Universität für Bodenkultur Wien
University of Natural Resources
and Life Sciences, Vienna

Master Thesis

Feeding behaviour of lactating sows: Influence of time of day, temperature and day of lactation on the ad libitum feed supply

Submitted by

Sören Emanuel PANUSCH, BSc

in the framework of the Master programme

Nutztierwissenschaften

in partial fulfilment of the requirements for the academic degree

Diplom-Ingenieur

Vienna, June 2022

Supervisor:
Assoc. Prof. Priv.-Doz. Dr. med. vet. Christine Leeb
Division of Livestock Sciences
Department of Sustainable Agricultural Systems

Co-supervised by

Univ. Prof. Dipl.-Ing. Dr. nat. techn. Werner Zollitsch
Division of Livestock Sciences
Department of Sustainable Agricultural Systems

Acknowledgement

Many thanks to my supervisors at the university, Werner Zollitsch, Christine Leeb and Sarah Gorr. I would also like to thank Thomas Parsons. The constructive feedback, the intensive cooperation and the joint meetings made this Master's thesis possible in the first place. I would especially like to thank Sarah Gorr for the data that she provided and that I was allowed to use. I also want to thank Birgit Fürst-Waltl for her help with the statistical analyses.

Furthermore, I would like to thank the Schwersmann family and the Silkenbömer family, who laid the foundation for my agricultural education. Last but not least, I want to thank Hendrik Surmann, who had a decisive influence on my agricultural education.

Affidavit

I hereby declare that I have authored this master thesis independently, and that I have not used any assistance other than that which is permitted. The work contained herein is my own except where explicitly stated otherwise. All ideas taken in wording or in basic content from unpublished sources or from published literature are duly identified and cited, and the precise references included.

I further declare that this master thesis has not been submitted, in whole or in part, in the same or a similar form, to any other educational institution as part of the requirements for an academic degree.

I hereby confirm that I am familiar with the standards of Scientific Integrity and with the guidelines of Good Scientific Practice, and that this work fully complies with these standards and guidelines.

28.05.2022 S.Pal

Date, Signature

Table of Contents

Table of figures

List of tables

1. Introduction

Agricultural production is under pressure due to global crises such as climate change, African swine fever and the constantly growing demands of consumers. Depending on the region of the world, these demands concern the mere supply of food or higher standards of production (FAO, 2020, Friker and Schüpbach, 2021). Intensive farming and the conditions under which animals are kept are often criticised, in particular the way, lactating sows are housed is often subject of debates (Bundesanstalt für Landwirtschaft und Ernährung, 2021). One approach to do more justice to the animals and their needs is to better understand their behaviour. The ancestors of the modern domestic pig, which still exist show specific behavioural patterns that are linked to external influences and internal drivers. An important aspect seems to be the time of day and the change between day and night, i.e. from light to darkness. Similar behavioural patterns can also be observed in modern pigs (Briedermann, 2009, Horsted et al., 2012). In modern sow husbandry, however, there are often daily rhythms, which are fixed by humans, e.g. feeding at specific times of the day. This type of feeding management is often based on defined feed quantities, which, in lactating sows mainly consider the litter size and day of lactation (Jeroch et al., 2008). For sows, however, lactation is a dynamically developing process that is subject to many influencing factors, such as diseases that can occur with farrowing or increased feed requirements (Lochner and Breker, 2015).

A sufficient feed supply during lactation influences the further development of the animals in the herd. Also piglets benefit from a maximised feed intake of their mothers resulting in an adequate milk supply. Consequently, this has also impact on the success of the farm and sow health (Kirchgeßner et al., 2014). success of the farm and sow health (Kirchgeßner et al., 2014).

With modern ad libitum systems (constant access to feed), the animals can be given the opportunity to freely determine the daytime, duration and quantity of their feed intake. This feeding system in combination with a computer programme can automatically record all feeding events, including time and quantities distributed. Based on these protocols, behavioural patterns of the animals can be tracked. Additionally, potential influencing factors, like parity or light, can be recorded and their impact on animal behaviour determined. Another controllable parameter in a pig barn is the temperature, which is regarded as an important influencing factor in affecting welfare and feed intake (Malmkvist et al., 2012).

So far, only limited knowledge is available about the feeding behaviour of lactating sows without restrictions on feed supply, but in the present study there is an opportunity to study that behaviour through an ad libitum system for lactating sows.

In order to study the patterns of feeding behaviour of lactating sows and to gain more knowledge on influencing factors, the following thesis was carried out.

The objective of this thesis was to describe patterns of the feed quantity released from an ad libitum feeding system for lactating sows, reflecting their feeding behaviour. Furthermore, the influence of three factors on this pattern was investigated: the time of day, temperature and day of lactation.

The hypothesis was that lactating sows show specific behavioural patterns, which depend on the day of lactation, temperature, and time of day. The hypotheses were that with increasing lactation days, feed gain increases. With increased temperature, feed consumption would decrease and be shifted to cooler times of the day.

2. Literature

In this chapter of the thesis, the origin of today's domestic pig is explained, followed by a description of feeding and foraging behaviour of wild pigs. In addition, the behaviour of domestic pigs in a seminatural environment is examined and compared with wild boars. Subsequently, the feeding behaviour of lactating sows in modern farms is considered, with a focus on feeding management. The influence of time of day, temperature in the barn and lactation day are highlighted as key mechanisms on the lactating sows feed intake.

2.1 The behaviour of wild boars and feral pigs

Today all domestic pig breeds, *Sus scrofa forma domestica*, descended from the wild species *Sus scrofa*. Human influence in the form of artificial selection resulted in today's domestic pigs. Most domestic pigs live in an artificial habitat provided by humans and usually designed in a special way. The wild pig differs from the domesticated animal in several aspects, which include anatomical characteristics and behaviour (Jeroch et al., 2008).

The wild boar is distributed across a large range and is found on every continent except Antarctica (DJV, n. d.). The length of daylight differs significantly in the different regions of the world, to which wild boars and also feral pigs adapt their daily routines (Graves, 1984). In Europe, wild boars are mainly nocturnal and prefer fringe structures between woodlands and open terrain. In these structures, the wild boar, as an omnivore, also accepts crops as a source of feed, including cultivated cereals such as wheat and barley, which are fed to domestic pigs too (Kirchgeßner et al., 2014, Lemel et al., 2003). The activity of wild boars begins at sunset, if this shifts to a later time, the activity phase of wild boars also moves to the later hour. Other factors with a decisive influence on the behaviour of wild boar include the degree of humidity (Lemel et al., 2003).

Another influencing factor on the foraging behaviour of wild boars and feral pigs is the season, which has a main impact on the feed supply. The different available feed resources can be reached with varying degrees of effort. Typically, pigs search for feed by moving aroundtheir snout very close to the ground. When a promising spot is found, pigs root into the soil, digging up the ground, mostly only the upper layer. The diet includes grass, herbs, tubers, roots, fruits and seeds, worms, insects, mice and eggs, small animals and carrion (DJV, n. d., Graves, 1984). The search for different sources of energy and protein is associated with an enormous effort which should not be underestimated. This effort is also reflected in the hourly proportion pigs spend performing various activities. In general, a distinction can be made between an active and a passive phase. In the passive phase, pigs mostly rest in a lying position, often in they dig shallow pits for it. Wild boars additionally use plant material in their lying area for bedding as protection from cold temperatures (Graves, 1984). Within 24-hours wild boars use eight to eleven hours for their active phase, which decreases with increasing age. According to Briedermann (2009), the average duration of activities during daytime is on average 34.3 minutes and during night-time 10.5 minutes. The activity and resting phases are each divided into two blocks. Complementing the active phase, the hourly average of the resting phase is 32 to 40 minutes long, which equals to 13 to 16 hours a day. Thus, adult animals are inactive for 55 % to 67 % of the day and active for 33 % to 45 % within 24 hours.

From the eight to eleven hours of active behaviour, 85 % of this time the pigs are occupied with foraging. Of the remaining 15 %, 5 % are used for playing and fighting behaviour. The remaining 10 % are behaviours associated with varying activities (Briedermann, 2009). The most important factor for the beginning and the end of the activity period is the light-dark change. The two main phases of activity also coincide with sunrise and sunset (Lemel et al., 2003, Rivero et al., 2019, Russo et al., 1997). In addition, Russo et al. (1997) showed a partitioning of activity in wild boar, in the Mediterranean region of Italy, into two active and two resting phases. The duration of the active phases was longer than expected, as 65 % of the time was spent active, which was explained by a feed shortage due to drought in the summer (Russo et al., 1997). Cousse and Janeau (1991) pointed out, that 53 % of the daytime is used for activity, Janeau and Spitz (1984) found only 50 % and Douaud (1983) and Mauget (1980) only 41 %, but all these results are in line with Briedermann (2009). Lemel et al. (2003) showed the fluctuations of activity durtions in a diagram, which can be seen inFehler! Verweisquelle konnte nicht gefunden werden. **Figure 1**.

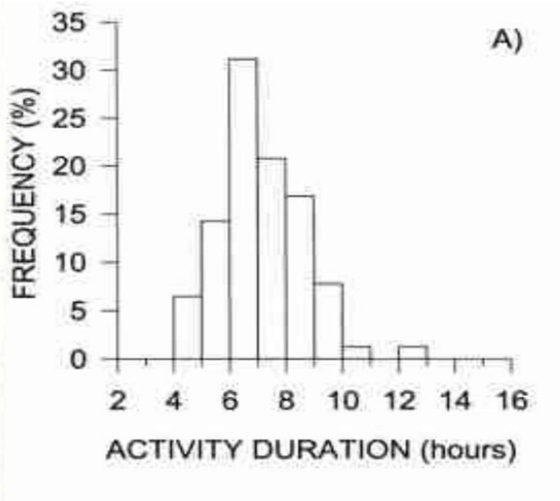

Figure 1: Fluctuations in the activity period of wild boars

Source: (Lemel et al., 2003)

It can be concluded that a 24-hour day of wild boars and feral pigs is divided into two distinct phases. The active phase is dominated by the urge and compulsion to forage. Searching for food, especially insects, worms and plant parts lying below the surface, is an energy-intensive behaviour.

2.2 Pigs in a seminatural environment

Foraging and chewing do not play a significant role in today's housing and feeding conditions of conventional pig husbandry. Pigs spend hardly any time foraging, and the duration of feed intake is usually very short. This is especially the case in feeding systems that use restricted feeding (Jeroch et al., 2008). Rooting and other interactions with feed and environment are more likely to be found in organic pig farming, where the pigs are supplied with roughage and bedding material in the form of green fodder, hay or straw (Council of the European Union, 2007, Kirchgeßner et al., 2014) This contributes to a species-specific feeding behaviour. Feedstuffs that are rich in texture require the pigs to engage with them more intensively. Chewing intensity and chewing ability, similar to the strength of the dentition, are lower compared to wild boar, but domestic pigs will readily accept this type of feed. The supply of roughage can contribute to the prevention of behavioural disorders (Jeroch et al., 2008). To understand the needs of pigs, it is necessary to look not only at their ancestors and wild relatives but also at the behavioural patterns they show themselves. This should be examined in an environment that is close to nature or as close to nature as possible. An animal can only show its natural behaviour in an environment that allows it to do so. Moreover, observed behaviours allow conclusions to be drawn about the animal's needs, which also exist in a non-natural environment.

In this part of the thesis, the main focus is on feeding habits, foraging and related activities shown by modern pig breeds in such environments. Piglets start grazing about four weeks after birth. In the same time frame, they also start to root (Petersen, 1994). With the start of these activities, the piglets significantly reduce the amount of time they use for other activities. This represents an important shift in the pigs' time budget. The same time marks the beginning of the regular intake of solid feed in addition to the sow's milk. This process continued until complete weaning from sow's milk. In fact, Petersen (1994) describes that increased chewing activity in piglets was associated with complete abstinence from milk. This was the case in week eight to week ten after birth. This means that pigs conduct feed-related activities early after birth. Adult pigs also show a wide range of activities related to exploratory and foraging behaviour. This can indicate that pigs are generally curious animals. Their exploratory activities are encouraged by their surroundings and the materials they can manipulate or investigate (Stolba and Wood-Gush, 1989, Studnitz et al., 2007).

As opportunistic creatures, pigs have a high motivation to investigate their environment (Petersen, 1994). This urge is often driven by two reasons, firstly the need for energy and nutrients in the form of feed and secondly the need to gather information about the environment. The collection of information in the environment is not limited to edible objects alone, but also includes non-edible materials that are examined by pigs. Typical actions in this context are sniffing at objects, chewing at them as well as biting and rooting (Studnitz et al., 2007). Rooting is highly prioritised by pigs and is preferred to other behaviours. An important driving force is hunger, which causes the animals to spend more time exploring their environment. Still, when pigs are not fed restrictively, which means they always have access to a non-limited amount of food, they show this exploratory behaviour. This is not shown exclusively due to the need to seek feed. This indicates a permanent subliminal urge through appetite (Studnitz et al., 2007).

The second important driver is curiosity. This curiosity is often directed toward novel objects that are unfamiliar. Pigs actively search for novelties in their surrounding. This behaviour continues until other needs such as hunger or exhaustion become more urgent (Studnitz et al., 2007). Whether it is foraging or grazing, the motivation to do so is not solely influenced by previous experiences, hunger and external irritants. In addition, the general biological time budget is also important. Pigs can change their time budget and feeding behaviour when the availability of feed changes (Andresen and Redbo, 1998, Studnitz et al., 2007). Lower amounts of feed lead to an increase in the time spent foraging. Apparently, pigs can adapt to different feeding situations and adjust the amount of time they spend on certain behaviours according to the circumstances (Andresen and Redbo, 1998). Furthermore, pigs are willing to invest time and energy to get feed even if they were offered free access to it. The fact that animals forage despite the availability of free feed suggests that behaviour is also driven by the need to obtain information about the environment. This information could help increase the long-term chances of survival in the wild. This behaviour is still important for the survival of wild boar today (Graves, 1984, Studnitz et al., 2007). That pigs in a semi-natural environment show such behaviour despite freely available feed was shown by Stolba and Wood-Gush (1989). A semi-natural environment in this study means the area is limited by barriers. Also, the enclosure is characterised by different types of vegetation, such as grass or forest. The pigs were offered feed once a day at a certain time (Stolba and Wood-Gush, 1989). This characterisation of a seminatural environment also applies to the publication of Horsted et al. (2012). In this study, too, the swine were given feed in addition to the natural resources found in the area. Also, in this study, feeding took place at a specific time during the day (Horsted et al., 2012).

In both studies, the domestic pigs showed preferences toward certain activities. Similar to the previously described patterns in wild boars, the domestic pigs rested approximately 50 % of the day. Horsted et al. (2012) found that resting was the most frequently observed behaviour with 54.4 % of all observations. The next most frequent behaviour was rooting with 19.3 %, followed by eating the provided feed with 7.8 %. The frequency of grazing was very low and reached only 0.5 %. If all activities associated with autonomous foraging are added together, these account for 24.4 %. This is remarkable, considering that the pigs were offered feed for unrestricted intake. Overall, feeding behaviour accounts for a share of 32.2 % of the total daily activities (Horsted et al., 2012). As a matter of fact, Stolba and Wood-Gush (1989) observed a similar preference of swine for forage-associated behaviours. This behaviour was recorded in over fifty percent of the observations. In contrast to Horsted et al. (2012), however, grazing accounted for 31 % and rooting for only 21 %. In total, this is 52 % of all observed activities. The different values for grazing can be attributed to several factors. On the one hand, the structure of the area is an important factor. Grass areas can be worn down quickly by pigs so that further grazing can be prevented (Andresen and Redbo, 1998, Jørgensen et al., 2005). On the other hand, the seasons and the associated changes in the environment also influence the animals' behaviour (Petersen, 1994). These literature sources underline that foraging is an important behaviour of domestic pigs. The time spent foraging is fluctuating in the development of a piglet into an adult pig. Beginning as playful behaviour, the previously more benefit-oriented behavioural pattern solidifies (Newberry and Wood-Gush, 1988).

In addition, Rivero et al. (2019) analysed several papers and sources on the foraging behaviour of several modern domestic pig breeds, traditional domestic pig breeds and wild boars. The foraging behaviour of wild boar is neglected here. The included breeds were Duroc, Landrace, Yorkshire, Large White, Tamworth and Iberian pig. The Pasture Crops were mostly grass with clover or lucerne. The overall foraging behaviour shown in the studies varied significantly. The highest percentages were between 30.8 % to

55 %. The overall distribution between grazing and rooting was balanced. In the individual sources, however, one of the behaviours often predominated (Rivero et al., 2019). The Iberian pigs are particularly interesting in this context. This long-established breed of domestic pig is traditionally fattened over two years in southern Spain. In the second year, the animals are left to fend for themselves in clear oak forests and are not given any additional feed. As the area on which the Iberian pigs are kept is often limited, this environment is described as semi-natural (Rivero et al., 2019). This was exactly the case in the study by Martínez-Macipe et al. (2020), in which the behaviour of Iberian pigs in such a system was examined over a period of two years. In the first year, the animals were offered additional feed besides the natural resources they found by themselves. After reaching a live weight of about 90 kg to 115 kg, the farmers stop supplementary feeding. This is also reflected in the behavioural patterns, the total average of exploratory behaviour, which included foraging, was roughly 28.5 % (Martínez-Macipe et al., 2020). In the first year, this was only seen in 17.8 % of the observations. In the second year, without additional feed, this behaviour was observed in 50 % of the observations. This significant effect was called the "Montanera Effect" (Martínez-Macipe et al., 2020). Furthermore, the range between 17.8 % and 50 % shows two things. First, pigs are motivated to forage even when they have access to sufficient feed that meets their nutritional requirements. Second, when pigs are not offered additional feed, foraging becomes the dominant active behaviour. Similar high proportions of foraging are documented by Rodríguez-Estévez et al. (2009), the Iberian pigs spend more than 54 % of their daily light time with foraging behaviour. In this study, the pigs were also not offered additional feed and weighed approximately 110 kg. Furthermore, the housing conditions were the same as by Martínez-Macipe et al. (2020).

