Master thesis

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# A cow type for concentrate-free feeding systems – What characteristics does it display?


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**Masterarbeit für Mirjam Holinger**

**“Welche Eigenschaften zeichnen eine gute Grundfutterkuh aus?”**

In den letzten 40 Jahren ist der Einsatz von Kraftfutter in der Wiederkäuerernährung sehr stark angestiegen. Diese Entwicklung ist in zweierlei Hinsicht problematisch: einerseits ist das Verdauungssystem der Wiederkäuer auf die Verdauung rohfaserreicher Futtermittel ausgerichtet und nicht auf die Verdauung von Getreide; deshalb entstehen bei der Verfütterung von grösseren Mengen an Kraftfutter oft Gesundheitsprobleme. Andererseits ist es nicht sinnvoll, Nahrungsmittel oder Ackerflächen, die auch für die menschliche Ernährung geeignet wären, für Tiere zu nutzen, die diese Nahrungsmittel gar nicht brauchen. Für die biologische Landwirtschaft sind diese Probleme besonders brisant, da einerseits die artgerechte Haltung und Fütterung der Tiere und andererseits ein verantwortlicher Umgang mit den vorhandenen Ressourcen wesentliche Pfeiler dieser Landbauform sind.

In der Schweiz ist gemäss Bio Suisse-Richtlinien die Fütterung von nur 10% Kraftfutter an Wiederkäuer erlaubt. Die meisten Biobetriebe arbeiten aber mit konventionellen Zuchtlinien. Diese haben fast immer die Veranlagung für hohe Produktionsleistungen und sind deshalb in der Regel auch auf hohe Kraftfuttergaben angewiesen, ohne die es zu Gesundheitsproblemen kommen kann. In der Tierzucht hat man bis heute kaum Indikatoren für eine Anpassung eines Tieres an das vorhandene Futterangebot.  Es müssen solche Eigenschaften gefunden werden, die züchterisch bearbeitet werden können.

In dieser Masterarbeit soll nach Indikatoren gesucht werden, die diejenigen Kühe identifizieren, die mit einer reinen Grundfutterration ohne Kraftfutter eine angemessene Produktionsleistung bei guter Gesundheit zeigen. Eigenschaften der Körperkondition, des Fressverhaltens und des Exterieurs sollen dabei berücksichtigt werden. Die Arbeit soll anhand von Tierdaten von ca. 15 Betrieben, die seit mindestens einem Jahr kraftfutterfrei füttern, durchgeführt werden. Diese Betriebe sind am Projekt „Feed no Food“ des FiBL beteiligt und sind deshalb einem regelmässigen Monitoring unterstellt. Exterieurbeurteilungen sind für die meisten dieser Tiere vorhanden. Durch die Auswertung der vorhandenen Tierdaten soll mittels Regressionsmodellen ermittelt werden, ob diese erhobenen Eigenschaften der Tiere unter reinen Raufutterbedingungen einen erklärenden Einfluss auf ihre Gesundheit haben. Zusätzlich soll beispielhaft für eine Herde das Fressverhalten als möglicher Indikator für die Raufutterverzehrskapazität der Kühe mit deren Gesundheits- und Fruchtbarkeitsstatus korreliert werden. Diese Arbeit soll dazu beitragen, Eigenschaften von Milchkühen zu finden, die mit raufutterbetonter Fütterung züchterisch gefördert werden sollten.

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## Summary

Feeding of concentrates to ruminants in organic farming in Switzerland is questionable due to several aspects: (i) suitability for ruminants, (ii) land use change caused by soy cultivation, (ii) organic principles of closed circuits, and (iv) ethical considerations when ruminants directly compete with human nutrition.
In the past decades breeding strategies in the dairy sector focused primarily on milk production which led to increased energy requirements. A reduction of concentrates in the ration may thus lead to a more negative energy balance and may be detrimental for health and fertility. Published genotype x feeding system interactions suggest that different breeds, strains or genotypes react differently to different levels of feeding. The aim of this study was to analyze potential auxiliary traits for their relationship with health and fertility in order to find typical traits for cows that remain healthy and fertile under concentrate-free feeding conditions. The study was carried out as part of the "Feed no Food"-project at FiBL.

Physical parameters of interest were type traits related to body size and volumetric dimensions, BCS and milk components. Type traits were corrected for breed. Parameters for health and fertility were calving interval, somatic cell score (SCS), treatment incidences, and lameness score for a subset of animals. Data from totally 159 dairy cows on 14 organic farms were available. Generalized linear mixed effects models with health and fertility parameters as outcome variables were calculated for this data set. Feeding behaviour was measured using a pressure sensor developed at ART in Tänikon. 26 cows on one farm were equipped with this sensor attached to a halter for three times 24 hours in September and December each. Behavioural parameters were analyzed through correlations and linear regression for individual patterns and influence of stage of lactation. Relationships among behavioural, physical, health, and fertility parameters were evaluated through spearman correlations.

A larger BCS range within one lactation was found to be associated to prolonged calving intervals and more fertility and total treatment incidences. Fat-to-protein ratio (FPR) values of above 1.5 also indicated longer calving intervals but reduced SCS. Both, BCS range and FPR of above 1.5, are well known in literature as predictors of certain health and fertility disorders. Due to their considerable heritability, both traits have potential to be used in breeding strategies for concentrate-free feeding systems. Yet, the connection between FPR and SCS was unexpected and might be caused by decreasing milk yields as consequence of udder inflammation and thus a less negative energy balance. Contrary to the prevailing view, smaller cows (height at the withers) were associated with slightly more treatment incidences. Cows in higher lactations showed impaired health (SCS) and fertility (calving interval).
Values for traits related to feed intake (feeding duration, mastications while feeding) as well as number of boli produced, mastications per boli, rumination and feeding rate (mastications/min) revealed individual patterns when comparing the two measurement periods. No influence of stage of lactation was found. Rumination duration and mastications per bolus were not as individually consistent between the two

measuring periods and they were partly influenced by stage of lactation. Except for single correlations between behavioural traits and lameness, no relationship between feeding behaviour and health or fertility parameters could be found.

The individual pattern of some of the behavioural traits might to a certain degree be due to genetic determination. Further investigations with more animals are necessary to detect any potential connections to health or fertility and to assess heritability. Advanced instruments to measure chewing activity in cows are currently being tested and could possibly simplify large-scale observations.

# Table of contents

## Abbreviations

BCS............Body condition score

CI................Calving interval

DIM ...........Days in milk

DM ............Dry matter

DMI ...........Dry matter intake

DMY ..........Daily milk yield

DSN ...........Deutsches Schwarzbuntes Niederungsrind (Native German cattle breed)

FiBL............Forschungsinstitut für biologischen Landbau (Research Institute of Organic Agriculture)

FPR ............Fat-to-protein ratio

HF...............Holstein-Friesian

HS...............Height at the sacrum (stature)

HW ............Height at the withers

NEB ...........Negative energy balance

NEFA..........Non-esterified fatty acids

SBZV ..........Swiss Brown Cattle Breeder's Federation (Schweizer Braunviehzuchtverband)

SCC.............Somatic cell count

SCS ............Somatic cell score

SD...............Standard deviation

TMR...........Total mixed ration

## List of figures



## List of tables

# 1 Introduction

In most regions, Switzerland offers ideal grass growing conditions. Gross yields can exceed 13 tons DM per hectare grassland and year (AGRIDEA, 2008). 75 % of the agricultural area are pastures or meadows (Burren et al., 2010), mostly not suited to be used as arable land but perfectly suited to be used with ruminants. Owing to these prerequisites, Switzerland has a long tradition of sheep, goat and cattle husbandry, milk production and milk processing. Swiss cattle breeding focused for a long time on dual purpose animals. Continuous selection of best adapted and well producing animals led to the formation of well-known Swiss breeds as for example the Simmental and the Original Brown breed, which have been exported worldwide.

However, in the 1960s Swiss farmers started to crossbreed local breeds with North American strains of different dairy breeds (Gerber, 2005). In the USA performance had been the main selection criteria. In consequence milk yield of Swiss cows approximately doubled within the last 40 years (SBZV, 2011). From 1988 to 2007 average lifespan decreased from between 3.6 and 4.3 to between 3.3 and 3.9 lactations depending on breed (data from Austria, in Knaus (2009)). Alongside with milk production demand for nutrients and energy in the ration increased steadily. Cows of a bigger stature are able to consume more feed. Nevertheless, the correlated response in roughage[1] intake is only able to cover approximately half of the extra requirements (Van Arendonk et al., 1991). Therefore feed for high yielding cows needs to have a higher nutrient density, a density which often even high quality roughage can hardly achieve. Burren et al. (2010) estimate that above a daily milk yield of 30 kg part of the ration has to consist of concentrates[2]. In the USA, where topography allows a great share of land to be used as arable land, production of concentrates is well feasible. But in a mountainous area like Switzerland, the demand of high genetic merit cows led to an increased import of feedstuff. According to Blum (2011) 40% of the 1.6 million tons DM concentrates fed in Switzerland in 2007 were imported; 34% of those imports were used as feed in the dairy sector. Approximately 200,000 hectares of arable land in other countries are necessary to produce the amount of imported feedstuff (Blum, 2011).

These figures apply for the entire dairy cattle sector. For organic farms in Switzerland the amount of concentrates in the ration for dairy cows is limited to 10% of DM (BioSuisse, 2011). Nonetheless, feeding of concentrates to ruminants in organic farming can be questioned generally due to several aspects:

- **Organic principles:** The guidelines of BioSuisse state: “The feeding of livestock should not be in direct competition with human nutrition. … Livestock feed is to be produced on the holding” (BioSuisse, 2011).

[1] The definition of roughage according to the guidelines of Biosuisse (2011): Straw, feed from permanent meadows and leys (fresh, ensiled or dried), whole maize plants, sugar beet pulp, fodder beets and potatoes (unprocessed), wastes from fruit and vegetable processing (apples, grapes, carrots, beetroots etc.), brewer‘s grains, husks of spelt, barley, oats and rice, husks of soya-beans, cocoa and millet (conclusive list).

[2] Concentrates is thus all feedstuff which is not listed as roughage above, most importantly grains and soy.

- **Animal health:** A high proportion of feedstuff rich in energy or protein in the ration of ruminants can be detrimental for their health and is therefore not suitable for ruminants. Highly fermentable carbohydrates may lead to decreased rumen pH, cornification of rumen epithelium and finally to deteriorated absorption (latent acidosis). An excess of protein in the feed can impair liver functions and cause capillary damages in claws leading to lameness (Kreuzer, 2010). Elevated urea and ammonia concentrations in the blood resulting from a high protein diet can adversely influence reproduction organs (Leroy et al., 2008).
- **Land use change:** The growing of soy especially in Southern America is often associated with land use change, which is responsible for emitting previously bound carbon and thus contributes to global climate change (IPCC, 2007; Arima et al., 2011). The transatlantic shipping of soy on the other hand contributed by only 3% to the total climate change impacts of soy in $CO_2$-equivalents, according to a model calculation by Lehuger et al. (2009) .
- **Ethical considerations:** Production of soy, grains, and also maize as feedstuff for ruminants stands in direct competition to the production of food for human nutrition.

In spite of these points supporting a reduced usage of concentrates in organic dairy farming, the increased enteric fermentation and emission of methane with a ration high in roughage may constitute a counter-argument. But while high roughage diets are associated with higher enteric emissions of methane, low roughage diets produce more emissions from manure. The extent to which concentrates can reduce the overall emissions depends on the type of concentrates (Hindrichsen et al., 2005).

For organic farming the “intensive approach” is not suitable. Instead, the ambition is to have an appropriate breeding strategy, to adapt cows optimally to the low-input conditions of organic systems. Postler and Bapst (2000) summarized the breeding goals like this: “Organic farming aspires to breed a healthy cow, which is able to produce a good milk yield from the holding’s own fodder over a period as long as possible. It should exhibit among others the following characteristics: elastic metabolism, high roughage intake capacity, healthy claws and feet, good fertility, milk production adapted to location and feeding, one calf a year.” Furthermore, cows should be able to adapt their production to changing environments, for example seasonally changing qualities of fodder (Spengler Neff, 2011). Still, organic animal husbandry was and is mostly using conventional genetics. Some providers of artificial insemination offer semen of bulls with favored characteristics for organic systems (for example bulls with the “Kleeblatt”-label, offered by Swissgenetics), but those traits are often measured in a conventional farming environment (Spengler Neff, 2011).

Because many Swiss organic farmers use conventional genetics for breeding and thus keep cows with high demands in energy, there are widespread misgivings that a reduction of concentrates in the ration would lead to impaired health, especially in terms of fertility problems and ketosis. Therefore the project "Feed no Food" was launched at the Research Institute of Organic Agriculture (Forschungsinstitut für biologischen Landbau, FiBL) in 2009 (Notz et al., 2011). The goal was to examine how an abandonment or a reduction of concentrates would influence cow health, as well as economic and ecological aspects. 74 organic and bio-dynamic farms participated in the project, whereof 5 were located in Germany, the others in Switzerland. The farms were grouped into four categories according to the farmer's preferences:

1. Goal: Reduction to 0% of the ration
2. Goal: Reduction to below 5% of the ration, while using as much as possible holding's own or domestic produced feed
3. Goal: Retention of a ration with 10% according to the guidelines of BioSuisse (2011) while using as much domestic feed as possible (control group)
4. Farms that had already fed dairy cows without concentrates (Notz et al., 2011)

The project was finished by the end of 2011, results are not published yet.

For a long-term establishment of concentrate-free feeding systems, a corresponding breeding strategy would be necessary. It is known that there are some interactions between genotype and feeding system in terms of milk, fat and protein yield, efficiency, fertility, grazing behaviour and body condition score (BCS) (e.g.Kolver et al., 2002; Horan et al., 2005a; McCarthy et al., 2007; for review see Hammami et al., 2009). Those studies were carried out with different breeds or with different strains of one breed. Current projects in Switzerland investigated differences between strains and between different cow types under full-grazing conditions, but always under inclusion of some amounts of concentrates in the ration (Burren et al., 2010; Hofstetter et al., 2011a; Hofstetter et al., 2011b). Genotype x feeding system interactions indicate that different breeds, strains or cow types react differently to different levels of feeding. Thus, there might also be genetic differences between individual cows in their ability to adapt to a given environment, which would be an individual x environment interaction according to Hammami et al. (2009). If health traits are taken as indicators for the ability to adapt, correlated type traits, milk components or feeding behaviour traits could be used as auxiliary traits. Auxiliary traits have the advantage that their measurement is easier, cheaper, and can be done earlier in an animal's life.

The objective of this thesis is to identify relationships between health traits and physical and behavioural traits in dairy cows on an individual, breed-independent level under concentrate-free, organic feeding conditions. The hypothetical connections between the traits of interest are shown in Figure 1.

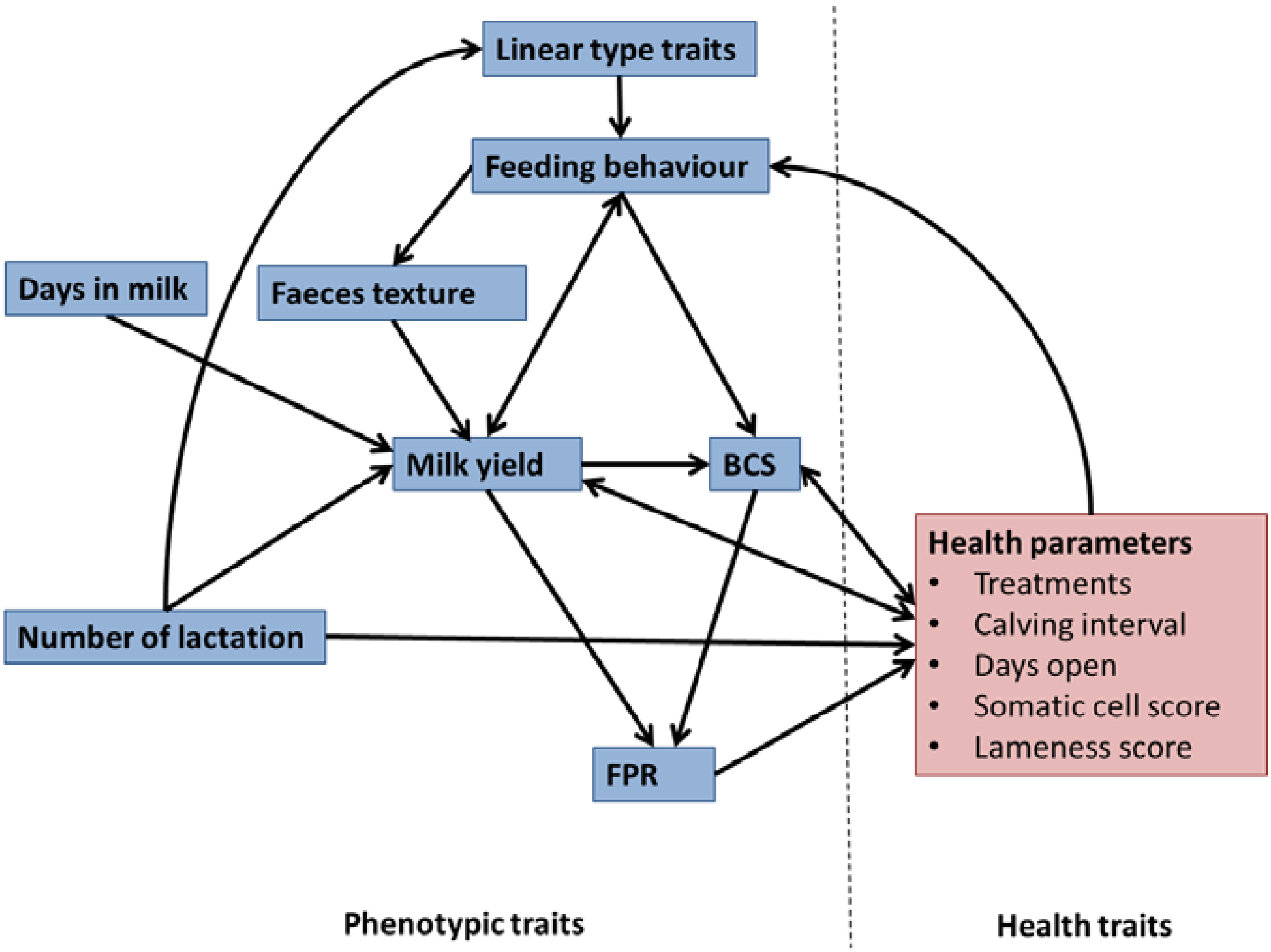



*Figure 1: Hypothetical connections among variables*

# 2 Literature

## 2.1 Impacts of genetics

### *2.1.1 Type traits*

The past and current selection strategies focusing primarily on production traits have caused changes not only in milk yield but also in body size and condition, health and fertility of dairy cows. The trend was and is going towards larger dairy cows. The results of Berry et al. (2004) indicate that all type traits except some udder traits are positively genetically[3] correlated to milk yield. Stature and body depth were found to be correlated with milk yield by 0.22 and 0.24 (Brotherstone, 1994). Phenotypic correlations showed the same trend but were lower. Yet, the generally positive relationship between body traits and milk yield was not confirmed in all studies. Parke et al. (1999) notified negligible phenotypic and genetic correlations between

[3] Genetic correlation: Additive genetic covariance between two quantitative traits, also expressing the correlation between breeding values. Phenotypic correlation: Phenotypic covariance between two quantitative traits in a population, calculated from the measured phenotypic values (Kräusslich (Ed), 1994).

fat corrected milk and capacity, size (heart girth) and stature (height at the sacrum).

