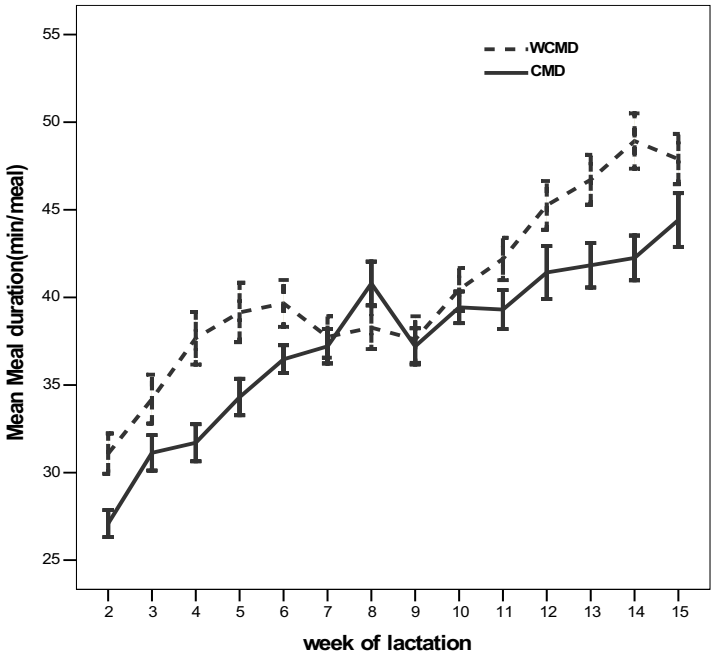

Figure 7.2 Means of meal duration for cows with clinical metabolic disorders (CMD) and healthy cows (WCMD) from 2nd to 15th week of lactation. Bars represent the standard error of means.

Figure 7.3 shows the trend in daily mealtime for CMD and WCMD cows during the course of the study. Similar to the difference in meal duration, the difference in daily mealtime increased until the 6th wk, decreased from the 7th to the 10th wk, and then increased. Cows with clinical metabolic disorders had a significantly smaller meal size (kg/meal) than healthy cows (3.30 vs. 3.38, $P < 0.01$).

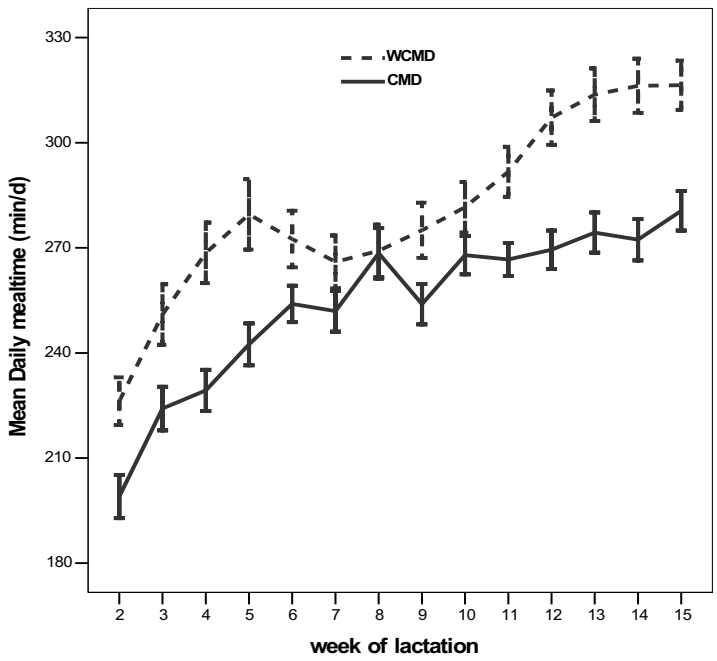

Figure 7.3 Means of daily mealtime for cows with clinical metabolic disorders (CMD) and healthy cows (WCMD) from 2nd to 15th week of lactation. Bars represent the standard error of means.

The trend of meal size for CMD and WCMD showed a strong difference during the first 4 wk of lactation, but the difference diminished until after the 10th wk there was no difference between the two groups anymore (Figure 7.4). The healthy cows also ate approximately 3 kg DM per day more than the cows with clinical metabolic disorders (P <.001) during the first 21 d of lactation.

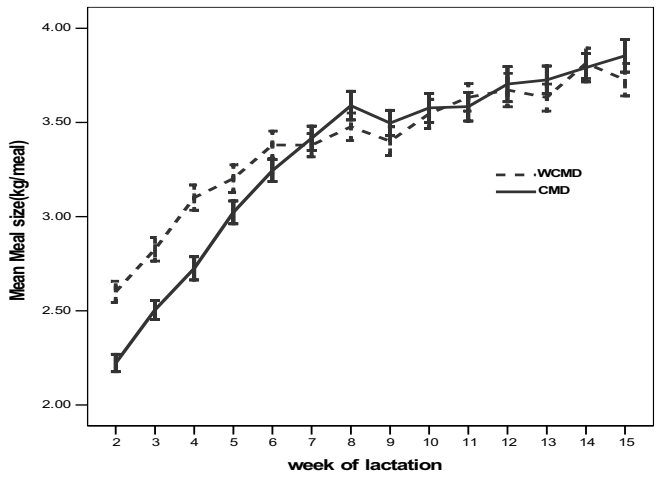

Figure 7.4 Means of meal size for cows with clinical metabolic disorders (CMD) and healthy cows (WCMD) from 2nd to 15th week of lactation. Bars represent the standard error of means.

The trends in daily DMI between CMD and WCMD cows were very different in the first 4 wk of lactation, until becoming identical after the 10th wk of lactation (Figure 7.5). There was a significant difference in feeding rate between CMD and WCMD cows during the first 21 d of lactation (86.08 vs. 92.85, $P< 0.01$).

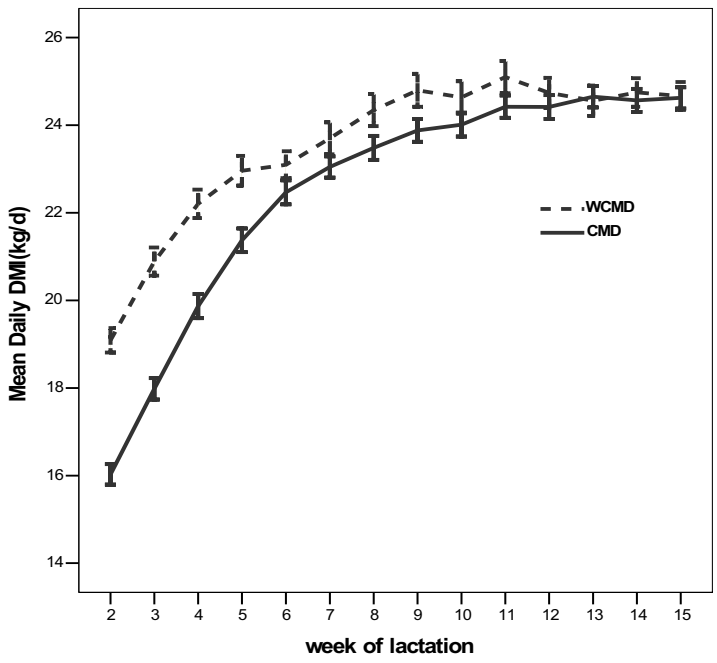

Figure 7.5 Means of daily DMI for cows with clinical metabolic disorders (CMD) and healthy cows (WCMD) from 2nd to 15th week of lactation. Bars represent the standard error of means.

Figure 7.6 shows the trends in feeding rates for CMD and WCMD cows. The difference in feeding rate was greater during the first two weeks after the diagnosis. Then it became smaller, but increased again from the 10th wk to the end of the study. CMD Cows produced about 4.5 kg less ECM per day than WCMD cows during the first 21 d of lactation ($P < 0.01$).

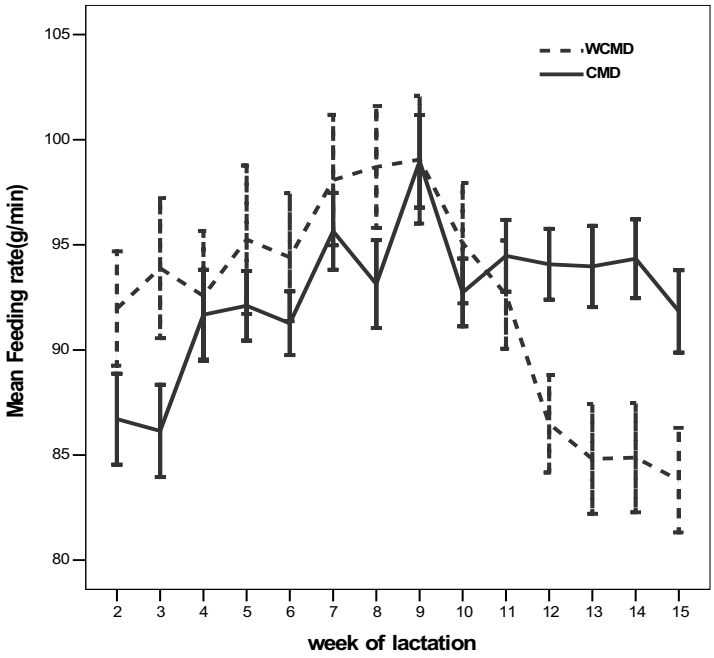

Figure 7.6 Means of feeding rate for cows with clinical metabolic disorders (CMD) and healthy cows (WCMD) from 2nd to 15th week of lactation. Bars represent the standard error of means.

The trend in milk yield for CMD and WCMD cows showed a great difference for 3 wk after the diagnosis (Figure 7.7). This difference continued until the 10th wk of lactation. CMD cows also produced milk with a higher percentage of milk fat, but a lower percentage of milk protein and lactose (4.45, 3.22, and 4.72% vs. 4.31, 3.42, and 4.81%, respectively, $P < 0.01$).

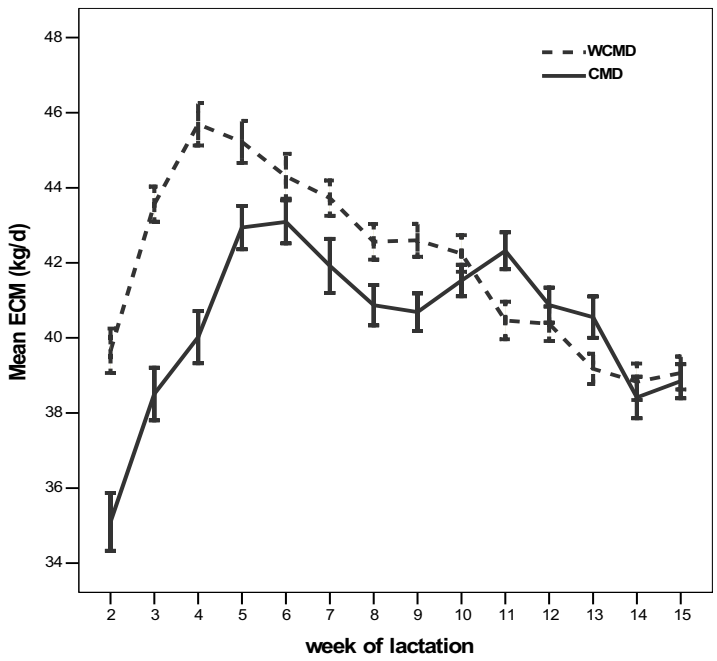

Figure 7.7 Means of energy-corrected milk (ECM) for cows with clinical metabolic disorders (CMD) and healthy cows (WCMD) from the 2nd to 15th week of lactation. Bars represent the standard error of means.

Feeding behaviour characteristics, feed intake, and milk production parameters for SCMD and WSCMD cows are shown in Table 7.2.

Table 7.2 Means of feeding behaviour, feed intake, and milk yield values for cows with sub-clinical metabolic disorders (SCMD) and without sub-clinical metabolic disorders (WSCMD) during the second and third week of lactation.