The above-mentioned studies show that traditional and modern pig breeds possess the urge to forage, even if they have sufficient feed available. The reasons for foraging are primarily the need for energy and secondarily the drive to obtain information. For pigs, it is often not possible to express this behavioural pattern in restricted feeding systems. However, an ad-libitum feeding system could be a compromise to better meet the needs of the animals. This could be a compromise between efficient pig husbandry and the ability to adjust their foraging behaviour to artificial conditions (Studnitz et al., 2007).

2.3 Feed intake of lactating sows

In contrast to the Iberico pigs kept in forests and swine kept in fields with energy crops, the pigs in modern farming facilities are kept in a highly artificial environment. In this environment, the animals often have very limited opportunities to fully express their natural behaviour. A special situation is the lactation period of sows, during which they often cannot move freely. This depends on the barn environment and herd management. At the same time, it is a very challenging period for the sows, who are exposed to high metabolic stress. Successfully mastering these challenges is crucial for further breeding with individual animals. Knowledge about the behaviour of the animals and especially their feeding patterns can help to achieve this goal (Eissen et al., 2000, Graves, 1984, Passillé and Robert, 1989).

The environment of an animal, in interaction with the genetic predisposition, determines the potential animal performance. A substantial part of the breeding performance of sows is defined by lactation performance. Lactation performance itself is regularly defined by the number of weaned piglets. Suckling performance, and thus also the breeding performance of a sow, can be strongly influenced by the feeding scheme. Feeding constitutes one important environmental factor. Success in many branches within pig husbandry depends to a large extent on feeding management (Kirchgeßner et al., 2014). The feeding regime has to cope with the increased milk yields of modern sows. The increase is a result of breeding efforts, especially concerning litter size, and the improvement of husbandry conditions (Eissen et al., 2000). The suckling phase is only a short period of a few weeks for the majority of sows. When the peak of lactation and thus milk production is reached, weaning is already imminent. On many farms, the suckling period is three to four weeks long (Jeroch et al., 2008). Milk production generally peaks around the third week of lactation and then slowly decreases, as shown in **Figure 2** below. At the same time, the nutrient content of the sow milk increases. Lactating pigs can reach an average daily milk yield of eight to ten litres by the fifth week. However, such a performance depends on a good genetic disposition and proper feeding (Jeroch et al., 2008, Kirchgeßner et al., 2014).

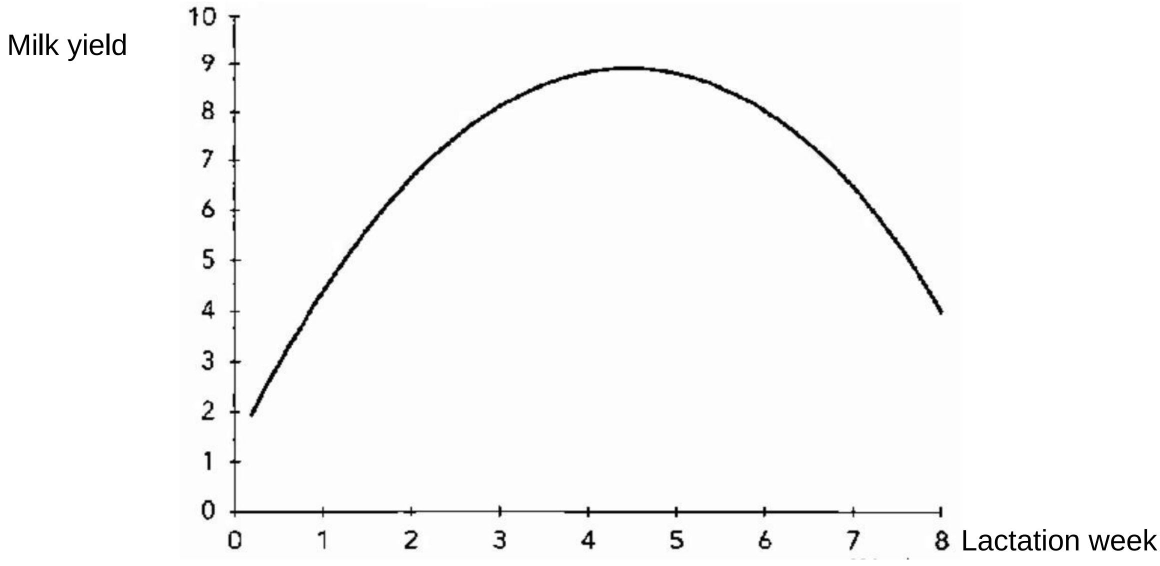

Figure 2: Milk yield course of a lactation period

Source: (Kirchgeßner et al., 2014)

In case the feed intake is not high enough to meet the needs associated with milk production, sows compensate by mobilising body tissue, especially fat and protein (Jeroch et al., 2008). The main loss of body mass in the second to third week of lactation occurs at the same time as the highest increase in milk quantity (Eissen et al., 2000). The loss of body mass during the suckling period can reach ten to twenty kilograms. This corresponds to about 5 % to 7.5 % of the live weight. According to Kirchgeßner et al. (2014), the backfat thickness should not be less than 20 mm. This is an important factor for further gestations. A severe reduction of body weight and especially backfat that falls significantly below this range can lead to impaired health and fertility (Jeroch et al., 2008, Poulopoulou et al., 2018). This includes a longer interval between weaning and oestrus, a decreased ovulation and conception rate, an increased embryonic mortality and a more frequent occurrence of anoestrus (Eissen et al., 2000, Sulabo et al., 2010).

The nutrient and energy requirements of a sow result from the milk production and the maintenance requirement (Noblet et al., 1990). The live weight and thus the maintenance requirement increase steadily from the first to the fourth parity. From the fourth parity onwards, sows are considered fully grown and their live weight should remain constant from then on ,apart from weight loss during lactation (Jeroch et al., 2008). The daily maintenance requirement of a sow weighing 160 kg is approximately 20 MJ ME and of a sow weighing 200 kg approximately 25 MJ ME daily (Jeroch et al., 2008. Kirchgeßner et al., 2014, Yoder et al., 2012). The performance of sows in the long term is best served by reducing fluctuations in fat reserves and body weight in general. In this way, extreme fluctuations in the physical condition and resulting performance weaknesses can be avoided. The chemical composition of the body at farrowing should be considered as an important aspect, taking into account the expected performance of reproduction and feed intake during the sows' next lactation (Eissen et al., 2000, Noblet et al., 1990, Sulabo et al., 2010).

The average number of piglets is between ten to fourteen piglets per sow (Jeroch et al., 2008). However, breeding sows with a higher average number of piglets per litter are also offered by breeding organisations and used by farmers (Grave and Fritz, 2015). Gilts usually have fewer piglets. In practice, the number of piglets and their weight is used as an indicator of milk yield as mentioned before. The actual milk yield is difficult to quantify on farms. However, this energy output in the form of milk accounts for the decisive share of the total energy demand. For each kilogram of milk produced with an energy content of 5 MJ/kg, a lactating sow needs 7.1 MJ ME. The proportion of energy used for milk production is between 65 % and 85 % (Choi et al., 2019, Jeroch et al., 2008,. Kim et al., 2020, Kirchgeßner et al., 2014). If a milk quantity of 9 kg is assumed, this results in a required amount of 63.9 MJ ME for the production of milk alone.

As it is also difficult to measure the actual milk consumption of the piglets, the feed quantity for sows is based on the number of piglets and not the concrete quantity of milk consumed. Depending on the ME content of the feed, a sow needs about 1.5 kg to 2 kg of feed per day plus 0.4 kg to 0.5 kg for each suckling piglet. For twelve to fourteen piglets, this would add up to 6.5 kg to 9.0 kg of feed. In most cases, however, the feed intake is lower (Jeroch et al., 2008). Under practical conditions, an average daily feed intake of only 5 kg can be expected. For gilts, the intake is even lower at only 4 kg (Kirchgeßner et al., 2014, Noblet et al., 1990). However, the average value may be higher depending on the publication (Kruse et al., 2011).

Ensuring the highest possible feed consumption during the peak of the lactation period is a particular challenge (Poulopoulou et al., 2018). Often, feed is not offered ad libitum during the first week. Instead, the feed supply is increased by 1 kg per day, starting with 1 kg. This is done until the intended feed quantity or the sow's satiety limit is reached. This results in an energy intake that can be easily below the requirements for the first five to seven days. But, this practice is intended to prevent the risk of digestive disorders resulting in insufficient feed intake later during lactation (Jeroch et al., 2008). This addresses the behaviour often shown by sows, where feed intake is low immediately after farrowing. This naturally increases again as lactation progresses (Eissen et al., 2000). After the previously limited feeding, it is possible to switch to an ad libitum quantity. This means that there should no longer be an undersupply due to insufficient amounts of feed. Here, other factors than the sheer amount of feed can be given a higher weighting. In the first days of lactation, however, the amount of feed may still be too low. Sows while lactating can be fed individually to ensure sufficient intake. This is a common practice in current systems where sows can be fed individually (Kirchgeßner et al., 2014). Often the daily feed ration is divided into two meals. However, Jeroch et al. (2008) already mentioned that the feed intake can be increased by 0.3 kg to 0.5 kg per day if the feed is divided into four meals. This makes the feeding frequency an important aspect of the feeding management (Noblet et al., 1990, Poulopoulou et al., 2018). During the beginning of lactation, voluntary feed consumption may be limited due to gastrointestinal capacity. The gastrointestinal tract needs time to adjust to the new feeding situation and a higher daily feed amount. Based on this, feed intake divided into small portions seems to be beneficial (Eissen et al., 2000, Imaeda and Yoshioka, 2007).

Hence, there is a clear correlation between feed intake and body condition of the sows during lactation. Further, the body condition is related to the animal's health and thus also how long the animals remain in the herd (Poulopoulou et al., 2018). The necessary energy for milk production is provided by the body reserves and the feed. Feeding thus has a direct influence on milk production, which itself has an enormous influence on piglet growth (Choi et al., 2019, Sulabo et al., 2010). Consequently, feeding is immensely important for the growth of litter and thus for economic success (Alonso-Spilsbury et al., 207, Kirner and Stürmer, 2021, Kim et al., 2020, Young et al., 2011). As a result, an important factor in sow husbandry is to provide the animals with sufficient nutrients and energy. First, the quality and composition of the feed can help to ensure that the feed intake is sufficient or as good as possible. Second, the technical solutions for feeding are important. Knowledge about the sows' feeding behaviour can help to develop feeding systems that fit the sows' behaviour and create synergy effects (Choi et al., 2018).

When it comes to feeding sows, a distinction is made between restrictive or ad libitum feeding. Ad libitum feeding or full feeding of sows means that the animals are offered feed that is freely available at all times so that each sow can eat as much as she wants or needs (Ziron, 2010). This feeding system can be realised by manual feeding. By now there are also technical solutions for ad-libitum feeding (Big Dutchman, n. d.). Sows fed ad libitum tend to consume more feed overall and daily than sows fed restricted. In addition, ad libitum fed sows have a lower body weight loss in lactation compared to restricted fed sows, this difference can be up to 9 kg. After farrowing and at weaning, there is no difference in the live weight range between ad libitum and restricted fed sows. Also generally similar is the backfat thickness after farrowing and at weaning. The back fat loss during lactation also does not differ between sows fed restricted and sows fed ad libitum fed sows (Sulabo et al., 2010).

The urge to feed in sows is influenced by several internal and external factors. One of the internal factors is a limited appetite, which prevents the pigs from overeating. This can occur on an animal-by-animal basis in most feeding systems (Guillemet et al., 2006). The appetite itself is influenced by the live weight, parity and genetic predisposition of the animal (Gourdine et al., 2006, Quiniou et al., 2000b). Feed intake of different breeds may differ during the course of lactation. However, this intrinsic factor does not seem to change the total amount of feed consumption (Yoder et al., 2012). Besides the intrinsic influences that are often difficult or impossible to change in a short term, there are also external influences on feeding behaviour. These external influences can be changed more easily and faster. Some of these influences are the design of the feed ration, the ambient temperature and the light periods in the pen (Quiniou et al., 2000b). Of these listed parameters, the temperature is a particularly important factor in the practical context. Therefore, the influence of temperature on sows will be discussed more in detail in the next chapter.

2.3.1 Temperature

Since the beginning of continuous temperature records, it has become steadily warmer. The extent of warming varies greatly across the globe. In the foreseeable future, the warming trend will continue (Skuce et al., 2013, Planckh and Fuchs, 2020).

Livestock farms have to cope with sometimes drastic harvest losses of hay, silage and grain due to global warming. Most livestock species have trouble with the effects of the increased number of hot days per year (Bailey et al., 2008, Planckh and Fuchs, 2020, Mendelsohn, 2007). The predictive power of economic agricultural models is therefore becoming increasingly inaccurate (Quiggin and Horowitz, 1999). The negative effects of the climate have often been masked by technological progress in recent decades. The negative impacts of a much faster temperature rise will be more difficult to manage on every level. Today, temperature and its impact on livestock is an important factor in farming and will become even more central in the future (Mendelsohn, 2007, Skuce et al., 2013). Already, annual estimated losses due to heat stress in the USA-livestock sector alone, according to Mayorga et al. (2019), amount to nearly US $ 1 billion for pigs and US $ 1.5 billion for dairy cattle.

Temperature fluctuations are significant between the seasons and the time of day and night. In pig husbandry, the environment is often managed through a automated control system. This is intended to maintain the animal's welfare, health and to enable good performance. High production efficiency can be ensured through the regulated stable climate. The thermal environment in a barn can be defined by several factors. These factors are the relative humidity, the air temperature, the heat radiation from surfaces and the air velocity. The air temperature and the relative humidity are typically used as criteria for controlling the ventilation rate in a barn (Choi et al., 2019, Seedorf et al., 1998, Zheng et al., 2021). An outside temperature of 0 °C to 10 °C seems to have a negligible influence on the temperature in pig pens. This was shown at least for barn types commonly found in Northern Europe. However, where outside temperatures fall below or exceed this range, the temperature in a barn can be strongly influenced by the outside temperature, which is illustrated in **Figure 3** below (Seedorf et al., 1998).

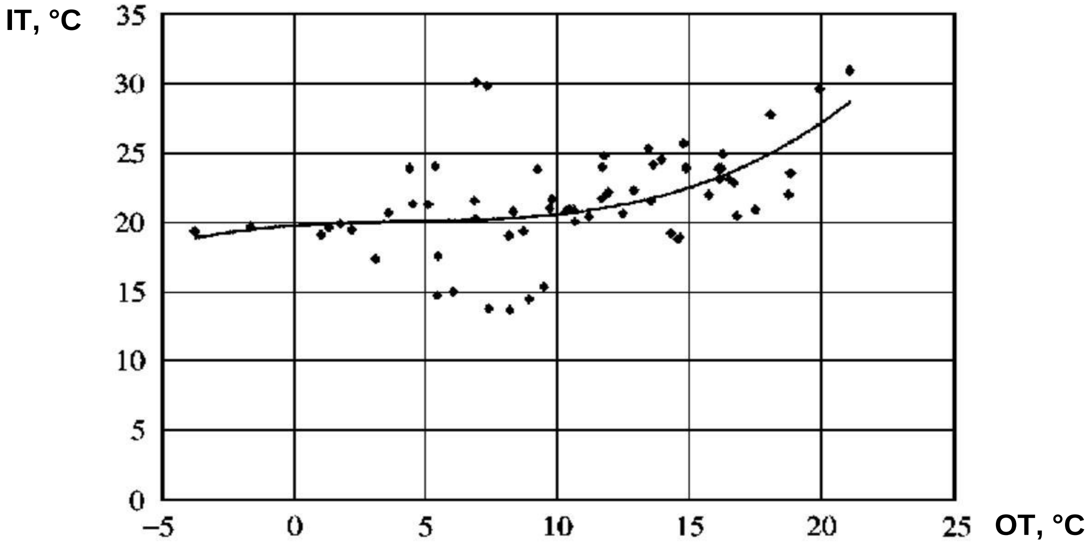

Figure 3: Influence of the outside temperature (OT) on the inside temperature (IT) of pig pens in °C

Source: (Seedorf et al., 1998)

Ambient temperature affects the concentration of air pollutants, like bioaerosols and gases. As a result, the temperature can have a detrimental effect on health. Moreover, whether an ambient temperature is too cold or too warm strongly depends on the size and weight of the swine. If the temperature is too low, this can lead to higher feed consumption and thus, to economical losses. The animals need extra energy to achieve a desirable daily weight gain. An environment that is too warm can lead to several negative consequences, which will be discussed later in this chapter. This is especially the case in the hot summer months (Seedorf et al., 1998).

Regulating the temperature in a farrowing pen involves several challenges. First, pigs cannot sweat. The ability to regulate their body heat is limited. Pigs have only a small number of sweat glands, which can only contribute to cooling to a limited extent due to the thick layer of fat under the skin. Pigs are dependent on panting as a strong respiratory activity for cooling (Mayorga et al., 2019, Seedorf et al., 1998). Therefore, maintaining the thermoneutral zone in a barn is even more important. In addition, a sow weighs more than a hundred times what a piglet weighs after birth. As a consequence, the requirements of sows and piglets in terms of ambient temperature are very different. Piglets lose body heat rapidly after birth due to the enormous temperature change of their surrounding and moisture evaporation at the body surface.