### *2.1.2 Body condition and energy balance*

Cows with higher milk yields gain less weight during lactation, have a lower minimum weight that is reached later in lactation, show increased intake and body tissue mobilization, as well as a more negative energy balance (NEB) (Veerkamp and Koenen, 1999). In a long-term study Pryce et al. (2001) compared cows selected for high milk fat and milk protein to control cows and found that animals of the selection line were significantly thinner (lower BCS) and lost more condition in early lactation.
Milk yield is strongly positively correlated with dry matter intake (DMI) (between 0.44 and 0.65 in a comparison of different studies, in Veerkamp (1998)). Although, this might only apply for diets high in concentrates: A comparison of high and low genetic merit animals showed that the high genetic merit cows were not able to eat much more if fed a diet high in roughage, resulting in smaller differences in performance. Yet, under a diet high in concentrates they had a higher intake than animals of low genetic merit (Veerkamp et al., 1994). Nonetheless, the extra feed intake is often not able to cover the extra requirements of increased milk yield (Veerkamp and Koenen, 1999) and the residual energy required has to be taken from body tissue storages. This process is enhanced during the first weeks postpartum because intake capacity is not fully exhausted until between 8 and 22 weeks after calving (Ingvartsen and Andersen, 2000).

Energy balance can be defined as the difference between energy consumed and energy used for maintenance and production. In a phase of NEB animals oxidize non-esterified fatty acids (NEFA) from body fat deposits to produce energy (Goff and Horst, 1997).
To some extent a NEB following calving and a loss of BCS during this time is perfectly normal and cannot be eliminated by improved feeding (Roche et al., 2009). Experiments showed that very energy-rich diet fed in early lactation did not affect body lipid mobilization and BCS loss, but reduced the duration of BCS loss slightly. On the other hand a severe feed restriction did not always result in a greater BCS loss (Roche et al., 2006). This confirms the findings by Smith and McNamara (1990) that lipolysis is genetically determined (homeorhesis), while lipogenesis is environmentally influenced.

There is evidence that selection for higher milk yield has changed physiological functions in dairy cows. Homeorhetic processes of partitioning nutrients to different sinks with important biological functions in the organism have been affected. These processes are responsible for an adequate nourishment of the neonate through milk production and are largely genetically controlled (Roche et al., 2009). However, in dairy cows selected for high yield, additional nutrients are increasingly partitioned towards milk production (Dillon et al., 2006) and more body resources are mobilized through lipolysis (McNamara and Hillers, 1986).

### *2.1.3 Health and fertility*

Owing to these changes in physiology, health and especially fertility traits as well as longevity of dairy cows have deteriorated over the past decades (e.g. Uribe et al., 1995; Pryce et al., 1999; Ingvartsen et al., 2003; Windig et al., 2006). The genetic correlation between milk, - fat and - protein yields and calving interval were 0.61, 0.56, and 0.57 respectively (Pryce et al., 2000). High genetic merit Holstein-Friesians (HF) in comparison with low genetic merit HF performed worse for all fertility traits (oestrus not observed, calving interval, days to first heat, days to first service, days open and conception at first service) as well as for metritis incidences (Pryce et al., 1999). McGowan et al. (1996) observed a positive relationship between milk yield of heifers and days to first oestrus. For cows, milk yield was positively related to number of services. Milk production was found to be genetically positively correlated with mastitis, ketosis and leg problems (Uribe et al., 1995). In a review of 25 studies Ingvartsen et al. (2003) could confirm a clear relationship between mastitis and milk production, while no evidence was found for an increased risk of dystocia, retained placenta, metritis, ketosis, left-displaced abomasum and lameness. Windig et al. (2006) described the same trend of genetic correlations between milk yield and fertility traits as well as mastitis, but also found that the magnitude of these correlations was depending on environment (farm size, production intensity and fertility level of the herd). A comparison of several milk and dual purpose breeds and crossbreds resulted in the conclusion that HF cows had the highest yield, the shortest lifespan, lowest BCS and lowest rate of animals to be pregnant at the end of the breeding season (Walsh et al., 2008).

The aforementioned correlations between genetic merit for milk yield and health and fertility problems are caused or aggravated by the metabolic load of the NEB, coming along with the higher milk yield. While milk yield increased between 1951 and 1989 and conception rates of cows deteriorated, conception rates of heifers remained the same (Butler and Smith, 1989). This indicates that the declining fertility is primarily caused by the NEB and its implications on the organism. In the study by Pryce et al. (2001) thinner cows (10 weeks after calving) and cows which lost more BCS had considerably worse reproductive performance. The adverse relationship between BCS and fertility remained, even after correction for milk yield. In another study excessive BCS loss 5 weeks postpartum (more than 1 point on the 5 point scale) was associated with significant increase in interval to first ovulation after calving and decrease in success of first service (Butler and Smith, 1989). The genetic correlation between BCS and calving interval was -0.55 (average BCS in the first 10 weeks of lactation; Pryce et al., 2000) and -0.13 at 150 days in milk (DIM) when corrected for milk yield (Wall et al., 2007). A direct link between NEB and fertility could be shown by de Vries and Veerkamp (2000). In their study a low nadir of energy balance was related to delayed resumption of luteal activity. Cows with higher levels of NEFA and β-hydroxybutyrate as well as lower BCS and less energy body content had longer calving intervals and lower conception rates (Oikonomou et al., 2008).

Fat mobilization processes may induce several disorders with direct impacts on fertility. There is a limit to the amount of fatty acids the liver can fully oxidize or export. When this limit is reached, triglycerides

accumulate in the hepatocytes and acetyl-coenzyme A, a product of the fat degradation process, is converted into the ketone bodies acetoacetate and β-hydroxybutyrate instead of being used in the citric acid cycle. The appearance of these ketone bodies in blood, urine or milk is an indicator for the fatty liver-ketosis syndrome, which mostly becomes clinically apparent 10 days to 3 weeks after parturition. Affected animals show reduced appetite and a decline in milk production (Goff and Horst, 1997). Milk fat and protein as well as their ratio are also indicators for energy balance (see chapter 2.5.2).
Ketosis in turn is associated with other health disorders such as retained placenta, metritis, endometritis, mastitis and left-displaced abomasum (Toni et al., 2011). Collard et al. (2000) found correlations between NEB and lameness, locomotive and digestive problems. A lower NEB nadir and a higher total energy deficit came along with more locomotive problems and lameness. Digestive problems were more prevalent when numbers of days in NEB were longer.

### *2.1.4 Efficiency*

Efficiency, mostly feed efficiency, describes how efficient a cow can convert input (feed energy and protein) into output (valuable products as milk, body tissue, offspring). Another measurement of efficiency is the so called milk production efficiency (MPE). It is defined as kg energy-corrected milk (ECM) per kg metabolic body weight (Hofstetter et al., 2011a).

As feed intake and thus feed efficiency are often difficult to assess under farm conditions, correlated traits are of interest in order to select for feed efficiency. Gross energetic efficiency (energy in milk / total energy intake) is genetically and phenotypically correlated with milk yield (Dickinson et al., 1969; Veerkamp and Emmans, 1995); and milk yield was described above to be positively correlated with some body size traits. Therefore a positive correlation between body size and feed efficiency could be assumed. Nonetheless, several studies found figures showing the opposite. Yerex et al. (1988) compared cows which were selected for a small size over 3 generations with cows selected for large size. Feed efficiency was defined as kg of total digestible nutrients consumed per fat corrected milk produced. After three generations, cows of the small line were on average 3 cm smaller (height at the withers), 50 kg lighter and 2.8% more efficient than the large line. Dickinson et al. (1969) found a strong negative correlation between gross energetic efficiency and type traits as chest girth, chest depth, height at the withers, average body weight and body weight change during lactation for Ayshire, Brown Swiss and HF cows. Equally, the study by Parke et al. (1999) described that feed efficiency was phenotypically and genetically negatively correlated with all body size measures, but most significantly with body weight, capacity, size and stature. More recently Hofstetter et al. (2011a) compared small and large cows of the Swiss Fleckvieh and Swiss Braunvieh breed and found no significant differences in feed conversion efficiency and milk production efficiency between the two cow types under pasture-based conditions. Equally, Schori and Münger (2010) could not observe any differences between New Zealand HF (smaller and lighter animals) and Swiss bred HF cows in terms of feed conversion efficiency (kg ECM per kg DMI). In the same trial, however, a significantly higher MPE for New Zealand cows was reported (Roth et al., 2010).

The sources for the variation in gross efficiency are probably yield, the capacity for feed intake, the extent to which body tissue is mobilized and differences in partitioning of nutrients to products (Veerkamp and Emmans, 1995). Accordingly, the most important components to improve feed efficiency by selection are capacity for feed intake, body condition changes and the amount of energy needed for milk yield, weight gain and maintenance (Veerkamp, 1998).

#### *2.1.5 Greenhouse gases*

4% of all global greenhouse gases originate from the dairy sector, whereof approximately half is methane (FAO, 2010). Because global warming potential of $CH_4$ is estimated to be 25 times higher than that of $CO_2$ (IPCC, 2007), there is rising interest to find ways how to reduce emissions from livestock production. Moreover, $CH_4$ production in the rumen represents a loss in feed energy.

One approach is to improve productivity and efficiency through breeding and nutrition (Steinfeld, 2006). High yielding dairy cows are associated with lower enteric $CH_4$ output per kg milk even though having higher feed intakes and higher total enteric $CH_4$ outputs, because they partition a greater part of their nutrient intake to milk production and the share of maintenance requirements can be allocated to a higher milk yield (Bell et al., 2010). Nevertheless, in a study by Bell et al. (2011) heifers from a line selected for high milk fat and protein had higher enteric $CH_4$ emissions before entering the herd than control animals because of their higher growth rate and energy demand. Once in the herd, the high genetic merit animals produced up to the third lactation about 14% less $CH_4$ through fermentation and manure. Considering the whole lifetime there was no difference between high and low genetic merit animals. However, higher DMI and longer lactation periods were associated with lower lifetime $CH_4$ emission per kg ECM, and both traits were positively correlated with milk yield (Bell et al., 2011).

A study which did not only look at $CH_4$ but also integrated nitrous oxide ($N_2O$) from soils, and carbon dioxide ($CO_2$) from energy use and carbon loss from soil, found that greenhouse gas emissions per kg of milk solids increase with increasing genetic potential of the strains. The New Zealand and high durability strain of HF had lower overall emission than the high production strain, because the latter suffered from declined fertility. The higher replacement rate was accompanied by more nonproductive animals contributing to the emissions (O'Brien et al., 2010).

### 2.2 Impacts of feeding level

#### *2.2.1 Definition*

Feeding level describes the share of concentrates and roughages in a diet and hence the nutrient density. Most studies compared high levels of concentrates with low levels (Veerkamp et al., 1994; McGowan et al., 1996; Pryce et al., 1999). All those studies were carried out at the Langhill Dairy Cattle Research Centre in Scotland. The share of concentrates in dry matter for the low level diet was 20% and reached 1000 kg per cow and year. In the high level ration, concentrates contributed 45% and reached 2500 kg per cow and year. Other studies compared a total mixed ration with grazing (Kolver et al., 2002; Cutullic et al., 2011), where cows on pasture did not receive any concentrate supplementation.

### *2.2.2 Performance and body condition*

Impacts on performance are in line with expectation that a higher nutrient density leads to higher milk yield. All publications at hand confirmed this relationship (e.g. McCarthy et al., 2007; Walsh et al., 2008; Cutullic et al., 2011). In terms of milk components, results are not consistent. Some studies reported lower milk fat and milk protein yields for cows in the low-fed group (Walsh et al., 2008), while others reported only lower milk protein (Cutullic et al., 2011) or higher milk fat contents (McCarthy et al., 2007). Milk components seem to be strongly dependent on the type of diet, the amount of concentrates, the amount of body tissue mobilization, and genetics, therefore comparisons between different studies are difficult.
Findings describing the impact of feeding level on body condition and energy balance are also not consistent. A lower feeding level is often associated with an increased loss in body condition and body weight (Walsh et al., 2008; Cutullic et al., 2011) as well as a lower net energy intake (Berry et al., 2006). However, Cutullic et al. (2011) reported similar blood NEFA levels for both treatment groups 20 and 60 days after calving, but reduced glucose concentrations of low-fed cows, indicating that metabolic load on low-fed animals was not substantially higher. The same conclusion was drawn by Berry et al. (2006), who found no differences in duration and extent of the NEB between cows on low and on high feeding levels, respectively. Also, no difference was found between high and low concentrate treatments in body tissue mobilization and body lipid content in the trial by Veerkamp et al. (1994).

### *2.2.3 Health and fertility*

Generally, it is assumed that low feeding levels have rather deteriorating consequences for fertility and health. The here descripted studies did not support this assumption (Gilmore et al., 2011) or even found converse results (McGowan et al., 1996; Pryce et al., 1999; Walsh et al., 2008).
Gilmore et al. (2011) conducted a feeding experiment with the purpose to improve fertility through better adapted feed. They compared a diet high in fat and starch, one with protected proteins, and one which was individually adapted to cow’s demand to a control diet based on best practice management. No significant differences in any investigated fertility traits were found. A study in a grass-based seasonal calving system on the other hand, found that cows on a low concentrate diet required fewer services per conception and the probability to be pregnant 6 weeks after start of the breeding season was higher (Walsh et al., 2008). Similarly, a low concentrate diet was associated with fewer days to first estrus and first service (Pryce et al., 1999). McGowan et al. (1996) did not find any differences between feeding levels in terms of fertility traits

in cows. Nonetheless, there were differences observed in heifers. Heifers on a high concentrate diet showed more days to first estrus, had a longer calving interval and needed more services. A comparison experiment of a total mixed ration with a concentrate-free diet resulted in similar pregnancy rates at the end of the breeding season for both treatments. Ovulation was more often detected in low-fed cows and detections relied more frequently on standing behaviour. In cows of the Normande breed, more animals in the low-fed group were pregnant 21 days after the insemination than in the high-fed group (Cutullic et al., 2011).

In summary, the neutral or even positive effect of a low feeding level on fertility can be explained in several ways: Firstly, fertility is rather the result of specific selection strategies. Production level and not feed is decisive for fertility. And secondly, cows seem to be able to adapt their performance to a level which is favourable for fertility (Pryce et al., 1999; Walsh et al., 2008).

#### *2.2.4 Greenhouse gases*

Methanogenesis is dependent on the type and amount of carbohydrates digested and excreted. Hence composition of the feed ration has an influence on the amount of $CH_4$ produced by dairy cows. A diet which is low in roughage (fibers) and high in concentrates (easily digestible carbohydrates) is generally assumed to have a lower $CH_4$ output in the cow. This was confirmed for the production of $CH_4$ through enteric fermentation. A non-grazing, low roughage diet resulted in 8 % lower enteric $CH_4$ emissions than a grazing, high roughage diet. But due to the non-grazing management system and the slurry production, $CH_4$ emissions from manure partially offset the reduction in methane (Bell et al., 2011). Variations of different carbohydrates in concentrate feed showed that sugars enhance enteric methanogenesis while lignified and thus hardly digestible fibers tend to reduce enteric as well as slurry $CH_4$ production (Hindrichsen et al., 2005). Thus, the effect of concentrates on total methane emission depends on type and composition of carbohydrates.

O'Brien et al. (2010) found that the effect of feeding level on greenhouse gases ($CH_4$, $N_20$ and $CO_2$) depends on strain. High durability and high production HF strains had reduced emissions per unit of product on a high concentrate diet, because they showed a large milk production response to increased concentrate supplementation. When emissions were calculated per hectare, the high concentrate ration produced the highest emissions followed by the high stocking system and a control pasture system, because of a decrease in DMI of the herd.

### 2.3 Impacts of genotype x environment interactions

#### *2.3.1 Definition*

"Genotype x environment interaction occurs when performances of different genotypes are not equally affected by different environments" (Falconer (1952), cited in Hammami et al., 2009). If there is a genotype x environment interaction the same genotype develops different phenotypes in different environments, which is also known as phenotypic plasticity. A scaling effect exists when the differences between genotypes vary between environments but their ranking stays the same. Re-ranking on the other hand is the effect, when genotypes also change their ranks between environments. So the superior animal or breed in one condition is not the best under another condition. Genotype can refer to a breed, crossbreed, breeding values of individual animals or even to genetic characteristics as QTLs (quantitative trait loci) or genes (Hammami et al., 2009). In studies with dairy cattle genotypes are often breeds or strains within breeds. Environment can be for example country, herd, management system or feeding level (Hammami et al., 2009). Possible explanations for genotype x environment interactions may be that some alleles are only expressed in specific environments or that gene regulation alters across different environments (Schlichting and Pigliucci, 1995).

Genotype x environment interactions are of interest in breeding because breeding values achieved under certain conditions might not be achieved under different conditions and thus genetic progress can be reduced. When re-ranking occurs and traits are negatively genetically correlated in the two environments, genetic gain can even be negative. Genotype x environment interactions become rather apparent when genotype and/or environment are more diverse (Dillon et al., 2006).