	2nd week				3rd week			
	SCMD	WSCMD	SEM[1]	P-Value	SCMD	WSCMD	SEM	P-Value
Cows, no.	8	14			9	14		
Meal frequency	7.39	7.66	0.26	0.31	7.58	7.56	0.24	0.94
Meal duration (min/meal)	26.12	32.07	1.82	0.01	29.51	35.46	2.47	0.01
Daily mealtime (min/d)	190.04	233.63	11.84	0.01	216.99	256.41	14.57	0.000
Meal size (kg/meal)	2.44	2.62	0.092	0.04	2.5	2.93	0.102	0.000
Daily DMI (kg/d)	17.36	19.3	0.47	0.01	18.61	21.44	0.51	0.000
Feeding rate (g/min)	102.88	89.42	4.96	0.01	95.18	95.06	5.77	0.98
ECM[2] (kg/d)	37.29	39.01	1.15	0.14	43.72	42.56	1.10	0.27

[1]SEM = the standard error of means
[2]ECM = energy-corrected milk

There was no significant difference in meal frequency per day or in the number of visits per meal in the second and third week of lactation between these cows. The mean of the meal duration for cows with sub-clinical metabolic disorders was about 6 min shorter than that for healthy cows in the second and third week of lactation (26.12 and 29.51 vs. 32.07 and 35.46 min/meal, respectively, P <0.01). The SCMD cows spent about 40 min less at daily mealtime than WSCMD cows in the second and third wk of lactation (190.04 and 216.99 vs. 233.66 and 256.41, respectively, P <0.01). Healthy cows ate a significantly larger meal size than SCMD cows in the second and third wk of lactation (P <0.01). They also ate ca. 2 kg DM per day in the second wk and 3 kg in the third week more than SCMD cows (17.36 and 18.61 vs. 19.30 and 21.44, respectively, P <0.01). The feeding rate was significantly different in the second wk (P<0.01), but not in the third wk (P <0.98). We found no significant difference in milk production between SCMD and WSCMD cows.

7.4 Discussion

In our study, milk production was lower in cows that developed clinical metabolic disorders than healthy cows during the first 21 d of lactation. This reduction in milk production is likely a consequence of the lower DMI observed in the cows with clinical metabolic disorders after calving. Numerous studies reported a loss of milk production in cows with metabolic disorders compared with healthy cows. For example, Detillieux et al. (1997) reported that the left displaced abomasum (LDA) cows yielded 557 kg less milk than healthy cows from the beginning of lactation until the 60th d after the diagnosis. Deluyker et al. (1991) found that LDA caused a total loss of 402 kg in the first 49 d of lactation. Kocak and Ekiz (2006) reported a milk yield loss of 184.3 and 285.6 kg for LDA and ketosis, respectively. Our results agreed with these findings, which showed an average milk yield loss of 4.5 kg/d by cows with metabolic disorders compared to healthy cows. Milk fat percentage was higher for CMD cows than WCMD cows. This agreed with results from other researchers (Brumby et al., 1975; Dann et al., 2005). Cows in negative energy balance mobilise adipose lipid reserves, and the resulting long-chain fatty acids are incorporated into the milk fat (Palmquist et al., 1993).

There is little information about the effects of health disorders on feeding behaviour and feed intake. Sowell et al. (1999) stated that time spent eating was lower (ca. 35%) for steers demonstrating visible signs of bovine respiratory disease than for healthy animals. Zamet et al. (1979) found a 21% lower DMI in metritic cows after calving. Urton et al. (2005) studied the relationship between metritis and the feeding behaviour of dairy cows. They found that cows with signs of metritis spent on average 22 min/d less with eating than healthy cows. Huzzey et al. (2007) reported that the severely metritic cows spent 30 min less feeding time and ate 4 kg less DMI than healthy cows during the first 3-wk postpartum period. These

findings agree with our results, which showed shorter daily mealtime and smaller DMI for cows with clinical and sub-clinical metabolic disorders than for healthy cows. In our previous study (Azizi et al., submitted), we established a significant relationship between daily mealtime and daily DMI. A result of shorter daily mealtime as well as reduced daily DMI is poor rumen fill. The poorly filled rumen enables the abomasum to shift to the left and the abomasum will finally dislocate clinically (Van Winden et al., 2002). As a consequence of reduced feed intake, the blood concentration of calcium and glucose dropped, followed by a decrease in blood insulin concentration (Herdt, 2000). Another effect of low glucose levels in ruminants is ketone body production, leading to a rise of blood BHBA concentrations (Herdt, 2000). In addition, a rise in ASAT activity in the blood has been assumed the result of protein mobilisation from muscles in order to deliver glycogenic amino acids as glucose precursors (Herdt, 2000).

The trend of the parameters over the course of the study showed that, in general, the meal frequency, meal duration, and daily mealtime of CMD cows were lower than those of WCMD cows. On the other hand, meal size after the 7th wk, and daily DMI after the 12th wk of lactation were equal for CMD and WCMD cows. Dairy farmers can use the knowledge of animal behaviour to improve cow well-being. Urton et al. (2005) and Huzzey et al. (2007) stated that reduced feeding time can be used to identify dairy cows at risk for metritis. We also concluded that feeding behaviour characteristics, especially daily mealtime, can be used to identify sub-clinical metabolic disorders in dairy cattle.

Acknowledgment

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CHAPTER 8: General discussion

The overall objective of this PhD thesis was to investigate the relationships between feeding behaviour, feed intake, milk production, and metabolic-related production diseases of dairy cows during early lactation. This objective was addressed in four steps:

1) analysis of feeding behaviour characteristics and feed intake parameters based on individual visits,

2) analysis of feeding behaviour characteristics and feed intake parameters based on meals,

3) assessment of the effects of parity, stage of lactation, and milk yield level on feeding behaviour and feed intake, and

4) assessment of the effect of metabolic disorders on feeding behaviour, feed intake, and milk production.

8.1 Feeding behaviour analysis based on visits at feeders

The visit was the shortest unit in which intake was recorded. Therefore, in Chapter 4, the feeding behaviour characteristics of high-producing dairy cows during early lactation in terms of visits were analysed. In this study, a visit was defined as the time spent by an individual cow with her head in one of the trough, regardless of whether the cow was eating or not. The results presented in Chapter 4 showed that the number of visits, visit duration, daily eating time, intake per visit, and daily feed intake were in range of the results reported by other researchers (Vasilatos and Wangsness, 1980; Friggens et al., 1998; Tolkamp et al., 2000). Cows could achieve the similar intake with widely different combinations of intake per visit and daily number of visits. Part of this variation may be related to innate individual differences between cows. Subordinate cows were sometimes displaced from a trough by

cows that were more dominant. This was observed especially during peak intake periods (i.e., after fresh feed was supplied in the morning and after the cows' return from milking). Therefore, at least part of the visits will have ended involuntarily. The frequency of displacement is probably related not only to the cow's position in the social hierarchy but also to the cow pressure per feeder (Elizalde and Mayne, 1993).

8.2 Feeding behaviour analysis based on meal criterion

The satiety concept predicts that the probability of an animal starting a meal depends on the time since the end of the last meal (Metz, 1975). Based on this concept, Tolkamp et al. (1998) modelled the frequency distribution of LN-transformed feeding intervals and obtained meaningful meal criteria for dairy cows kept in loose housing with conventional milking. The frequency presented in Figure 3.3 shows a similar shape to published frequency distributions in dairy cows (Tolkamp and Kyriazakis, 1999; DeVries et al., 2003; Melin et al., 2005).

In the first well-documented short-term feeding behaviour analysis of cows, Metz (1975) considered meal criteria in the range of 20 to 60 min as suitable because few intervals between feeding events of such length were recorded. Other studies used definitions of meals that were either arbitrary or based on the assumption that meals are randomly distributed in time, resulting in meal criteria as short as 2 min (Harb and Campling, 1985), 4 min (Dawson and Mayne, 1998), 5 min (Rook and Huckle, 1997), 6 min (Patterson et al., 1998), 7.5 min (Dado and Allen, 1993), 8 min (Dürst et al., 1993; Forbes et al., 1986; Heinrichs and Conrad, 1987), 10 min (Harms et al., 2002), and 13 min (Morita et al., 1996). These differences may be attributed to a high degree of variation in the feeding behaviour of cows, which may be the result of variable DMI and major physiological changes in these animals. It is possible that meal criteria estimates will depend on the stage of lactation, milk yield level, the type of feed,

the management system, the possible competition for feeder space, etc. (Tolkamp et al., 2000).

Although the concept of satiety does not have a very precise physiological meaning (Forbes, 1995), it seems likely that satiety is more affected by the amount of feed consumed than by the time spent feeding (Van Soest, 1982).

In chapter 5, we described how meal characteristic could best be applied to the feeding behaviour in dairy cows. The use of the frequency distributions shows a first peak corresponding to the intervals within meals and the second peak represents the intervals between meals (Figure 3.2). This distribution thus provides an objective and biologically relevant basis for identifying a meal criterion, namely the interval where the two distributions intersect (Tolkamp et al., 1998). This meal criterion, calculated on an individual animal basis or on a group basis, is then used to determine the derived characteristics of the feeding behaviour. Even though individual cows differed to some degree in their meal criteria, there was no differences between those feeding behaviour characteristics calculated using a pooled criterion (from all animals and over the course of the study; 28.5 min) and those calculated by means of the individual criteria. Therefore, we concluded that in some conditions, like the condition of our study, where cows are at the same stage of lactation and fed the same diet, a pooled meal criterion is adequate. This is supported by findings of DeVries et al. (2003). However, in some cases where there is considerable variation in criteria (e.g., between cows or time periods), it would be recommended that researchers exercise caution when using a pooled meal criterion (DeVries et al., 2003). This is confirmed by Huzzey et al. (2005), who also calculated individual and pooled meal criteria. Even though the pooled criterion (26.4 min) in that study was similar to that reported in Chapter 5, those researchers found that the pooled criterion underestimated meal frequency.

The daily number and average size of short feeding bouts that are recorded are very sensitive to changes in experimental conditions and vary with the methodology used. This limits the

usefulness of visits as the basic unit for the analysis of short-term feeding behaviour. The grouping of short feeding bouts into meals sidesteps many of the complications associated with the analysis of short-term feeding behaviour in terms of visits (Tolkamp et al., 2000).

Tolkamp et al. (2000) concluded that meals are the most biologically relevant unit for the analysis of short-term feeding behaviour. When the log-normal methods to estimate meal criteria were developed, it was assumed that eating bouts would end when animals were satiated, and that satiety, in turn, would lead to a low probability of cows initiating another bout after short intervals (Tolkamp et al., 1998; Tolkamp and Kyriazakis, 1999).

The main application of the meal criterion calculated in Chapter 5 was to calculate meal-based characteristics of feeding behaviour, including meal frequency, meal duration and daily mealtime.

8.3 Effects of parity on feeding behaviour and feed intake

The effects of parity were studied in Chapter 5 (comparison of first, second, and third-and-more lactation) and in Chapter 6 (comparison of primiparous and multiparous cows). Parity affected the feeding behaviour and feed intake in that there were with fewer meals per day, longer meal duration, shorter daily mealtime, more DMI, and higher feeding rate in multiparous cows than in primiparous cows. Ingvartsen and Andersen (2000) stated that voluntary DMI is considerably higher in multiparous cows compared with primiparous cows. The intake capacity of primiparous cows calving at an age of 2yr is only around 80% of that of multiparous cows in the first part of lactation (Kristensen and Ingvartsen, 1985). The effect of parity is attributed to differences in body weight, which are thought to be due to increased rumen fill of primiparous cows (Dado and Allen, 1994). This assumption is supported by the results of Chapter 6, which illustrated a great difference in BW between primiparous and multiparous cows (572 ± 42 vs. 687 ± 63 kg). In contrast to our results, some authors [e.g.,

Dado and Allen (1994) and Bowman et al., (2003)] had found longer daily feeding time in multiparous cows than in primiparous cows. We observed that primiparous cows require a longer eating time. This is supported by findings of Beauchemin and Rode (1997), who reported that multiparous cows spent less time eating and more time ruminating than primiparous cows did, although multiparous cows spent less time eating and ruminating per kilogram of DM. Some authors [e.g., Campling and Morgan (1981) and Beauchemin and Rode (1994)] concluded that younger cows ate more slowly than older cows. They stated that the increased time is necessary for younger cows to masticate feed, which should be an important consideration in feeding management strategies designed to maximise feed intake. Ad lib. feed availability and decreased competition at the feeder may encourage higher feed intake by younger cows.

The relationship between parity and time spent eating and ruminating may depend on the type of diet. With a high fibre diet, like the one used in our study, cattle with a greater intake capacity (multiparous cows) tend to chew feed more efficiently during eating and ruminating, requiring less chewing time per unit of feed DM consumed, because the relationship between rumination capacity and body size is near unity (DeBoever et al., 1990).

8.4 Effect of stage of lactation on feeding behaviour and feed intake

Only few researches on the feeding behaviour of dairy cows have considered the effects of differences in the stage of lactation. DeVries et al. (2003) examined the feeding behaviour of the same group of cows at three different time periods, from early to peak lactation. Theseauthors found several changes in the feeding behaviour of dairy cattle in early to peak stages of lactation. These findings are in agreement with the results of Chapter 5, which showed significant changes in all three time periods during early lactation. This was not

surprising since DMI has been shown to be continually increasing from the beginning of lactation to approximately 9 wk into lactation (Kertz et al., 1991).