Shortly after birth, colostrum intake is an important factor for the survival of the piglets and their adaptation to the new environment. One reason for that is the heat transfer from the milk to the piglet, another reason is the immune system strengthening effect (Alexopoulos et al., 2018, Seedorf et al., 1998, Zheng et al., 2021).

Pigs have different optimal temperature ranges which mainly depend on the body size and weight of the pigs, apart from the differences between breeds (Misztal, 2017, O'Grady et al., 1985). The temperature range in which animals do not have to expend additional energy for body heat production or suffer from too high temperatures is called the thermoneutral zone. The thermoneutral zone for lactating sows is approximately between 16 °C and 22 °C (Silva et al., 2006). This temperature range can vary according to the literature. The thermoneutral zone of a lactating sow conflicts with that of a new born piglet, whose thermoneutral zone is between 30 °C and 37 °C. Due to the increasing size and body weight gain of piglets during the lactation period, the thermoneutral temperature range decreases downwards to cooler temperatures. Lanferdini et al. (2018) stated a thermoneutral range for piglets of 30 °C to 32 °C. Temperatures around and below 16 °C are called the lower critical temperature. The range around and above 22 °C is called the upper critical temperature. The lower critical temperature is mainly important in the cold season and can be easily controlled via heating and ventilation rate. The upper critical temperatures in the summer season are more problematic today and will become even more problematic in the future. To a certain extent, it is possible to control the indoor temperature via the exhaust airflow and ventilators. Managing and lowering the barn temperature is not always successful. This results in increased heat stress for the lactating sows (Black et al., 1993, Kemp and Verstegen, 1987, Lanferdini et al., 2018, Skuce et al., 2013).

When the temperature exceeds the upper critical temperature, pigs and, more specifically, lactating sows react with further mechanisms besides the main one of increased respiratory rate to reduce body heat in a hot environment. For example, the blood flow to the skin is enhanced, which leads to an increased surface temperature and thus to heat loss through heat conduction. Another element of adaptation is to reduce the locomotion activity. This element of adaptation is already limited in lactating sows in crates. Many movement activities are not possible in crates anyway (Malmkvist et al., 2012, Lucy and Safranski, 2017). The mechanisms listed do not occur randomly. With steadily increasing heat, swine react with a certain sequence of actions. First, the rate of latent heat reduction is increased by panting. Then the own heat production is reduced by avoiding movement. If cooling is insufficient, the rectal temperature increases. If all these measures are insufficient, the body temperature increases further. In addition, the heat caused by the muscle work to cool the body leads to heat increases itself (Brown-Brandl et al., 2001).

The thermoregulatory processes of any sow under heat stress or cold stress are energy-consuming (Kemp and Verstegen, 1987, Kim et al., 2020). If the ambient temperature falls below thermoneutrality, additional energy from metabolic processes must be used to keep homeothermy (Collin et al., 2001). In a hot environment, sows reduce their feed intake, sometimes considerably, to lower their body temperature. This is a key mechanism to regulate the temperature (Kim et al., 2020, Silva et al., 2006). When the temperature in a barn rises from 18 °C to 28 °C, the decrease in feed intake can be up to 43 % (Eissen et al., 2000). The reason for this is that the ingested food is broken down in the sow's body. The metabolic processes that take place in the process lead to the generation of heat. This heat increases the total body temperature (Black et al., 1993, Blaxter, 1989).

In accordance with the thermoneutral ranges, the ambient temperature of 25 °C seems to be a boundary above which a negative influence of the temperature on the feed intake appears. This means that the sows increase or reduce feed intake in favour of maintaining homeothermy. Conversely, sows prefer to feed at temperatures below 25 °C and also consume more feed if they can themselves determine the time of feed intake, depending on the ambient temperature (Malmkvist et al., 2012, Mayorga et al., 2019, Quiniou et al., 2000a). The decrease in the total amount of feed consumed per day and over the whole lactation period seems to be a result of a lower amount of feed per meal. Nevertheless, the number of meals seems to remain the same even in hot temperatures. The difference in feed quantities consumed between temperatures above the thermoneutral zone and those in the zone can amount to more than two kilograms per day (Gourdine et al., 2006, Renaudeau et al., 2003). However, the number of meals also seems to be variable, Renaudeau et al. (2002) already showed a significant influence of temperature on the number of meals one year earlier. Sows were feeding 9.4 times per day at 20 °C and only 6.5 times per day at 29 °C. Quiniou et al. (2000b) stated that when ambient temperatures are high, sows not only reduce the amount of feed they consume, but also the time they spend feeding. In a 24-hour rhythm and at a temperature of 29 °C, sows spent 29 minutes feeding. At a temperature of 18 °C, the time was more than twice as high at 61 minutes per day. The negative effect of different levels of heat in the barn can be seen in **Figure 4**. As the heat increases, feed intake decreases and so do the growth rates. Growth depression was measured using a control group that was also fed ad libitum but at temperatures in the thermoneutral range (Mayorga et al., 2019). The effects of heat were categorised from mild to severe. These categories were linked to the increases in body temperature.

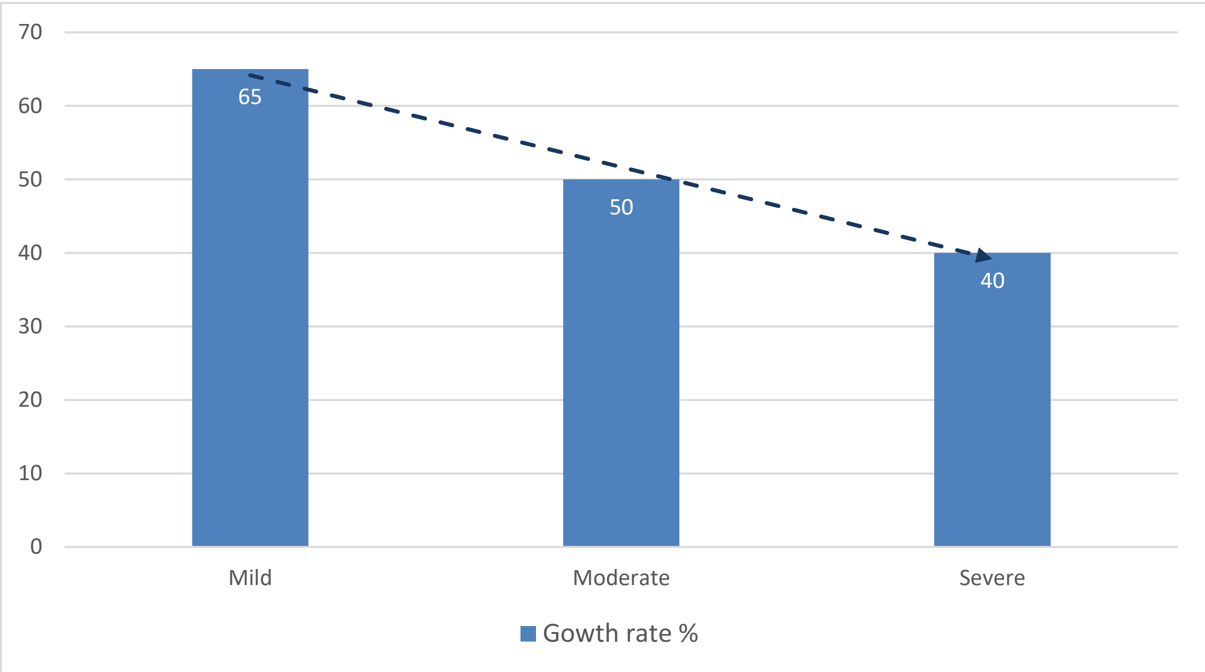

Figure 4: Effect of heat stress on growth rate compared to ad libitum feeding in a thermally neutral environment

Adapted from Mayorga et al. (2019)

Cooling of the ambient temperature results in the opposite effect (Black et al., 1993). For example, Malmkvist et al. (2012) showed that the amount of feed consumed was higher at lower room temperatures. At 15 °C ambient temperature, the amount of feed intake per day was up to 0.4 kg higher than at 25 °C in the first seven days of lactation. During the first fourteen days feed intake was highest at 15 °C and thus higher than at 20 °C or 25 °C. Only in the last seven days of the lactation period did the trend reverse.

This is supported by the fact that feeding times at night, and thus during cooler periods, have a positive effect on feed intake and can lower body mass loss. Lower temperatures at night can still be too high, however. This is especially relevant in tropical regions, where high temperatures at night combined with high humidity result in constant heat stress for sows (Choi et al., 2019, Renaudeau et al., 2003). Black et al. (1993) reports that a reduced feed intake due to the higher temperature can be reflected by a 10 to 30 % lower milk yield. In line with this, Silva et al. (2009) showed that floor cooling can lead to a 23 % increase in milk production in lactating sows. This is attributed to increased feed intake and normal blood flow to the mammary gland due to less heat stress. In addition, a significant proportion of the energy for milk production in a hot environment is taken from the body fat tissue. This leads to fat loss in the animal (Kemp and Verstegen, 1987). Sows exposed to heat stress during pregnancy tend to farrow earlier (Lucy and Safranski, 2017). A temperature that exceeds the thermoneutral zone occurs mainly in summer. The season and therefore the temperature can not only affect the farrowing date but also negatively influence the weight of the piglets at weaning (Gourdine et al., 2006, Yoder et al., 2012). The difference in weight gain at the end of a lactation period can be up to 8 % when comparing piglets raised in a hot environment with those raised in a thermoneutral zone (Lanferdini et al., 2018).

The room temperature also influences the water intake and thus the relation of the water-feed intake. At temperatures above 25 °C, the ratio of water to feed intake can double, with up to 8.1 litres being consumed per kg of feed (Kruse et al., 2011, Quiniou et al., 2000b). For lactating sows, unrestricted access to freshwater is essential. This has a positive effect on milk production at high temperatures. Further, chilled water in a hot environment even has various positive effects on the performance of sows and piglets. For example, feed and water intake can be increased, milk yield can be improved, respiratory rate and rectal temperature can be lowered. This can result in increased weaning weights of piglets (Jeon et al., 2006, Jeroch et al., 2008).

Sows can adapt to higher temperatures to a certain degree over extended periods. Yet it is difficult for them to realise their full performance potential. They show this adaptability both in outdoor systems and in closed indoor systems (Horsted et al., 2012, Malmkvist et al., 2012). One possible approach to improve the adaptability to high temperatures is breeding. There are already breeding lines that are less sensitive to hot temperatures. However, in no breed the feeding behaviour is unaffected by high temperatures (Bergsma and Hermesch, 2012, Gourdine et al., 2006). According to

Skuce et al. (2013), one way to counteract the effect of the heat is to use slower growing animals. However, this mainly applies to fattening pigs. This approach is particularly helpful for fattening pigs and not so much for sows. This leads to less heat accumulation in barns by the animals. In addition, as already described, more heat-tolerant breeds would be an option for the future. A sustainable breeding strategy with a focus on future heat stress can lead to more stable pork production in hot periods in the long term. In particular, the growing pig markets in regions with tropical conditions can benefit from changed selection criteria. Thermal stress is already one of the main stressors for pig performance in these regions (Mayorga et al., 2019, Silva et al., 2009). Nevertheless, selection currently does not place undue emphasis on traits that lead to more robustness and flexibility in the context of environmental influences such as heat. The current selection for primary (productive) traits leads to an increased metabolic heat production in the animals and eventually also to an increased temperature in the barn. The trend is therefore more towards genetic pig lines that are even more susceptible to stress caused by high temperatures (Brown-Brandl et al., 2001, Misztal, 2017). One way to avoid high temperatures is to feed at night, as already mentioned, in other words, the time of day can be incorporated into feeding management. The effects of heat on animals will become even more severe in the future due to climate change. The effects will be increasingly negative, affecting animal health and performance (Liu et al., 2005).

2.3.2 Time of day

The temperature in pig pens strongly depends on the time of day. The fluctuations in temperature over the course of the day are related to the rising and setting of the sun. Besides the temperature, the light conditions in the stables also change during the day. Both factors complementarily influence pigs. Many other known factors influence the rhythm of animals too. In general, animals seem to follow approximately a 24-hour rhythm (Villagrá et al., 2007). This statement is also consistent with the previously described behaviours of wild boar and the triggers of certain behaviours such as foraging. The time of feed consumption in animals is caused by metabolic signals, like satiety, while at the same time being influenced by the endogenous circadian clock. The endogenous circadian clock is influenced by external environmental variables, the most important of which is the light and dark cycle (Maselyne et al., 2015, van Erp et al., 2020).

In many countries, the possibility of influence through light is ensured by legislation. In England, for example, a minimum duration and minimum brightness of lighting are prescribed. In Austria, the light as a factor in pig husbandry is laid down in a regulation on animal husbandry. In Annex 5, Minimum Requirements for the Keeping of Pigs, it states under the item light that if the animals do not have permanent access to the outdoors, the stables must have windows or other open or transparent surfaces through which daylight can enter. The surface must reach the extent of at least 3 % of the floor area of the barn. In the animal area of the barn, a light intensity of at least 40 lux must be achieved for at least eight hours per day (Bundesministerium für Gesundheit und Frauen, 2004, Taylor et al., 2006). Therefore, light and changes of it are environmental factors that are usually always present in the environment of pigs.

Villagrá et al. (2007) studied the behaviour of growing pigs in barns concerning diurnal rhythm. Their work revealed that the pigs showed behaviour similar to the natural behaviour. This was specifically expressed by two increases in feeding activities during the daily light phase. Two farms that offered the feed ad libitum were investigated. On both farms, the first peak appeared at around 9am and the second at 7pm. The only difference between the two farms was the level of the feeding peaks at these times. This means that the basic times at which the pigs fed did not differ. Only one of the two certain times was preferred for feeding. According to Villagrá et al. (2007), this depended among other things on the temperatures in the barn. The fact that the two peaks were in the light phase of the day does not seem to have been a coincidence. Taylor et al. (2006) found dominant inactivity in growing pigs, this accounted for 78.7% of the day. The rest of the time, the pigs used to be active mainly during the daily light periods. The time between 1am and 7am was rarely used for activities. At these times, localities with low illumination were also preferred. Therefore, a preference for relative darkness during inactivity was inferred for the animals (Taylor et al., 2006). During darkness, lactating sows show, as well as fattening pigs, a generally, a lower activity level and lower proportion of activities such as feeding, sitting and rooting (Passillé and Robert, 1989). Montogomery et al. (1978) similarly note a strong diurnal pattern in gilts. The largest proportion of feed intake took place during the light phases in the barn. Switching on the light in the morning was a strong trigger for feed intake during the study and also in other studies as well (Gourdine et al., 2006). However, the unambiguousness and significance of the results are diminished by the simultaneous presentation of fresh feed. Occasionally this and the simultaneous switching on of the lights and the start of work in the barn can motivate the pigs to start feeding (de Haer, 1992, Feddes et al., 1989, Renaudeau et al., 2002, Xin and DeShazer, 1991).

Further results from Guillemet et al. (2006) also showed a strong diurnal rhythm in primiparous lactating sows. The study looked at the animal's feed intake without taking into account the effect of piglets. The morning and the afternoon were identified as preferred times for feed intake. These accounted for the majority of time spent feeding. This is consistent with the observations of Quiniou et al. (2000b) in multiparous lactating sows. In addition, a larger amount of feed was consumed as one meal during the day than at night. Preferring the daily light phase as feeding time, therefore, resulted in an accumulated feed intake of 78 % of the total amount of feed intake (Quiniou et al., 2000b). But, the results of total consumption during the light phase can vary depending on the study (Collin et al., 2001), (de Haer, 1992), (Renaudeau et al., 2002). This preference to consume feed during the light phase can also be observed in water intake (Bigelow and Houpt, 1988). Concurring with Guillemet et al. (2006) and Quiniou et al. (2000b), Renaudeau et al. (2003), Gourdine et al. (2006), Guillemet et al. (2006), Renaudeau et al. (2002), Passillé and Robert (1989), Choi et al. (2018) also reported that the morning and afternoon are preferred as the main time of the day for feed intake in lactating sows fed ad libitum. There are also results from de Haer (1992) for gilts and from Feddes et al. (1989) for fattening pigs with the same result. This conformity remains relative, as shown in **Figure 5**.The figure shows the respective peaks in feeding activity from the sources listed below the graph. It is clear that the data is more compact and the peaks are higher in the morning. The data for the afternoon are more spread out and extend late into the evening.