### *2.3.2 Performance and body condition*

Feeding level has a stronger influence on performance of high genetic merit cows than it has on performance of low genetic merit cows. In a comparison of Normande and HF cows, feeding level was shown to have a greater effect on milk production in HF (Cutullic et al., 2011). While the difference between the high and the low fed group in HF was 2700 kg of milk, it was only 1800 kg between the Normande groups. Horan et al. (2005a) found genotype x diet interactions for yields of milk, fat and protein in different HF strains. Even a re-ranking effect was published by Kolver et al. (2002) for milk solids yield in mid and late lactation between a New Zealand and an overseas strain of HF (North American and Dutch genetics). When fed a total mixed ration, the overseas produced more milk solids but under grazing conditions the New Zealand cows performed better. Similarly, McCarthy et al. (2007) compared three strains of HF under grazing conditions (different concentrate allowances and stocking rates) and observed genotype x diet interactions for total DMI, grass herbage DMI and milk yield. The high production strain had significantly higher intakes (total DMI and grass herbage DMI) in the high concentrate treatment than the high durability and the New Zealand strain. In the high stocking treatment the New Zealand strain had a higher grass herbage intake than the other two strains. There were also differences between the strains in their reaction to concentrate supplementation. Substitution rates of herbage by concentrates were highest for the New Zealand strain, lowest for the high production strain, and intermediate for the high durability strain (0.75, 0.16 and 0.57 kg herbage per kg concentrates, respectively). Furthermore, the milk yield responses to concentrates varied and were 1.81, 1.02 and 0.61 kg milk per kg concentrate DM, for the high

production, high durability and New Zealand strain respectively (McCarthy et al., 2007).
For controlled experiments no study is known that describes a genotype x diet interaction for BCS, BCS loss or body tissue mobilization; neither when comparing different strains of the HF breed (Veerkamp et al., 1994; Horan et al., 2005a; McCarthy et al., 2007) nor when HF cows were compared to Normande cows under low and high feeding levels (Cutullic et al., 2011). This suggests that different breeds or strains react similarly to different feeding levels in terms of body tissue mobilization. However, Berry et al. (2003b) calculated interactions for BCS and BCS change using data from 66 herds with HF dairy cows across Ireland. Interactions were found for genetic standard deviation of BCS change up to 60 DIM under different nutritional environments.
No genotype x diet interaction was known for feed efficiency (Veerkamp et al., 1994)

#### *2.3.3 Health and fertility*

In terms of health and fertility, only few studies describe genotype x feeding level interactions. Pryce et al. (1999) looked at the disorders ketosis, metritis, retained placenta, milk fever, lameness as well as several fertility measures and could not find an interaction between HF selected for high milk fat and protein yield and a control line and feeding level. No interaction was observed for re-establishment of ovarian activity, conception rate to first insemination (Horan et al., 2005b), days from calving to first service, days from calving to confirmed pregnancy and overall pregnancy rate 6 weeks after the start of the breeding season (Walsh et al., 2008). However, Cutullic et al. (2011) describe an interaction for the time from calving to commencement of luteal activity. While HF cows needed 31.3 and 35.8 days in the high- and low-fed group respectively, Normande cows needed 28.9 and 25.1 days. The rate of cows remaining empty after the breeding season when fed a TMR was 14% for New Zealand and 29% for overseas HF (North American and Dutch genetics). On an all-pasture diet the difference was significantly larger, 7% and 62% for the two strains (Kolver et al., 2002).

In conclusion, there is strong evidence that due to genotype x feeding system interactions cows selected for high production in a feedlot environment are not best suited in a grass based or low-input feeding system (McCarthy et al., 2007).

## 2.4 Genetics of feeding behaviour

#### *2.4.1 Inter-species and inter-breed differences*

In a comparison trial of crossbred water buffaloes and Brahman cattle on a high roughage diet, buffaloes were found to be more efficient consumers of this kind of feed. They had higher DMI as percentage of BW and per metabolic BW, while concentrate intake was similar for both species. The higher intake of buffaloes was explained by longer meal durations and fewer breaks between meals. Buffaloes also chewed slower while ruminating, had larger mastication muscles, defecated more often and drank longer and more often.

All this was interpreted as a more efficient rumination process (Vega et al., 2010). Buffaloes in another study also tended to excrete smaller particles than cattle, which also indicates a more thorough rumination (Kennedy et al., 1992).

More studies concern inter-breed differences in feeding behaviour. Durst et al. (1993) compared Jersey, HF and Simmental cows. They found Jersey cows to eat less but to spend more time feeding and to have the highest level of total feed intake per kg of live weight. Jersey cows also showed higher grass meal frequencies, but grass meal size and mean feeding rate (kg/min) within grass meals were smaller than in HF and Simmental cows. For all three breeds, feeding rate and live weight were highly correlated, and differences in feeding rate disappeared when corrected for live weight. Aharoni et al. (2009) similarly observed longer grazing times for the small breed (small Baladi) than for the large breed (Beefmaster x Simford crossbred) and a higher organic matter intake per metabolic body weight.

### *2.4.2 Within-breed differences*

In Switzerland several studies compared different strains of the HF breed under pasture conditions. According to the observations by Schori and Münger (2010), New Zealand HF cows spent more time ruminating and had a higher number of mastications during rumination and feeding than Swiss HF. No difference was found for feeding and idling time and for grass DMI per metabolic body weight. New Zealand cows tended to stand less, lie more and make more steps (Schori and Münger, 2010). Darms (2011) could not confirm these finding: No differences in feeding or ruminating behaviour were observed, but Swiss HF cows spent more time walking. Furthermore, both cow types grazed equally long on patches, where grass was higher and herbage composition different due to faeces deposition ("Geilstellen"). Converse results were generated in a similar study with the same animals: Here the New Zealand cows fed significantly longer in those highly fertilized patches than Swiss cows (Roth et al., 2010).

A study from Ireland also detected that New Zealand HF cows behaved differently compared to high production and high durability North American HF (McCarthy et al., 2007). The New Zealand strain had the longest grazing time, produced the highest number of boli, and had overall the longest handling time (grazing and ruminating together), but ingested less DM herbage per hour. This was confirmed by Sheahan et al. (2011), who found New Zealand cows to spend more time grazing, less time ruminating and to pick up less mass per bite.

These findings suggest that there is considerable genetic variability in feeding. Moreover, within a certain strain and feeding system, grazing behavioural variables explain nearly half of the variation in milk yield and could thus be a valuable part of breeding programs especially for grass based systems. The large genetic variation observed might result in rapid responses to selection, but heritability still remains to be assessed (McCarthy et al., 2007).

## 2.5 Relationship between phenotypic traits and health / fertility

### *2.5.1 BCS and type traits*

BCS is a better indicator of body reserves than body weight, as the latter is strongly dependent on parity, stage of lactation and breed (Roche et al., 2009). The negative correlation between NEB, BCS, BCS loss and fertility parameters has been described above (Chapter 2.1.3). Even so a low BCS is associated with fertility problems; a high BCS at calving may also have consequences for fertility and health parameters. Fat cows at calving (BCS ≥ 4) were less likely to conceive to first insemination (Heuer et al., 1999) and fat cows at drying off were more likely to develop cystic ovarian disease, reproductive problems and foot problems than cows in normal body condition (Gearhart et al., 1990). A BCS at calving of more than 3.5 leads to reduced DMI and thus to a stronger NEB and risk of metabolic disorders like ketosis (Gillund et al., 2001) and milk fever (Roche and Berry, 2006). A calving BCS of below 2.5 on the other hand also increases the risk for milk fever (Roche and Berry, 2006). For udder health a higher BCS seems favourable. Higher BCS across lactation was shown to be related to lower SCC, also when corrected for milk yield (Berry et al., 2004; Wall et al., 2007).

Generally, type traits connected to body size are negatively correlated to fertility traits and positively to milk production (Berry et al., 2004). Genetically taller (stature) and deeper (body depth) animals have inferior pregnancy rates to first service, need more services (Berry et al., 2004), have longer days open, more days from first to last service (Zink et al., 2011) and have longer calving intervals (Pryce et al., 2000; ). In Wall et al. (2007) the correlation between stature, body depth and calving interval was explained by level of milk production. The relationship between chest width and fertility though was rather ambiguous. A larger chest width was in one study associated with more services, a longer interval from calving to first service and a lower pregnancy rate to first service (Berry et al., 2004), while another study found shorter calving intervals but lower non return rates to first service, also when corrected for milk yield (Wall et al., 2007).

Between health disorders as mastitis (Rogers et al., 1991; Zwald et al., 2004), metritis, displaced abomasum, ketosis, lameness, cystic ovaries (Zwald et al., 2004) and type traits only very low genetic correlations have been found (Zwald et al., 2004; Wall et al., 2007). However, lifespan was described to be significantly shorter for larger and deeper cows (Wall et al., 2007). In a comparison of a small HF line versus a large line, the small line had fewer leg problems, internal infections, required fewer services to conception in first lactation but had poorer udder conformation. The small line had a 15.4% longer productive life (Hansen et al., 1999).

### *2.5.2 Milk components*

An increase in fat mobilization and a decrease in energy intake postpartum are reflected in higher milk fat and lower milk protein contents (Eicher, 2004). FPR was described to be a better indicator for energy balance (Buttchereit et al., 2011) and subclinical ketosis (Duffield et al., 1997) than both components on their own and BCS. Genetic correlation between FPR and energy balance was highest (r=-0.62) at 15 DIM. As there is also a correlation between FPR and energy-corrected milk yield, a selection for lower early lactation FPR would result in moderately decreased milk production (Buttchereit et al., 2011). The threshold of protein-to-fat ratio was set at 0.75, corresponding to a FPR of 1.33. Above this value a subclinical ketosis is probable (Heuer et al., 1999). Toni et al. (2011) concluded that disease incidences are lowest when the FPR 7 days after calving lies between 1 and 1.5. Culling risk increased when the FPR was >1.5 or <1. Cows with a FPR of > 2 showed increased postpartum diseases such as retained placenta, left-displaced abomasum, metritis and clinical endometritis. No relationship between FPR and mastitis could be seen. Milk production was lower within the first 100 DIM for animals with a FPR of >2 or <1 (7 days postpartum). Over the whole lactation only values <1 were correlated with lower milk yields (Toni et al., 2011). In milk samples taken at approximately 20 DIM, a FPR of >1.5 was described to increase risk for ketosis, displaced abomasum, ovarian cyst, lameness and mastitis and to be associated with higher milk yield (Heuer et al., 1999). Instead of FPR, also the change of fat percentage during early lactation was suggested as an indicator for energy balance and subclinical ketosis. Changes in protein were only slightly related to energy balance, thus the variation in FPR results from fat percentage anyway (de Vries and Veerkamp, 2000).

#### *2.5.3 Feeding behaviour*

Obviously, there is a short term relationship between feeding behaviour and health disorders. Cows with health problems have reduced appetite and spend less time feeding. Short term feeding behaviour is used as an instrument for early detection and monitoring of disorders as subclinical ketosis, acidosis, locomotion and lameness (Gonzalez et al., 2008; Goldhawk et al., 2009). But as far as known no study examined long-term, individual feeding behaviour characteristics in relation to health or fertility parameters, although some amount of genetic variability in behavioural traits was found (see Chapter 2.4).

#### *2.5.4 Faeces particle sizes*

Faeces particle sizes are usually analyzed when investigating rumination processes and rumination efficiency (Evans et al., 1973; Bae et al., 1983; Kennedy et al., 1992). No study has been found that searched for individual, feed independent characteristics in faeces particle sizes and linked them to health and fertility traits.

## 2.6 Heritability

Table 1 presents heritability estimates for the phenotypic traits of interest. Because several of the traits have varying heritabilities across lactation, stage of lactation is specified for the particular studies where available. Little is known about heritability of feeding behaviour parameters, but there are estimates for heritability of DMI. DMI was shown to have a similar heritability to yield and ranged between 0.16 and 0.49 (for review see Veerkamp, 1998). Heritability estimates for feeding behaviour variables origin partly from studies with fattening and breeding bulls and are thus only to some extent transferable to dairy cows.

Most phenotypic traits show moderate to high heritability estimates.

***Table 1: Heritability estimates of phenotypic traits***

| | Parameter | $h^2$ | Annotation | Source |
|---|---|---|---|---|
| Type traits | Height at the sacrum | 0.39 | | Zink et al. (2011) |
| | (Stature) | 0.42 | | Berry et al. (2004) |
| | | 0.59 | | Pryce et al. (2000) |
| | Chest girth | 0.35 | Brown Swiss | |
| | | 0.36 | Red & white cattle | de Haas et al. (2007) |
| | | 0.38 | HF | |
| | Chest width | 0.25 | | Berry et al. (2004) |
| | | 0.39 | | Pryce et al. (2000) |
| | Body depth | 0.24 | | Nemcova et al. (2011) |
| | | 0.37 | | Berry et al. (2004) |
| | | 0.59 | Red & white cattle | de Haas et al. (2007) |
| | Muscularity | 0.42 | Brown Swiss | de Haas et al. (2007) |
| | | 0.59 | Red & white cattle | |
| BCS | BCS | 0.28 | 7 DIM | Pryce et al. (2001) |
| | | 0.51 | 105 DIM | Berry et al. (2003a) |
| | | 0.59 | 15 DIM | Buttchereit et al. (2011) |
| | BCS change | 0.09 | between 0 and 70 DIM | Pryce et al. (2001) |
| | | 0.19 | between 0 and 70 DIM | Berry et al. (2003a) |
| Milk components | Milk fat (%) | 0.54 | 15 DIM | Buttchereit et al. (2011) |
| | | 0.59 | full lactation | Loker et al. (2012) |
| | | 0.72 | full lactation | Brotherstone (1994) |
| | Milk protein (%) | 0.27 | 180 DIM | Buttchereit et al. (2011) |
| | | 0.6 | full lactation | Loker et al. (2012) |
| | | 0.61 | 15 DIM | Buttchereit et al. (2011) |
| | FPR | 0.2 | 105 DIM | Buttchereit et al. (2011) |
| | | 0.42 | full lactation | Loker et al. (2012) |
| | | 0.54 | 15 DIM | Buttchereit et al. (2011) |
| | Milk yield | 0.26 | 0 DIM | Berry et al. (2003a) |
| | | 0.44 | 105 DIM | Berry et al. (2003a) |
| | | 0.5 | - | Pryce et al. (2000) |
| Feeding behaviour | Feeding duration | 0.14 – 0.25 | study with bulls | Durunna et al. (2011) |
| | | 0.4 | study with bulls | Wassmuth and Alps (2000) |
| | Rumination duration | 0.15 | across several farms | Santha et al. (1988) |
| | | 0.42 | within farm | |

## 2.7 Implications for this thesis

Summing up, the reaction of dairy cows to a low level of feeding partly depends on their genetics and cannot be predicted solely by feeding level. Cows have been found to react differently to different levels of feeding in terms of milk yield, DMI and fertility. Moreover, auxiliary traits as body traits and milk components show a relationship to health and fertility parameters. They have considerable heritability and could thus be used for selection. But these relationships have so far not been investigated under concentrate-free, organic feeding conditions.

Feeding behaviour parameters seem to have some genetic basis. If feeding behaviour shows any connection to health and/or fertility, these parameters might as well be used as auxiliary traits in breeding programs especially adapted for concentrate-free, organic farming systems.

# 3 Animals, materials and methods

## 3.1 Farms and animals

Data from 14 farms were analyzed in data set "Physical". All 14 farms participated in the FiBL-project "Feed no Food" and had been composing their feed rations without any concentrates at least since October 2009. Some farms had been working without any roughage for more than 30 years.

Two farms were located in Southern Germany while the other 12 farms were spread across Switzerland (in the cantons of AG, BE, GL, GR, LU, SG, SO, ZH). The two German farms as well as three Swiss farms operated according to the bio-dynamic guidelines. All Swiss farms were certified with the Bio Suisse label. Table 2 presents the means and ranges of some key figures of all farms.

***Table 2: Key figures describing the 14 farms***

| | Mean | Range |
|---|---|---|
| **Farm area** | 50 ha | CH: 17.5 – 36 ha<br>D: 135 and 150 ha |
| **Number of dairy cows** | 18 | CH: 9 - 18<br>D: 39 and 45 |
| **Approximate milk yield per cow and year** | 5200 kg | 4000-7000 kg |
| **Years of concentrate-free feeding** | 8 | 2 to more than 35 |

Monthly milk recording results, carried out routinely by the breeding associations, were available for the whole period under investigation. Calving dates and lactation numbers were drawn from this dataset. Only animals with two calving dates between 1$^{st}$ October 2009 and 30$^{th}$ September 2011, and thus having an entire lactation during this period, were selected for analysis. 159 animals were selected; on average 11 cows per farm (range 3 to 22). For those few cows which already had two lactations within this time period only the first one was integrated. Average age of cows at the first of the two calving dates was 5.3 years (SD±2.3), median lactation number was 3.

One farm in the data set was object of a herd division trial, where one group received concentrates according to the usual practices while the other group went through a stepwise reduction until feeding exclusively on roughage (Klocke et al., 2011). Because this trial ended in May 2011, only animals from the concentrate-free group with a second calving date before May 2011 were included in the analysis.

## 3.2 General assignments

Two different data sets were generated (see Table 3). Behavioural traits and faecal samples were collected from animals of just one farm. Those animals are grouped in the data set "Behaviour". All other animals (from 14 farms) are grouped in the dataset "Physical". Animals from dataset "Behaviour" which had a complete lactation within the required time period are also part of data set "Physical" (17 cows).