Friggens et al. (1998) studied the effects of the stage of lactation on the short-term feeding behaviour of dairy cows. They found no significant effects of the stage of lactation on short-term feeding behaviour, with the exception of feeding time. These authors also reported that, even though DMI dropped in the later stages of lactation, there was no associated change in feeding behaviour. The difference between these findings and those of Chapter 5 of this study may be caused by different measures of feeding behaviour and no definition of meal criterion (Friggens et al., 1998).

8.5 Effect of milk yield level on feeding behaviour and feed intake

The results in Chapter 6 showed a significant effect of the milk yield level on the feeding behaviour and feed intake of dairy cows. Heinrichs and Conrad (1987) reported that under ad-libitum conditions, high-producing cows consume 9 to 14 meals daily, whereas lower-producing cows consume only 7 meals per day. By contrast, the results described in Chapter 6 demonstrated that the higher-producing cows had a lower meal frequency and lower daily mealtime but a higher daily DMI and feeding rate than the lower-producing cows. The differences between these findings, as already mentioned, might be due to differences in production levels, behaviour definition description, chemical composition and physical form of diet, management, and environment.

8.6 Effect of metabolic-related production diseases on feeding behaviour and feed intake

Previous studies used feeding behaviour monitoring to identify metritic cows (Zamet et al., 1979; Urton et al., 2005) and sick feedlot-housed steers (Sowell et al., 1998; 1999) successfully. Zamet et al. (1979) monitored the health and feed intake of free-stall housed cows during a transition period. They pointed out a 21% lower DMI in metritic cows after calving (4 to 30 DIM). Urton et al. (2005) also found a 29% lower feeding time after calving for cows diagnosed with metritis.

Metabolic disorders play a central role in the feeding-health-production complex (Østergaard et al., 2000). To our knowledge, the study in Chapter 7 is the first to show how metabolic disorders relate to the feeding behaviour of dairy cows. The results from this study showed a 12.34% lower daily mealtime, 18.22% lower daily DMI, and 7.86% lower feeding rate for cows with clinical metabolic disorders over the course of the study (7 to 105 DIM). Cows with sub-clinical metabolic disorders had a 23% lower daily mealtime than healthy cows in the second week of lactation. These results suggest that feeding behaviour and feed intake can be used to identify cows with sub-clinical and clinical metabolic disorders. Daily mealtime might be a useful tool to predict the health status in dairy cattle.

It is necessary to mention that the health disorders during the transition period and early lactation are interrelated, and the conditions conducive to the development of one problem in one category can lead to a disorder in another category. For example, milk fever or sub-clinical hypocalcemia can lead to the loss of muscular tonicity resulting in an increased risk of retained placenta and/or displaced abomasums. Curtis et al. (1985) conducted a retrospective analysis of the risk factors associated with metabolic problems. They reported that cows having retained placentas were more at risk for developing mastitis and ketosis. Cows with

ketosis were 12 times more likely to develop displaced abomasums. Therefore, the prevention of one problem can decrease the incidence of others.

8.7 General conclusion

The present PhD thesis investigated the relationships between feeding behaviour, feed intake, milk production, and metabolic-related production diseases of high-producing dairy cows during early lactation. The results of this investigation have led to the following conclusions:

1. The use of the $\log_{10}$ –normal model described by Tolkamp et al. (1998) and developed by DeVries et al. (2003) allows for the identification of a biologically relevant meal criterion in order to estimate the feeding behaviour of lactating dairy cows with unrestricted access to the feeder. Our findings are in agreement with these authors, who stated that the meal criterion provides an objective basis for calculations of meal frequency, meal duration, and daily mealtime, and suggest that this technique be employed in future research on feeding behaviour.
2. The high correlation between short-term feeding behaviour such as meal duration and meal size suggest that measuring of time spent eating could be used to estimate feed intake.
3. The differences in feeding behaviour and feed intake between younger and older cows serves as an argument for separate grouping and management of heifers and older cows, at least during the early stage of lactation.
4. High-producing dairy cows spent less daily mealtime but ate more quickly than low-producing dairy cows.
5. The lower daily mealtime by cows with clinical and sub-clinical metabolic-related production diseases compared with healthy cows can be used to identify cows at risk for health disorders.

6. The dry period, and in particular the late dry period, is a critical period in which the quality of all inputs will directly impact the productive performance in the next lactation as well as the incidence of diseases associated with calving. On the other hand, some problems originate before calving. Therefore, further research is required to determine how soon before calving at-risk cows can be identified.
7. The current PhD thesis investigated the feeding behaviour characteristics and feed intake parameters of lactating dairy cows on a group level. It developed a reliable method for the analysis of feeding behaviour.

   Future studies should be done on an individual level of cows to investigate the relationships between feeding behaviour and occurrence of health disorders. Moreover, investigations should be focus on the complexity of behaviour patterns. In this context, feeding behaviour characteristics should be combined with behavioural measures such as activity, resting, rumination, and drinking.

CHAPTER 9: References

Albright, J. L. 1993. Feeding behavior of dairy cattle. J. Dairy Sci. 76:485-498.

Allen, M. S. 1996. Physical constraints on voluntary intake of forage by ruminants. J. Anim. Sci. 74:3063-3075.

Allen, M. S. 2000. Effects of diet on short/term regulation of feed intake by lactating dairy cattle. J. dairy Sci. 83:1595-1624.

Allen, M. S., B. J. Bradford, and K. J. Harvatine. 2005. The cow as a model to study food intake regulation. Annu. Rev. Nutr. 25:523-547.

Allen, M. S., and B. J. Bradford. 2007. Regulation of feed intake in transition cows: Application of the hepatic oxidation hypothesis. 22nd Annual Southwest Nutrition & Management Conference. February 22-23, 2007. Tempe, AZ – 138.

Allen, M. S., and D. R. Mertens. 1988. Evaluating constraints of fiber digestion by rumen microbes. J. Nutr. 118:261-270.

Anil, M. H., and J. M. Forbes. 1980. Feeding in sheep during intraportal infusions of short-chain fatty acids and effect of liver denervation. J. Physiol. 298:407-414.

Azizi, O., O. Kaufmann, and L. Hasselmann. Variations in the feeding behaviour of high-yielding dairy cows in relation to parity during early to peak lactation. Submitted to J. Livestock science.

Baile, C. A. 1971. Metabolites as feedbacks for control of feed intake and receptor sites in goats and sheep. Physiol. Behav. 7:819-826.

Baile, C. A. 1975. Control of feed intake in ruminants. In digestion and metabolism in the ruminant. I. W. McDonald and A. C. I. Warner, ed.

Baile, C. A., and J. Mayer. 1969. Depression of feed intake of goats by metabolites injected during meals. Am. J. Physiol. 217:1830-1836.

Bauman, D. E., and W. B. Currie. 1980. Partitioning of nutrients during pregenancy and lactation: a review of mechanisms involving homeostasis and homeorhesis. J. Dairy Sci. 63:1514-1529.

Beauchemin, K. A., and J. G. BUCHANAN-SMITH. 1989. Effects of dietary neutral detergent fiber concentration and supplementary long hay on chewing activities and milk production of dairy cows. J. Dairy Sci. 72:2288-2294.

Beauchemin, K. A., B. I. Farr, L. M. Rode, and G: B. Schaalje. 1994. Effect of alfalfa silage chop length and supplementary long hay on chewing and milk production of dairy cows. J. Dairy Sci. 77:1326-1339.

Beauchemin, K. A., and L. M. Rode. 1994. Compressed baled alfalfa hay for primiparous and multiparous dairy cows. J. Dairy Sci. 77: 1003-1012.

Beauchemin, K. A., and L. M. Rode. 1997. Minimum versus optimum concentrations of fiber in dairy cow diets based on barley silage and concentrates of barley or corn. J. Dairy Sci. 80:1629-1639.

Bell, A. W., 1995. Regulation of organic nutrient metabolism during transition from late pregnancy to early lactation. J. Anim. Sci. 73:2804-2819.

Betrics, S. J., R. Grummer, C. Cadorniga-Valino, and E. E. Stoddard. 1992. Effect of pre-partum dry matter intake on liver triglyceride concentration and early lactation. J. Dairy Sci. 75:1914-1922.

Bennink, M. R., T. R. Tyler, G. M. Ward, and D. E. Johnson. 1978. Ionic milieu of bovine and ovine rumen as affected by diet. J. Dairy Sci. 61: 315-323.

Bobe, G., J. W. Young, D. C. Beitz. 2004. Pathology, etiology, prevention, and treatment of fatty liver in dairy cows. J. Dairy Sci. 87: 3105-3124.

Bowman, G. R., K. A. Beauchemin, and J. A. Shclford. 2003. Fibrolytic enzymes and parity effects on feeding behavior, salivation, and ruminal pH of lactating dairy cows. J. Dairy Sci. 86:565-575.

Brumby, P. E., M. Anderson, B. Tuckley, and J. E. Storry. 1975. Lipid metabolism in the cow during starvation-induced ketosis. Biochem. J. 146:609-615.

Campling, R. C. and C. A. Morgan. 1981. Eating behaviour of housed dairy cows – a review. Dairy Sci. Abstr. 43:57-63.

Canale, C. J., P. L. Burgess, L. D. Muller, and G. A. Varga. 1990. Calcium salts of fatty acids in diets that differ in neutral detergent fiber: Effect on lactation performance and nutrient digestibility. J. Dairy Sci. 73:1031-1038.

Carter, R. R., and W. L. Grovum. 1990. A review of the physiological significance of hypertonic body fluids on feed intake and ruminal function: Salviation, motility and microbes. J. anim. Sci. 68:2811-2832.

Chase, L. E., 1993. Developing nutrition programs for high producing dairy herds. J. Dairy Sci. 76: 3278-3290.

Chilibroste, P., 1999. Grazing time: The missing link. A study of the plant-animal interface by integration of experimental and modeling approaches. Ph.D. Diss., Wageningen agric. Univ., The Netherlands.

Choi, B. R., and M. S. Allen. 1999. Intake regulation by volatile fatty acids and physical fill. S. Afr. Anim. Sci. 29:40-41 (Abstr.).

Conrad, H. R., A. D. Pratt, and J. W. Hibbs. 1964. Regulation of feed intake in dairy cows. I. Change in importance of physical and physiological factors with increasing digestibility. J. Dairy Sci. 74:54-64-

Crichlow, E. C., and B. F. Leek. 1980. The importance of pH in relation to acid-excitation of epithelial receptors in the reticulo-rumen of sheep. J. Physiol. 310:60P-61P (Abstr.).

Curtis, S. E., and K. A. Houpt. 1983. Animal etiology: its emergence in animal science. J. Anim. Sci. 57:234-247.

Curtis, C. R., H. N. erb, C.J. Sniffen, R. D. Smith, and D. S. Kronfield. 1985. Path analysis of dry period nutrition, postpartum metabolic and reproductive disorders, and mastitis in Hostein cows. J. Dairy Sci. 68:2347-2360.

Dado, R. G., and M. S. Allen. 1993. Continuous computer acquisition of feed and water intakes, chewing reticular motility and ruminal pH of cattle. J. Dairy Sci. 76:1589-1600.

Dado, R. G., and M. S. Allen. 1994. Variation in and relationships among feeding, chewing and drinking variables for lactating dairy cows. J. Dairy sci. 77:132-144.

Dawson, L. E. R., and C. S. Mayne. 1998. The effect of silage fermentation characteristics on dry matter intake of steers. Anim. Sci. 66:105-113.

Dann, H. M., D. E. Morin, G. A. Bollero, M. R. Murphy, and J. K. Drackley. 2005. Prepartum intake, postpartum induction of ketosis, and periparturient disorders affect the metabolic status of dairy cows. J. Dairy Sci. 88: 3249-3264.

De Boever, J. L., J. I. Andries, D. L. De Brabander, B. G. Cottyn, and F. X. Buysse. 1990. Chewing activity of ruminants as a measure of physical structure. A review of factors affecting it. Anim. Feed. Sci. Tehnol. 27:281-291.

Delagarde, R., J. P. Caudal, and j. L. Peyraud. 1999. Development of an automatic bitemeter for grazing cattle. Ann. Zootech. 48:329-339.

Deluyker, H. A., J. M. Gay, L. D. Weaver, and A. S. Azari. 1991. Change of milk yield with clinical disease for a high producing dairy herd. J. Dairy Sci. 74:436-445.

Detillieux, J. C., Y. T. Gröhn, S. W. Eicker, and R. L. Quaas. 1997. Effects of left displaced abomasum on test day milk of Holstein cows. J. Dairy Sci. 80: 121-126.

DeVries, T. J., M. A. G. von Keyserlink, D. M. Weary, and K. A. Beauchemin. 2003. Measuring the feeding behavior of lactating dairy cows in early to peak lactation. J. Dairy Sci. 86:3354-3361.

DeVries, T. J., M. A. G. von Keyserlink, , and K. A. Beauchemin. 2005. Frequency of feed delivery affects the behavior of lactating dairy cows. J. Dairy Sci. 88:3553-3562.