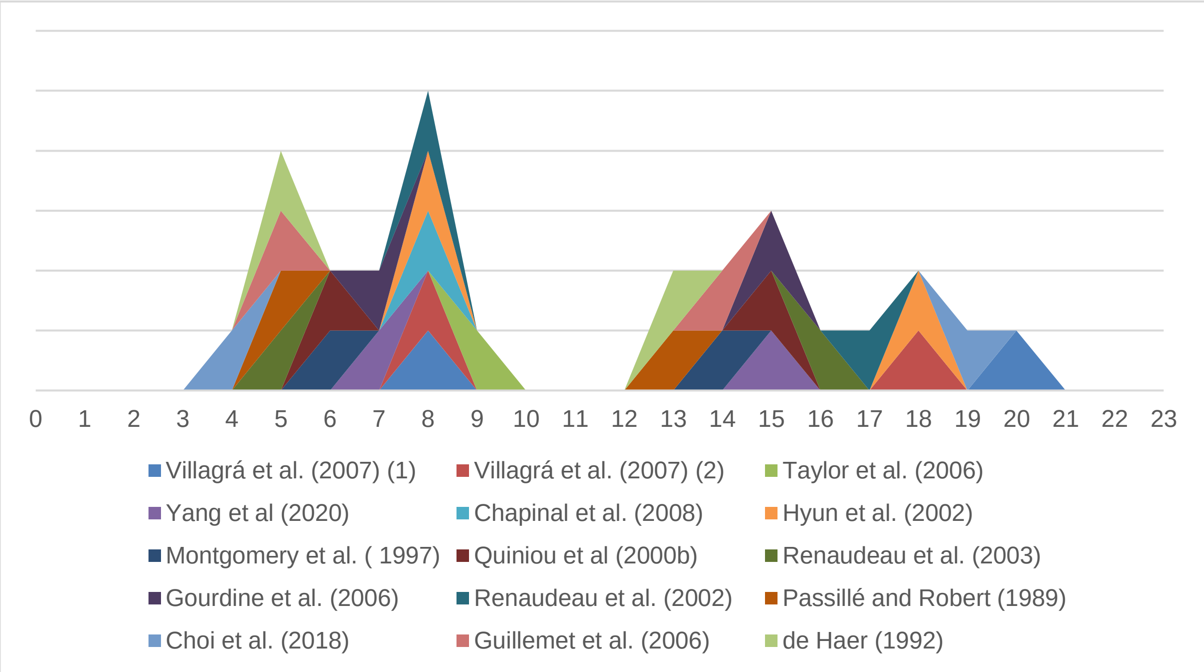

Figure 5: Times of daily maximum feeding activity

During the night phases, sows prefer postures that can be associated with inactivity. Sows show an increased recumbency posture at night and an increased standing and sitting behaviour during the day. The last two behaviours can be associated with active behaviour. Hence, not only in growing pigs but also in sows, the time of day affects the activity. As a result, lactating sows consume less feed during the night (Gourdine et al., 2006, Zheng et al., 2018).

Sows show increased activity during the two changes between light and dark, even when they are not fed at these times. However, behaviour was also found to be affected by other influences. Pigs are very synchroactive animals and can be strongly influenced by animals in the same compartment or barn. Sows that can feed themselves freely tend to link their feed intake to feeding times of other sows in the same compartment that are fed at fixed times (Jensen et al., 2000, Peng et al., 2007).

Pigs also adapt their feeding behaviour in the length of feeding, the amount eaten per meal and per minute, the single daily feed intakes at the trough to the external environmental conditions. The feeding system, the feeding practice and also the group size or whether the animal is kept individually are key factors (de Haer, 1992, Eissen et al., 2000, Hyun and Ellis, 2002). As described in the previous chapter, temperature can significantly influence the behaviour of pigs and therefore also lead to a shift in the time of feed intake. Feed intake during the night can increase to over 50 % at very high temperatures. In addition, the time between feeding in the morning and evening is stretched out by sows to avoid hot temperatures over the midday period (Choi et al., 2019, Quiniou et al., 2000b, Renaudeau et al., 2003).

Van Erp et al. (2020) looked at the relationship between the time of day and the rhythms of the animals. They stated that feeding concepts that are asynchronous with the circadian clock can lead to higher fat accumulation. However, pigs that were fed at night showed nevertheless increased activity in the morning when the light was switched on. In addition, there was a second peak of activity at 4pm, which could not be explained by management effects. The time of day seems to be still a major trigger for activity even when feeding times do not correspond to the circadian clock (Chapinal et al., 2008). Further, a deterioration in energy absorption was observed in pigs fed at night. This was associated with increased methane production (van Erp et al., 2020). The fact that the animals can feed at the times they prefer is thus not only an aspect of animal welfare, but also one of feeding efficiency, climate impact, feed and water wastage. Furthermore to understand the behaviour of swine can provide important pieces of information about the health status of the animal. But to notice abnormal behaviour it is necessary to know the normal behaviour patterns (Peng et al., 2007, 2007, van Erp et al., 2020, Yang et al., 2020).

Free feed intake can prevent the development of a strong feeling of hunger in pigs at any time (Maselyne et al., 2015). Sows in group housing and with a limited amount of feed per 24 hours show a strong increase in feed intake as soon as the same is available again. Hunger and satiety are known to influence feed intake. However, as already described, feeding is also subject to other influences. Some influences on the rhythm and timing of feed intake may be innate or learned. Also, the breed and the body size of a pig affect the feeding behaviour (Bigelow and Houpt, 1988, Quiniou et al., 1999, Renaudeau et al., 2002). In contrast to innate drivers, external effects offer the possibility of exerting an influence. The light period can be easily controlled in the barn and lead to changed behaviour patterns in lactating sows (Simitzis et al., 2013). As one effect Mabry et al. (1982) described significantly higher milk yields in sows and a higher survival rate of piglets due to extended photoperiods and assumed that one reason for this was the effect of light on the hormone balance of the animals. It can be seen that the time of day has an important influence on animal behaviour. At the same time, light that is closely related to the time of day can also be controlled by humans and thus manipulated for the animals.

2.3.3 Day of lactation

As lactation progresses, the metabolic stress of the sows becomes greater, as already described. Lactating sows adapt their feeding behaviour to this. A low feed intake directly after farrowing increases to a maximum in the second to the third week of lactation and then remains at this level (Bergsma and Hermesch, 2012, Eissen et al., 2000). The steepest increase in feed intake is observed during the first week after farrowing (Dourmad, 1991). When planning the feed ration, the high losses in body weight of the sows must be taken into account in the form of high energy contents in the feed. However, in textbooks, a fixed energy quantity is often given which is increased for each piglet that the sow has to feed. This does not result in a feed curve adapted to the sow's needs depending on the lactation day (Jeroch et al., 2008, van Erp et al., 2020; Noblet et al., 1990). A feed curve could offer the possibility to adjust the feeding flexibly to the differences between animals and between breeds. Feed variables such as duration and frequency also differ between genetically different strains (Rauw et al., 2006, Yoder et al., 2012). In practice, the feed is sometimes offered in a limited quantity during the first days and fed ad libitum from a certain day onwards. The exact day of transition from limited to unlimited feed often depends on the individual farm.

Poor feeding management in the first days of lactation can lead to adverse development later on. Whereas a well-designed feeding strategy can enable optimal performance (Lei et al., 2018). Often no distinction is made between sows with different numbers of farrowings, although gilts and older sows have different needs. The parity class has already proven to be a factor that influences the water and feed intake just as much as the temperature. Furthermore, feed intake on the same day of lactation may differ between sows of different parity classes and is influenced by the parity itself. A significantly higher feed intake could be observed in sows with the second litter compared to sows with the first litter. This could be influenced by the incomplete development of gilts, but differences can also be seen between sows that have already had two or three litters (Kruse et al., 2011, Yoder et al., 2012). Further, the number of meals per day can vary between different lactation days. Not only feeding but also other behavioural patterns are changed by prolonged lactation. For example, sows were found to lie on their udders more frequently in the later part of the lactation period. In addition, piglets and sows influence each other. The behaviour of piglets also adapts with development. Older piglets move further away from the sow with increasing age and opportunity (Renaudeau et al., 2003, Passillé and Robert, 1989). Considering lactation based on single days and not only based on weeks, may offers the potential to improve both animal welfare and performance. This takes into account the changing needs of the sows through lactation. Possibly it would also be feasible to recognise deviations from normal behaviour at an early stage and react to them.

3. Animals, Materials and Methods

This Master's thesis refers to data collected in 2019 from July to November including the seasons from summer to early winter. Data were collected at the University of Pennsylvania, Swine Teaching and Research Centre of the School of Veterinary Medicine, which is part of the New Bolton Centre campus. The barn is located in south eastern Pennsylvania near the New Jersey border and thus in relative proximity to the Atlantic Ocean. Data from 37 sows were included in this study. Four identically constructed farrowing rooms were used for data collection, each containing ten farrowing pens. Data were collected using a feeding computer system connected to a sensor at each farrowing pen. Video recordings of 15 sows were analysed, with each sow recorded for four days, three at the beginning of data collection and one at the end.

Housing and management

The rectangular 4.2 m² farrowing pens measured 2.0 m x 2.1 m, with the feeding trough facing away from the aisle and farrowing crates situated across the pen. From the evening before the calculated farrowing date until the fourth day of lactation, the hinged farrowing crates remained closed. The pens contained 0.8 x 0.6 m heating pads for piglets, which were operated with water to a target temperature of 32 °C (MIK International GmbH & Co.KG). A two-week farrowing rhythm was operated in the facility and weaning took place at day 28 after farrowing. Data were collected from the sows of six batches. The piglets were offered supplementary creep feed in addition to the sow's milk from the second week onwards.

Animals

All animals were crosses of Landrace x Yorkshire. The parity of the sows ranged from one to six, with an average of 1.86. Therefore, gilts formed group 1 (n=13), group 2 (n=13) consisted of three sows with parity one and ten sows with parity two. The oldest group 3 (n=11) included five sows with parity three, two sows with parity four, one sow with parity five and three sows with parity six. The heaviest sow weighed 340 kg and the lightest sow weighed 171 kg. The number of weaned and thus reared piglets varied largely across sows, with the lowest number of three piglets and the highest number of 15 piglets. An average of 11.05 weaned piglets per sow/litter was recorded.

37 of original 40 sows were included in this study based on the inclusion criteria of a minimum of four kg feed intake per day as a threshold, due to which one sows was excluded from further analyses. All sows were fed with the same ad libitum feeding system. In addition, two other sows were excluded that had manipulated the feeding system. This could be determined from the video records.

In addition to the feeding management described below and its technical implementation, the room temperature was also recorded in each room. The recording was continuous and the maximum and minimum values of each day were noted for each room (**Table 1**).

3.1 Feeding system

The feeding concept, "MamaDos" is an ad libitum system developed by the Austrian company SCHAUER Agrotronic GmbH (**Figure 6**).

Figure 6: MamaDos feeding system (1=hopper, 2=auger, 3=downpipe, 4=sensor, 5=trough), Source: (Schauer Agrotronic, 2021)

The stainless-steel trough includes a separate inlet for water and another one for feed, with the water constantly available for the sows. Additionally, to the feed supplied, a certain amount of water is always delivered. The actual automatic ad lib system includes a pipe system above the trough. The feed is stored in a hopper (1), where at the lower end an auger (2) pushes the feed out of the hopper towards the downpipe. Through the downpipe (3), the feed falls into the trough (5) and can be consumed by the sow. A sensor (4) is placed above the downpipe, which is connecting the animal and the feeding computer. This device is connected to a metal rod that extends through the downpipe into the trough and can be reached by the sow. Through pushing the rod, the sow can trigger the sensor, whereupon the feed is dispensed into the trough. The sensitivity of the sensor (i.e., the number of times, the sow needs to push it) can be freely selected. During data collection, the rod and thus the sensor had to be triggered five times to deliver a portion of feed.

The quantity per portion can also be defined as wanted, for this experiment, it was always 100 grams, which was verified before data collection. Every output of feed was registered by the computer and saved in a log. An additional feature was used for 18 sows, where so-called "attraction portions" are dispensed automatically at fixed times (8:05, 11:20, 15:40 and 20:00) to encourage the sow to start feeding. Apart from the attraction portions, all work and management practices were the same for all sows and batches.

3.2 Feeding regime

The compound feed used was the same for all sows. The proportion of crude protein was 16 % and of lysine 0.85 %. One kilogram of feed contained an energy content of 14 MJ/ME., 3.5 % of crude fat, 5 % of crude fibre. Furthermore, the feed contained 0.3 ppm selenium, 230 ppm zinc, 0.45 % phosphorus and 0.5 % to 1 % calcium as trace and bulk elements.

All data logs included for this analysis were collected when the feed was available ad libitum. However, feed was offered restrictively (2,7kg/day/sow) when the sows were housed in the farrowing crates before the data collection period started. During this time, the sows were able to get to know the new environment and make their first experiences with the trough and the technical setup of the feeding system. Adapted to the individual farrowing day of each sow, sows were fed ad libitum from the third day after farrowing. However, since the change took place in the morning on day three, only feed data are included from the fourth day of lactation onwards. The observed period is therefore lactation day four to 27.

3.3 Data collection

To ensure equal influence due to management procedures of all sows, starting from the day of farrowing, all interactions with the animals took place on the same chronological day. Piglets were weighed during the first 24 hours after birth and sows when entering the farrowing pen and at the day of weaning. A weighing scale in the corridor in front of the rooms was used for this purpose. During the first 24 hours, the litters were balanced by cross-fostering. Furthermore, crates were opened on the fourth day. Male piglets were castrated around day seven, when weighing and recording of lesions of piglets and sows also occurred. Cameras were installed on the 21st day after farrowing.

Behaviour

Video material from a total of 15 sows was available for evaluation. An IPX DDK-1700D Infrared IP Dome Camera from Farmingland in the USA was used, which was mounted on the ceiling, resulting in a camera height of approximately two metres. A central position above the sows was chosen. The characteristics (Infrared) of the camera allowed video recording during night without disturbing the animals. The camera angle made it possible to determine, whether a sow had her head in the trough or not. Video recordings were started on the second day after farrowing. Since only the ad libitum feeding is relevant for this study, videos were analysed from the beginning of this phase. The video recording continued until the fifth day after farrowing. Complementary video recordings were made between the 20th and 23rd day after farrowing for each of the15 sows, which lasted over 24 hours. For the analysis of the videos, the VLC media player version 3.0.14 of the company VideoLAN from France and the programme Excel (version 2111 Build 16.0.14701.20240 from Microsoft Corporation in the USA) were used.

Furthermore, this Excel version was also used to organise the animal data. The original raw data from the feeding computer was saved as a digital file and contained the automatically generated feeding protocols. These protocols were completed with the data of the individual animals, this data includes for example the animal ID, the room number, the number of weaned piglets, the lactation days and the weight of the animals. However, these data only included the amounts of feed distributed, feed that was removed from the trough was not available and is not included.

The coherence of the feed logs was also checked on the basis of the video material. There was a high degree of agreement between the ICus listed in the protocols and the actual behaviour of the sows. An example of a captured error was due to pushing and shaking the back rods of the open farrowing crate of a sow. This resulted in feed being dispensed into the through, but not consumed by the animal. This behaviour was only observed in one sow, which was consequently excluded. Two other reasons were piglets, which manipulated the sensor in the trough during the last days of lactation. This resulted in incorrect feed outputs. The third most frequent reason, which also occurred only rarely, was that the sensor was activated by staff. Overall, it was found that in 90 % of the ICus checked, the sows had deliberately activated the sensor and then consumed the feed delivered.

Moreover, animal data were complemented with parity, batch, room, number of weaned piglets, total amount of feed and the amount of feed dispensed per day, as well as the maximum and minimum temperature in the room in °C and the average room temperature in °C. The weight at the beginning of the lactation period in the crate and the weight at weaning were also included, as well as the difference. The number of days fed ad libitum was also noted. Two sows did not reach 24 days of ad libitum feeding. The litter of one sow was weaned after 19 days, another one after 22 days, which was taken into account in the data analysis by adjusting the formulae.

Feeding protocol

In the feeding protocols, each feed output was recorded as one interaction event with the sensor. However, one feed output reflects five consecutive interactions with the sensor. When the sensor is continuously activated, feed is continuously dispensed and the feeding computer combines these outputs with the added feed quantity as one event. After the sensor is activated for the first time, an automatic timer is set to one minute. If the sow activates the sensor again within this minute, the feed quantities filled into the trough are added up. The timer starts again at one minute when the feed is dispensed again. Therefore, one noted interaction with the sensor may be related to a feed supply of more than 100 grams. In other words: If a total of 200 grams were filled into the trough, these 200 grams were recognised as one entry in the log, although the sensor was activated twice. The number of the single actuations of the sensor was not available.

In order to avoid a false interpretation of the term interaction, each contiguous feed output, that was recorded by the computer as one event, was also only counted once in the further statistics. All interactions that result in a feed output are therefore called "Interaction Cluster (ICus)”. These ICus include single outputs of 100 grams but also larger linked outputs of feed. Thereby, six automatically generated feeding protocols were generated, one protocol per batch. Each protocol had the same structure and contained a continuous chronological entry for each ICus. This entry included the crate number, the amount of feed, the start of the feed delivery with date and time, the end of the feed delivery with date and time and the current milliampere of the system. For each sow included, one feeding log was created.

3.4 Statistical analyses

The previously mentioned version of Excel was used for data preparation and validation. SAS 9.4 software from North Carolina USA for Windows was used for further statistical analysis of the data. Two models were set up based on the given data structure. One model relates to the feed supply under the aspect of the individual lactation days. The second model includes the feed expenditure based on the time of day respectively the single hours. For both models, the level of significance was set at $p \leq 0.05$.

Both models were designed as linear mixed models using PROC MIXED from SAS. In the first model, the weight at housing (Inweight), the parity group (Parity), the number of weaned piglets (Piglets), the daily average temperature (MeanTemp), the lactation day (Day), the squared effect of the day (Day*Day), the alternating effect of day and parity (Day*Parity), as well as the squared effect of the day and the parity were included (Day*Day*Parity). In the model, the identification number (ID) of the sows and the parity group were included as fixed effects. The ID was also integrated into the model as a random effect. The dependent variable was the feed output. In addition, the residuals were tested for normal distribution.

Model for the lactation days:

$$y_{ijklmn} = \mu + \alpha_i + \beta_j + \gamma_k + \delta_l + \zeta_m + \zeta_m * \zeta_m + \zeta_m * \beta_j + \zeta_m * \zeta_m * \beta_j + \varepsilon_{ijklmn}$$

y_{ijklmn}	=	Dependent variable
μ	=	Intercept
α_i	=	Inweight
β_j	=	Parity
γ_k	=	Piglets
δ_l	=	MeanTemp
ζ_m	=	Day
$\zeta_m * \zeta_m$	=	Quadratic effect of Day
$\zeta_m * \beta_j$	=	Interaction effect Day*Parity
$\zeta_m * \zeta_m * \beta_j$	=	Interaction effect Day*Day*Parity
ε_{ijklmn}	=	Residual

The second model included the further parameter of the time of day. This effect was embedded in the model in the form of the time hour (Hour) as an additional variable. In this way, the individual ICus and feed outputs could be assigned to a specific time period of the day and the data structure could be analysed for this aspect. The parameters ID and Parity already mentioned above were also included. The fixed effects in the model were ID, Parity and Hour. ID was integrated as a random effect, as in the previous model. The dependent variable was again feed output.