***Table 3: Differences between the two data sets***

| | | Data set "Physical" | Data set "Behaviour" |
|---|---|---|---|
| | | 159 cows on 14 farms | 30 cows on 1 farm |
| **Physical parameters** | Type traits | ✓ | ✓ |
| | BCS | ✓ | ✓ |
| | Milk components and yield | ✓ | ✓ |
| | Faecal samples | ✗ | ✓ |
| **Behavioural parameters** | Feeding and rumination behaviour | ✗ | ✓ |
| **Health parameters** | Calving interval | ✓ | ✗ |
| | Somatic cell score | ✓ | ✓ |
| | Days open | ✗ | ✓ |
| | Treatments | ✓ | ✓ |
| | Lameness score | ✗ | ✓ |
| | FPR >1.5 | ✓ | ✓ |

## 3.3 Physical parameters

### *3.3.1 Type traits*

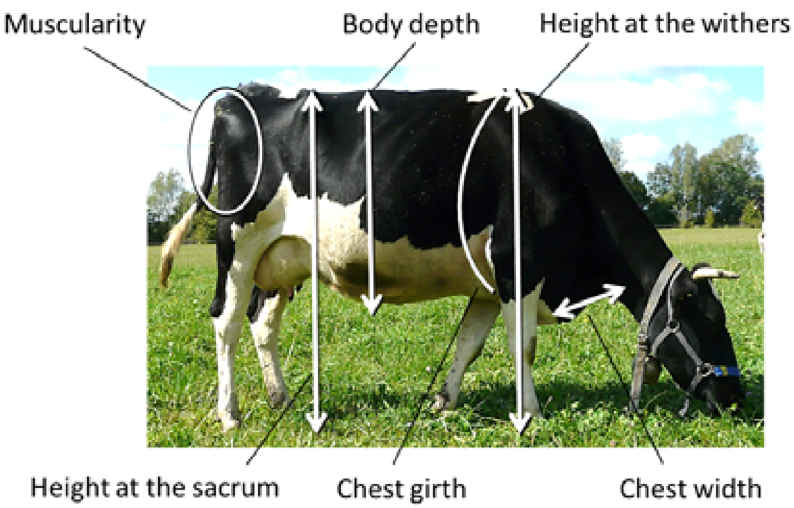



***Figure 2: Type traits shown on a cow***

Type traits of interest were: Muscularity, body depth, height at the withers, height at the sacrum, chest girth and chest width (Figure 2). These parameters were chosen because they reflect the volumetric dimension of cows and were shown to be related with DMI (Gravert, 1985; Wall et al., 2007). Forty-nine animals had already been routinely assessed for type traits by specialists of the corresponding breeding association. Due to different assessment schemes among the different breeding associations (Braunvieh Schweiz - former Schweizer Braunviehzuchtverband (SBZV) - and Swissherdbook), only HW, chest width and muscularity were available for all animals. One breeding association estimates body depth scores on a scale between 1 and 9 (Swissherdbook, 2010) while the other measures it in centimeters (SBZV, 2009). Therefore, in order to have a consistent scale, the score was converted into centimeters using the formula described by Swissherdbook (Swissherdbook, 2010): Value in cm = 2 * score + 70 (+72 for second and higher lactations).

Type traits of 55 cows on 5 farms were additionally assessed for this thesis by supervisors and author. The traits HW, HS, chest width, body depth and muscularity were assessed according to the instructions of the Swiss Brown Cattle Breeders' Federation (SBZV, 2005 & 2009). Moreover chest girth was measured with a cattle weight measuring tape right behind the forelegs. Body weight was estimated according to the measuring tape.

For analysis of the data set "Physical", not the absolute values of type traits were used but instead, in order to get a comparable measurement, the deviation from the specific breed average was computed for each animal. Thus, the relative values spread around 100%, the exact breed average. Breed averages for all breeds in the data set for the year 2010 - Braunvieh, Original Braunvieh, Fleckvieh, Holstein, Red Holstein, Simmental, Grauvieh and Jersey – were provided by the breeding associations (Andreas Bigler,

Swissherdbook, personal communication, 24. October 2011; Willy Schmid, SBZV, personal communication, 27. October 2011; Schnyder and Berweger, 2006). Breed averages were discriminated in first, second and later lactations (see Appendix 1). From two farms no type trait data were available.
The selected farm for data set "Behaviour" did not have any type traits data available. Hence, type traits were assessed for this thesis as described above. In this data set the type trait figures were analyzed in absolute values, because all animals belonged to the same breed (HF with varying percentage of DSN blood).

### *3.3.2 Body condition score (BCS)*

Body condition score (BCS) was assessed on-farm as part of the "Feed no Food"-project. Each animal was assessed four times a year by the same person. For BCS estimations the 5-point-scale developed by Edmonson et al. (1989) was used. Only BCS scores from the corresponding lactation were used (assessed between the two calving dates). BCS range was calculated if the cow had been assessed at least three times. 5 animals did not fulfill this criterion and BCS range was not included for those animals. BCS range is the difference between the highest and the lowest score (minimum BCS) within one lactation.
For animals in the data set "Behaviour", BCS values from December 2010 until December 2011 were included, thus not necessarily all data were collected during the current lactation. All animals had at least 3 assessments during this period.

### *3.3.3 Milk components and yield*

Information about milk components and milk yield was provided by the monthly milk recordings, carried out by breeders associations in Switzerland (Swissherdbook and Braunvieh Schweiz) and by LKV Baden-Wuerttemberg in Germany (Landesverband Baden-Württemberg für Leistungsprüfung in der Tierzucht e.V.). Only recordings from within the first 100 days of lactation (2-3 samples) were integrated. This was done in order to have comparable figures for all animals and because this time period is generally regarded as the most sensitive period for metabolic disorders as well as fertility problems. Milk samples taken within 5 days after calving were not included because their composition differs substantially from later samples (Dohoo, 1993).
The FPR was converted into a binary variable with 1 for a maximum FPR of >1.5 and 0 for ≤1.5 (the limit for Jersey cows was set at 1.7 due to their differing milk composition), the new variable was called binFPR. A FPR of below 1 may be an indicator for acidosis and an insufficient fiber content in the diet (Toni et al., 2011). As insufficient fiber content was not expected to be of relevance in concentrate-free feeding rations, all maximum FPR values of below 1.5 were set as 0
Energy corrected milk yield (ECM) was calculated according to Beerda et al. (2007):
ECM = 0.337+0.116 x average fat content + 0.06 x average protein content.

Milk production efficiency was defined as average ECM per day in kg per metabolic body weight ($BW^{0.75}$) (Hofstetter et al., 2011a).

In the data set "Behaviour", if the current lactation had not yet reached 100 days, milk recording data from the previous lactation were used.

## 3.4 Behavioural parameters

### *3.4.1 Experimental farm and climate*

Feeding behaviour was observed on a farm in the federal state of Baden-Wuerttemberg in Southern Germany. The selected farm was working according to the guidelines of biodynamic agriculture. The area under cultivation was 135 hectares, whereof 105 hectares were used as forage area. 40 dairy cows were kept in a loose-housing cubicle system. Cows belonged to the HF breed with varying proportion of DSN genetics (Deutsches Schwarzbuntes Niederungsrind, a native German breed). Natural mating was performed by a DSN-bull. The replacement rate was around 30% per year. The approximate milk yield in 2011 was 5600 kg per cow and lactation which is slightly more than the other 13 farms' average. Average age of the dairy cows was 6.5 years, median lactation number 2.5 (range 1 – 12). Compared to all dairy farms in Baden-Wuerttemberg, cows of the experimental farm had lower milk, milk fat and protein yield, better fertility traits but higher SCC in 2011 (Landesverband Baden-Württemberg für Leistungsprüfung in der Tierzucht e.V.).

The herd was observed during two periods: Once in September (5.-16.September 2011) during summer feed and once in December (5.-14.December 2011) during winter feed. The average temperature at noon in summer was 20°C and in winter 6°C. During the time on pasture in summer no rainfall was measured. During both observational periods no strong temperature or weather change occurred, so that climatic conditions can be regarded as steady for each period.

### *3.4.2 Feeding*

For more than 30 years the feed ration on the selected farm had not contained any concentrates. Summer feed consisted of pasture during daytime and forage harvesting in the evening. Cows spent the night in the barn. Pasture was grazed in a portioning system, increasing the available area daily. 8 days after start of the observational period the herd was moved to a new pasture. The botanical composition on the pasture was assessed according to the AGFF bulletin number 3 (Daccord et al., 2007). Both pastures used during the summer observation period were permanent pastures and botanically similar. Forage harvested for feeding in the barn at night originated from two temporal meadows. The results of the quality estimates for pasture and harvested forage according to Daccord et al. (2007) are presented in Table 4.

*Table 4: Estimates of pasture and forage quality (summer feed)*

| | Botanical composition | Age of feed | Energy content[1] (MJ NEL/kg DM) | Protein content[2] (g/kg DM) | Fiber content[3] (g/kg DM) |
|---|---|---|---|---|---|
| **Pasture 1** | >70% grasses, whereof <50% ryegrasses | 7 weeks<br>4th usage | 5.7 | 94 APDE<br>90 APDN | 260 CF<br>495 NDF<br>294 ADF |
| **Pasture 2** | 50-70% grasses, whereof <50% ryegrasses | 5 weeks<br>3rd usage | 6.1 | 102 APDE<br>109 APDN | 220 CF<br>411 NDF<br>258 ADF |
| **Meadow 1** | 100% alfalfa (seed blend) | 6 weeks<br>4th usage | 6.1 | 106 APDE<br>123 APDN | 195 CF<br>334 NDF<br>238 ADF |
| **Meadow 2** | 40% Egyptian clover<br>25% Persian clover<br>35% Annual ryegrass<br>(seed blend) | 5 weeks<br>4th usage | 6.4 | 111 APDE<br>137 APDN | 176 CF<br>309 NDF<br>217 ADF |

[1] NEL = Net energy lactation, DM = Dry matter.
[2] APDE = Absorbable protein in the gut, synthesized by energy available in the rumen, APDN = Absorbable protein in the gut, synthesized by crude protein available in the rumen
[3]CF=Crude fiber, NDF=Neutral detergent fiber, ADF=Acid detergent fiber

Winter feed consisted of ventilated hay and baled grass silage (40 and 60 % in DM respectively). Hay originated from the second and third cut of a permanent meadow. One half of the daily grass silage ration originated from the first cut of a permanent meadow, the other half originated from a temporal meadow which was a mixture of legumes and grass. Feed samples have been analyzed in March 2009 (Table 5). Since then feed production and conservation did not change substantially, so that these results still represent the current winter feed basis.

*Table 5: Results of feed analysis from March 2009 (winter feed)*

| | DM (in % of fresh weight) | Energy content[1] (MJ NEL/kg DM) | Protein content[2] (g/kg DM) | Fiber content[3] (g/kg DM) |
|---|---|---|---|---|
| **Hay, ventilated** | 94 | 5.5 | 90 APDE<br>88 APDN | 245 CF<br>455 NDF<br>287 ADF |
| **Grass silage, temporal meadow, rich in legumes** | 57 | 5.3 | 73 APDE<br>93 APDN | 284 CF<br>438 NDF<br>300 ADF |
| **Grass silage, permanent meadow, predominantly grasses** | 41 | 5.6 | 81 APDE<br>86 APDN | 243 CF<br>449 NDF<br>270 ADF |

[1] NEL = Net energy lactation, DM = Dry matter.
[2] APDE = Absorbable protein in the gut, synthesized by energy available in the rumen, APDN = Absorbable protein in the gut, synthesized by crude protein available in the rumen
[3]CF=Crude fiber, NDF=Neutral detergent fiber, ADF=Acid detergent fiber

### *3.4.3 Measurement of jaw movements by a pressure sensor*

Feeding and rumination behaviour was measured using a pressure sensor as described in Nydegger et al. (2011). The sensor consisted of an oil-filled tube and a MSR-data logger both attached to a halter (see Figure 3). While cows were chewing or ruminating pressure was executed on the oil-filled tube and recorded in the data logger. A learning file was created for every animal, defining a characteristic period of ruminating and feeding. On the basis of this individual learning file, a script – in the R-software language - was able to allocate jaw movements to "feeding", "ruminating" or "other activities" (R Development Core Team, 2011). The output of the R-script was a graphical illustration on one hand (Figure 4) and values of the measured parameters in a txt-file on the other hand. Measured parameters were: Time spent feeding, time spent ruminating, number of mastications while feeding and while ruminating and number of boli produced. Average number of mastications per bolus was calculated by dividing number of mastications while ruminating by the number of boli produced. Rate of feeding and ruminating in mastications/min was calculated by dividing number of mastications while feeding or ruminating by time spent feeding or ruminating.

The R-script was programmed to regard peaks as mastications if their maximum was at least 30 millibar above a locally adjusted median. However, as some halters could not be attached tight enough and the pressure on the oil-filled tube was therefore not strong enough, those records had to be analyzed with minimum amplitude of 20 millibars. Totally 17 out of 168 records were analyzed with the smaller amplitude and results were visually inspected for comparability. Two records could not be used because recording duration was not completed.

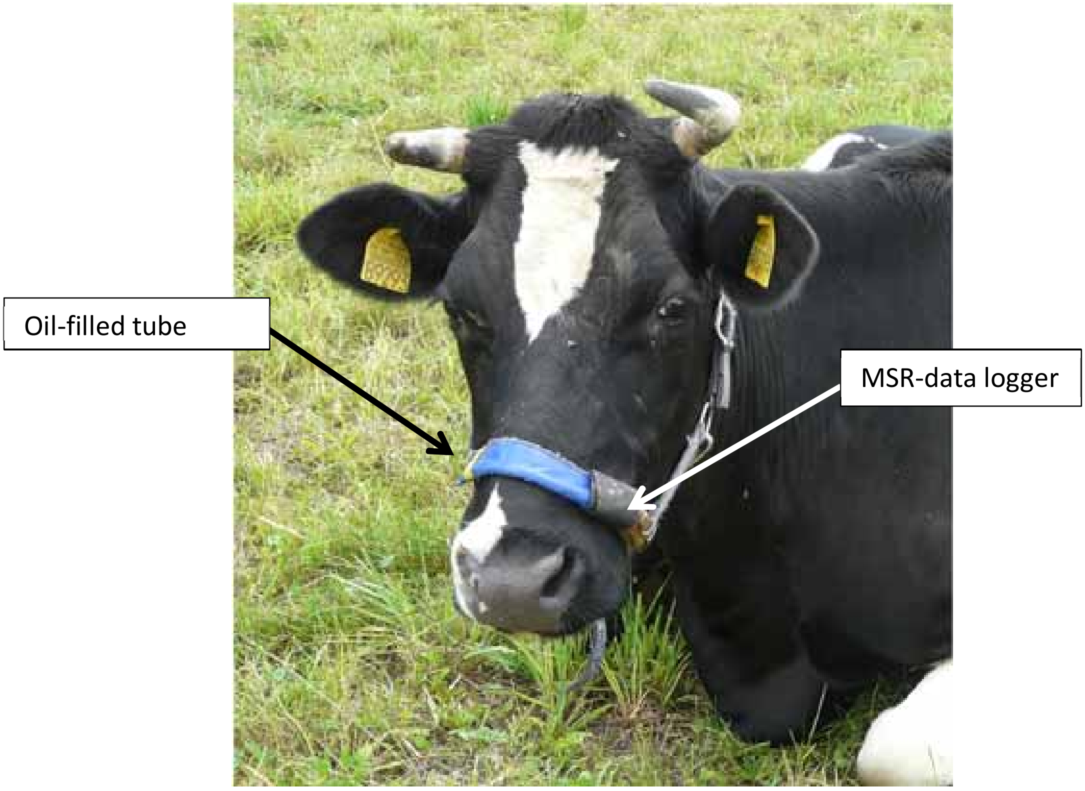



***Figure 3: Halter with pressure sensor attached to the cow's head***

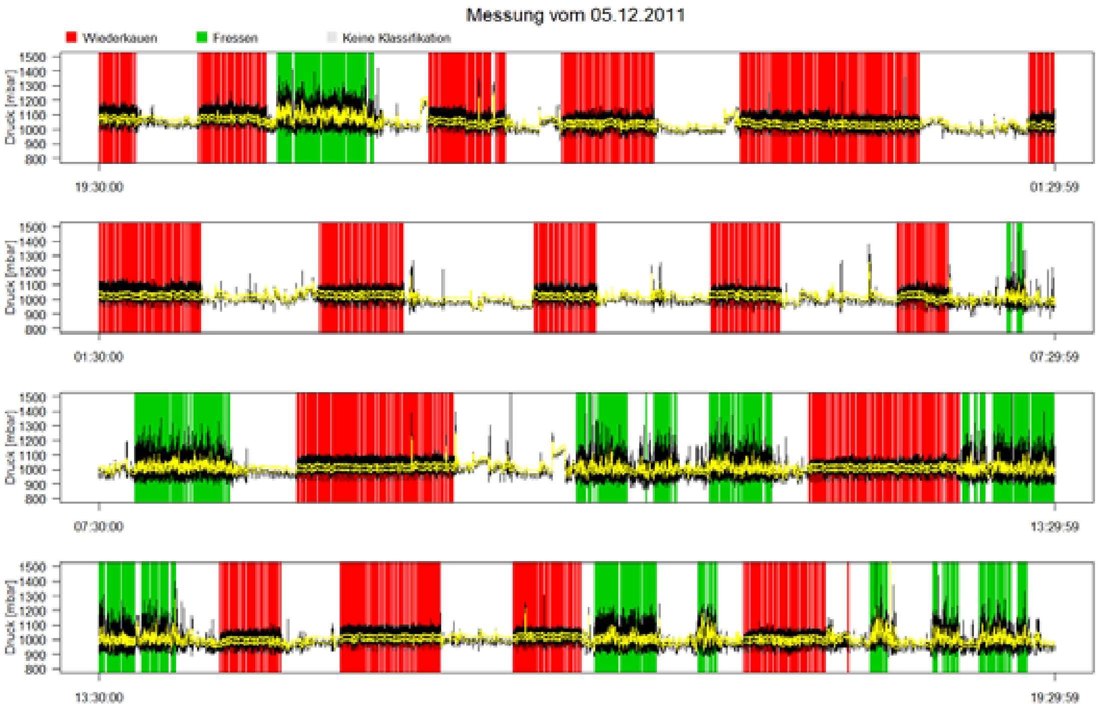
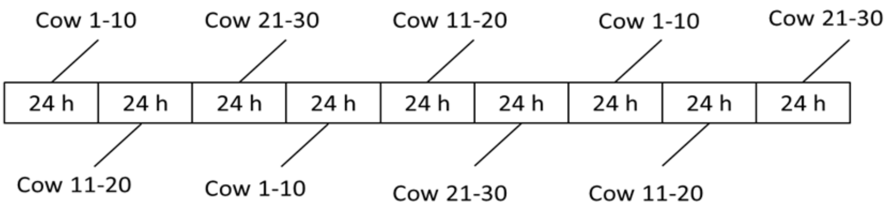


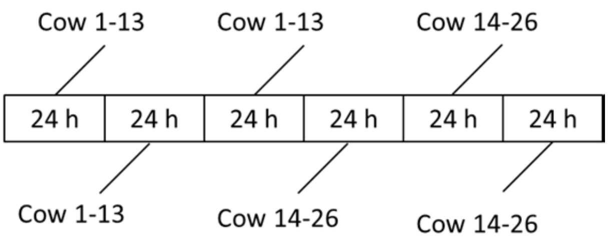

***Figure 4: Example of feeding and ruminating of a cow as measured by the pressure sensor in 24 hours***

During measurement periods all management factors were kept as steady as possible. Cows wearing a halter were always part of the herd and the usual daily routine.