DeVries, T. J. 2006. The effects of feeding management and feed area design on dairy cattle behavior. PhD thesis, The university of British Columbia, Vancouver V6T 1Z4, Canada. 182pp.

DeVries, T. J. and M. A. G. von Keyserlingk. 2006. Feed Stalls Affect the Social and Feeding Behavior of Lactating Dairy Cows. J. Dairy Sci. 89:3522-3531.

Dijkstra, J., H. Boer, J. Van Bruchem, M. Bruining, and S. Tamminga. 1993. Absorption of volatile fatty acids from the rumen of lactating dairy cows as influenced by volatile fatty acid concentration, pH, and rumen liquid volume. Br. J. Nutr. 69:385-396.

Dirksen, G. 1962. die Erweiterung, Verlagerung und Drehung des Lebmages beim Rind. Berlin and Hamburg. Verlag Paul Parey.

Drackley, J. K., 1999. Biology of dairy cows during the transition period: the final frontier? J. Dairy Sci. 82:2259-2273.

Drackley J. K., 2003. Interrelationships of prepartum dry matter intake with postpartum intake and hepatic lipid accumulation. J. Dairy Sci. 86:104-105.

Drackley J. K., T. R. Overton, and G. N. Douglas. 2001. Adaptations of glucose and long-chain fatty acid metabolism in liver of dairy cows during the periparturient period. J. Dairy Sci. 84 (E-Suppl.):E100-E112.

Drackley, J. K., H. M. Dann, G. N. Douglas, N. A. J. Guretzky, N. B. Litherland, J. P. Underwood, and J. J. Loor. 2005. Physilogical and pathological adaptations in dairy cows that may increase susceptibility to periparturient diseases and disorders. ITAL. J. Anim. Sci. 4: 323-344.

Dürst, B., M. Senn, and W. Langhans. 1993. Eating patterns of lactating dairy cows of 3 different breeds fed grass ad lib. Phys. Behav. 54:625-631.

Dyk, P. B. 1995. The association of prepartum nonesterified fatty acids and body condition with peripartum health problems on 95 Michigan dairy farms. M. S. Thesis, Michigan State Univ., East Lansing.

Elizalde, J. C., C. G. Aldrich, D. W. LaCount, J. K. Drackley, and N. R. Merchen. 1999. Ruminal and total digestibilities in steers fed diets containing liquefied or prilled saturated fatty acids. J. anim. Sci. 77:1930-1039.

Elliot, J. M., H. W. Symonds, and B. Pike. 1985. Effect on feed intake of infusing sodium propionate or sodium acetate into a mesenteric vein of cattle. J. Dairy Sci. 68:1165-1170.

Engelhardt, Th. (2005): Wege zur Senkung der Reproduktionsrate – Praktische Erfahrungen des Herdenmanagements und Versuchsergebnisse aus der Milchviehherde in Iden. Vortrag, 6. Jahrestagung der Wissenschaftlichen Gesellschaft der Milcherzeugerberater, Berlin, 13. – 15.09.2005

Feng, P., W. H. Hoover, T. K. Miller, and R. Blauwiekel. 1993. Interactions of fiber and nonstructural carbohydrates on lactation and ruminal function. J. Dairy Sci. 76:1324-1333.

Fleischer, P. M. Metzner, M. Beyerbach, M. Hoedemaker, and W. Klee. 2001. The relationship Between milk yield and the incidence of some diseases in dairy cows. J. Dairy Sci. 84:2025-2035.

Foster, L. A., N. K. Ames, and R. S. Emery. 1991. Food intake and serum insulin response to intraventricular infusions of insulin and IGF-I. Physiol. Behav. 50: 745-749.

Friend, T. H., and C. E. Polan. 1974. Social rank, feeding behaviour and free stall utilization by dairy cattle. J. Dairy Sci. 57:1214-1222.

Friend, T. H., C. E. Polan and M. L. McGiliard. 1977. Free stall and feed bunk requirements relative to behaviour, production and individual feed intake in dairy cows. J. Dairy Sci. 60:108-118.

Friggens, N. C., B. L. Nielsen, I. Kyriazakis, B. J. Tolkamp, and G. C. Emmens. 1998. Effects of food composition and stage of lactation on the short-term feeding behavior of dairy cows. J. Dairy Sci. 81:3268-3277.

Forbes, J. M. 1985. The importance of meals in the regulation of food intake. Proc. Nutr. Soc. Aust. 10:14-24.

Forbes, J. M. 1986. The effects of sex hormones, pregnancy, and lactation on digestion, metabolism, and voluntary food intake. Pages 420-435 *in* Control of digestion and metabolism in ruminants. L. P. Milligan, W. L. Grovum, and A. Dobson, ed. Prentice-Hall, Englewood Cliffs, NJ.

Forbes, J. M. 1995. Feeding behaviour. Pages 11-31 in Voluntary food intake and diet Selection in farm animals. J. M. Forbes, ed. CAB International, Wallingford, UK.

Forbes, J. M. 1996. Integration of regulatory signals controlling forage intake in ruminants. J. Anim. Sci. 74:3029-3035.

Geishauser, T., K. Leslie, and T. Duffield. 2000. Preventation and prediction of displaced abomasums in dairy cows. Bovine Pract. 34: 51-55.

Gill, M., and Romney. 1994. The relationship between the control of meal size and the control of daily intake in in ruminants. Livest. Prod. Sci. 39:13-18.

Goff, J. P., and R. L. Horst. 1997. Physiological changes at parturition and their relationship to metabolic disorders. J. Dairy Sci. 80:1260-1268.

Goff, J. P. 1999. Mastitis and retained placenta-relationship to bovine immunology and nutrition. Adv. Dairy Technol. 11:185-192.

Grant, R. J., and J. L. Albright. 2000. Feeding behaviour. Pages 365-382 in farm animal metabolism and nutrition. J: P. F. DMello, ed. CABI Publihing, Wallingford, Oxon, UK.

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

Grant, R. J. 2006. Motivating cows: creating the right environment. Pages, 43-47 *in* Penn State dairy cattle Nutrition Workshop.

Groot Koerkamp, P. W. G., A. P. Bos, and E. van Henten. 2007. Percision Livestock Farming: Creating order beyond control. Pages 17-26. 3rd European conference on Percision Livestock Farmin, Skiathos, Greece.

Grummer, R. R., 1993. Etiology of lipid-related metabolic disorders in periparturient dairy cows. J. Dairy Sci. 76:3882-3896.

Grummer, R. R., 1995. Impact of changes in organic nutrient metabolism on feeding the transition dairy cow. J. Anim. Sci. 73:2820-2833.

Grovum, W. L. 1995. Mechanisms explaining the effects of short chain fatty acids on ffed intake in ruminant-osmotic pressure, insulin and glucagons. Pages 173-197 in Ruminant Physiology: digestion, Metabolism, Growth and Reproduction. W. v. Englehardt, S. Leonhard-Marek, G. Breves, D. Geisecke, ed. Fredinand Enke Verlag, Stuttgart, Germany.

Gruber, L. 2002. Regulation und Vorhersage der Futteraufnahme von Milchkühen. Bayerische Arbeitsgemeinschaft Tierernährung. Fachtagung „Aktuelle Fragen der Fütterungsberatung“, 30.09. – 01.10.2002 in Freising-Weihenstephan, Tagungsunterlage 29-45.

Grum,, D. E., L. R. Hansen, and J. K. Drackley. 1996. Nutrition during the dra period and hepatic lipid metabolism of periparturient dairy cows. J. Dairy sci. 79:1850-1864.

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

Harding, R., and B. F. Leek. 1972. Rapidly adapting mechanoreceptors in the reticulo-rumen that also respond to chemicals. J. Physiol. 223:32-33.

Harms, j., G. wendl, and H. Schön. 2002. Influence of cow traffic on milking and animal behaviour in a robotic milking system. Pages 114-118 in Proc. First N. Amer. Conf. on Robotic Milking, Toronto, Canada.

Hayirli, A., R. R. grummer, E. V. Nordhein, and P. M. Crump. 2002. Animal and dietary factors affecting feed intake during the prefresh transition period in Holsteins. J. Dairy sci. 85:3430-3443.

Hedlund, L. and J. Rolls. 1977. Behavior of lactating dairy cows during total confinement. J. Dairy Sce. 60:1807-1812.

Heinrichs, A. J., and H. R. Conrad. 1987. Measuring feed intake patterns and meal size of lactating dairy cows. J. Dairy Sci. 70:705-711.

Herdt, T. H. 2000. Ruminant adaptation to negative energy balance. Influences on the etiology of ketosis and fatty liver. Vet. Clin. N. Am-Food A. 16:215-230.

Hoffman, P. C., D. K. Combs, and M. D. Caster. 1998. Performance of lactating dairy cows fed alfalfa silage or perennial ryegrass silage. J. Dairy Sci. 81: 162-168.

Horst, R. L., J. P. Goff, T. A. Reinhardt, and D. R. Buxton. 1997. Strategies for preventing milk fever in dairy cattle. J. Dairy Sci. 80:1269-1280.

Huzzey, J. M., M. A. G. von Keyserlingk, and D. M. Weary. 2005. Changes in feeding, drinking, and standing behavior of dairy cows during the transition period. J. Dairy Sci. 88:2454-2461.

Huzzey, J. M., D. M. Veira, D. M. Weary, and M. A. G. von Keyserlingk, 2007, Prepartum behavior and dry matter intake identify dairy cows at risk for metritis, J. Dairy Sci. 90:3220-3233

Ingvartsen, K. L. and H. R. Andersen, and J. Foldager. 1992. Effect of sex and pregnancy on feed intake capacity of growing cattle. Acta Agric. Scand., Sect. A, Anim. Sci. 42:40-46.

Ingvartsen, K. L. and J. B. Andersen. 2000. Integration of metabolism and intake regulation: a review focusing on periparturient animals. J. Dairy Sci. 83:1573-1597.

Ingvartsen, K. L., R. J. Dewhurst, and N. C. Friggens. 2003. On the relationship between lactational performance and health: is it yield or metabolic imbalance that cause production disease in dairy cattle? A position paper. Livest. Prod. Sci. 83:277-308.

Jackson, D. A., C. L. Johnson, and J. M. Forbes. 1991. The effect of compound composition and silage characteristics on silage intake, feeding behaviour, production of milk and live weight change in lactating dairy cows. Anim. Prod. 52:11-20.

Jorritsma, R., T. Wensing, T. A. M. Kruip, P. L. A. M. Vos, J. P. T. M. Noordhizen. 2003. Metabolic changes in early lactation and impaired reproductive performance in dairy cows. Vet. Res. 34: 11-26.

Kaufmann, O., 2005. Ansprüche der Kühe erfüllen – die Zentrale Aufgabe des Herdenmanagement.

Kaufmann, O., O. Azizi, and L., Hasselmann. 2007. Untersuchungen zum Fressverhalten hochleistender Milchkuehen in der Fruehlaktation. Züchtungskunde. 79:219-230.

Kertz, A. F., L. F. Reutzel, and G. M. Thomson. 1991. dry matter intake fro parturition to midlactation. J. Dairy Sci. 74:2290-2295.

Kleppe, B. B., R. J. Alello, R. R. Grummer, and L. E. Armentano. 1988. Triglyceride accumulation and very low density lipoprotein secetion by rat and goat hepatocytes in vitro. J. Dairy Sci. 71:1813-1822.

Knapp, J. R., and R. L. Baldwin. 1990. Regulation of ketogenesis in dairy cattle. J. Anim. Sci. 68:522 (abstr.).

Kocak, O., and B. Ekiz, 2006, Effects of left displacement abomasums, ketosis and digestive disorders on milk yield in dairy cows. Bulg. J. Vet. Med., 9. No 4, 273-280.

Kononoff, P.J., S: K. Ivan, W. Matzke, R. J. Grant, R. A. stock and T. J. Klopfenstein. 2006. Milk production of dairy cows fed wet corn Gluten feed during dry period and lactation. J. Dairy Sci. 89: 2608-2617.

Kristensen, V. F., and K. L. Ingvartesn. 1985. Variations in voluntary feed intake in cattle related to animal factores. Dairy cows. Pages 302-303 *in* 36th annual Meeting of the EAAP, Summaries, Kallithea, Greece.

Kronfeld, D.S. 1970. Ketone body metabolism, its control, and its implications in pregnancy toxaemia, acetoneamia, and feeding standards. Page 566 *in* Physiology of digestion and metabolism in the ruminant. A. T. Phillipson, ed. Proc. 3rd Int. Symp., Cambridge, England.

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

Laca, E. A., E. D. Ungar, and M. W. Demment. 1994. Mechanisms of handling time and intake rate of a large mammalian grazer. Appl. Anim. Behav. Sci. 39:3-19.