Model for the time of day:

$$y_{njk} = \mu + \eta_n + \beta_j + \gamma_k + \varepsilon_{njkl}$$

y_{ijk}	=	Dependent variable
μ	=	Intercept
η_n	=	Hour
β_j	=	Parity
γ_k	=	Piglets
ε_{njkl}	=	Residual

The feeding protocols were analysed based on these two models, including the descriptive analysis of the data with Excel. For this purpose, a day was divided into a 24-hour format to analyse the feed supply per hour. In addition, the 24-hours of a day were divided into four equally long blocks of six hours each. The first block was from midnight to 6am. This division is supposed to visualise the distribution of the ICus.

4. Results

In this chapter the results of the dependence of feed output on the time of day are characterised. This is followed by an analysis to describe the influence of temperature on animal behaviour. Subsequently, in the last chapter, further results which relate to the influence of the lactation day are presented.

4.1 Time of day

The distribution of feed output over the 24 hours day can be seen in **Figure 7**. The higher the bar, the more feed was dispensed by the feeding system within one hour as mean value over all lactation days (n=881 days from n=37 sows). The x-axis starts at midnight, 0 o'clock, to 1am in the night with the highest value reached between 8am and 9am and another peak was at 3pm to 4pm.

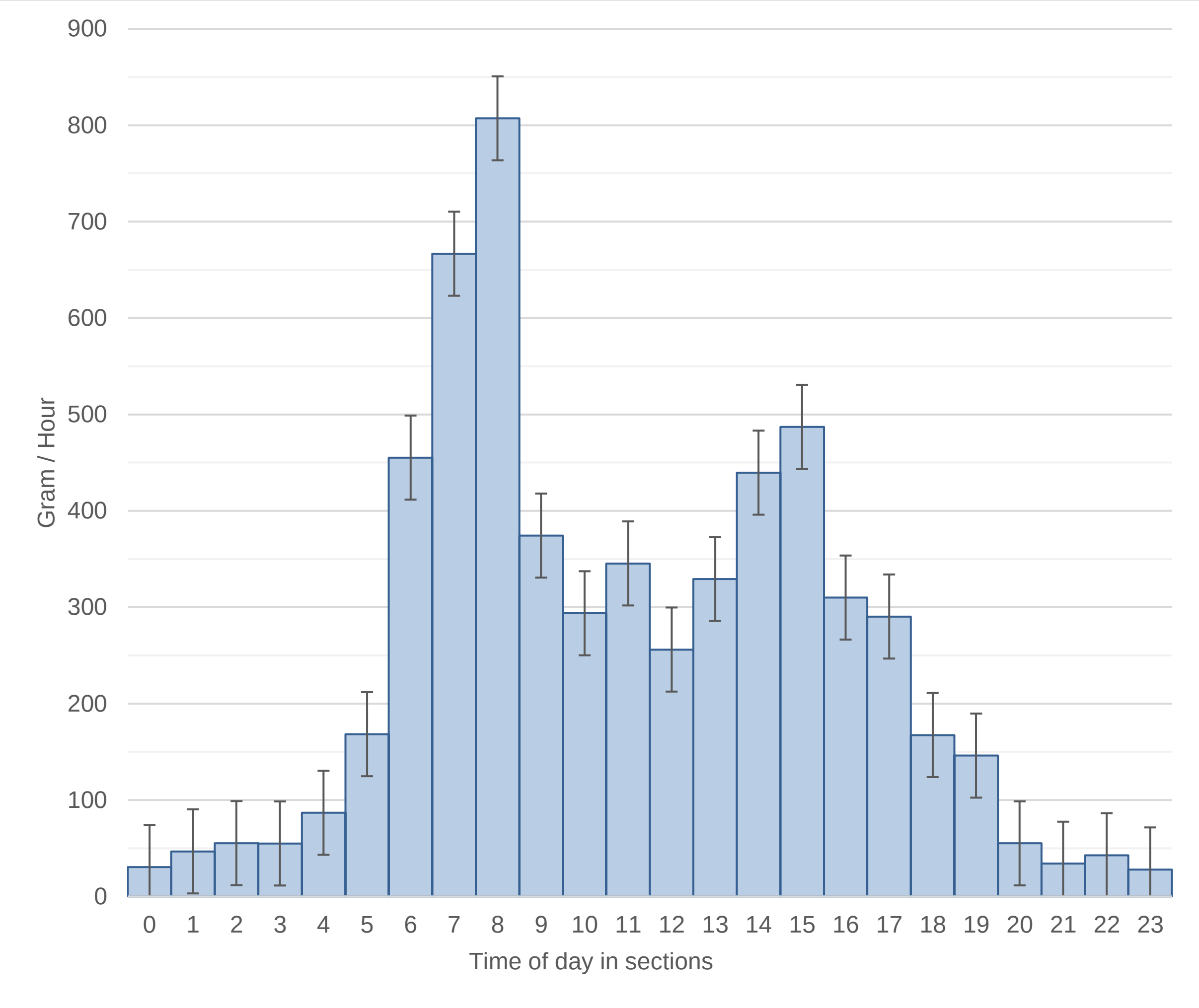

Figure 7: Average feed output in grams / hour during 24 hours of a day (n=37 sows, n=881 days)

The error bars in **Figure 7** show a wide overlap during several hours, especially during the night and the evening. Two peaks are visible, the highest in the morning at 8am after a steep rise, beginning at 6am. After the first peak, the feed output drops to a plateau between 9am to 1pm, followed by another, shallower rise at 3pm. After the second peak, the trend line flattens out and drops to a low level at 9pm. This low level remains relatively constant from until 4am.

If the feed quantities are summarised in the different day times night, morning, afternoon, and evening, the largest quantity is delivered in the morning. Between 6am to 11am, 49 % of the feed was retrieved on average. During the afternoon between 12pm and 5pm 35 % of the total feed quantity, the second-highest amount of food was retrieved. During each, the evening and the night, the lowest amount, 8 % of the feed was delivered.

A similar bar chart can be seen in **Figure 8,** which presents as x-axes also the time between 0 to 23 and therefore a 24-hour day. The y-axis is defined by the mean "Interaction Cluster ICus" (Interaction of sow with sensor resulting in feed output) occurring in the respective day time (n = 12,948 recorded ICus).

The most important additional information in this graph is the relation of the ICus to the retrieved kilograms of feed. At 8am, 2.21 ICus result in approx. 365 grams per ICus feed output. At 11am there is a high value of 1.17 ICus, but with a low feed output of 295 grams per ICus, derived from several individual sensor activations. In contrast to this, at 2pm 0.97 ICus resulted in 453 grams per ICus, which indicates, that the sensor was used by the sow for a longer consecutive period resulting in larger amounts of feed dispensed during one ICus.

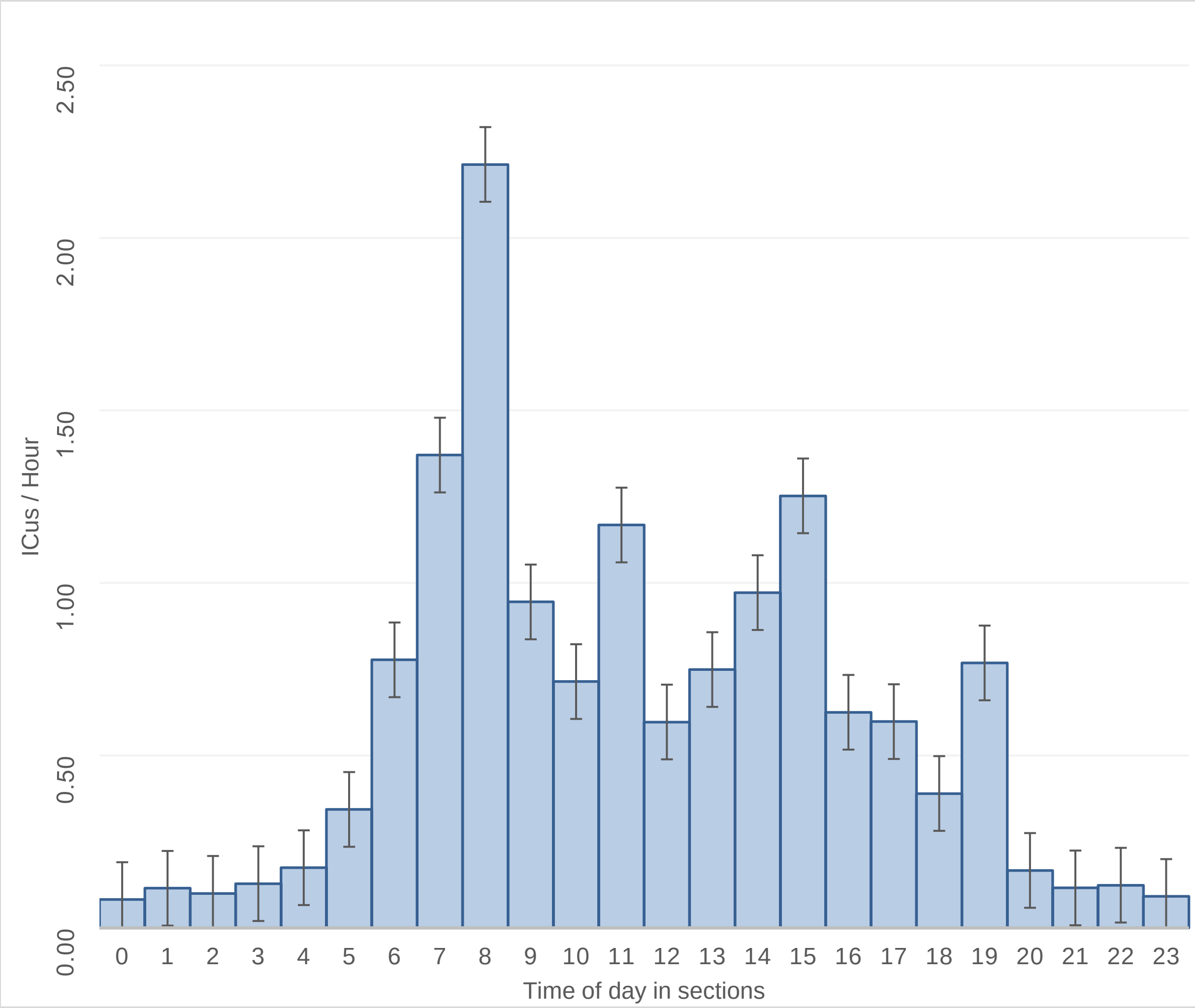

Figure 8: Average Interaction Cluster per individual hours of a day (n=37 sows, n=881 days)

If the frequency of the ICus / hour is compared with that of the grams / hour in the four phases of the day, only a small difference becomes apparent (**Figure 9**). At night the relative number of ICus is 7 %, in the morning feed supply and ICus are both 49 % and in the afternoon there is a difference of 2 %. The largest difference occurs at night with 3 %, where the ICus reach 11 % and the feed supply only 8 %. The single feed outputs are therefore longer and the quantity higher. The differences in the percentage distribution of absolute values can be seen in **Figure 9** below.

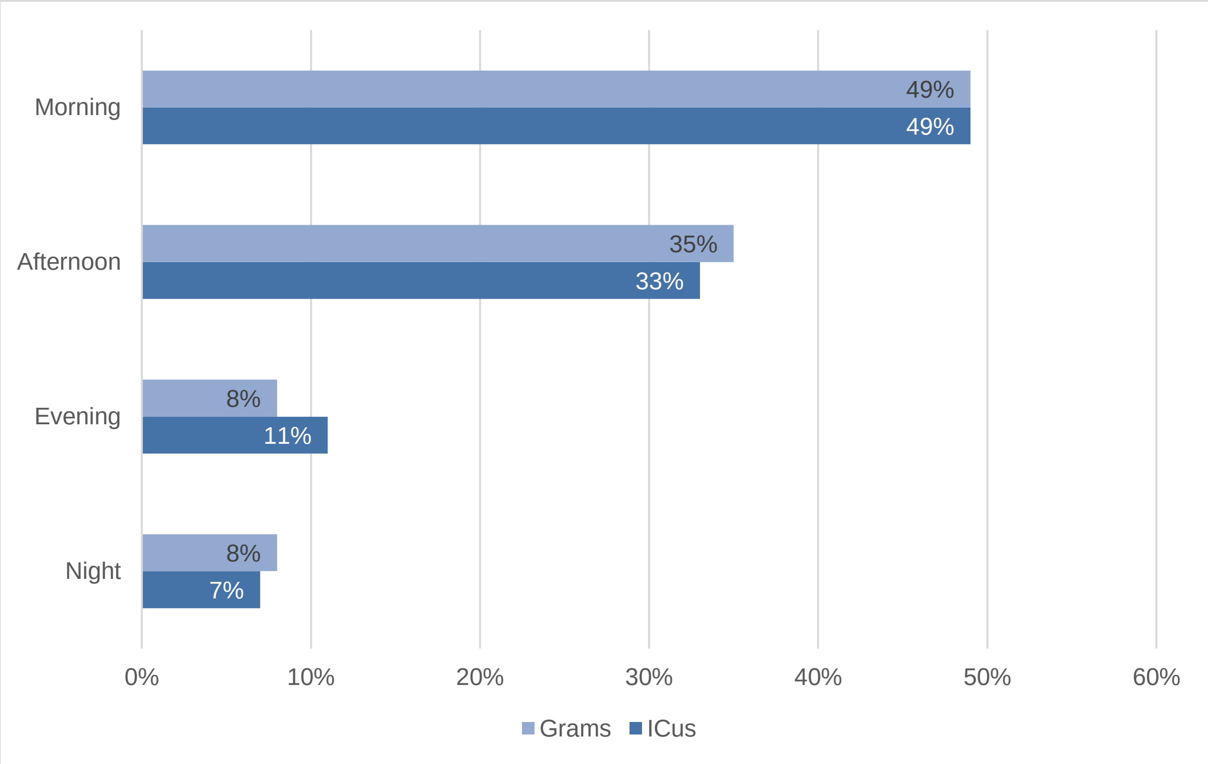

Figure 9: Average distribution of Interaction Cluster and feed amounts in g/hour (n=37 sows, n=887 days, n=12,948 ICus)

It is evident that the lactating sows prefer the morning and the afternoon to retrieve feed. Of all the ICus recorded, 82 % occur in the morning and afternoon. The proportion of feed output during these phases of the day is 84 %. In both cases, the morning alone accounts for 49 %.

The time of day did significantly influence on the amount of feed dispensed (p<.001) and with increasing number of weaned piglets more feed was delivered (p=0.006). However, the factor “Parity” did not significantly influence on the feed delivered per hour (p=0.438). The other two variables Hour and Piglets, however, had a significant influence on the feed output. The P-value for the factor piglet is p=0.006. Thus, the number of piglets had a significant influence on the feed amount requested by the sows.

4.2 Temperature

The average temperature during all days and farrowing rooms was 24.51°C (Fehler! Verweisquelle konnte nicht gefunden werden.**Table 1**). While the maximum values in July regularly exceeded 30 °C, the maximum values in November were not above 26 °C on any day of measurement, reflecting the seasonal temperature fluctuations to which the sows were exposed. The influence of temperature on the animals' behaviour and their interactions with the feeding system did significantly ($p<.001$) influence the amount of feed supply, with rising temperatures, lower feed delivery was found.

Table 1: Temperature range and average temperature of the four farrowing rooms

Room	1	2	3	4
Maximum Temperature (°C)	35.5	35.2	35.22	34.61
Minimum Temperature (°C)	18.88	14.6	18	14.55
Average Temperature (°C)	24.73	24.6	24.62	23.73

4.3 Day of lactation

The influence of the lactation day on the average feed output over the course of 24 days of lactation of all sows is presented in **Figure 10** (n=881 lactation days of 37 sows). The lowest daily feed delivery is on the first day of lactation with an average of 3898 grams distributed and the highest amount, 7225 grams delivered on the last lactation day. Therefore, the difference between the mean minimum and mean maximum is 3327 grams. Especially in the first six days, the increase in feed quantities recorded by the system is steep, from day 4 to day 9, additionally more than 2 kg per sow were retrieved. This makes the increase in the first few days more pronounced than in the rest of the lactation. Interestingly, particularly in the middle segment, the amount of feed fluctuates and at some days even decreases.