In September 2011 30 lactating cows were equipped with the pressure sensor, three times for 24 hours each. 10 pressure sensors were in use. Cows were alternately wearing the halters so as to keep feeding and climate as equal as possible. Thus the following sequence resulted:




In December 2011 13 pressure sensors were in use, measuring chewing activity of 26 cows, again three times for 24 hours each. 4 cows could not be observed anymore, because one of them had been slaughtered meanwhile and three of them were not lactating at that time. Four cows were shortly before drying off, thus measurements had to be completed quickly and no alternation was made between the two groups. Sequence in December was the following:




## 3.5 Faeces particle sizes

Faeces samples were taken once in September and once in December for every cow. Samples were frozen after collection and defrosted on the day of analysis. The method of partitioning particles according to their size was similar to the one described in Evans et al. (1973). The adapted method has been developed and tested for repeatability at FiBL (Erika Perler, FiBL, personal communication, 29. Sepember 2011).

The apparatus consisted of a set of four wire-mesh screens with a diameter of 20 cm, vertically arranged. The top screen had a mesh size of 4 mm, the second of 2 mm, the third of 1 mm and the lowest of 0.3 mm. 100 g of the faeces fresh matter were put in the top screen and a jet of tap water washed the particles through the following screens. The first two screens were washed for 10-15 seconds each, the third and fourth screen were washed until the outflowing water was clear. Afterwards the leftovers in the screens were put into an aluminium tray, dried for 12 hours at 105°C and reweighed. The same was done with a 50 g sample of fresh matter to determine DM of the base material.

## 3.6 Health parameters

All allopathic medical treatments (no complementary treatments) from the farms' veterinary treatment records were available. Distinguished treatment reasons for this analysis were mastitis (during lactation and during dry periods), fertility problems and metabolic disorders. Only treatments from the corresponding lactation per cow were included. All treatment variables were converted into binary variables with 1 for one or more treatments and 0 for no treatment.

As an indicator for fertility the calving interval was calculated for the corresponding lactation. Number of inseminations could not be used for all animals, because several farms kept a bull in their herd so they often did not know the exact dates and numbers of matings. As an indicator for udder health, the average somatic cell score (SCS) within the first 100 DIM was used. The somatic cell count in 100,000 cells / ml (SCC), as it is specified in the milk recordings, was converted into the normally distributed somatic cell score through the formula: $SCS = \log_2 (SCC/100{,}000) + 3$ (Wiggans and Shook, 1987). Hence a SCC of 50,000/ml corresponds to a SCS of 2, 100,000/ml to a 3, 200,000 to a 4, and so on.

In the data set "Behaviour" calving interval was not available for all animals, because some had not yet finished their first lactation (available for 22 cows). Therefore the time from calving to successful mating (days open) was used here as an indicator for fertility (available for 29 cows). If in multiparous cows pregnancy was not verified yet, days open from the previous lactation were taken instead. Thus days open could be calculated for all except one first lactation animal. No allopathic veterinary treatments were applied to the dairy cows on this farm within the period of interest. As an additional health indicator for cows in data set "Behaviour", a lameness score was given by the farmer for each cow. Score 0 meant no treatment in the foot trimming crush in the past year.  Score 1 corresponded to one treatment and Score 2 to two or more treatments.

## 3.7 Statistical Analysis

Statistical analyses were conducted using the R-software, version 2.14.1 (R Development Core Team, 2011). For data set "Physical" generalized linear mixed effects models were computed with farm as a random effect and different health indicators as outcome variables. Models were reduced in a stepwise backwards manner, with a level of significance of p=0.05. The start model formula was the following:

$$y_{ijklmnop}=\mu+DMY_i+HW_j+CW_k+M_l+BCSmin_m+BCSrange_n+FPR_o+LN_p+F_{ijklmnop}+\varepsilon_{ijklmnop}$$

with

$Y_{ijklmnop}$ = Total treatments, fertility treatments, metabolic treatments (as binary variables), somatic cell score or calving interval (continuous)

$\mu$ = overall mean

$DMY_i$ = average daily milk yield within the first 100 days of lactation (continuous)

$HW_j$ = height at the withers (continuous)

$CW_k$ = chest width (continuous)

$M_l$ = muscularity (continuous)

$BCSmin_m$ = minimal BCS within one lactation (continuous)

$BCSrange_n$ = maximum BCS range within one lactation (continuous)

$FPR_o$ = maximum fat-to-protein ratio (FPR) within the first 100 DIM (binary variable with 1 = FPR>1.5 and 0 = FPR ≤1.5)

$LN_p$ = lactation number (continuous)

$F_{ijklmnop}$ = random effect of farms

$\varepsilon_{ijklmnop}$ = random error term

Breed was not included as a factor because the breed relevant type traits had been corrected for breed. Explanatory variables were only integrated in the same model if correlating by $r_s \leq 0.5$. Distributions of residuals were plotted and visually inspected for all models to satisfy model assumptions (normal distribution, homoscedasticity). Five animals had to be removed from the data set because they clearly distorted the distribution and had a decisive influence on the model outcome. Reasons for removing were in detail: lactation number (number 10 and 11), calving interval (242 days), minimum BCS (3.25) and height at the withers (155 cm). Finally, number of cows for the model calculations was 97.

Due to the small number of animals in data set "Behaviour", no models similar to those described above for data set "Physical" could be calculated. Therefore relationships among all variables were evaluated by Spearman correlations. Level of significance was set at p=0.05.

In order to identify relations between feeding behaviour parameters and days in milk (DIM) as well as relations between feeding behaviour parameters measured during summer and winter feeding respectively, linear regression models of the following type were calculated:

$$Y_i=\beta_0 + \beta_1 * x_{i1}+\beta 2 * x_{i2}+\varepsilon_i \quad i=1,\ldots.,26$$

where Y was a feeding behaviour parameter in summer, $x_1$ the same feeding behaviour parameter in winter and $x_2$ was DIM at the start of the measuring period in summer. For example:

$$(\text{Feeding time in summer})_i=\beta_0 + \beta_1 * (\text{Feeding time in winter})_i+\beta 2 * (\text{DIM in summer})_i+\varepsilon_i \quad i=1,\ldots.,26$$

Equally, feeding behaviour parameters measured in winter were put as Y, the corresponding value from summer as $x_1$ and DIM in winter as $x_2$.

# 4 Results

## 4.1 Data set „Physical“

Table 6 shows mean, median, range and number of observations for physical parameters in data set "Physical". Forty-six cows had a maximum FPR of >1.5 during the first 100 days of lactation, the other 113 ≤1.5. The average SCS of all 159 animals was 2.35 (SD±1.69). The average calving interval was 369.6 days (SD±41.5). Number of medical treatments, their category as well as number of animals with one or more treatment incidence are presented in Table 7.

*Table 6: Descriptive statistics of physical parameters in data set "Physical"*

| | Parameter | Mean (±SD) | Median[2] | Range | n |
|---|---|---|---|---|---|
| Type traits | HW[1] (cm) | 140.4 (±5.12) | | 123 - 155 | 104 |
| | HS[1] (cm) | 142.6 (±4.93) | | 123 – 157 | 96 |
| | Chest girth (cm) | 201.5 (±8.12) | | 183 - 225 | 82 |
| | Chest width (score 1-9) | | 5 | 2 – 8 | 104 |
| | Body depth (cm) | 81.9 (±4.44) | | 67 - 93 | 101 |
| | Muscularity (score 1-9) | | 5 | 3 - 8 | 104 |
| BCS | Minimum BCS | | 2.75 | 2 – 3.25 | 159 |
| | Maximum BCS range (loss) | | 0.25 | 0 – 1.25 | 154 |
| Milk components[3] | Milk fat (g/kg) | 3.97 (±0.53) | | 2.88 – 5.54 | 159 |
| | Milk protein (g/kg) | 3.15 (±0.30) | | 2.48 – 4.17 | 159 |
| | Milk yield (kg/day) | 20.98 (±4.06) | | 11 – 33.7 | 159 |
| | Milk production efficiency (kg ECM/day*$BW^{075}$) | 0.16 (±0.03) | | 0.09 – 0.25 | 82 |

[1]HW=Height at the withers, HS=Height at the sacrum.
[2]Median instead of mean was calculated for scored variables.
[3]Averages of all milk samples within the first 5-100 days in milk

*Table 7: Description of medical treatments*

| Reason for treatment | Number of treatments[1] | Number of cows with >1 treatment |
|---|---|---|
| Mastitis | 20 | 11 |
| Fertility | 16 | 11 |
| Metabolic disorders | 10 | 7 |
| Miscellaneous | 8 | 4 |
| Total treatments | 54 | 28 |

[1]159 cows, during one lactation each

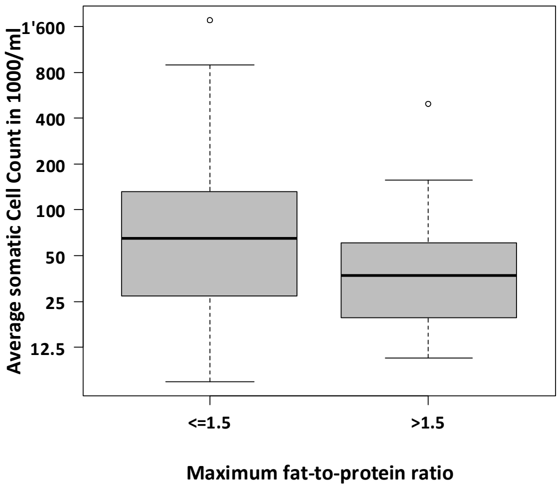
Type trait data were not available for all farms and within farms not for all animals. For the selected traits in the model – height at the withers, chest width and muscularity – 104 observations were available (number of observations in Table 6). Because some outlier animals had to be removed and BCS range was not available for 5 animals, the final model was calculated with 97 animals from 12 farms.

Results of the mixed effect models with health parameters as explanatory variables are presented in Table 8. The model for treatments due to metabolic disorders had to be discarded because of too strong distortions due to the low number of treatments.

***Table 8: Results of generalized linear mixed effects models***

| Outcome variables | Explanatory variables | Estimate | $F_{1,83}$ | z-value | p-value |
|---|---|---|---|---|---|
| **Average SCS** | binFPR | -1.04 | 8.52 | - | **0.004** |
| | LN | 0.29 | 11.36 | - | **0.001** |
| **Calving interval** | binFPR | 20.02 | 4.77 | - | **0.03** |
| | BCS range | 32.66 | 6.00 | - | **0.01** |
| | LN | 5.18 | 5.43 | - | **0.02** |
| **Fertility treatments** | BCS range | 3.82 | - | 2.2 | **0.03** |
| **Total treatments** | HW | -0.25 | - | -2.17 | **0.03** |
| | BCS range | 2.75 | - | 2.56 | **0.01** |

SCS=Somatic cell score, binFPR=binary fat-to-protein ratio, LN=Lactation number, BCS=Body condition score, HW=Height at the withers.



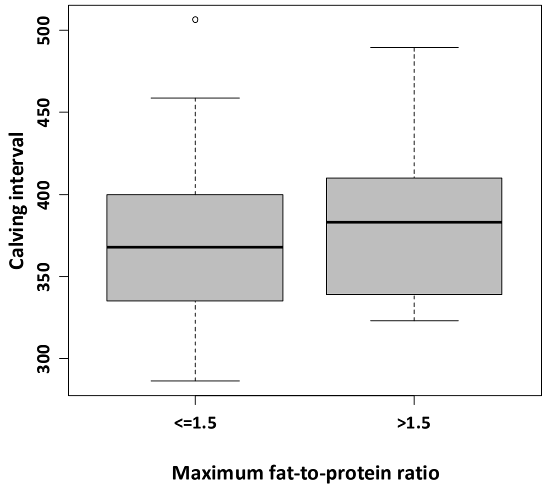
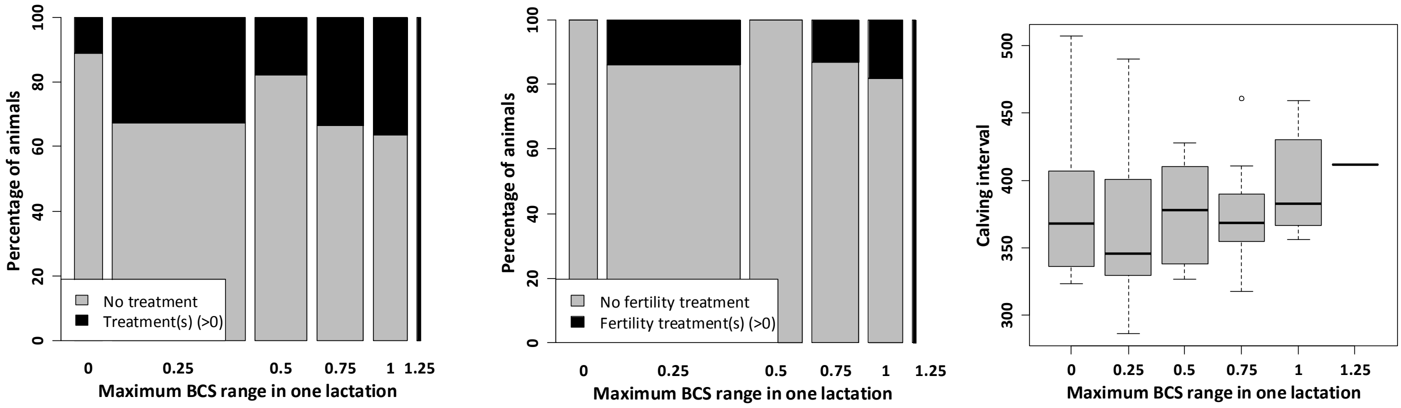




***Figure 5: Boxplots of (a) the average SCC and (b) calving interval depending on maximum fat-to-protein ratio within the first 100 DIM (n=97)***

Cows with a FPR of >1.5 had a lower average SCS but an increased calving interval (Figure 5; Table 8). A larger BCS range within one lactation was associated with more treatment incidences, both fertility treatments and total treatments (Figure 6; Table 8) as well as increased calving intervals (Figure 6; Table 8) There was also a relationship between size of cows (height at the withers) and treatment incidences: Smaller cows were at higher risk to be treated (Figure 7; Table 8). But means of both groups, the treated animals and the non-treated animals, were considerably lower than their corresponding breed average (mean treated group = 96.5% of breed average, mean non-treated group = 96.8%, mean of all animals = 96.7%).

Finally, older cows had increased average SCS and longer calving intervals (Figure 8; Table 8).




**Width of bars reflects number of animals in the particular BCS range category**

***Figure 6: Barplots and boxplot of (a) total treatments, (b) fertility treatments and (c) calving interval depending on BCS range (n=97)***

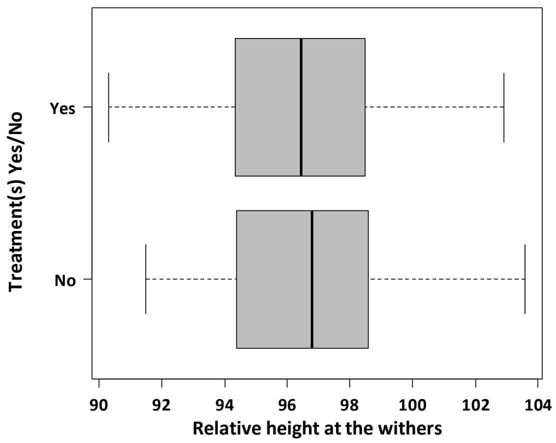



***Figure 7: Boxplots of total treatments depending on height at the withers (relative to the corresponding breed average; n=97)***

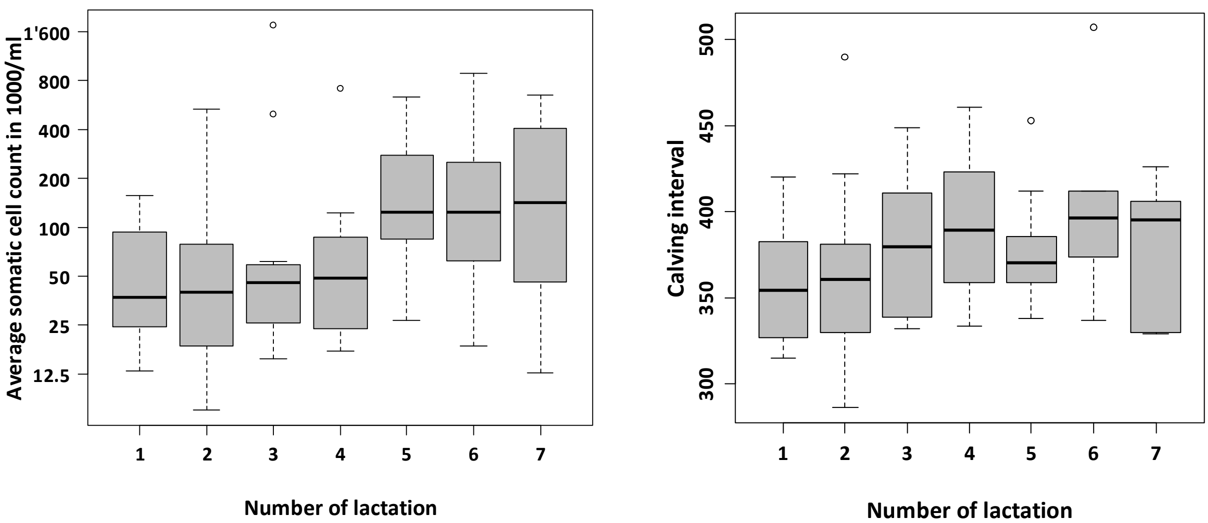



***Figure 8: Boxplots of (a) average SCC and (b) calving interval depending on LN (n=97)***

Spearman correlations for all variables in data set “Physical” are presented in Table 9, highlighted according to their value. Cows in a more advanced lactation produced more milk in the first 100 DIM ($r_s$=0.39), had a wider chest and a larger chest girth ($r_s$=0.28 and $r_s$=0.26). Milk production efficiency was correlated with average DMY ($r_s$=0.85) and with the binary FPR ($r_s$=0.34). High average milk protein content was associated with an increase in average SCS ($r_s$=0.28) and a larger chest girth ($r_s$=0.35). A lower minimum BCS value indicated an augmented BCS range ($r_s$=-0.27).