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

Lam, W. F., A. A. M. Masclee, E. S. M. Müller, and C. B. H. W. Lamers. 1997. Effect of hyperglycemia on gastric acid secretion during gastric phase of digestion. Am. J. Physiol. 272:G1116-G1121.

Lean, I. J., M. L. Bruss, H. F. Troutt, J. C. Galland, T. B. Farver, J. Rostami, C. A. Holmberg, and L. D. Weaver. 1994. Bovine ketosis and somatotrophin: risk factors for ketosis and effects of ketosis on health and production. Res. Vet. Sci. 57:200-209.

LeBlanc, S. J., K. E. Leslie, and T. F. Duffleid. 2005. Metabolic predictors of displaced abomasums in dairy cattle. J. Dairy Sci. 88:159-170.

Leek, B. F., and R. H. Harding. 1975. Sensory nervous receptors in the ruminant stomach and the reflex control of reticulo-ruminal motility. Pages 60-76 in digestion and Metabolism in the Ruminant. I. W. MacDonald, and A. C. I. Warner, ed. University of New England Publishing Unit, Armidale, Australia.

Litherland, N. B., H. M. Dann, A. S. Hansen, and J. K. Drackley. 2003. Prepartum nutrient intake alters metabolism by liver slices from peripartal dairy cows. J. Dairy Sci. 86:105-106 (abstr.).

Manns, J. G., and J. M. Boda. 1967. Insulin release by acetate, propionate, butyrate, and glucose in lambs and adult sheep. Am. J. Physiol. 212:747-755.

Marquardt, J. R., R. L. Horst, and N. A. Jorgensen. 1977. Effects of parity on dry matter intake at parturition in dairy cattle. J. Dairy Sci. 60:929-934.

Matsui, K., and T. Okubo. 1991. A method for quantification of jaw movements suitable for use on free-ranging cattle. Appl. Anim. Behav. Sci. 32:107-116.

Matsui, K. 1994. A new ambulatory data logger for a long-trem determination of grazing and rumination behaviour on free-ranging cattle, sheep and goats. Appl. Anim. Behave. Sci. 39:123-130.

Mbanya, J. N., M. H. Anil, and J. M. Forbes. 1993. The voluntary intake of hay and silage by lactating cows in response to ruminal infusion of acetate or propionate, or both, with or without distension of the rumen by ballon. Br. J. Nutr. 69:713-720.

McDonald, P., R. A. Edwards, J. F. D. Greenhalgh, and C. A. Morgan. 2002. Animal nutrition. 6th edition. Pearson Education Limited. Harlow, UK.

Melin, M., H. Wiktorsson, and L. Norell. 2005. Analysis of feeding and drinking patterns of dairy cows in two cow traffic situations in automatic milking systems. J. Dairy Sci. 88:71-85.

Mertens, D. R. 1994. Regulation of forage intake. Page 450-493 in Forage quality, evaluation, and utilization. G. c. Fahey, Jr, M. Collins, D. R. Mertens, and L. E. Moser, ed., American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America, Madison, WI.

Metz, J. H. M. 1975. Time patterns of feeding and rumination in domestic cattle. Ph.D. Diss., NL 75-12, Wageningen agric. Univ., Wageningen, The Netherlands.

Metz, J. H. M. 1983. Food competition in cattle. Page 164 *in* Farm animal housing and welfare. S. H. Baxter, M. R. Baxter,and J. a. D. MacCormack, ed. Marinus Nijhoff Publ., The Hague, The Netherlands.

Metz, J. H. M. 1985. The reaction of cows to short-term deprivation of lying. Appl. Anim. Behehav. Sci. 13:310-3222.

Meyer, A. H., W. Langhans, and E. Scharrer. 1989. Vasopressin reduces food intake in goats. Q. J. Exp. Physiol. 74:465-473.

Miller, K., and D. G. M. Wood-Gush. 1991. Some effects of housing on the social behaviour of dairy cows. Anim. Prod. 53:271-278.

Miron, J., E. Yosef, M. Nikbachat, A. Zenou, and E. Maltz. 2004. Feeding behavior and performance of dairy cows fed pelleted nonroughage fiber byproducts. J. Dairy Sci. 87: 1372-1379

Morita, S., S. Devir, C. Ketelaar-DE Lauwere, A. C. Smits, H. Hogeveen, and J. H. M. Metz. 1996. Effects of concentrate intake on subsequent roughage intake and eating behavior of cows in an automatic milking system. J. Dairy Sci. 79: 1572-1580.

Nielsen, B. L., 1999. On the interpretation of feeding behaviour measures and the use of feeding rate as an indicator of social constraint. Appl. Anim. Behav. Sci. 63:79-91.

Nocek, J. E., and D. G. Braund. 1985. Effect of feeding frequency on diurnal dry matter and water consumption, liquid dilution rate, and milk yield in first lactation. J. Dairy Sci. 68:2238-2247.

NRC. 2001. Nutritional Requirements of Dairy Cattle. 7th rev. ed. Natl. Acad. Sci., Washington, DC.

Oba, M., and M. S. Allen. 1999. Evaluation of the importance of the digestibility of neutral detergent fiber from forage: Effects on dry matter intake and milk yield of dairy cows. J. Dairy Sci. 82:589–596.

Oba, M., and M. S. Allen. 2003. Effects of corn grain conservation method on feeding behavior and productivity of lactating dairy cows at two dietary starch concentration. J. Dairy Sci. 86(1):174–183.

O'Connell, J. M., W. J. Meansy, and P. S. Giller. 1993. Behavioural studies-their role in improving housing facilities for overwintering dairy cows. Pages 298-305 *in* Livestock environment IV, 4th International Symposium. Univ. Warwick, Conventry, England.

Olofsson, J. 1999. Competition for total mixed diets fed for ad libitum intake using one or four cows per feeding station. J. Dairy Sci. 82:69-79.

Olofsson, J., G. Pettersson, and H. Wiktorsson. 2000. Feeding behaviour in an automatic milking system. Page 189 *in* Robotic Milking. Proceedings of the International Symposium. H. Hogeveen and A. Meijering, ed. Wageningen Pres, Wageningen, The Netherlands.

Østergaard, S., and y. T. Gröhn. 2000. Concentrate feeding, dry matter intake, and metabolic disorders in Danish dairy cows. Livest. Prod. Sci. 65:107-118.

Overton, t. R., J. K. Drakley, C. J. Ottemann-Abbamonte, A. D. Beaulieu, L. S. Emmert, and J. H. Clark. 1999. Substrate utilization for hepatic gluconeogenesis is altered by increased glucose demand in ruminants. J. Anim. Sci. 77:1940-1951.

Palmquist, D. L., A. D. Beaulieu, and D. M. Barbano. 1993. Feed and animal factors influencing milk fat composition. J. Dairy Sci. 76: 1753-1771.

Patterson, D. C., T. Yan, F. J. Gordon, and D. J. Kilpatrick. 1998. Effects of bacterial inoculation of unwilted and wilted grass silages. 2. Intake, performance and eating behaviour by dairy cattle. J. agric. Sci. Camb. 131:113-119.

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

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

Pullen, D. L., D. L. Palmquist, and R. S. Emery. 1989. Effect on days of lactation and methionine hydroxa analog on incorporation of plasma fatty acids into plasma triglycerides. J. Dairy Sci. 72:49-58.

Rajala-Schultz, P.J., J, T. Gröhn, and C. E. McCulloch. 1999. Effects of milk fever, ketosis, and lameness on milk yield in dairy cows. J. Dairy Sci. 82:288-294.

Raya, S. 2006. Beziehungen zwischen der Futteraufnahme, dem Fressverhalten von Milchkühen pre-partum und dem Kalbenverlauf, der Fruchbarkeit und der Gesundheit. M.Sc. Thesis. Humboldt University, Berlin, Germany.

Reynolds, C. K., P. C. Aikman, B. Lupoli, D. J. Humphries, and D. E. Beever. 2003. Splanchnic metabolism of dairy cows during the transition from late gestation through early lactation. J. Dairy Sci. 86:1201-1217.

Rook, A. J., and C. A. Huckle. 1995. Synchronization of ingestive behaviour by grazing dairy cows. Anim. Beh. 20:637-643.

Rook, A. J., and C. A. Huckle. 1997. Activity bout criteria for grazing cows. Appl. Anim. Behav. Sci. 54:89-98.

Rutter, S. M., R. A. Champion, and P. D. Penning. 1997. An automatic system to record foraging behavious in free-ranging ruminants. Appl. Anim. Behav. Sci. 54:185-195.

SAS Institute. 2003. User's Guide: statistics. Version 9 Edition. INC., Cary, NC.

Scheibe, K. M., Th. Schleusner, A. Berger, K. Eichhorn, J. Langbein, L. Dal Zotto, and W. J. Streich. 1998. ETHOSYS(R)- new system for recording and analysis of behaviour of free-ranging domestic animals and wildlife. Appl. Anim. Behav. Sci. 55:195-211.

Senn, M., B. Dürst, A. Kaufmann, and W. Langhans. 1995. Feeding patterns of lactating cows of three different breeds fed hay, corn silage, and grass silage. Physiol. Behav. 58:229-236.

Shabi, Z., M. R. Murphy, and U. Moallem. 2005. Within-day feeding behavior of lactating dairy cows measured using a real-time control system. J. Dairy Sci. 88: 1848-1854.

Simpson, S. J., and A. R. Ludlow. 1986. Why locusts start to feed: a comparison of causal factors. Anim. Beh. 34:480-496.

Sowell, B. F., J. P. G. Bowman, M. E. Branine, and M. E. Hubbert. 1998. Radio frequency technology to measure feeding behavior and health of feedlot steers. Appl. Anim. Behav. 59:277-284.

Sowell, B. F., M. E. Braniane, J. G. P. Bowman, M. E. Hubbert, H. E. Sherwood, and W. Quimby. 1999. Feeding and watering behavior of healthy and morbid steers in a commercial feedlot. J. Anim. Sci. 77:1105-1112.

Spain, J. N., and W. A. Scheer. 2004. Transition cow nutrition and mastitis-balancing all the factors. Proc. 43. Annu. Meet. National Mastitis council, Feb. 1-4. charlotte, Nc. pp. 237-255.

Stamer, E., W. Junge, and E. Kalm. 1997. Temporal pattern of feeding of dairy cows kept in groups. Arch. Tierzücht. 40:195-214.

Stangassinger, M., and D. Giesecke. 1986. Splanchnic metabolism of glucose and related energy substrates. Pages 347–366 *in* Control of Digestion and Metabolism in Ruminants. L. P. Milligan, W. L. Grovum, and A. Dobson, ed., Prentice Hall, Englewood Cliffs, NJ.

Staufenbiel, R., and U. Schöder. 2005. Nutzung von Stoffwechselprofilen in der prophylaktischen veterinärmedizinischen Bestandsbetreuung von Milchkuhherden. DGfZ – SCHRIFTENREIHE. 42:80-99.

Staufenbiel, R. 2007. Personal information.

Strang, B. D., S. J. Bertics, R. R. Grummer, and L. E. Armentano. 1998. Effect of long-chain fatty acids on triglyceride accumulation, gluconeogenesis, and ureagenesis in bovine hepatoctes. J. Dairy Sci. 81:728-739.

Taweel, H. Z., B. M. Tas, J. dijkstra, and S. Tamminga. 2004. Intake regulation and grazing behavior of dairy cows under continuous stocking. J. Dairy Sci. 87:3417-3427.

Tolkamp, B. J., D. J. Allcroft, E. J. Austin, B. L. Nielsen, and I. Kyriazakis. 1998. Satiety splits feeding behavior into bouts. J. Theor. Biol. 194:235-250.

Tolkamp, B. J., and Kyriazakis. 1999. To split behavior into bouts, log-transform the intervals. Anim. Behav. 57:807-817.

Tolkamp, B. J., D. P. N. Schweitzer, and I. Kyriazakis. 2000. The biologically relevant unit for the analysis of short-term feeding behavior of dairy cows. J. Dairy Sci. 83:2057-2068.

Tyrell, H. F., and J. T. Reid. 1965. Calculating the energy content of cow's milk. J. Dairy Sci. 40:1265-1269.

Ungar, E. D. 1996. Ingestive behaviour. *In* The ecology and management of grazing system. Pages 185-217. CAB International. Wallingford, UK.

Urton, G., M. A. G. von Keyserlingk, and D. M. Weary. 2005. Feeding behavior identifies dairy cows at risk for metritis. J. Dairy sci. 88:2843-2849.

Ungar, E. D., and S. M. Rutter. 2006. Classifying cattle jaw movements: comparing IGER Behaviour recorder and acoustic techniques. Appl. Anim. Behav. Sci. 98:11-27.

Van Soest, P. J. 1965. Symposium of factors influencing the voluntary intake of herbage by ruminants: Voluntary intake in relation to chemical composition and digestibility. J. Anim. Sci. 24:834-843.