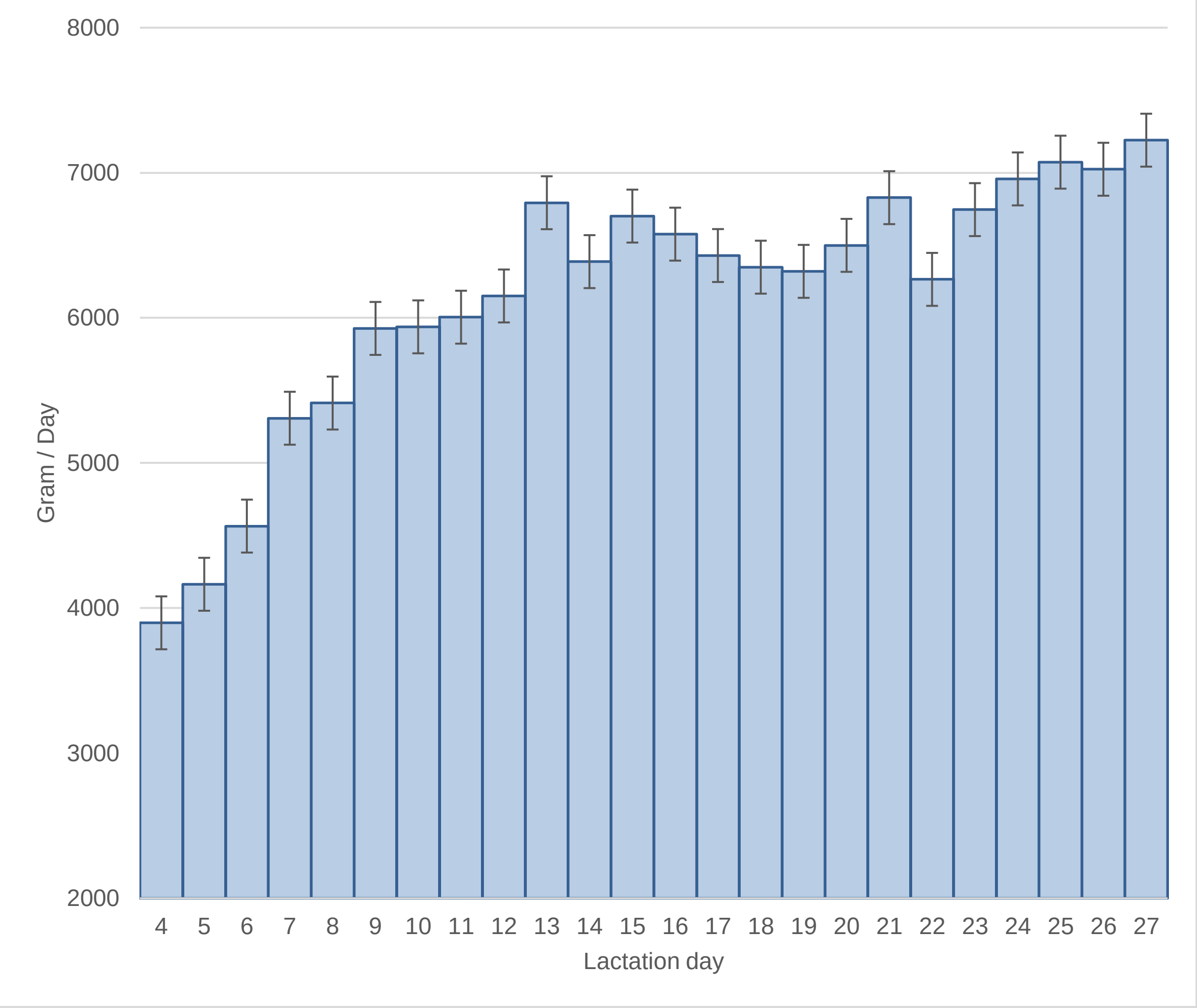

Figure 10: Average amount of feed supply during 24 ad libitum fed days of lactation (n=37 sows, n=881 days)

Four further graphs (**Figure 11-14**) present more details regarding the positive significant effect of lactation day on amount of feed supplied (p<0.001). The number of weaned piglets (p=0.037) also had a significant increasing effect on feed supply. The time of day (p<0.001) had a significant effect as well, showing the differences in feed supply depending on the time of day.

Parity of sows did not significantly influence the amount of feed delivered (p=0.094), however, in interaction with lactation day (p=0.006), a significance negative effect was found. The weight of the sows had no significant influence on the amount of feed supplied (p=0.414).

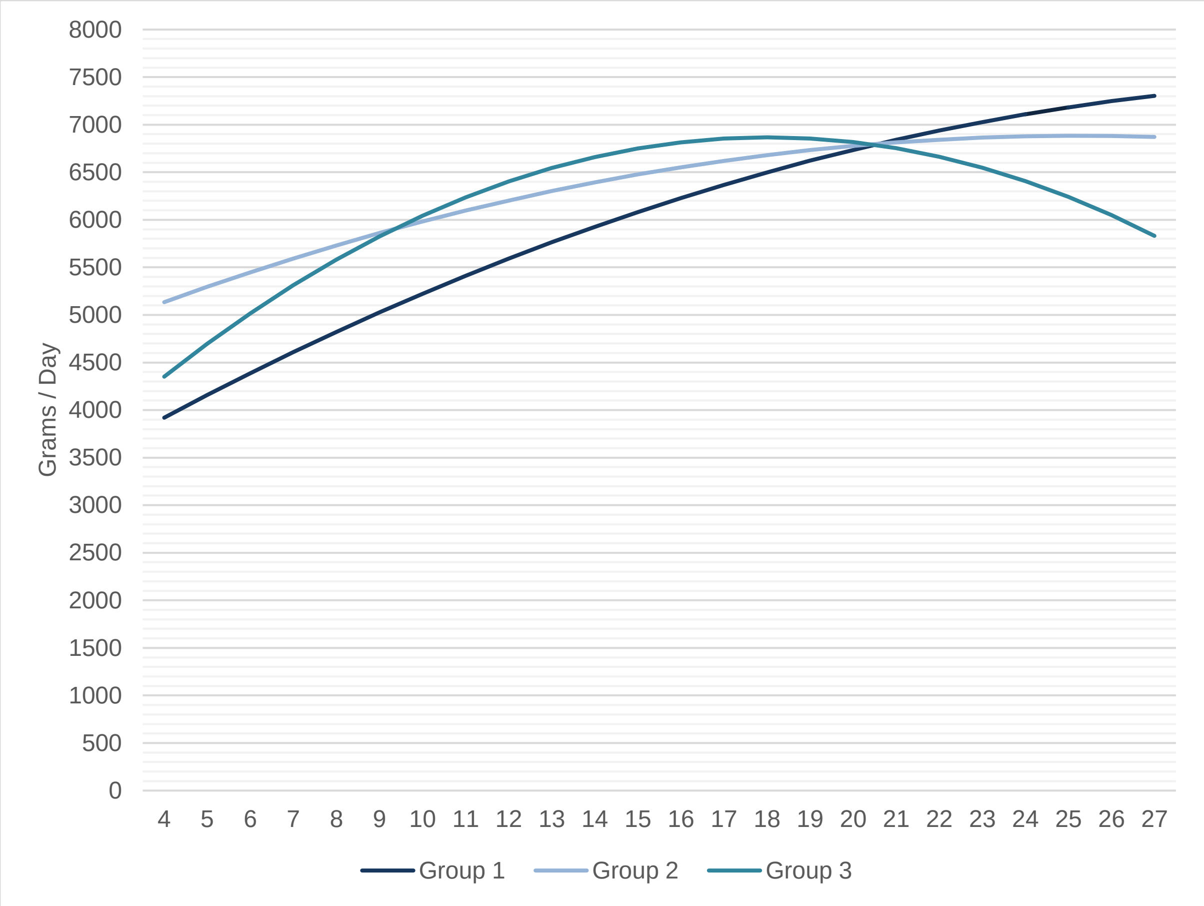

Figure 11: Feed delivered daily throughout lactation for sows of different lactation groups (n=37 sows, n=881 days)

The first graph in **Figure 11** shows the development of feed output over the course of lactation in relation to each other. If the three curves in **Figure 11** are compared, the differences between the groups can be seen.

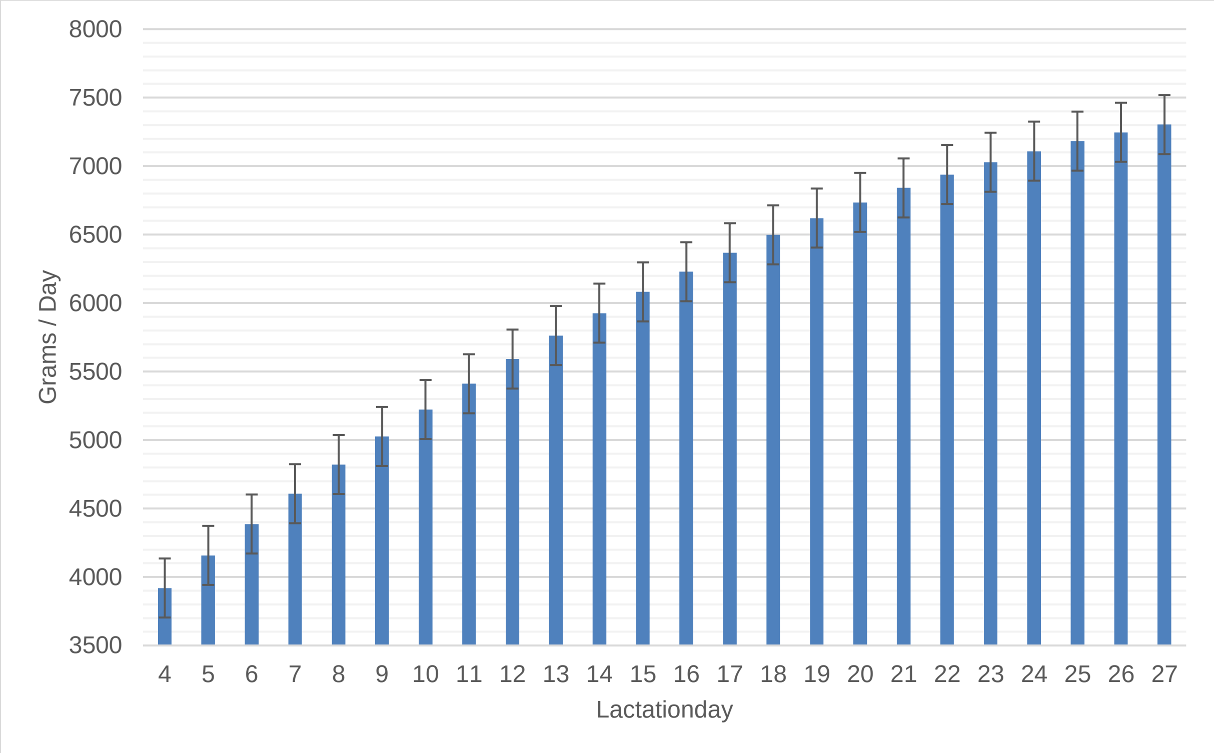

Figure 12: Feed output from day 4 to 27 of parity group 1 (n=13 sows. n=312 days)

The second graph in **Figure 12** refers to the sows in group 1, the gilts, where a negative effect with the feed amount was found. A low beginning level of feed output can be seen in group 1. On day 4 only 3920 grams were recorded. However, the amount of feed distributed increases sharply in the gilts. The gilts consumed 147 grams more feed per day on average. The increase is highest in the first five days with more than 200 grams per day.

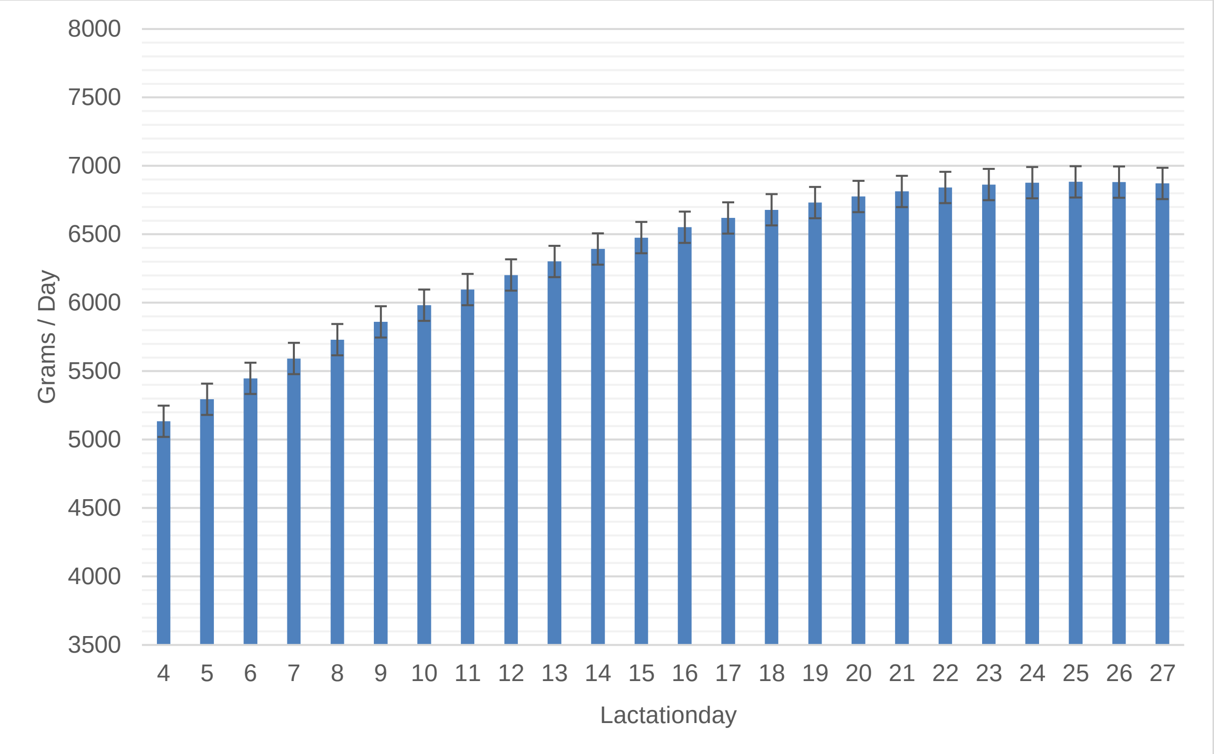

Figure 13: Feed output from day 4 to 27 of parity group 2 (n=13 sows, n=264 days)

A positive association of sows in group 2 with the amount of feed was found. The graph in **Figure 13** describes the course of the feed quantities of parity group 2. On the first day, the amount of feed is already 5134 grams, followed by an upward trend, which flattens continuously and drops little at the end. On average, the feed quantity increased by 76 grams per day.

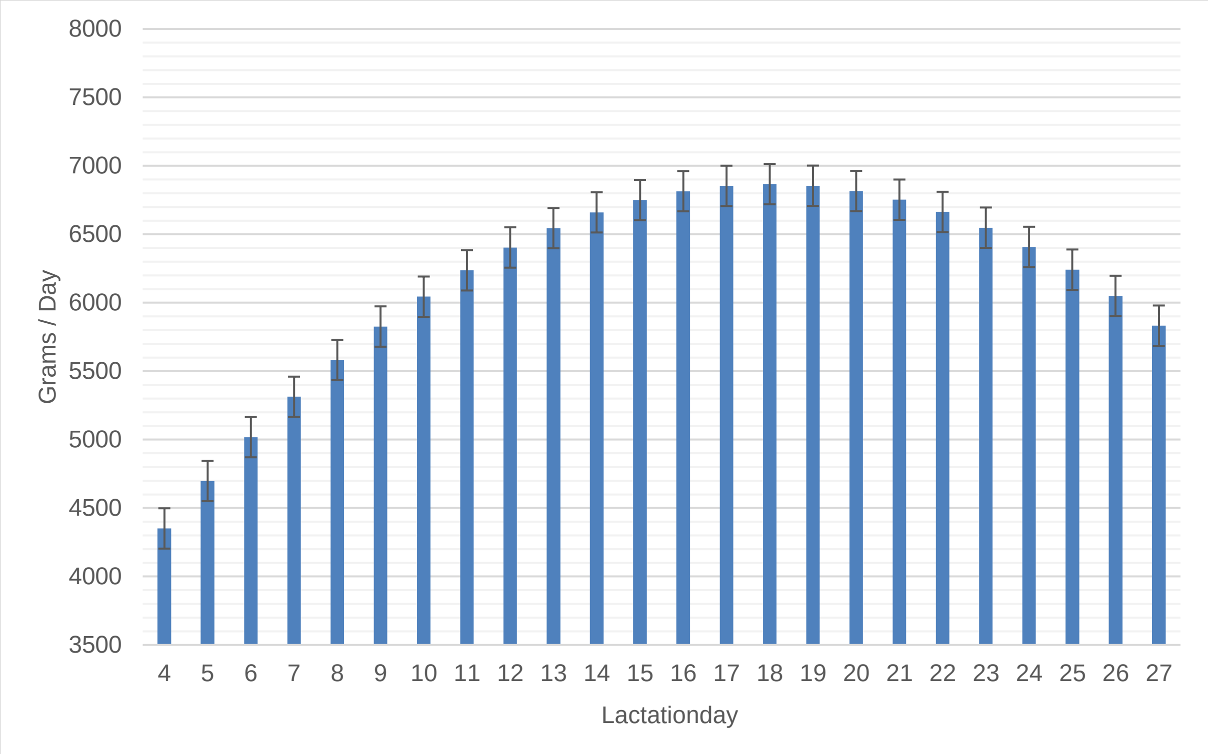

Figure 14: Feed output from day 4 to 27 of parity group 3 (n=11 sows, n=305 days)

The fourth graph in **Figure 14** is based on the sows in group 3, where neither positive nor negative effects were found. **Figure 14** describes the course for the lactating sows in group 3, with 4351 grams recorded on day 4. After that, the amount increases rapidly it peaks on day 18, followed by a drop. The average increase in feed quantity supply within the first 14 days quickly decreases again until the tipping point on day 18.

5. Discussion

The results of the thesis are discussed in the following chapter based on the research questions. First of all, the influence of the time of day on the feed output is discussed and classified in the context of the literature. This is followed by a consideration of the findings regarding the influence of temperature in the barns on the feed amount. Finally, the differences found between lactation days are discussed. It must be considered that the feed quantities mentioned here are presented without deductions due to losses. Nevertheless, the novel feeding system provides insightful data on the feeding behaviour of lactating sows.