*Table 9: Correlation matrix of variables in data set "Physical"*

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LN | 0.39 | 0.29 | 0.23 | 0.13 | -0.055 | … | … | -0.11 | 0.17 | -0.13 | 0.06 | -0.11 | 0.23 | … | … | … | 0.28 | 0.26 | -0.19 |
| | avgDMY | 0.076 | … | 0.12 | … | … | … | -0.17 | 0.092 | … | -0.18 | 0.11 | 0.85 | … | … | -0.23 | 0.20 | 0.093 | … |
| | | avgSCS | 0.055 | 0.13 | … | 0.19 | 0.13 | -0.077 | 0.081 | 0.13 | 0.28 | -0.075 | … | … | 0.088 | 0.078 | 0.18 | 0.20 | … |
| | | | CI | -0.072 | 0.15 | 0.17 | 0.14 | -0.14 | 0.21 | … | … | 0.13 | 0.10 | … | … | … | 0.076 | … | -0.17 |
| | | | | Mastitis treatments | 0.059 | -0.087 | 0.61 | … | … | … | … | … | 0.09 | -0.13 | -0.074 | 0.13 | 0.066 | 0.087 | 0.089 |
| | | | | | Fertility treatments | 0.13 | 0.54 | 0.19 | 0.11 | 0.14 | … | 0.14 | 0.076 | 0.072 | 0.063 | -0.095 | … | … | … |
| | | | | | | Metabolic treatments | 0.43 | 0.15 | -0.056 | … | 0.14 | … | … | … | 0.12 | 0.078 | 0.056 | … | -0.17 |
| | | | | | | | Total treatments | 0.10 | … | 0.14 | 0.11 | 0.15 | 0.098 | -0.12 | -0.053 | 0.059 | … | -0.055 | … |
| | | | | | | | | minBCS | -0.27 | 0.066 | 0.11 | … | -0.084 | 0.094 | 0.18 | 0.087 | 0.12 | 0.22 | 0.16 |
| | | | | | | | | | BCSrange | … | 0.14 | -0.10 | -0.14 | 0.061 | … | 0.06 | 0.25 | 0.20 | 0.099 |
| | | | | | | | | | | avgFat | 0.43 | 0.47 | 0.28 | … | … | 0.091 | 0.051 | 0.12 | 0.14 |
| | | | | | | | | | | | avgProtein | -0.18 | -0.15 | -0.061 | … | 0.15 | 0.11 | 0.35 | 0.096 |
| | | | | | | | | | | | | binFPR | 0.34 | … | … | -0.082 | -0.058 | -0.098 | … |
| | | | | | | | | | | | | | MPE | -0.16 | -0.092 | -0.28 | 0.06 | -0.23 | -0.20 |
| | | | | | | | | | | | | | | HS | 0.81 | 0.19 | 0.21 | 0.43 | … |
| | | | | | | | | | | | | | | | HW | 0.24 | 0.14 | 0.37 | … |
| | | | | | | | | | | | | | | | | Body depth | 0.18 | 0.29 | 0.097 |
| | | | | | | | | | | | | | | | | | Chest width | 0.34 | 0.34 |
| | | | | | | | | | | | | | | | | | | Chest girth | 0.12 |
| | | | | | | | | | | | | | | | | | | | Muscularity |

LN=Lactation number, DMY=Daily milk yield, SCS=Somatic cell score, CI=Calving interval, BCS=Body condition score, FPR=Fat-to-protein ratio, MPE= Milk production efficiency, HS=Height at the sacrum, HW=Height at the withers

## 4.2 Data set „Behaviour"

Data set "Behaviour" contains all physical parameters like type traits, milk components and BCS for 30 cows on one farm, but moreover individual feeding behaviour parameters and faecal particle sizes. Health and fertility parameters differ slightly from those used in data set "Physical". Mean, range and number of observations are presented in Table 10. Additional indicators for health problems were the binary FPR and a lameness score. Four cows had a maximum FPR of >1.5 (binary FPR = 1), 26 ≤1.5 (binary FPR = 0). Twenty-four received a lameness score of 0, and 3 animals each had a lameness score of 1 and 2 respectively. Descriptive statistics of physical parameters in data set "Behaviour" can be found in Appendix 2.

***Table 10: Descriptive statistics of health and fertility parameters in data set „Behaviour"***

| Parameter | Mean (±SD) | Range | n |
|---|---|---|---|
| **Average SCS** | 3.6 (±1.6) | 1.23 – 7.23 | 30 |
| **Calving interval (days)** | 400.7 (±54.3) | 325 - 553 | 22 |
| **Days open (days)** | 140.7 (±98.3) | 46 - 504 | 29 |

[1]Median instead of mean was calculated for scored variables.

To find out whether there is any individual characteristic in the partitioning of faecal fraction sizes, correlations between fraction weights in DM in September and December were calculated (Table 11). Except for the DM weight of the total sample ($r_s$=0.40), no correlation could be found, indicating that fraction sizes in faeces are mainly feed dependent. Therefore these values were not used for any further computations.

***Table 11: Correlations among faeces fraction sizes over time***

| | | December | | | | | |
|---|---|---|---|---|---|---|---|
| | | **DM** | **>0.3 and ≤1mm** | **>1mm and ≤2mm** | **>2mm and ≤4mm** | **>4mm** | **>0.3mm (total)** |
| **September** | **DM** | **0.40*** | | | | | |
| | **>0.3 and ≤1mm** | | -0.05 | | | | |
| | **>1mm and ≤2mm** | | | -0.17 | | | |
| | **>2mm and ≤4mm** | | | | 0.05 | | |
| | **>4mm** | | | | | 0.02 | |
| | **>0.3mm (total)** | | | | | | 0.05 |

Spearman correlations
*p<0.05

Analogical to the procedure with faecal fraction sizes, feeding behaviour parameters from the two measuring periods were evaluated for correlations (Table 12). In this case the values from the measuring period in September correlated significantly with the values measured in December, except for the parameter "Mastications while ruminating". Means of the totally six measurements (six times 24 hours) were only calculated if parameters did correlate.

Data from the four animals only observed in September were not included.

***Table 12: Correlation of feeding behaviour parameters over time***

| | | December | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | **Rumination time** | **Feeding time** | **Number of boli** | **Mastications ruminating** | **Mastications feeding** | **Mastications per bolus** | **Rumination rate** | **Feeding rate** |
| **September** | **Rumination time** | **0.39*** | | | | | | | |
| | **Feeding time** | | **0.67**** | | | | | | |
| | **Number of boli** | | | **0.51**** | | | | | |
| | **Mastications ruminating** | | | | 0.32 | | | | |
| | **Mastications feeding** | | | | | **0.58**** | | | |
| | **Mastications per bolus** | | | | | | **0.72**** | | |
| | **Rumination rate** | | | | | | | **0.88**** | |
| | **Feeding rate** | | | | | | | | **0.58**** |

Spearman correlations
*p<0.05 **p<0.001

Differences in feeding behaviour might be mainly linked to the specific stage of lactation and thus consequentially to milk production. Results of linear regressions in Table 13 clarify these assumptions. Time spent feeding was not linked to days in milk (DIM) neither in September nor in December (p=0.5 and p=0.12), but strongly linked to the each other measuring period (p<0.001 for both). Cows that had relatively longer feeding durations in summer also spent more time feeding in winter. Rumination time on the other hand was not found to be individually consistent over time (p=0.15 and p=0.17), and showed a relationship to DIM only in September (p=0.02). Equally, the number of boli produced per day was linked to DIM in September (p=0.001), but only by trend in December (p=0.08). For number of boli, however, there was a considerable relationship between measurements in September and December (p<0.001 and p=0.003). Mastications per bolus was not linked to DIM neither in September (p=0.83) nor in December (p=0.5), but significantly linked between the measuring periods (p<0.001 for both points in time). The same applies for both, rate at feeding and at ruminating. Their correlations between the two measuring periods were highly significant (p=0.006 for feeding rate and p<0.001 for rumination rate), while both were not correlated to DIM.

Number of mastications while feeding and ruminating are strongly correlated to feeding and rumination time respectively ($r_s$=0.72 and $r_s$=0.95; Table 14). Hence the statements for feeding and rumination time apply as well for the corresponding number of mastications.

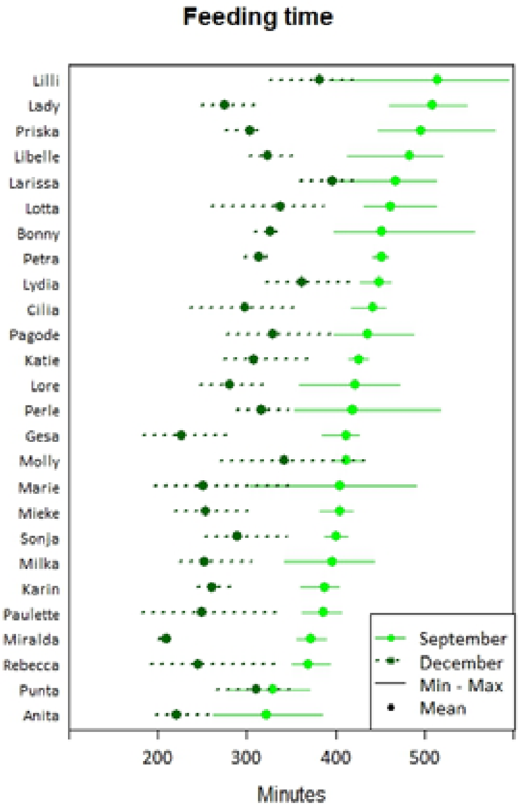
***Table 13: Relations between feeding parameters and DIM***

| Outcome variables | Explanatory variables | Estimate | p-Value | $F_{2,23}$-Value | adjusted $R^2$ | p-value |
|---|---|---|---|---|---|---|
| **Feeding time Sept** | Feeding time Dec | 0.60 | **<0.001** | 7.60 | 0.34 | 0.003 |
| | DIM Sept | -0.04 | 0.5 | | | |
| **Feeding time Dec** | Feeding time Sept | 0.51 | **<0.001** | 9.30 | 0.40 | 0.001 |
| | DIM Dec | -0.10 | 0.12 | | | |
| **Rumination time Sept** | Rumination time Dec | 0.27 | 0.15 | 3.94 | 0.19 | 0.03 |
| | DIM Sept | -0.11 | **0.02** | | | |
| **Rumination time Dec** | Rumination time Sept | 0.29 | 0.17 | 2.67 | 0.12 | 0.09 |
| | DIM Dec | -0.10 | 0.08 | | | |
| **Number of boli Sept** | Number of boli Dec | 0.57 | **<0.001** | 14.8 | 0.52 | <0.001 |
| | DIM Sept | -0.23 | **0.001** | | | |
| **Number of boli Dec** | Number of boli Sept | 0.41 | **0.003** | 7.12 | 0.33 | 0.004 |
| | DIM Dec | -0.15 | 0.08 | | | |
| **Mastications per bolus Sept** | Mastications per bolus Dec | 0.74 | **<0.001** | 15.54 | 0.54 | <0.001 |
| | DIM Sept | 0 | 0.83 | | | |
| **Mastications per bolus Dec** | Mastications per bolus Sep | 0.79 | **<0.001** | 15.93 | 0.54 | <0.001 |
| | DIM Dec | 0 | 0.5 | | | |
| **Feeding rate Sept** | Feeding rate Dec | 0.56 | **0.006** | 5.03 | 0.24 | 0.01 |
| | DIM Sept | 0 | 0.35 | | | |
| **Feeding rate Dec** | Feeding rate Sept | 0.55 | **0.006** | 4.67 | 0.23 | 0.02 |
| | DIM Dec | 0 | 0.55 | | | |
| **Rumination rate Sept** | Rumination rate Dec | 0.83 | **<0.001** | 31.54 | 0.71 | <0.001 |
| | DIM Sept | 0 | 0.18 | | | |
| **Rumination rate Dec** | Rumination rate Sept | 0.80 | **<0.001** | 29.80 | 0.70 | <0.001 |
| | DIM Dec | 0 | 0.36 | | | |

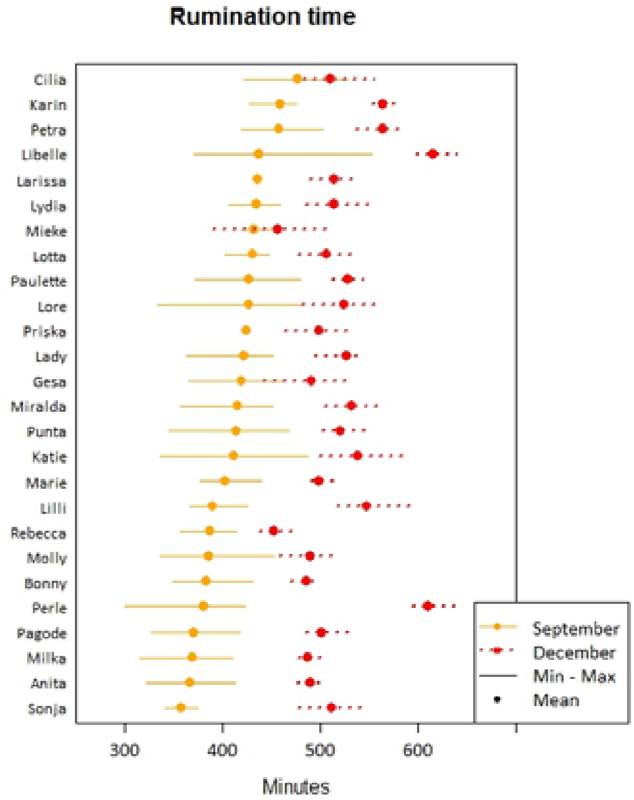
DIM=Days in milk

Generally, in September cows spent slightly more time feeding than ruminating (424 vs. 412 minutes) and also chewed more often during feeding (29912 vs.27330 mastications per day; Figure 10). In December the time ratio was inverted: Cows spent more time ruminating than feeding (518 vs. 295 minutes) and made more mastications during ruminating (35349 vs. 20335). Standard deviations for rumination time were lower than that for feeding time in both measuring periods (30.9 and 38.8 vs. 49.2 and 48.9). Together with increased rumination time in December also number of mastications per bolus increased (from 49.7 mastications per bolus in September to 61.6 in December) (Figure 10). For feeding and rumination time as well as for mastications while feeding and while ruminating the difference between the two observation periods was by far larger than the standard deviation within one observation period. The relationship between rumination time and mastications per bolus was confirmed by the positive correlation of $r_s$=0.52 (Table 14). The number of boli produced per day was only slightly higher in December than in September (576.9 vs. 553.2; Figure 10. Feeding and ruminating rate (mastications per minute) did not differ largely at the two observed points in time, neither did their standard deviation. Moreover, animals with a high rate during feeding also showed a rather high rate during ruminating ($r_s$=0.56; Table 14). For the traits number of boli, feeding and rumination rate the difference between the two observation periods was smaller than the standard deviation within one observation period.

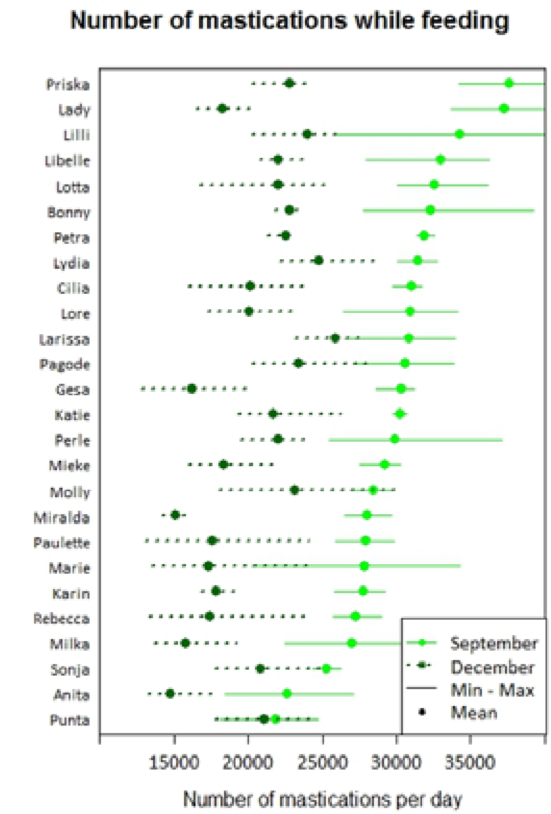
On an individual level striking was the rumination behaviour of cow Priska. She produced in September and in December the lowest number of boli, but chewed at the same time most often per bolus, and had the fastest chewing rate at feeding as well as at ruminating (Figure 10). This negative relationship between number of boli produced and mastications per bolus was also found across all animals ($r_s$=-0.52; Table 14). Feeding time was only slightly correlated with rumination time ($r_s$=0.3).