Van Soest, P. J. 1982. Nutritional ecology of the ruminant. O & B Books Inc., Corvallis, OR.

Van Soest, P. J. 1994. Nutritional ecology of the ruminant. 2nd ed. Cornell University Press, Ithaca, NY.

Van Winden, S. C. L., C. R. Brattinga, K. E. Müller, J. P. T. M. Noordhuizen, and A. C. Beynen. 2002. The position of the abomasum in dairy cows during the first six weeks after calving. Vet. Rec. 151:446-449.

Van Winden, S. C. L., R. Jorritsma, K. E. Müller, and J. P. T. M. Noordhuizen. 2003. Feed intake, milk yield, and metabolic parameters prior to left displaced abomasums in dairy cows. J. Dairy sci. 86:1465-1471.

Vasilatos , R., and P. J. Wangsness. 1980. Feeding behavior of lactating dairy cows as measured by time-lapse photography. J. Dairy Sci. 63:412-416.

Vasquez-Anon, M., S. Bertics, M. Luck, R. R. Grummer, and J. Pinheiro. 1994. Peripartum liver triglyceride and plasma metabolites in dairy cows. J. Dairy Sci. 77:1521-1528.

Waldo, D. R. 1986. Effect of forage quality on intake and forage concentrate interactions. J. Dairy Sci. 69:617-631.

Wallace, R. L., G. C. McCoy, T. R. Overton, and J. H. Clark. 1996. Effect of adverse health events on dry matter consumption, milk production, and body weight loss of dairy cows during early lactation. J. Dairy Sci. 79: (suppl. 1):205 (abstr.).

Warner, A. C. I., and B. D. Stacy. 1968. The fate of water in the rumen. 2. Water balances throughout the feeding cycle in sheep. Br. J. Nutr. 22:389-410.

Weiss, W. P., and W. L. Shockey. 1991. Value of orchardgrass and alfalfa silages fed with varying anounts of concentrates to dairy cows. J. Dairy Sci. 74:1933-1943.

Yeates, M. P., B. J. Tolkamp, D. J. Allcroft, and I. Kyriazakis. 2001. The use of mixed distribution models to determine bout criteria for analysis of animal behavior. J.Theor. Biol. 213:413-425.

Zamet, C. N., V. F. Colebrander, C. J. Callahan, B. F. Chew, R. E. Erb, and N. J. Moeller. 1979. Variables associated with peripartum traits in dairy cows. I. Effect of dietary forages and disorders on voluntary intake of feed, body weight and milk yield. Theriogenology 11:229-244.

ZUSAMMENFASSUNG

Das allgemeine Ziel der vorliegenden Doktorarbeit war es, den Zusammenhang von Fressverhalten, Futteraufnahme, Milchproduktion und Stoffwechselkrankheiten bei Milchkühen in der Frühlaktation zu untersuchen. Dafür wurden Daten von 70 laktierenden Deutschen Holstein-Friesischen Milchkühen (1. -7. Laktation) gesammelt. Das Fressverhalten wurde mittels eines elektronischen Fütterungssystems überwacht, welches die elektronische Kennung jeder einzelnen Kuh beinhaltete. Während der ersten Studie dieser Arbeit basierte die Analyse des Fressverhaltens der Milchkühe auf jedem Einzelbesuch; dabei war ein Besuch als die Zeit definiert, in der eine einzelne Kuh mit ihrem Kopf im Trog verweilte, unabhängig davon, wie die Kuh diese Zeit verbrachte.

Während der zweiten und dritten Studie wurden die Besuche in Mahlzeiten unterteilt, die auf einem Mahlzeitenkriterium basieren, welches wie folgt berechnet wurde: Eine Mischung aus zwei normalen Verteilungen wurde an die Verteilungen der Intervallängen zwischen den Besuchen, die mittels des natürlichen Logarithmuses umgerechnet wurden waren, angepasst. Innerhalb dieser Studien wurde der Einfluss der Laktation, des Laktationsstatus und des Milchleistungsniveaus auf das Fressverhalten und die Futteraufnahme untersucht. Die letzte Studie bestimmte die Auswirkungen von Stoffwechselkrankheiten auf das Fressverhalten, die Futteraufnahme und die Milchproduktion.

Die Ergebnisse deuten darauf hin, dass die Mahlzeit die wichtigere Einheit als der Einzelbesuch ist, um das Fressverhalten zu beschreiben. Laktationsnummer, Laktationsstatus und Milchleistungsniveau waren entscheidend für die Charakteristika des Fressverhaltens und die Futteraufnahme. Die höher Korrelation zwischen Fressverhalten, z.B. Dauer und Umfang einer Mahlzeit, verweisen darauf, dass das Messen der Fresszeit für das Berechnen der Futteraufnahme genutzt werden kann.

Stoffwechselkrankheiten hatten einen entscheidenen Einfluss auf das Fressverhalten, die Futteraufnahme und die Milchproduktion. Die Beobachtung der Charakteristika des Fressverhaltens könnte bei der Früherkennung des bei Kühen bestehenden erhöhten Risikos an Stoffwechselstörungen hilfreich sein.

Schlagwörter: Fressverhalten, Futteraufnahme, Milchkuh, Frühlaktation

APPENDIX 1

Analysis of feeding behaviour of high-yielding dairy cows in early lactation

Abstract

The feeding behavior and feed intake of dairy cows in early lactation were analyzed. This study aimed to determine the relationships between selected parameters of feeding behaviour and feed intake per cow and day. Information concerning feed intake of each individual dairy cow is especially valuable for herd management particularly in early lactation. However, technical requirements for implementation are rarely given. Therefore, relationships between feeding behaviour parameters, which can be recorded with practice – oriented sensor technology, and feed intake are of special interest. The investigation was based on data of 70 high-yielding dairy cows (23 in 1st lactation, 47 multiparous) with a mean annual yield of 12000 kg. The cows were fed by using a feed intake data acquisition system(feeder). By means of feeders and electronic animal identification, every single visit of each individual cow was documented regarding time of entry and time of leave as well as feed consumed. The study was conducted from 7th - 105th day of lactation. During this period 222,231 visits at feeder were recorded and added to the evaluation. The followings values were calculated for the parameters number of visits per day, mean duration of visits per day, total daily feed duration and daily dry matter intake(mean ± SD): 32,07 ± 12.86visits, 6.97 ± 2.64 minutes, 201.42 ± 59.23 minutes and 21.58 ± 4.19 kg dry matter. The results showed that there were significant relationships between total feeding duration and number of visits and between total daily feeding duration and longest visit per day. On the other hand, there was only a weak relationship between the total feeding duration and the dry matter intake per day.

(**Key words**: dairy cow, feeding behaviour, feed intake, early lactation).

1 Introduction

The time spent eating, as well as the pattern of meals, can obviously have a considerable impact on the total daily intake of dairy cattle (Grant and Albright, 2000). Therefore, a great deal of recent research in dairy nutrition and management has focused not only on changes in intake, but also on changes in feeding behaviour (DeVries et al., 2003).

The development of computerised systems for recording the feed intake of dairy cows has made it possible to increase significantly the amount of feeding behaviour information that is recorded automatically, which has led to various suggestions for the analyses and application of such data (DeVries et al., 2003; Nielsen, 1998).

Melin et al. (2005) pointed out that the feeding behaviour and feed intake of lactating dairy cows can be influenced by the composition of the ration and the environmental factors in the feed alley. Among other influential factors concerning management and husbandry conditions, Urton et al. (2005) found that cows with some signs of metritis spend on average 22 min/d less time at the feed alley than non-metritic cows do.

The objective of the present study was to examine the patterns of the feeding behaviour of cows during early lactation by means of several automatically measurable parameters. Simultaneously, in order to derive the possible tool of sensor-based monitoring, the relationship between feeding behaviour and feed intake were to be analysed.

2 Material and methods

2.1 Animals, housing, feeding

The experiment took place in the Centre of Research for Animal Husbandry and Technology of the Regional Office for Agriculture and Horticulture (Sachsen-Anhalt, Iden). Cows were

housed in a free-stall bran, which was equipped with an automatic feeding system. The ratio between cows and feeder was 2: 1.

For this study, data were collected from 70 high-producing dairy cows – 55 German Holstein and 15 cross-breeds (F1) of Brown Swiss-German Holstein (only 1st lactation). Twenty-three of the cows were in 1st lactation and 47 were in 2nd to 7th lactation. Data for each cow were recorded from the 7th to the 105th day of lactation. The cows calved between 3 July 2005 and 7 October 2005. They were milked three times a day (04.00 a.m., 12.00 p.m., and 08.00 p.m.). The cows were fed a total mixed ration (TMR) once a day between 06.00 and 08.00 a.m. ad libitum. The TMR contained an average of 6.99 MJ NEL/kg DM, 16.68% CP and 17.46% CF. The troughs were cleaned before feeding every day.

The chemical composition of the ration was analysed weekly. The experiment was conducted from 10 July 2005 to 16 January 2005. Throughout the study, the animals had an average milk yield of 38.83 ± 7.96 (mean SD) kg/d with a fat content of 3.93 ± 0.60% and a protein content of 3.24 ± 0,26 %.

2.2 Measurement

The individual analysis of feeding behaviour and feed intake was carried out by using an automatic feeder and electronic identification. Each feeder was equipped with an access gate, which could be programmed to allow specific cows access to a trough, and two infrared sensors, which recorded the presence of a cow in the feeder. The electronic identification was carried out by using an ear-responder. Based on this system, the start and end time of each visit as well as the amount of feed consumed for each cows were recorded. By means of these primary data, it was possible to calculate the number of visits, the time of each visit, the total eating time in a day as well as the feed intake. A visit was defined as the time spent by an individual cow with her head in one of the troughs, regardless of how the cow spent that time.

2.3 Statistical analyses

The individual animal was considered as the observational unit in all analyses. The daily recordings as well as calculated parameters were assigned to the corresponding day of lactation of each cow. The parameters of interest were the number of visits, the duration of each visit, the feed intake per visit, the feeding rate, the total daily eating time, and the total daily feed intake. From the daily values, the mean values for each week of lactation and for the whole time of the study were calculated. In addition, the standard deviation as well as the maximum and minimum were calculated. The correlation analysis between individual parameters was carried out using Pearson. For the analysis of data, the statistical package of SPSS (Version 14.0) was used. The results of the current study are part of the total work available. Another differentiation according to lactation number and genotype should be included in further studies.

3 Results

The analysis of the feeding behaviour and dry matter intake (DMI) over the course of the study from the 7th to the 105th day of lactation showed an average of 32.07 visits at the feeder per day and an average of 6.79 min for each visit. The average of the daily total eating time was 201.42 min/d. The average of the daily DMI was 21.58 kg/d (Table 1).

Table 1 Kennzahlen des Fressverhaltens und der Trockenmasseaufnahme von Milchkühen für den Zeitraum vom 7. bis 105. Laktationstag
Characteristics of feeding behaviour and dry matter intake of dairy cows from 7th to 105th day of lactation

Parameter	Mittelwert	SD	Maximum	Minimum
Anzahl an Besuchen[1]	32,07	12,86	115,00	6,00
Besuchsdauer[2] (Min./Besuch)	6,79	2,63	25,81	1,28
Gesamtfressdauer[3] (Min./Tag)	201,42	59,23	501,55	41,73
Trockenmasseaufnahme (kg/Tag)	21,58	4,20	42,65	6,79

[1]Anzahl aller Besuche am Fressplatz (mit und ohne Futteraufnahme) je Tag und Kuh
[2]Zeitdifferenz zwischen Start- und Endzeit des Fressplatzbesuchs (Min.)
[3]Summe der Dauer aller Fressplatzbesuche (Min.) je Tag und Kuh

All parameter showed a high variation. For example, while the minimum of the number of visits, the visit duration and the daily total eating time were merely ca. 25% of the corresponding means, the maximum values were three times these means. The minimum value for the daily DMI was about one-third of the mean value and the maximum value of daily feed intake was 42 kg, which was double the mean value.

The development of the feeding behaviour and feed intake during early lactation is illustrated in the following figures. Figure 1 shows the number of visits per day. During the first four weeks of lactation, an increase in the average of the number of visits per day from 26 to 31 was found.