5.1 Time of day

Time of day was an important and significant influencing factor on the feeding behaviour of lactating sows. The two-peaked curve of the feed output shows a clear preference of the animals which preferred the morning and the afternoon for feeding. **Figure 15**, based on **Figure 5** (see also chapter 2.3.2), gives an overview of existing literature in combination with our research findings, where especially the peak from 8am to 9am is obvious and even higher than reported in other studies (Villagrá et al., 2007). This is consistent with the literature finding that the morning is the preferred time for feed intake for pigs in general and also for lactating sows (Guillemet et al., 2006). However, the preferred time for feeding can also vary to some extent from farm to farm and is influenced by multiple external influencing factors like the location and the technologies installed (Maselyne et al., 2015, Villagrá et al., 2007)

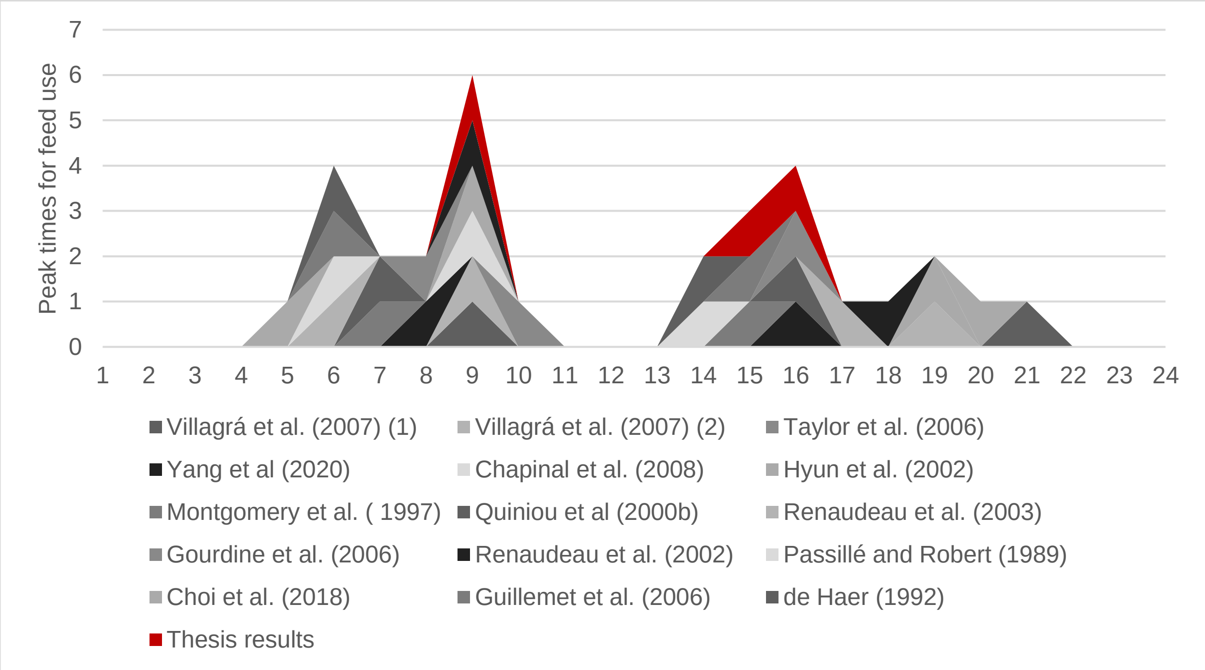

Figure 15: Peaks of feed supplied throughout an average lactation day (results from literature and own results)

This distribution of feeding times can be observed in **Figure 15,** especially from 4am to 11am and even more pronounced in the afternoon. The peak distribution in the morning is more compact and peaks at 9am. The results presented here are consistent with those of Hyun et al. (2002) and the other peaks at 9am. De Haer (1992) reported a peak at 2pm, whereas Villagrá et al. (2007) at 9pm, the latter attributed to the hot summer in Spain. Furthermore, this wide range may be due to different experimental set-ups, but also illustrates how variable the preferred feeding time can be and how adaptable lactating sows are in their behavioural patterns. Since this thesis covers the period from summer to early winter, the peaks in the morning and afternoon seem to be normal, most likely influenced by the animals' circadian clock, or due to the weakening daylight (Renaudeau et al., 2002). The change from light to darkness is known to be an important trigger (Taylor et al., 2006). This is a comparable triggering event in the barn environment as work by staff or the activities of the other animals. These events can trigger the animals to be active. The distribution of ICus shows a similar pattern like **Figure 15**. A peak in the morning and a peak in the afternoon with 2.21 ICus and 1.25 ICus are shown. The evening and night remain very low as well. However, the distribution of the ICus to the feeding amounts is not constant. Several separate sensor actuations take place in the evening hours. A high proportion of ICus in the evening with a low proportion of feed supply in the same period indicates frequent and temporally separated feed supply. Small feeding events were therefore observed more frequently. It results from the ICus and the feed amounts supplied that the fluctuations between activity and feed amounts are in the low percentage range.

The reasons for the feed intake in the morning are similarly influenced by many factors. A high peak in the morning can commonly be observed and reflects the animals' preferred feeding time as reported also in other studies (Gourdine et al., 2006, Quiniou et al., 2000b). However, the reason for the increase at this specific time of the day could be the beginning of lighting and the start of work by staff members in the barn (Renaudeau et al. 2002, Choi et al. 2018, Gourdine et al. 2006). This assumption was supported by the fact that from video-observations sows were seen responding to the activities in the barn in the morning, even when the significance of the videos is not fully indicative due to the relatively limited amount of data. Furthermore, sows might have been influenced by the presence of other feeding systems in the same building, as apart from the ab libitum system, feeding devices with fixed feeding times were also used (Gorr, 2020). Pigs, as highly synchronous animals can be influenced and animated to feed by the sounds of other pigs, even if this is less significant for sows in individual pens (de Haer, 1992). As especially wild boars show a very synchronous feeding behaviour, this can be seen as an important aspect of feeding also of domesticated pigs (Briedermann, 2009).

The low feeding activity at night is in line with Taylor et al. (2006) findings that pigs are mostly inactive at night. This supports the hypothesis, that light is an important influencing factor. The large proportion of 84 % of the total feed used during the morning and afternoon in this study partly exceeds the values of Quiniou et al. (2000b) with 78 % or those of Montogomery et al. (1978) with 70 %. However, it must be taken into account, that the light phases were not recorded in our study, so that the value may be lower. Nevertheless, this finding supports the observations described earlier that it is mainly the daytime hours and not the night hours that are used for feeding (Dourmad, 1993, Quiniou et al., 2000b). **Figure 7** shows that feed was released on average 24 hours a day. Constant eating corresponds to the statements of Rivero et al. (2019) and Briedermann (2009) who found foraging to be the most frequent active behaviour in pigs in a seminatural environment and in wild boars. The sows had constant access to unlimited feed in this study. Some sows did not activate the sensor at all during the night, but these were only a few individuals. The vast majority of the animals took the opportunity to obtain feed at any time of the day.

5.2 Temperature

When considering the thermoneutral zone of lactating sows at approximately 16 °C to 22 °C, the significant effect of temperature on feed supply seems logical (Lanferdini et al., 2018, Silva et al., 2006, Kemp and Verstegen, 1987, Lucy and Safranski, 2017). High temperatures occurred frequently in our study and regularly exceeded the 30 °C threshold. Within the large range of live weights, the effect of heat was less severe for some sows, but in general, peak temperatures were above the thermoneutral zone on several days. In contrast, the temperature range was never in a critical range with regard to low temperatures. The lower critical temperature was only occasionally and only slightly below the thermoneutral range. In contrast, the difference between the upper range of the thermoneutral zone and the highest temperature measured was 13.5°C. This difference makes the upper-temperature range more relevant for this thesis.

The significance of temperature concerning feed intake is well known and reported by Kemp and Verstegen (1987) and Renaudeau et al. (2002). This is supported by Eissen et al. (2000), who reported a decrease in feed intake of up to 43 % at high temperatures. In addition, the average temperature measured was 24.5 °C, which is only 0.49 degrees below the threshold at which negative effects on feed intake are generally expected (Malmkvist et al. 2012). A higher feed intake in the temperature range below 25 °C for lactating sows was also reported by Quiniou et al. (2000a). Consequently, the measured average temperature is not only above the thermoneutral zone but also just below a temperature range that leads to a high probability of a decrease in feed intake. The value also shows that the thermal pressure on the animals during data collection was evident.

The results presented here on the influence of temperature on feeding behaviour confirm Choi et al (2019), who identified feeding times and temperature as a controllable element of the feeding strategy. Feeding time could be adapted to the preferences of sows, e.g. in summer during the evening or early morning, when it is cooler. In this way, the metabolic heat stress is not combined with stress induced by the ambient temperature. This avoidance of heat stress can alleviate the negative influence of high temperatures. Temperatures also depend on the location together with a ventilation system in the building, the critical hours can vary from farm to farm (Villagrá et al., 2007).

The restructuring of sow groups and the associated relocation of sows to other pens is a frequent process on farms. This results in an environment for sows that changes at short intervals. How short the intervals are depends on the farm. This allows farmers to shift the feeding times for new groups in the farrowing pen to later hours from the warmer months onwards.

The shifting of feeding times that deviate too much from the internal rhythm of the pigs can be problematic. Van Erp et al. (2020) showed that feeding times that deviate too drastically from the circadian clock can also have negative effects on animal health. Ad libitum feeding gives the animal the freedom to choose when to feed, avoiding possible negative effects of feeding at an inappropriate time. Therefore, the feeding time must be chosen carefully. In addition, adaptation of feeding time or, better, ad libitum feeding is an instrument that is easy to use to improve the welfare of the sows.

Temperature, however, cannot be considered separately from other important environmental factors, such as air humidity, which is directly related to the room temperature. Furthermore, air humidity in combination with the temperature influences the air quality and therefore affects animal health (Seedorf et al., 1998). The effects of humidity on the feed intake of lactating sows can also be very critical. Research combining effects of temperature and humidity, could be promising to describe the influence of the temperature even more precisely (Bergsma and Hermesch, 2012).

In addition, the influence of temperature and the farmers’ response to it can contribute to the economic success or failure of farms (Mayorga et al., 2019). High temperatures impact directly on animal health, but also on performance in later gestation and on piglets and their later performance, as Yoder et al. (2012) reported.

Especially in the context of challenges such as climate change and other difficulties, a high level of resilience of farms must be fostered (Friker and Schüpbach, 2021, Mendelsohn, 2007). One way would be to use more heat-resistant breeds. The effect of selecting breeds with resistance to heat has been described as significant before (Gourdine et al., 2006).

5.3 Day of lactation

The individual lactation days are decisive for the feed intake of lactating sows. The low feed intake at the beginning of lactation described in the literature, which continues to increase as lactation progresses, is partly consistent with the results of this study (Eissen et al., 2000). This can be seen particularly well in **Figure 10**, where during the first six days the average feed output is lower than in the following two weeks. At this point, also a certain learning effect of the sows with regard to the feeding system can also be considered when interpreting the feed curve. The increase of feed output is very steep and within a few days, the amount multiplies. This supports the report of Dourmad (1991), who also recorded a strong increase during the first weeks, indicating a substantial influence of the day of lactation on the feed output. This also makes a significant difference regarding energy input, as a lactating sow consuming 4 kg feed is supplied with 52 MJ/ME, and with 7 kg feed on the last day of lactation with 91 MJ/ME. These results are in coherence with feed recommendations issued for lactating sows (Jeroch et al., 2008, Yoder et al., 2012). However, the dynamic effects such as appetite, growing piglets or metabolic changes that influence feed intake during lactation are often not considered within feeding strategies. The results of the present study show a relatively even level of feed delivered in the last two weeks of lactation. The feed output is still increasing but the increase is lower on a continuously high level, which is also reflected in the literature (Bergsma and Hermesch, 2012).

The influence of poor feed management or, more precisely, insufficient feeding could be prevented by an ad libitum system. It allows the sows to feed according to their own needs. This applies to the time of day as well as the lactation day (Lei et al., 2018). With an ad libitum system, the different requirements of sows with different numbers of piglets and number of litters can also be met. The differences between gilts and older sows are described by Kruse et al. (2011) Noblet et al. (1990). Yoder et al. (2012), who, reported sows with a higher parity to have an increased feed intake. This increased feed intake can be partly attributed to the average increase in live weight up to the 4th lactation. Along with the growth, the energetic demand for maintenance also increases (Jeroch et al., 2008).

These findings are consistent with or results, showing a clear difference between gilts and sows with three or more litters in terms of the feed supply curve. The shapes of the three curves show the significant influence of the parity in interaction with the lactation day. This difference is particularly evident in the drop in the feeding curve of the oldest sow group in the last part of lactation. Already in the first days, the difference regarding the average of total feed quantity delivered between all three sow age groups can be seen. It can be assumed, that the ad libitum system allowed the sows to consume feed according to their biological and nutritional needs. The ad libitum system also made it possible to adapt to the needs of gilts as well as older sows in terms of feeding behaviour. An increase in the amount of feed from the first to the second parity could also be observed in other studies (Kruse et al., 2011). The feeding curve of the sows from the middle age group show a beginning change over the second and third lactation. At the end of the lactation period, the feed quantities also drop in this group. Thus, the almost straight feeding line of the gilts changes from a moderate arc shaped curve in group 2 to a pronounced curve in group 3. The substantial changes in the sequence measured by feed quantity occur in the last third of lactation. The contrasted curves show clear differences. The differences between group 1 and group 3 are particularly pronounced. These three curves show how fluctuating the feeding behaviour of sows can be over the course of lactation and that fluctuations can be dependent on parity and the lactation day itself.

Fluctuations in feed intake, can also be caused by other parameters, as an example the weaker increase in feed intake on lactation day 9 might be explained by management measures, as on this day the male piglets were castrated. The unrest in the pen or the possible change in the behaviour of the piglets could have had an influence on this. However, the other noticeable decrease in feed quantity on day 14 cannot be explained by such procedures. In contrast, the third decrease on day 22 could be explained by a standard vaccination of the sows against ileitis, circovirus and parvovirus three weeks after farrowing. The results presented here that the day of lactation has an influence on the pattern of feed intake is consistent with the previously reviewed literature. However, it is important to note that this effect is particularly pronounced in interaction with the sows' parity.

6. Conclusion

To conclude, the time of day, the temperature and the lactation day had a significant influence on the amount of feed dispensed and a clear pattern of feed delivered was identified, reflecting sows' feeding behaviour. The curve of feed output shows a clear bimodal distribution, with two peaks in the morning around 8am and in the afternoon around 3pm, with the highest total feed output in the morning. The temperature also significantly influenced feed retrieval, with rising temperatures, less feed was delivered. Furthermore, also the lactation day could be confirmed as significant factor, depending The results presented here convincingly show that the lactation of sows is influenced by many factors. However, sows do not deviate from their internal daily rhythms without strong external influences such as extremely high temperatures. An ad libitum system offers the animals the possibility to consume fresh feed according to their own needs, in terms of quantity and time of day. This offers the animals a certain freedom that can be linked to improved animal welfare. For further insights into the behavioural patterns of sows, it would be of interest to conduct further research on the diurnal rhythm with a closer link to detailed temperatures and air humidity. Better understanding and interpreting the behaviour of lactating sows in order to meet their needs will benefit not only farmers but also the animals themselves.

Abstract

Adequate feeding of lactating sows is influenced by many factors and is a decisive factor for the further performance of the animals and their piglets. Understanding the feeding behaviour of sows can help to improve feeding strategies. The subject of this Master thesis was feeding behaviour of lactating sows (n = 37, Landrace x Yorkshire) and the influence of the temperature, lactation day and time of day on the amount of feed retrieved by the sows per hour. The data were collected via a novel ad libitum feeding system that automatically generates exact feeding protocols combined with daily recordings of room temperature and individual animal data. The data collection took place from July to November 2019 at a sow farm, where the crates were opened on the fourth day after farrowing. Both, descriptive and analytical evaluation of the data using SAS revealed a significant influence of temperature (<.0001), day of lactation (<.0001) and time of day (<0001). A bimodal distribution of feed output was observed, which was mainly concentrated in the morning around 8am and reached the second peak in the afternoon around 3pm. An fluctuating increase over the lactation in used feed quantities over the course of the 24 observed lactation days could be determined. However, there was a clear difference between gilts and sows from parity three or more. The transition in feeding behaviour was well illustrated by sows from parity one and two. Gilts started with the lowest feed amount but ended with the highest feed supply at the end of lactation. The temperature was confirmed as an important factor influencing animal behaviour and feed output. Rising temperatures had a negative impact on the feed output. Therefore, the time of day and the associated temperatures can be considered as important factors to be considered, when adapting feeding strategies for lactating sows.