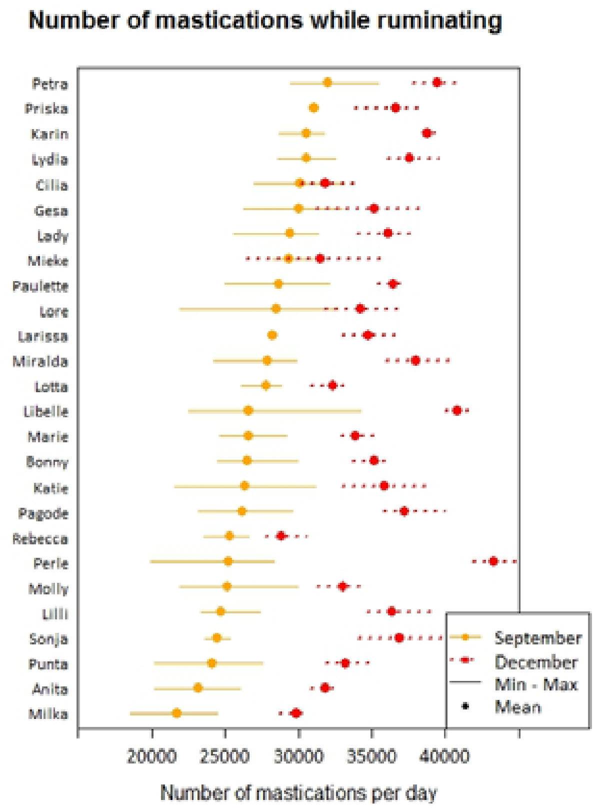

Mean September = 424 min in 24 h (±49.2)
Mean December = 295 min in 24 h (±48.9)




Mean September = 412 min in 24 h (±30.9)
Mean December = 518 min in 24 h (±38.8)

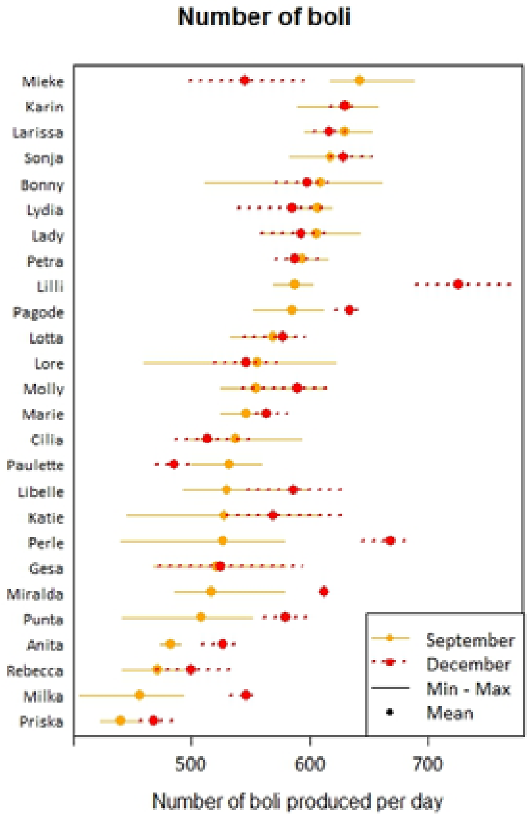



Mean September = 29912 mastications/day (±3670)
Mean December = 20335 mastications/min (±3126)

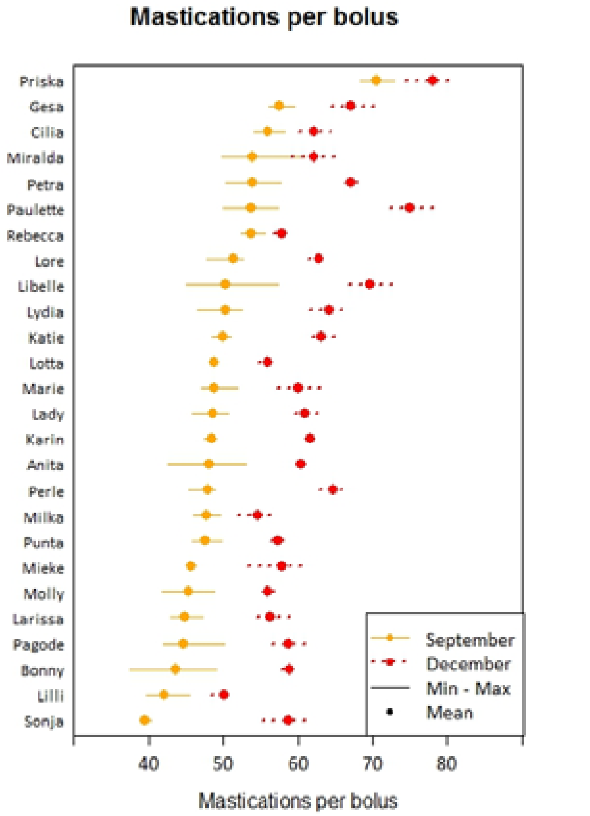



Mean September = 27330 mastications/day (±2640)
Mean December = 35349 mastications/min (±3340)

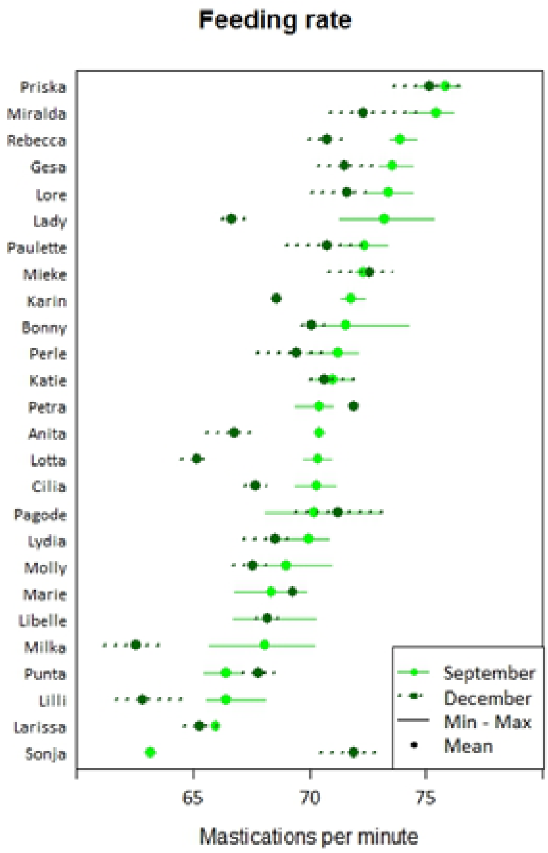
***Figure 9: Individual feeding behaviour parameters in September and December, ranked according to the values of the September measuring period (1)***



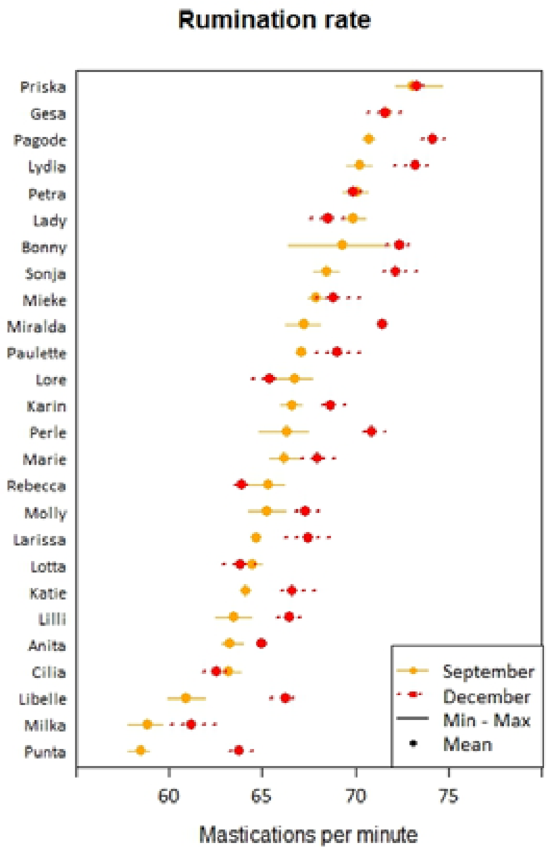

Mean September = 553.2 Boli (±55.8)
Mean December = 576.9 Mastications (±57.2)




Mean September = 49.7 Mastications per bolus (±6.0)
Mean December = 61.6 Mastications per bolus (±6.2)




Mean September = 70.5 mastications/min (±3)
Mean December = 69.1 mastications/min (±3)




Mean September = 66.3 mastications/min (±3.7)
Mean December = 68.1 mastications/min (±3.6)

***Figure 10: Individual feeding behaviour parameters in September and December, ranked according to the values of the September measuring period (2)***

Table 14 presents a correlation matrix of all variables in data set “Behaviour”. There was a moderate relationship between milk production and health: Average DMY as well as MPE were negatively related to average SCS ($r_s$=-0.39 and $r_s$=-0.31) and lameness ($r_s$=-0.38 and $r_s$=-0.42). The average DMY was clearly related to the time spent feeding and ruminating ($r_s$=45 and $r_s$=0.43). Feeding behaviour showed some low to moderate correlations with lameness. Cows with leg or claw problems spent rather less time feeding but at a higher feeding rate, produced fewer boli, but chewed more often per bolus ($r_s$=-0.37, $r_s$=0.38, $r_s$=-0.41, and $r_s$=0.37). A higher minimum BCS was associated with shorter feeding durations and less mastications while feeding ($r_s$=-0.55 and $r_s$=-0.60), while a larger BCS loss was associated with fewer boli and a slower rumination rate ($r_s$=-0.52 and $r_s$=-0.5).

Correlations between health parameters and type traits and BCS revealed only one distinct relationship: Larger cows were associated with longer calving intervals ($r_s$=0.52 for HS and $r_s$=0.4 for HW). Generally, lactation number was correlated to body size because type trait data was not corrected for age in this data set. Other than in the data set “Physical”, minimum BCS was strongly correlated with muscularity ($r_s$=0.59).

***Table 14: Correlations matrix of variables in data set „Behaviour“***

| | avgDMY | MPE | binFPR | avgSCS | Lameness | Days open | CI | minBCS | BCSrange | avgFat | avgProtein | HS | HW | Bodydepth | Chest width | Chest girth | Muscularity | RumT | FeedT | NrBoli | MFeed | MBolus | RumRate | FeedRate |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **LN** | [illegible] | -0.17 | -0.21 | [illegible] | 0.19 | -0.17 | [illegible] | -0.24 | 0.29 | -0.28 | 0.18 | 0.27 | 0.44 | 0.70 | [illegible] | 0.56 | -0.21 | [illegible] | 0.21 | -0.17 | 0.12 | [illegible] | -0.34 | -0.27 |
| **avgDMY** | | 0.90 | -0.091 | -0.39 | -0.31 | -0.088 | [illegible] | 0.14 | 0.096 | -0.14 | -0.24 | [illegible] | [illegible] | [illegible] | 0.17 | [illegible] | 0.17 | 0.45 | 0.43 | 0.21 | 0.33 | 0.13 | -0.072 | -0.091 |
| **MPE** | | | 0.12 | -0.38 | -0.42 | [illegible] | [illegible] | 0.19 | [illegible] | 0.10 | -0.28 | -0.20 | -0.19 | -0.12 | 0.13 | -0.24 | 0.22 | 0.45 | 0.36 | 0.32 | 0.32 | 0.13 | 0.11 | [illegible] |
| **binFPR** | | | | -0.19 | 0.24 | 0.20 | 0.26 | [illegible] | -0.076 | 0.49 | -0.28 | -0.32 | -0.18 | [illegible] | -0.24 | -0.29 | -0.42 | [illegible] | -0.085 | 0.00 | [illegible] | 0.17 | 0.17 | 0.20 |
| **avgSCS** | | | | | 0.09 | -0.24 | -0.20 | [illegible] | [illegible] | 0.19 | 0.30 | 0.19 | 0.16 | [illegible] | -0.17 | 0.22 | [illegible] | -0.37 | -0.14 | -0.34 | -0.19 | -0.13 | -0.28 | -0.18 |
| **Lameness** | | | | | | [illegible] | -0.083 | -0.14 | [illegible] | [illegible] | 0.19 | [illegible] | 0.14 | 0.16 | [illegible] | 0.26 | -0.31 | [illegible] | -0.37 | -0.41 | -0.26 | 0.37 | -0.12 | 0.38 |
| **Days open** | | | | | | | 0.59 | 0.25 | -0.23 | 0.24 | [illegible] | 0.15 | [illegible] | -0.27 | 0.13 | [illegible] | 0.22 | -0.11 | [illegible] | -0.16 | [illegible] | [illegible] | 0.07 | 0.25 |
| **CI** | | | | | | | | 0.33 | -0.25 | 0.20 | -0.11 | 0.52 | 0.40 | 0.097 | [illegible] | 0.30 | 0.14 | [illegible] | -0.12 | 0.18 | -0.16 | -0.25 | [illegible] | -0.16 |
| **minBCS** | | | | | | | | | [illegible] | 0.26 | 0.15 | -0.076 | -0.15 | -0.17 | 0.31 | [illegible] | 0.59 | -0.12 | -0.55 | -0.22 | -0.60 | [illegible] | -0.34 | [illegible] |
| **BCSrange** | | | | | | | | | | 0.073 | 0.33 | -0.20 | [illegible] | 0.12 | [illegible] | 0.13 | 0.14 | 0.14 | -0.21 | -0.51 | -0.35 | 0.22 | -0.50 | -0.15 |
| **avgFat** | | | | | | | | | | | 0.10 | -0.17 | -0.16 | -0.09 | -0.28 | [illegible] | [illegible] | [illegible] | -0.11 | -0.12 | -0.11 | [illegible] | [illegible] | -0.096 |
| **avgProtein** | | | | | | | | | | | | [illegible] | [illegible] | [illegible] | 0.11 | 0.19 | 0.13 | [illegible] | -0.25 | -0.46 | -0.24 | 0.31 | -0.16 | 0.19 |
| **HS** | | | | | | | | | | | | | 0.89 | 0.38 | -0.15 | 0.69 | -0.098 | -0.25 | 0.14 | [illegible] | 0.07 | -0.25 | -0.18 | -0.23 |
| **HW** | | | | | | | | | | | | | | 0.58 | -0.13 | 0.72 | -0.19 | -0.21 | [illegible] | -0.16 | [illegible] | -0.13 | -0.24 | -0.16 |
| **Bodydepth** | | | | | | | | | | | | | | | [illegible] | 0.61 | -0.16 | [illegible] | [illegible] | -0.07 | [illegible] | [illegible] | -0.32 | -0.20 |
| **Chest width** | | | | | | | | | | | | | | | | [illegible] | 0.55 | 0.25 | -0.19 | [illegible] | -0.22 | [illegible] | -0.25 | [illegible] |
| **Chest girth** | | | | | | | | | | | | | | | | | -0.075 | -0.069 | [illegible] | -0.37 | -0.089 | [illegible] | -0.53 | -0.37 |
| **Muscularity** | | | | | | | | | | | | | | | | | | [illegible] | -0.26 | [illegible] | -0.30 | -0.10 | -0.21 | [illegible] |
| **RumT** | | | | | | | | | | | | | | | | | | | 0.30 | 0.21 | 0.33 | 0.52 | [illegible] | 0.076 |
| **FeedT** | | | | | | | | | | | | | | | | | | | | 0.49 | 0.95 | -0.17 | 0.17 | -0.31 |
| **NrBoli** | | | | | | | | | | | | | | | | | | | | | 0.46 | -0.52 | 0.33 | -0.30 |
| **MFeed** | | | | | | | | | | | | | | | | | | | | | | [illegible] | 0.36 | [illegible] |
| **MBolus** | | | | | | | | | | | | | | | | | | | | | | | 0.21 | 0.65 |
| **RumRate** | | | | | | | | | | | | | | | | | | | | | | | | 0.56 |
| **FeedRate** | | | | | | | | | | | | | | | | | | | | | | | | |

LN=Lactation number, DMY=Daily milk yield, MPE, Milk production efficiency, FRP=Fat-to-protein ratio, SCS=Somatic cell score, CI=Calving interval, BCS=Body condition score, HS=Height at the sacrum, HW=Height at the withers, RumT=Rumination time, FeedT=Feeding time, NrBoli=Number of boli, MFeed=Mastications while feeding, MBolus=Mastications per bolus, RumRate=Rumination rate, FeedRate= Feeding rate

# 5 Discussion

Physical parameters of totally 159 dairy cows on 14 concentrate-free farms could be adopted from the "Feed no Food"-project at FiBL. Physical parameters were type traits, BCS and milk components. Feeding behaviour was observed on one farm on 26 cows, once at summer feeding and once at winter feeding. Feeding behaviour variables were examined for individual patterns, remaining consistent over time. Relations between physical and feeding behavioural parameters on one hand and health and fertility parameters on the other hand were analyzed.

## 5.1 Physical parameters

### *5.1.1 Model calculations*

Generalized linear mixed effects models with farm as random effect should reveal influence of physical parameters on health and fertility.

For the trait calving interval literature reports very low heritability ($h^2$= 0.02; Pryce et al. (2000)) and it takes comparably long until data for this parameter is available. Therefore, if the aim is to improve fertility in dairy cows, auxiliary traits are necessary that are sufficiently correlated with calving interval and other fertility traits.

The BCS range, which is the difference between the maximum and the minimum score out of at least three scores during the lactation of interest, was found to be related to calving interval, total treatments and fertility treatments (Figure 11). The unfavorable relationship between BCS loss and fertility has often been published; negative effects on calving interval, days to first heat and to first service (Pryce et al., 2001), conception rate to first service (Butler and Smith, 1989), days open and number of inseminations per conception have been described (Gillund et al., 2001; for review see Roche et al., 2009). In Pryce et al. (2001) calving interval was not significantly related to BCS loss when corrected for milk yield; days to first heat and to first service, however, remained significant. Buckley et al. (2003) only observed reduced pregnancy rates 42 days after start of the breeding season for cows with a precalving BCS of ≥3 and a BCS loss of >0.5 units until day 90 postpartum.

The influence of an increased BCS loss on total treatments might be due to the increased fertility treatments, which were part of total treatments, but also due to the enhanced lipid metabolism and its related risk for metabolic disorders. The relationship of BCS loss with metabolic disorders, however, could not be verified, because number of treatments in this area was very low.

The cited studies which describe a relationship between BCS loss and fertility, assessed BCS once at calving and then 5 (Butler and Smith, 1989) or 10 weeks (Pryce et al., 2001) later or regularly every month (Gillund et al., 2001). In the present study, BCS was assessed regularly four times a year. Thus most likely not all extremes in body condition were recorded, but the assessed values still resulted in significant relations between BCS loss and fertility. This suggests a strong impact of BCS loss and makes it a valuable and easy to record indicator.

Cows in a higher LN had increased SCS and longer calving intervals (Figure 11), both of which are indicators for impaired health and fertility respectively. The relationship between LN and SCS was explained in Steeneveld et al. (2008) by the history of clinical mastitis incidences. Cows with mastitis incidences in the previous lactation were more likely to suffer from mastitis. Hence, older cows accumulate a history of mastitis incidences and the risk to develop udder infections rises. The trend of calving interval across parities though was in conflict with previous findings. Declining calving intervals from first through to higher parities have been reported (Hossein-Zadeh, 2011; Wu et al., 2012). A prolonged first intercalving period could also be expected because many farmers tend to inseminate primiparous cows slightly later. However, the reduced fertility in older cows might be associated with the higher milk production and thus the more severe NEB (Butler and Smith, 1989).