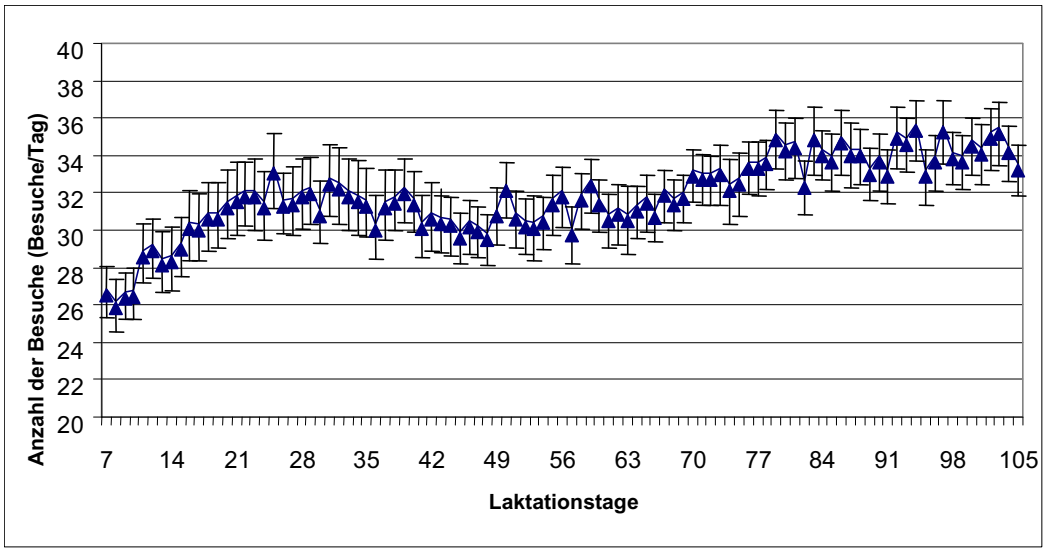

Figure 1. Anzahl Fressplatzbesuche (Mittelwerte und Standarfehler) je Kuh u. Tag vom 7. Bis 105. Laktationstag.
Number of visits at feeders (mean and standard errors) per cow and day from 7th to 105th day of lactation

Between the 5th and the 10th week of lactation, the average of the number of visits per day was stable with 31. After the 10th week of lactation, the frequency of visits was increased to 35. Concerning the average of the daily total eating time, during the first four weeks of lactation, there was a considerable increase from 130 to 180 min/d. From the 5th week of lactation, the eating time remained stable or slightly decreased, but reached 210 min/d after the 10th wk. From the 11th to the 15th wk of lactation, the total daily eating time increased by another 20 min and reached 230 min/d (Figure 2).

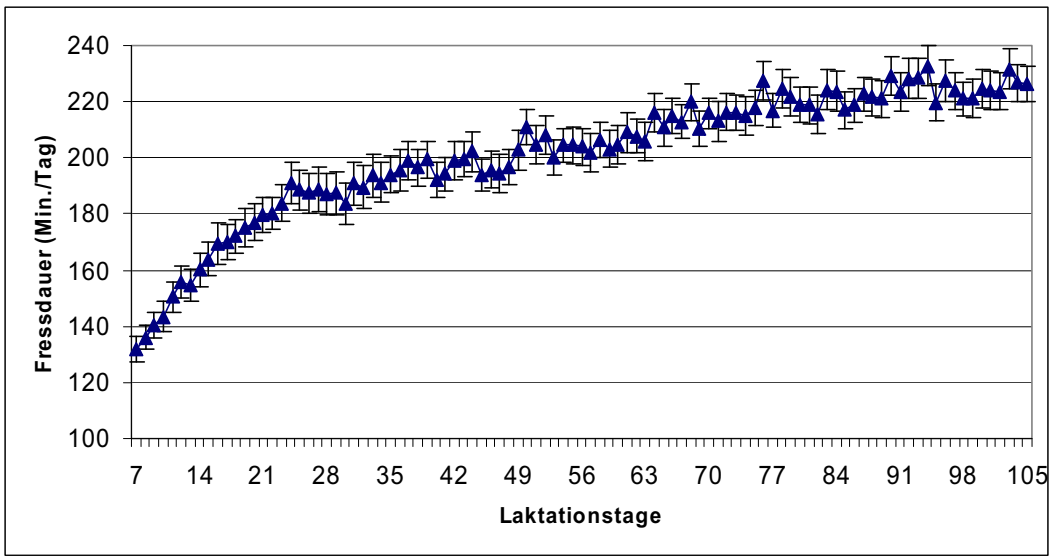

Figure 2. Gesamtfresszeit(Mittelwerte u. Standartfehler) je Kuh u. Tag vom 7. bis 105. Laktationstag
Total feeding duration(means and standard errors) per cow and day from 7th to 105th day of lactation

The average of the visit duration was 5.3 min at the beginning of the second wk. In the 6th wk of lactation, this mean value increased to 7.3 min. It then remained at this level until the 11th wk of lactation. Afterwards, the average of the visit duration decreased slowly to 7 min on the 105th day of lactation (Figure 3).

The development of the average daily dry matter intake during early lactation is shown in Figure 4. The average feed intake at the beginning of the second wk of lactation was 15.5 kg DM per cow and day. Until the end of the 4th wk of lactation, there was a considerable increase in feed intake: 1.5 kg DM per cow and week, so that it was 20 kg DM/ cow and day. Between the 5th and the 10th wk of lactation, the daily feed intake slowly increased further to 23.5 kg DM/ cow and day in the 10th wk of lactation. This value was stable until the 105th day of lactation.

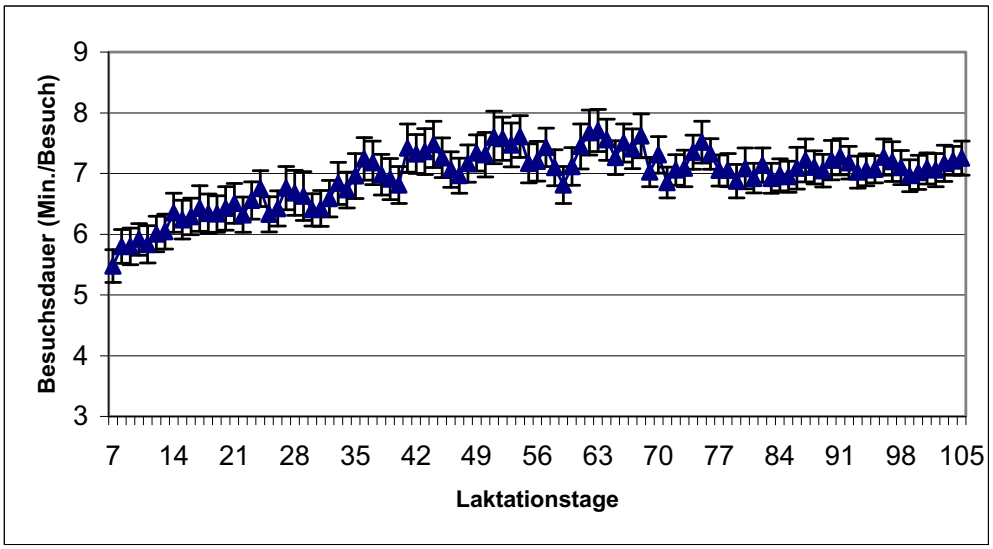

Figure 3. Durchschnittliche Dauer der Fressplatzbesuche (Mittelwerte u. Standartfehler) je Kuh u. Tag vom 7. bis 105. Laktationstag

Average duration of visits at feeders (means and standard errors) per cow and day from 7th to 105th day of lactation

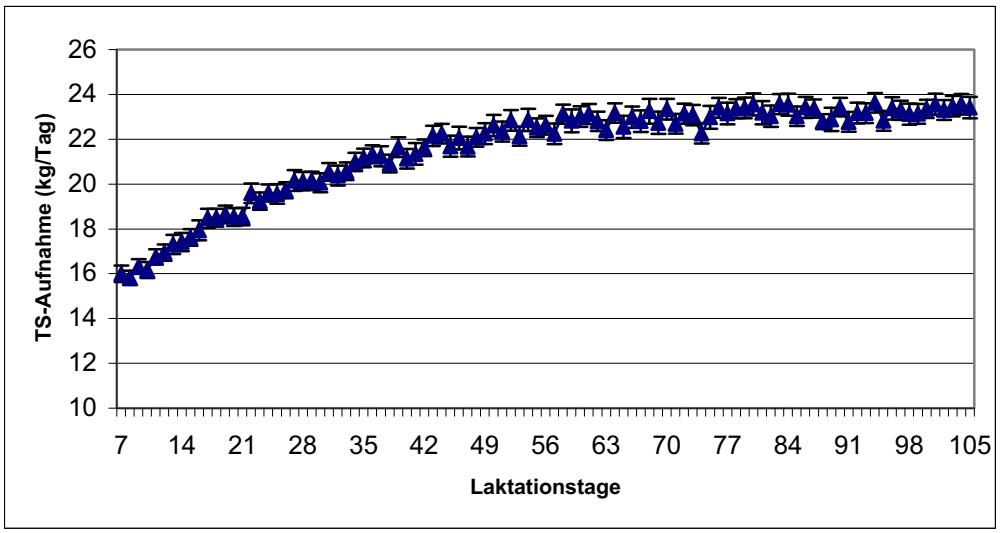

Figure 4. Trockenmasseaufnahme je Kuh u. Tag (Mittelwerte und Standartfehler)vom 7. bis 105. Laktationstag

Dry matter intake per cow and day (means and standard errors) from 7th to 105th day of lactation

To analyse the relationships between feeding behaviour and feed intake parameters, correlations were calculated. Considering the changes over the lactation, as shown in the figures, the correlations between different parameters were calculated on a weekly basis. For two examples each, the correlations between feeding behaviour parameters, as well as the correlations between feeding behaviour and actual feed intake are illustrated. In Figure 5, the correlations between the daily number of visits at the feeders and the total daily eating time are shown. Over the whole time of early lactation, the weekly correlations were between 0.40 and 0.52 ($p<0.01$).

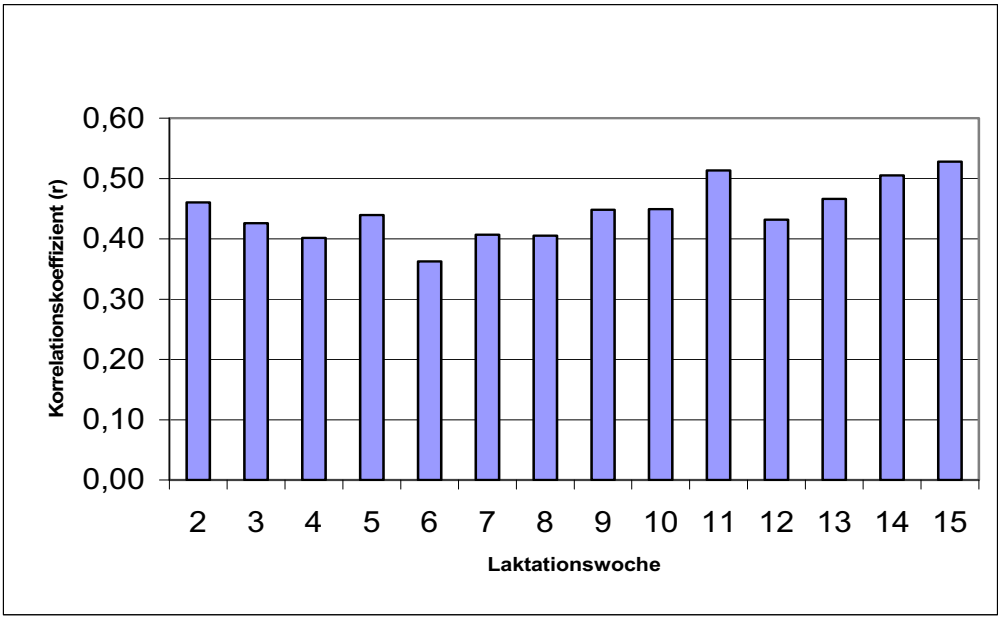

Figure 5. Beziehungen zwischen der Anzahl von Fressplatzbesuchen und Gesamtfressdauer pro Tag im Zeitraum der 2. bis 15. Laktationswoche
Relationships between number of visits at feeders and total feeding duration per day from 2nd to 15th week of lactation

The consideration of the relationship of a part-event to the relevant total behaviour is represented by the correlation between the longest visit at the feeder and the total daily eating time (Figure 6). The highest correlations between these parameters were found between the 2nd and the 9th wk of lactation.

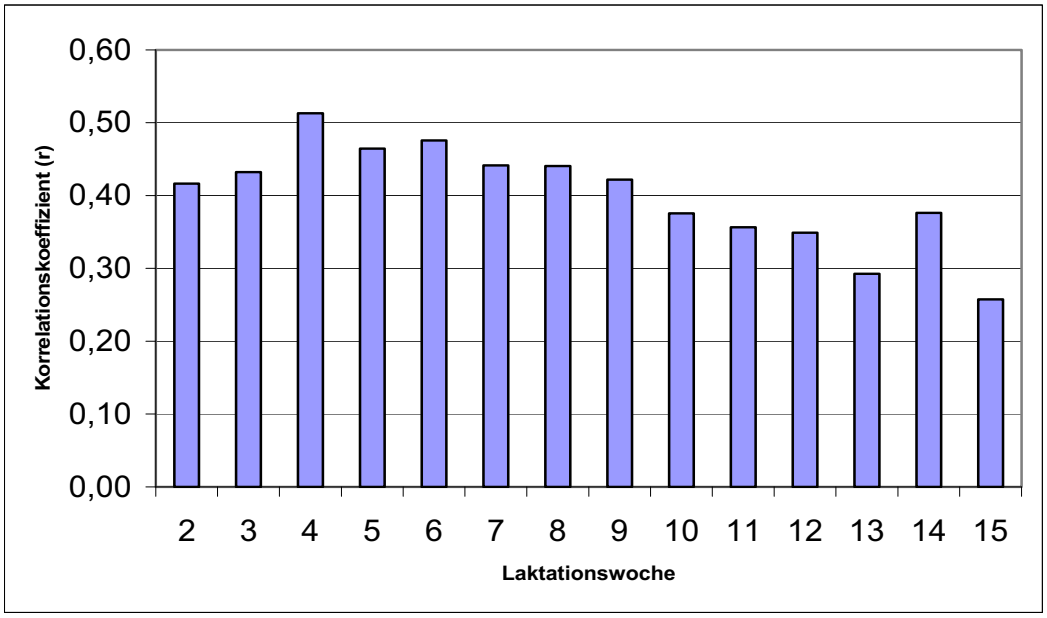

Figure 6. Beziehungen zwischen der Dauer des längsten Fressplatzbesuchs und der Gesamtfressdauer pro Tag im Zeitraum der 2. bis 15. Laktationswoche
Relationships between duration of the longest visit and total feeding duration per day from 2nd to 15th week of lactation

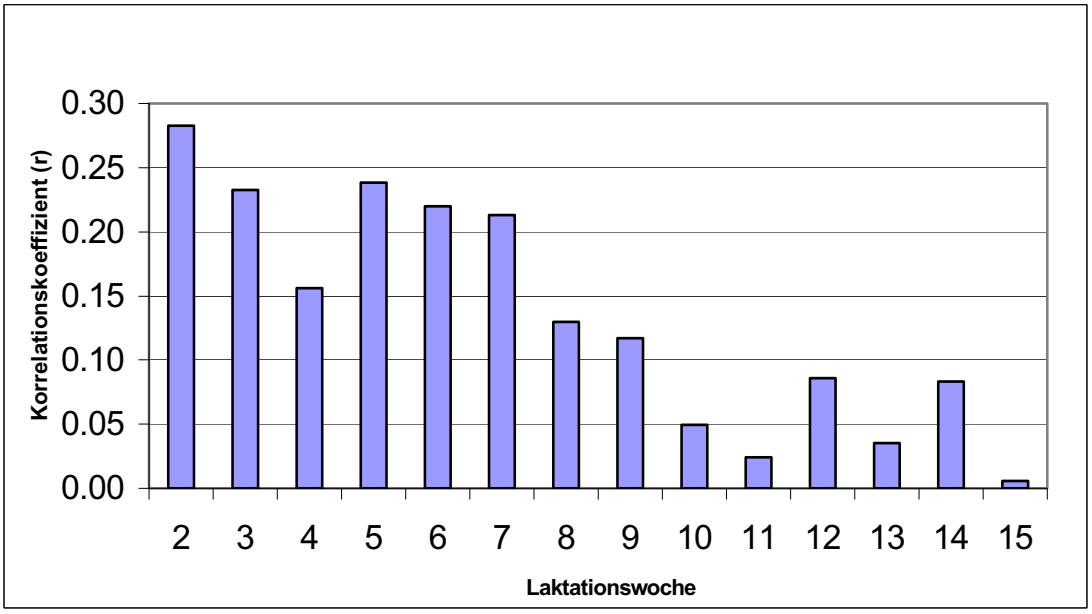

Figure 7. Beziehungen zwischen der Gesamtfressdauer und der Trockenmasseaufnahme pro Tag im Zeitraum der 2. bis 15. Laktationswoche
Relationships between total feeding duration and dry matter intake per day from 2nd to 15th week of lactation

Figure 7 illustrates the correlations between the total daily eating time and the daily DMI. The correlations were relatively low (r = 0.27 to 0.02).

A similar graph was found for the correlation between the average visit duration in a day and the daily feed intake (Figure 8).

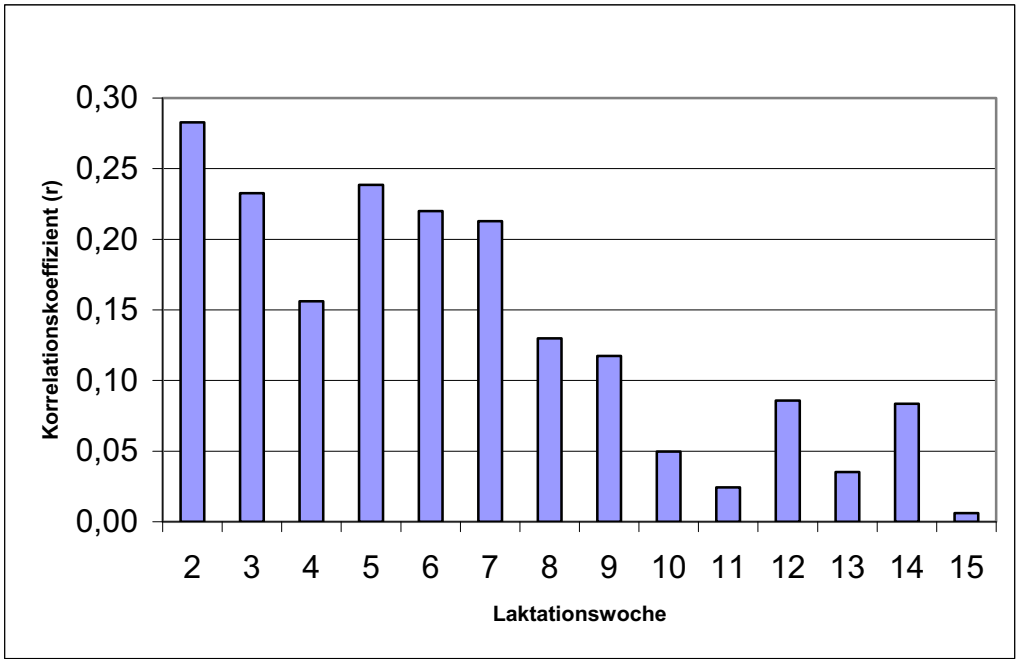

Figure 8. Beziehungen zwischen der durchschnittlichen Dauer der Fressplatzbesuche und der durchschnittlichen Trockenmasseaufnahme pro Tag im Zeitraum der 2. bis 15. Laktationswoche
Relationships between average of duration of visits at feeders and average of dry matter intake per day from 2nd to 15th week of lactation

An overview of all the individual parameters regarding feeding behaviour and feed intake between the 2nd and the 15th week of lactation is given in Table 2.

Table 2. Parameter des Fressverhaltens und der Trockensubstanzaufnahme in der Zeit von der 2. bis 15. Laktationswoche
Parameters of feeding behavior and dry matter intake in the period from 2nd to 15th week of lactation

Woche	Anzahl an Besuchen je Tag[1]		Besuchsdauer (Min/Besuch)[2]		tägliche Fressdauer (Min)[3]		Trockensubstanz-aufnahme	
	Mittel-wert	SD	Mittel-wert	SD	Mittel-wert	SD	Mittel-wert	SD
2	28	11.01	5.96	2.44	148.68	44.79	16.67	3.11
3	31	13.44	6.37	2.75	172.51	54.33	18.32	3.35
4	32	13.70	6.55	2.63	186.72	59.05	19.71	3.45
5	32	14.24	6.65	2.74	190.10	61.98	20.55	3.46
6	31	12.96	7.12	2.87	196.54	55.59	21.32	3.51
7	30	12.02	7.23	2.72	197.92	54.41	22.02	3.78
8	31	12.91	7.42	3.00	205.30	54.10	22.56	3.74
9	31	12.74	7.32	2.77	205.63	55.14	22.79	3.78
10	32	11.44	7.38	2.59	214.42	51.69	22.98	4.03
11	33	12.54	7.18	2.32	217.50	54.74	22.96	3.83
12	34	12.63	7.00	2.28	221.07	56.58	23.38	3.91
13	34	12.89	7.13	2.53	221.93	53.53	23.10	3.58
14	35	12.93	7.13	2.30	225.95	56.86	23.22	3.75
15	35	12.78	7.11	2.25	225.48	55.76	23.40	3.71

[1]Anzahl aller Besuche am Einzelfressplatz (mit und ohne Futteraufnahme) je Tag und Kuh
[2]Zeitdifferenz zwischen Start- und Endzeit des Fressplatzbesuchs (Min.)
[3]Summe der Dauer aller Fressplatzbesuche (Min.) je Tag und Kuh

4 Discussion

In the current study, the total daily eating time (from the 7th to the 105th day of lactation) was found to be an average of 201.42 min/d. Similar values had been reported by Vasilatos and Wangsness (1980), Tolkamp et al. (2000) and Shabi et al. (2005). The detailed evaluation of Tolkamp et al. (2000) concluded that the daily eating time of lactating dairy cows continuously increased up to an average of 225.1 min/d during early to mid-lactation. Vasilatos and Wangsness (1980) found an increase in daily eating time, which reached an average of 253 min/d as lactation progressed. By contrast, Shabi et al. (2005) found an average total daily eating time of 170 min/d in mid-lactation. A considerably high value of daily eating time was reported by Beauchemin and Buchanan-Smith (1989), who found an

average of 237 min/d for cows in the 2nd and more lactation during mid-lactation. They also reported an average daily feed intake of 18 kg DM/d. The results of the current study confirmed the results of DeVries et al. (2003), which had shown a similar increase in daily eating time from the beginning of lactation to the 15th wk of lactation.

Dado and Allen (1994) investigated the variations and relationships among feeding and drinking variables of lactating dairy cows during early lactation (63 ± 11 DIM). They found an average of 301 min/d for the total duration of stays at the feeders and 22.8 kg DM/d for the daily feed intake. The average number of visits at the feeder was 30 visits/d, which was considerably different from the value – 12 visits per day – reported by Shabi et al. (2005). From 6 to 7 meals per day were reported by Tolkamp et al. (2000) and DeVries et al. (2003). However, the number of visits at the feeder and the duration of each visit depend on the definition of measuring methods and mathematical analysis of data in the different studies. The current study is based on all visits at the feeders (without distinguishing between visits with or without feed intake), and the total duration of a stay at the feeder is defined as the total time measured from the start and end of each visit. Similar procedures were conducted by Tolkamp et al. (2000), and they reported an average of 22.74 kg DM/d for the feed intake, 31.6 visits per day and 5.2 min per visit, which are in agreement with our results. Over the course of study, only the average of the visit duration at the feeder (6.8 min) was different from the results of Tolkamp et al. (2000).

The correlation between the number of visits at the feeders per day and daily eating time was significant ($p < 0.01$), and it seems that the recording of the number of visits at the feeders could be used to estimate the total daily eating time. By contrast, the correlation between daily eating time and daily feed intake was too low, and could thus not be estimated. For forecast models of the feeding behaviour in early lactation, it seems that the significant correlation ($p < 0.01$) between the longest visit per day and the total daily eating time until the 9th wk of lactation is very important. From the third month of lactation, the correlations between the

individually measured parameters changed in different ways. This suggests that forecast models be adjusted to the different feeding behaviour patterns conditioned by physiological factors and that the interdependence of differing lactation periods be defined more precisely. Dado and Allen (1994) pointed out that some variations in the results of various studies may be caused by differences in the production level, behaviour definition description, chemical composition and physical form of the diet, as well as the management and environment.

5 Conclusion

The general conclusion is that the parameters characterising the feeding behaviour, which are measured for the individual animal and could be used to estimate feed intake, are influenced by many individual conditions and can be affected by a number of factors during the lactation period. However, it seems possible to work out some connections between different measurable parameters for the individual animal and to use these for estimation models. The results of the current study showed significant correlations between the parameters of the number of visits at the feeders, visit duration, daily eating time, and daily dry matter intake. These correlations varied during early lactation. There was a sharp increase in all parameters from the 2nd to the 4th wk of lactation. Some parameters of the visit duration increased during the first 9 wk of lactation, but then either stagnated or declined. Therefore, it can be argued that the average of the visit duration seems to be appropriate to draw conclusions for the dry matter intake. In this case, mathematical models are to be developed, which quantify the changes in visit duration of the individual animal.

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Eidesstattliche Erklärung

Hiermit erkläre ich, Osman Azizi, an Eides statt, die vorliegende Promotionsschrift selbstständig verfasst und keine anderen als die angegebenen Quellen und hilfsmittel benutzt zu haben.

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