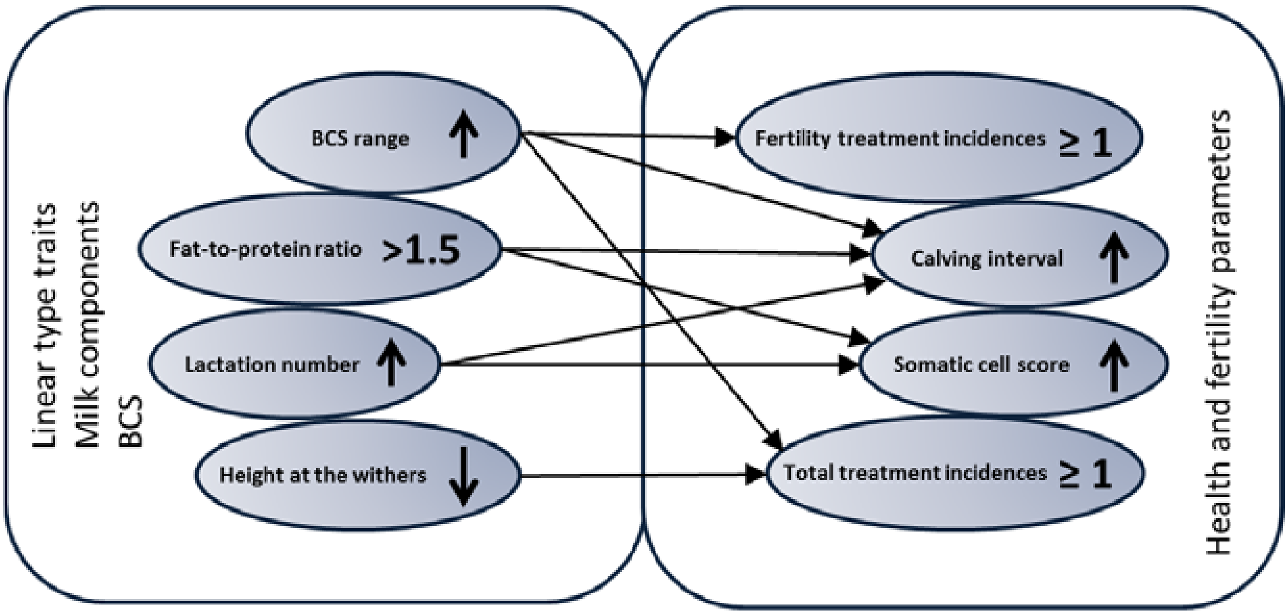



***Figure 11: Graphical illustration of connections between physical and health/fertility parameters***

Cows that were smaller at the withers relative to the specific breed average were more often medically treated (one or more treatments within the corresponding lactation; Figure 11). Several studies describe a negative relationship between height of dairy cows and their fertility (e.g. Pryce et al., 2000; Zink et al., 2011), probably largely explained by the increased milk yield of bigger cows (Wall et al., 2007). Moreover, smaller cows were found to have shorter lifespan (Hansen et al., 1999; Wall et al., 2007). Hence, the here described results are contrary to findings in literature. The average height at the withers of all animals in the data set was below breed averages. Thus, cow types in concentrate-free, organic farming systems in the selected regions seem to be smaller than breed averages; and results from literature might not apply for these animals.

No relationship between minimum BCS and any health or fertility parameters was found, indicating that development of body condition within a lactation period is a better predictor of health and fertility disorders than nadir BCS.

A binary FPR of 1 (maximum FPR of >1.5) was associated with lower average SCS and longer calving intervals (Figure 11). The relationship between FPR and SCC has been studied before. No relationship (Toni et al., 2011) or rather a positive relationship was found (Heuer et al., 1999; Jamrozik and Schaeffer, 2012). A high FPR is an indicator of a large NEB during a period of high milk production. High SCC in the milk on the other hand indicates an inflammation of the udder which may decrease milk production in an acute phase (Jamrozik and Schaeffer, 2012). Consequently, animals with udder infections might not reach high FPR values because of their reduced milk production.
The association of elevated FPR and decreased fertility has been found before (Podpecan et al., 2008). Fat mobilization processes, strong NEB, possibly subclinical ketosis - all of which may be indicated by high FPR values - have been described to have detrimental effects on reproductive organs.

### *5.1.2 Correlations*

For both, data set “Physical” and “Behaviour”, spearman correlations have been calculated in order to get a better impression of how single variables are interrelated. If not specified, the following paragraphs refer to findings in data set “Physical”, because the greater number of animals in this data set rather allows general statements.

In both data sets correlations showed that cows in their first and possibly also in their second lactation still grow. In data set “Physical” LN was correlated with chest width and chest girth, although all type trait values had been corrected for LN. Obviously, these corrections were too tentative. In data set “Behaviour” correlations to body size were expected, because no correction for age was made.
BCS range was found to be positively correlated with chest width. Veerkamp and Brotherstone (1997) describe a strong relationship between chest width and body condition at calving and average body condition during the first 26 weeks of lactation. Calving BCS, moreover, is associated with increased BCS loss (Roche et al., 2007). Thus, broader cows start lactation with a higher BCS but also lose more body condition during lactation.
In data set “Behaviour” calving interval positively correlated with height at the withers and height at the sacrum. Reduced fertility of larger cows has been described in literature (Pryce et al., 2000; Berry et al., 2004), but has also been explained through the detrimental effect of higher milk production associated with stature (Wall et al., 2007). In data set “Physical”, where body size was corrected for age and breed, no relationship was found between height and calving interval, indicating that the relationship found in data set “Behaviour” is either associated with age or with breed.

MPE and milk composition were correlated to type traits. A larger chest girth was associated with higher milk protein percentages, while a larger body depth and chest girth seemed to be detrimental for MPE. In Parke et al. (1999) body size traits as body weight, capacity (body depth and chest width) and stature (height at the withers) were linked to higher total energy intakes. In the present study chest girth was correlated to all other type traits and may therefore be considered as best indicator for overall body size. Hence, cows with larger chest girth, larger body size, consumed more energy which is reflected in higher milk protein contents.

The adverse effect of body depth and chest girth on MPE confirms the findings of Roth et al. (2010), who found the (smaller) New Zealand HF cows to have better efficiency in terms of milk production than the (larger) Swiss breeds. Parke et al. (1999) investigated feed efficiency instead of MPE, and also found cows with generally smaller body size traits to be more efficient.

A better MPE seemed to be gained by aggravated mobilization of body tissue. With increasing efficiency also the binary FPR and the average fat percentage rose, while no association existed between DMY and fat content. Correlations between MPE and protein as well as between FPR and protein were negligible, affirming the statement by de Vries and Veerkamp (2000) that energy balance is primarily indicated by fat percentage, rather than protein percentage.

Milk protein content, though, was found to be associated with the average SCS. This might be due to decreased milk yield caused by udder inflammation, as described in the previous chapter. Lower milk production leads to decreased dilution of milk solids.

In the smaller data set “Behaviour” animals with more leg and claw problems produced less milk and were thus less efficient in milk production. Cows with increasing locomotion problems have been shown before to spend less time feeding, to have lower DMI and to consequentially produce less milk (Bach et al., 2007).

## 5.2 Behavioural parameters

As far as known no publication investigated the relationship between long-term feeding behaviour and health and fertility in cows. In the data set “Behaviour” feeding behaviour, type traits, milk components and BCS from 26 cows on one farm were analyzed for relations with health and fertility parameters.

Feeding behaviour traits were measured using recently developed pressure sensors (Nydegger et al., 2011). The advantage of this sensor in comparison to the often used IGER rumination meter is the size of the logger. Especially around feeding racks, risk of damage is clearly lower and wearing comfort for cows is presumably better. The disadvantage so far is the time-consuming readout and processing of produced data. This makes an employment in practice at this stage impossible and constricts large scale observations.

If feeding behaviour parameters should serve as auxiliary traits for health and fertility, a precondition is that they are not only determined by environmental factors, that variance in phenotypes may be partly explained through genotypic variance (heritability). The described correlations between summer and winter observations for traits related to feeding implicate that these traits in contrast to some rumination traits (rumination time and mastications while ruminating) display some individual patterns (Table 15). Other rumination traits like mastications per bolus, number of boli and rumination rate, however, were also found to show an individual pattern over time. In observations by Schneider (2002) the parameter mastications per bolus had a larger interindividual than intraindividual variation. Hence, this parameter was equally interpreted to have an individual characteristic.

***Table 15: Interpretation of feeding behaviour regarding dependency on feed and individual patterns***

| | **Dependent on feed**[1] | **Individual pattern**[2] |
|---|---|---|
| **Feeding time** | ✓ | ✓ |
| **Mastications while feeding** | ✓ | ✓ |
| **Rumination time** | ✓ | ✗ |
| **Mastications while ruminating** | ✓ | ✗ |
| **Number of boli** | ✗ | ✓ |
| **Mastications per bolus** | ✓ | ✓ |
| **Feeding rate** | ✗ | ✓ |
| **Rumination rate** | ✗ | ✓ |

[1]A shift of the herd mean between the two measuring periods was interpreted as dependency on feed (Difference between the two temporal means > SD within one measuring period).
[2]A significant relation between measurements from September and December shown by regression analysis was interpreted as individual pattern

Influence of stage of lactation was assessed through regression. Stage of lactation is not an environmental factor and varying feeding behaviour across lactation could possibly be caused by genetic variance. There are several other examples of varying heritability during different stages of lactation (Chapter 2.6). But for this analysis, where only two stages of lactation per cow could be observed, influence of DIM had to be ruled out. Regression analysis revealed that except from rumination time and number of boli produced all traits did not seem to have a distinct relationship with stage of lactation.

In September the herd was on pasture during daytime, which explains the prolonged feeding time in comparison with December. In December rumination time was longer than in September and also longer than feeding time, assumingly caused by the increased fiber content of the winter feed ration. For the traits feeding and rumination time, mastications while feeding and while ruminating and mastications per bolus the difference between the observation periods was by far larger than the standard deviation within one observation period. This implies that the herd averages for these traits shift according to feed. For number of bolus, feeding and rumination rate this shift was not observed, indicating that these values don’t depend on feed (Table 15).

Individual feeding and rumination rate might dependent on live weight. Cows with larger chest girth, which is associated to live weight, chewed slower while ruminating. A connection between live weight and rumination rate has been found before, but only for primiparous cows (Schneider, 2002).

Cows that produced more milk spent more time feeding and ruminating. Previous trials described a connection between milk production and grazing time as well as herbage intake (Pulido and Leaver, 2001; McCarthy et al., 2007). But those studies compared the temporally immediate relationship between grazing behaviour and milk yield. In the present study though, each cow's average DMY from the first 100 DIM was compared to feeding behaviour during two fixed observation periods. Thus, a positive relationship was found even though DMY and behaviour were not measured at the same time.

Yet, a longer feeding time is not necessarily linked to higher intakes. Durst et al. (1993) compared feeding behaviour of Jersey, HF and Simmental cows in the barn and described Jerseys to feed less but to have longer feeding times. The lower feed intake was explained by a slower feeding rate of Jersey cows. Similarly, in a study with breeding bulls, Wassmuth and Alps (2000), did not find any connection between feeding duration and feed intake. Feeding duration might moreover be influenced by social hierarchy (Harb et al., 1985). But in the present study, cows were either on pasture or in a barn with more feeding places than animals, thus social constraints should not have played a significant role.

The impact of locomotion problems on feeding behaviour was the only relationship found between feeding behaviour and health or fertility parameters. Although the lameness score represented problems within the entire past year, it still correlated with some of the (short-time) behavioural parameters: Feeding time and number of boli were reduced while mastications per bolus and feeding rate increased. Hence, cows with leg or claw problems spent less time feeding but increased their rate at feeding, a connection which has been described before (Bach et al., 2007).

The cow Priska displayed in several parameters a distinctly different feeding behaviour to other cows. Interestingly, Priska died one month after the second observation period out of the sudden. An autopsy revealed a liver abscess as cause of death. Whether there is any link between this kind of disease and the particular feeding behaviour remains to be investigated.

## 5.3 Methodology

Calving interval was used as indicator for fertility. Yet, this parameter comes along with a certain bias as described in Pryce et al. (2000). Cows with poorest fertility don't reach a second lactation and thus don't appear in any analysis using calving interval as predictor of fertility. Better suited indicators would be for example number of services, days to first heat, or days to first service. However, this kind of data was not available for this thesis, because several farms practice natural mating.

Results of faeces particle sizes did not show any individual pattern between the samples from September and December, except for the DM content which was moderately correlated between the two points of time. Possibly more samples per feeding period would allow a more general statement on this behalf.

Number of observed animals and time of observation were assumingly too low to detect any relationship between feeding behaviour and health or fertility, other than the one found to lameness. Further investigations with more animals, ideally with half-sisters, are necessary to confirm the individual character of feeding behaviour, to reveal any connection to health or fertility and to assess potential heritability. However, with the current version of the pressure sensor large-scale, on-farm measurements of feeding behaviour don't seem feasible. Better applicable instruments are already in test-phase and might permit extended measurements.

# 6 Conclusion

BCS range within one lactation as well as FPR above the threshold of 1.5 are applicable predictors for health and fertility of dairy cows in organic, concentrate-free feeding systems. Both have been described before to be reasonably heritable and could thus be incorporated into specific breeding programs for this type of farming system, irrespective of breed.
The prevailing assumption that cows of bigger body size more often suffer from health disorders might not apply for the here analyzed preselected population under low-input conditions.

Some rumination traits and all traits related to feeding show an individual pattern over time and do not depend on stage of lactation. Accordingly, part of the variation between animals in terms of feeding behaviour might be genetically determined. Further investigations on a larger number of animals will be necessary to determine heritability and to reveal potential correlations with health and fertility.

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# Appendix

## Appendix 1: Breed averages of type traits

*Table 16: Breed averages of type traits*

| | | Height at the withers | Height at the sacrum | Chest girth | Chest width | Body depth | Muscularity |
|---|---|---|---|---|---|---|---|
| **Braunvieh** | 1.lact. | 141 | 144 | 192.1 | 5 | 79 | 5 |
| | 2.lact. | 144 | 146 | NA | 5 | 83 | 5 |
| | 3ff.lact | 145 | 147 | 198.3 | 5 | 85 | 5 |
| **Original Braunvieh** | 1.lact. | 139 | 141 | NA | 5 | 79 | 5 |
| | 2.lact. | 141 | 142 | NA | 5 | 82 | 5 |
| | 3ff.lact | 142 | 143 | NA | 5 | 83 | 5 |
| **Grauvieh** | 1.lact. | 127 | 129 | NA | 5 | 73 | 5 |
| | 2.lact. | 127 | 128 | NA | 5 | 74 | 5 |
| | 3ff.lact | 128 | 129 | NA | 5 | 76 | 5 |
| **Jersey** | 1.lact. | 124 | 125 | NA | 5 | 71 | 5 |
| | 2.lact. | 126 | 126 | NA | 5 | 73 | 5 |
| | 3ff.lact | 126 | 126 | NA | 5 | 75 | 5 |
| **Simmentaler** | 1.lact. | 142 | 143.6 | 195.6 | 5.2 | 80.4[1] | 6.3 |
| | 2.lact. | 145[2] | 145.6[2] | NA | 5.2 | 84.4[2] | 6.3 |
| | 3ff.lact | 146[2] | 146.6[2] | NA | 5.2 | 86.4[2] | 6.3 |
| **Fleckvieh** | 1.lact. | 142.9 | 144.2 | 194.9 | 4.9 | 81.4[1] | 5.5 |
| | 2.lact. | 145.9[2] | 146.2[2] | NA | 4.9 | 85.4[2] | 5.5 |
| | 3ff.lact | 146.9[2] | 147.2[2] | NA | 4.9 | 87.4[2] | 5.5 |
| **Red Holstein** | 1.lact. | 145.4 | 146.3 | 196.2 | 4.7 | 82.4[1] | 4.9 |
| | 2.lact. | 148.4[2] | 148.3[2] | NA | 4.7 | 86.4[2] | 4.9 |
| | 3ff.lact | 149.4[2] | 149.3[2] | NA | 4.7 | 88.4[2] | 4.9 |
| **Holstein** | 1.lact. | 146.8 | 148 | 196.9 | 4.7 | 82.8[1] | 4.7 |
| | 2.lact. | 149.8[2] | 150[2] | NA | 4.7 | 86.8[2] | 4.7 |
| | 3ff.lact | 150.8[2] | 151[2] | NA | 4.7 | 88.8[2] | 4.7 |

Source of data: Andreas Bigler, Swissherdbook, personal communication, 24. October 2011; Willy Schmid, SBZV, personal communication, 27. October 2011; Schnyder and Berweger, 2006.

[1]Swissherdbook estimates body depth in scores, therefore the score was converted into linear measure through the formula given in Swissherdbook (Swissherdbook, 2010) for animals in their first lactation (see chapter 3.3.1).

[2]For breeds which are part of the Swissherdbook breeders' association only averages were available for first lactation animals. Therefore the values for 2. and 3ff. lactation animals were estimated according to the development in Braunvieh cattle.

## Appendix 2: Physical parameters in data set “Behaviour”

***Table 17: Descriptive statistics of physical parameters in data set „Behaviour“***

| | Parameter | Mean (±SD) | Median[2] | Range | n |
|---|---|---|---|---|---|
| | Lactation number | | 2.5 | 1-12 | 30 |
| Type traits | HW[1] (cm) | 142.4 (±4.54) | | 131 - 150 | 30 |
| | HS[1] (cm) | 146 (±4.0) | | 137 - 153 | 30 |
| | Chest girth (cm) | 202.9 (±6.7) | | 193 - 222 | 30 |
| | Chest width (score 1-9) | | 5 | 3 – 8 | 30 |
| | Body depth (cm) | 79 (±5.71) | | 70-90 | 30 |
| | Muscularity (score 1-9) | | 6 | 3 - 8 | 30 |
| BCS | Minimum BCS | | 2.75 | 2 – 3 | 30 |
| | Maximum BCS range | | 0.5 | 0 – 1.25 | 30 |
| Milk components[3] | Milk fat (g/kg) | 3.56 (±0.53) | | 2.09 – 4.42 | 30 |
| | Milk protein (g/kg) | 3.0 (±0.21) | | 2.57 – 3.48 | 30 |
| | Milk yield (kg/day) | 21.58 (±4.3) | | 10.9 - 28 | 30 |
| | Milk production efficiency (kg ECM/day/BW$^{075}$) | 0.15 (±0.03) | | 0.07 – 0.2 | 30 |

[1]HW=Height at the withers, HS=Height at the sacrum.
[2]Median instead of mean was calculated for scored variables.
[3]Averages of all milk samples within the first 5-100 days in milk