Zusammenfassung

Die adäquate Fütterung laktierender Sauen wird von vielen Faktoren beeinflusst und ist ein entscheidender Faktor für die Leistung der Tiere und der Ferkel. Das Verständnis des Fressverhaltens von Sauen kann helfen, Fütterungsstrategien zu verbessern. Gegenstand dieser Masterarbeit war das Fressverhalten laktierender Sauen (n = 37, Landrasse x Edelschwein) und der Einfluss der Temperatur, des Laktationstages und der Tageszeit auf die stündlich abgerufenen Futtermengen. Die Daten wurden über ein neuartiges ad libitum Fütterungssystem erhoben, das automatisch exakte Fütterungsprotokolle erstellt, diese wurden mit täglichen Aufzeichnungen der Temperatur und individuellen Tierdaten kombiniert. Die Datenerhebung fand von Juli bis November 2019 in einem Sauenbetrieb statt. Die Kastenstände wurden am vierten Tag nach dem Abferkeln geöffnet. Deskriptive und analytische Auswertung der Daten mit SAS ergab einen signifikanten Einfluss von Temperatur (<.0001), Laktationstag (<.0001) und Tageszeit (<0001). Es wurde eine bimodale Verteilung der Futteraufnahme beobachtet, diese konzentrierte sich auf zwei Spitzen, den Morgen gegen 8 Uhr und den Nachmittag gegen 15 Uhr. Es konnte ein unstetiger Anstieg der verbrauchten Futtermengen über 24 beobachtete Laktationstage festgestellt werden. Es gab jedoch einen deutlichen Unterschied zwischen Jungsauen und Sauen ab der dritten Parität. Der Übergang im Fressverhalten war bei Sauen der ersten und zweiten Parität gut zu erkennen. Jungsauen begannen mit der geringsten Futtermenge, hatten aber am Ende der Laktation den höchsten Futterabruf. Es wurde bestätigt, dass die Temperatur ein wichtiger Faktor ist, der das Verhalten der Tiere und die Futtermenge beeinflusst. Steigende Temperaturen hatten eine negative Auswirkung auf die Futtermenge. Daher können die Tageszeit und die damit verbundenen Temperaturen als wichtige Faktoren angesehen werden, die bei der Anpassung der Fütterungsstrategien für laktierende Sauen zu berücksichtigen sind.

References

Alexopoulos, J. G., Lines, D. S., Hallett, S. and Plush, K. J. ‘A Review of Success Factors for Piglet Fostering in Lactation’ *Animals an open access journal from MDPI*, Vol. 8 (2018). https://doi.org/10.3390/ani8030038.

Alonso-Spilsbury, M., Ramirez-Necoechea, R., Gonzlez-Lozano, M., Mota-Rojas, D. and trujillo-Ortega, M. ‘Piglet Survival in Early Lactation: A Review’ *Journal of Animal and Veterinary Advances* (207) pp. 76–86.

Andresen, N. and Redbo, I. ‘Foraging behaviour of growing pigs on grassland in relation to stocking rate and feed crude protein level’ *Applied Animal Behaviour Science* (1998) pp. 183–197.

Bailey, J. A., Gordon, R., Burton, D. and Yiridoe, E. K. ‘Energy conservation on Nova Scotia farms: Baseline energy data’ *Energy*, Vol. 33 (2008) pp. 1144–1154. https://doi.org/10.1016/j.energy.2008.02.010.

Bergsma, R. and Hermesch, S. ‘Exploring breeding opportunities for reduced thermal sensitivity of feed intake in the lactating sow’ *Journal of animal science*, Vol. 90 (2012) pp. 85–98. https://doi.org/10.2527/jas.2011-4021.

Big Dutchman. Schweinehaltung-Sauenhaltung-EasySlider-Big-Dutchman. Available at: https://www.bigdutchman.de/de/schweinehaltung/produkte/detail/easyslider/ (last accessed 5 May 2022).

Bigelow, J. A. and Houpt, T. ‘Feeding and drinking patterns in young pigs’ *Physiology & Behavior*, Vol. 43 (1988) pp. 99–109. https://doi.org/10.1016/0031-9384(88)90104-7.

Black, J. L., Mullan, B. P., Lorschy, M. L. and Giles, L. R. ‘Lactation in the sow during heat stress’ *Livestock Production Science*, Vol. 35 (1993) pp. 153–170. https://doi.org/10.1016/0301-6226(93)90188-N.

Blaxter, K. L. *Energy metabolism in animals and man* (Cambridge: Cambridge Univ. Pr, 1989).

Briedermann, L. *Schwarzwild* (Stuttgart: Kosmos, 2009).

Brown-Brandl, T. M., Eigenberg, R. A., Nienaber, J. A. and Kachman, S. D. 'Thermoregulatory profile of a newer genetic line of pigs' *Livestock Production Science*, Vol. 71 (2001) pp. 253–260. https://doi.org/10.1016/S0301-6226(01)00184-1.

Bundesanstalt für Landwirtschaft und Ernährung (BLE) (Ed.). *Gesamtbetriebliches Haltungskonzept Schwein – Sauen und Ferkel* (Bonn, 2021).

Chapinal, N., Ruiz-de-la-Torre, J. L., Cerisuelo, A., Baucells, M. D., Gasa, J. and Manteca, X. 'Feeder use patterns in group-housed pregnant sows fed with an unprotected electronic sow feeder (Fitmix)' *Journal of applied animal welfare science JAAWS*, Vol. 11 (2008) pp. 319–336. https://doi.org/10.1080/10888700802329939.

Choi, Y., Hosseindoust, A., Kim, J., Lee, S., Kim, M., Kumar, A., Kim, K., Kim, Y. H. and Chae, B. J. 'An overview of hourly rhythm of demand-feeding pattern by a controlled feeding system on productive performance of lactating sows during summer' *Italian Journal of Animal Science*, Vol. 17 (2018) pp. 1–10. https://doi.org/10.1080/1828051X.2018.1438214.

Choi, Y., Moturi, J., Hosseindoust, A., Kim, M., Kim, K., Lee, J., Song, C., Kim, Y. and Chae, B. 'Night feeding in lactating sows is an essential management approach to decrease the detrimental impacts of heat stress' *Journal of animal science and technology*, Vol. 61 (2019) pp. 333–339. https://doi.org/10.5187/jast.2019.61.6.333.

Collin, A., van Milgen, J., Dubois, S. and Noblet, J. 'Effect of high temperature on feeding behaviour and heat production in group-housed young pigs' *The British journal of nutrition*, Vol. 86 (2001) pp. 63–70. https://doi.org/10.1079/bjn2001356.

Council of the European Union. *VERORDNUNG (EG) Nr. 834/2007 DES RATES vom 28. Juni 2007 über die ökologische/biologische Produktion und die Kennzeichnung von ökologischen/biologischen Erzeugnissen und zur Aufhebung der Verordnung (EWG) Nr. 2092/91* (28/06/2007).

Cousse, S. and Janeau, G. 'Time budget and polyphasic activity in wild boar, Sus scrofa L.' (1991) pp. 391–394.

de Haer, L. ‘Relevance of eating pattern for selection of growing pig’, Doctoral thesis, Istitute for Animal Production, Wageningen Agricultural University, Wageningen, 1992.

DJV. Wildschwein (Sus scrofa). Available at: https://www.jagdverband.de/zahlen-fakten/tiersteckbriefe/wildschwein-sus-scrofa (last accessed 6 November 2021).

Douaud, J. ‘Utilisation de l’espace et du temps et ses facteurs de modulation chez le sanglier, Sus scrofa, en milieu forestier ouvert (Massif des Dhuits, Haute-Marne).’, Thèse de 3ème Cycle, Université de Strasbourg, 1983.

Dourmad, J. Y. ‘Effect of feeding level in the gilt during pregnancy on voluntary feed intake during lactation and changes in body composition during gestation and lactation’ *Livestock Production Science*, Vol. 27 (1991) pp. 309–319. https://doi.org/10.1016/0301-6226(91)90126-B.

Dourmad, J. Y. ‘Standing and feeding behaviour of the lactating sow: effect of feeding level during pregnancy’ *Applied Animal Behaviour Science*, Vol. 37 (1993) pp. 311–319. https://doi.org/10.1016/0168-1591(93)90120-E.

Eissen, J., Kanis, E. and Kemp, B. ‘Sow factors affecting voluntary feed intake during lactation’ *Livestock Production Science*, Vol. 64 (2000) pp. 147–165. https://doi.org/10.1016/S0301-6226(99)00153-0.

FAO (Ed.). *The State of Food Security and Nutrition in the World 2020. Transforming food systems for affordable healthy diets* (2020).

Feddes, J., Young, B. A. and DeShazer, J. A. ‘Influence of temperature and light on feeding behaviour of pigs’ *Applied Animal Behaviour Science*, Vol. 23 (1989) pp. 215–222. https://doi.org/10.1016/0168-1591(89)90112-3.

Friker, B. and Schüpbach, G. ‘Bleibt wachsam! Die Wahrscheinlichkeit einer Einschleppung der Afrikanischen Schweinepest aus Ostasien ist fast so hoch wie aus Osteuropa’ *Schweizer Archiv fur Tierheilkunde*, Vol. 164 (2021) pp. 651–659. https://doi.org/10.17236/sat00319.

Gorr, S. C. ‘Feeding systems for lactating sows: Effects on welfare and productivity of sows and piglets’, Master thesis, Division of Livestock Science, University of Natural Resources and Life Sciences, Vienna, November 2020.

Gourdine, J. L., Bidanel, J. P., Noblet, J. and Renaudeau, D. ‘Effects of season and breed on the feeding behavior of multiparous lactating sows in a tropical humid climate’ *Italian Journal of Animal Science* (2006) pp. 469–480.

Grave, A.-M. and Fritz, A. Eine Erfolgsgeschichte: 15,3 Ferkel pro Sau. Available at: https://www.agrarheute.com/tier/schwein/erfolgsgeschichte-153-ferkel-pro-sau-441969 (last accessed 1 May 2022).

Graves, H. B. ‘Behavior and Ecology of Wild and Feral Swine (Sus Scrofa)’ *Journal of animal science* (1984) pp. 482–492.

Guillemet, R., Dourmad, J. Y. and Meunier-Salaün, M. C. ‘Feeding behavior in primiparous lactating sows: impact of a high-fiber diet during pregnancy’ *Journal of animal science*, Vol. 84 (2006) pp. 2474–2481. https://doi.org/10.2527/jas.2006-024.

Horsted, K., Kongsted, A. G., Jørgensen, U. and Sørensen, J. ‘Combined production of free-range pigs and energy crops—animal behaviour and crop damages’ *Livestock Science*, Vol. 150 (2012) pp. 200–208. https://doi.org/10.1016/j.livsci.2012.09.006.

Hyun, Y. and Ellis, M. ‘Effect of group size and feeder type on growth performance and feeding patterns in finishing pigs’ *Journal of animal science*, Vol. 80 (2002) pp. 568–574. https://doi.org/10.2527/2002.803568x.

Imaeda, N. and Yoshioka, G. ‘Season-dependent effect of daily frequency of feed distribution on the rate of feed consumption and reproductive performance in sows during lactation’ *Animal Science Journal*, Vol. 78 (2007) pp. 560–565. https://doi.org/10.1111/j.1740-0929.2007.00476.x.

Janeau, G. and Spitz, F. ‘L’espace chez le sanglier: occupation et mode d’utilisation journalier.’ *Gibier Faune Sauvage* (1984) pp. 73–89.

Jensen, K. H., Sørensen, L. S., Bertelsen, D., Pedersen, A. R., Jørgensen, E., Nielsen, N. P. and Vestergaard, K. S. ‘Management factors affecting activity and aggression in dynamic group housing systems with electronic sow feeding: a field trial’ *Animal Science*, Vol. 71 (2000) pp. 535–545. https://doi.org/10.1017/S1357729800055260.

Jeon, J. H., Yeon, S. C., Choi, Y. H., Min, W., Kim, S., Kim, P. J. and Chang, H. H. 'Effects of chilled drinking water on the performance of lactating sows and their litters during high ambient temperatures under farm conditions' *Livestock Science*, Vol. 105 (2006) pp. 86–93. https://doi.org/10.1016/j.livsci.2006.04.035.

Jeroch, H., Drochner, W., Simon, O. and Dänicke, S. (Eds.). *Ernährung landwirtschaftlicher Nutztiere. Ernährungsphysiologie, Futtermittelkunde, Fütterung* (Stuttgart: Ulmer, 2008).

Jørgensen, U., Dalgaard, T. and Kristensen, E. S. 'Biomass energy in organic farming—the potential role of short rotation coppice' *Biomass and Bioenergy*, Vol. 28 (2005) pp. 237–248. https://doi.org/10.1016/j.biombioe.2004.08.006.

Kemp, B. and Verstegen, M. W. A. 'The Influence of Climatic Environment on Sows', in Verstegen, M. W. A. and Henken, A. M. (Eds.) *Energy Metabolism in Farm Animals* (Dordrecht: Springer Netherlands, 1987) pp. 115–132.

Kim, K. Y., Choi, Y. H., Hosseindoust, A., Kim, M. J., Moturi, J., Kim, T. G., Song, C. H., Lee, J. H. and Chae, B. J. 'Effects of free feeding time system and energy level to improve the reproductive performance of lactating sows during summer' *Journal of animal science and technology*, Vol. 62 (2020) pp. 356–364. https://doi.org/10.5187/jast.2020.62.3.356.

Kirchgeßner, M., Stangl, G. I., Schwarz, F. J., Roth, F. X., Südekum, K.-H. and Eder, K. (Eds.). *Tierernährung. Leitfaden für Studium, Beratung und Praxis* (Frankfurt am Main: DLG-Verl., 2014).

Kirner, L. and Stürmer, B. Mehrkosten von und Erfahrungen mit höheren Tierwohlstandards in der österreichischen Schweinemast. 99. 2021.

Kruse, S., Traulsen, I. and Krieter, J. 'Analysis of water, feed intake and performance of lactating sows' *Livestock Science*, Vol. 135 (2011) pp. 177–183. https://doi.org/10.1016/j.livsci.2010.07.002.

Lanferdini, E., Palencia, J. Y. P., Vilas Boas Ribeiro, B. P., Lemes, M. A. G., Teixeira de Abreu, M. L., Souza Cantarelli, V. de and Ferreira, R. A. 'Heat negatively affects lactating swine: A meta-analysis' *Journal of thermal biology*, Vol. 74 (2018) pp. 325–330. https://doi.org/10.1016/j.jtherbio.2018.04.015.

Lei, X. J., Lee, S. in and Kim, I. H. 'Evaluation of three different patterns of feed intake during early lactation in lactating sows' *Animal science journal = Nihon chikusan Gakkaiho*, Vol. 89 (2018) pp. 1129–1133. https://doi.org/10.1111/asj.13029.

Lemel, J., Truvé, J. and Söderberg, B. 'Variation in ranging and activity behaviour of European wild boar Sus scrofa in Sweden' *Wildlife Biology* (2003) pp. 29–36.

Liu, D., Dong, A. and Deng, Z. 'Impact of Climate Warming on Agriculture in Northwest China' *Journal of Natural Resources* (2005) pp. 119–125.

Lochner, H. and Breker, J. (Eds.). *Fachstufe Landwirt. Fachtheorie für pflanzliche Produktion: Planen, Führen, Verwerten und Vermarkten von Kulturen tierische Produktion: Haltung, Fütterung, Zucht und Vermarkten von Nutztieren Energieproduktion: Erzeugen und Vermarkten regenerativer Energie* (München, Münster-Hiltrup: BLV Buchverlag GmbH & Co.KG; Landwirtschaftsverlag GmbH, 2015),

Lucy, M. C. and Safranski, T. J. 'Heat stress in pregnant sows: Thermal responses and subsequent performance of sows and their offspring' *Molecular reproduction and development*, Vol. 84 (2017) pp. 946–956. https://doi.org/10.1002/mrd.22844.

Mabry, J. W., Cunningham, F. L., Kraeling, R. R. and Rampacek, G. B. 'The Effect of Artificially Extended Photoperiod during Lactation on Maternal Performance of the Sow' *Journal of animal science* (1982) pp. 918–921.

Malmkvist, J., Pedersen, L. J., Kammersgaard, T. S. and Jørgensen, E. 'Influence of thermal environment on sows around farrowing and during the lactation period' *Journal of animal science*, Vol. 90 (2012) pp. 3186–3199. https://doi.org/10.2527/jas.2011-4342.

Martínez-Macipe, M., Mainau, E., Manteca, X. and Dalmau, A. 'Environmental and Management Factors Affecting the Time Budgets of Free-Ranging Iberian Pigs Reared in Spain' *Animals an open access journal from MDPI*, Vol. 10 (2020). https://doi.org/10.3390/ani10050798.

Maselyne, J., Saeys, W. and van Nuffel, A. 'Review: Quantifying animal feeding behaviour with a focus on pigs' *Physiology & Behavior*, Vol. 138 (2015) pp. 37–51. https://doi.org/10.1016/j.physbeh.2014.09.012.

Mauget, R. ‘Regulations ecologiques, comportamentales et physiologiques (fonction de reproduction), de l’adaptation du sanglier, Sus scrofa L., au milieu.’, Thèse d’Etat, Université de Tours, 1980.

Mayorga, E. J., Renaudeau, D., Ramirez, B. C., Ross, J. W. and Baumgard, L. H. ‘Heat stress adaptations in pigs’ *Animal frontiers the review magazine of animal agriculture*, Vol. 9 (2019) pp. 54–61. https://doi.org/10.1093/af/vfy035.

Mendelsohn, R. ‘Past Climate Change Impacts on Agriculture’, in *Agricultural Development: Farmers, Farm Production and Farm Markets* (Elsevier, 2007) pp. 3009–3031.

Misztal, I. ‘Breeding and genetics symposium: Resilience and lessons from studies in genetics of heat stress’ *Journal of animal science*, Vol. 95 (2017) p. 1780. https://doi.org/10.2527/jas2016.0953.

Montogomery, G., Flux, D. and Carr, J. ‘Feeding patterns in pigs: The effects of amino acid deficiency’ *Physiology & Behavior* (1978) pp. 693–698.

Newberry, R. C. and Wood-Gush, D. G. M. ‘Development of some behaviour patterns in piglets under semi-natural conditions’ *Animal Science*, Vol. 46 (1988) pp. 103–109. https://doi.org/10.1017/S0003356100003160.

Noblet, J., Dourmad, J. Y. and Etienne, M. ‘Energy utilitzaion in pregnant and lactating sows: modeling of energy requirements’ *Journal of animal science* (1990) pp. 562–572.

O'Grady, J. F., Lynch, P. B. and Kearney, P. A. ‘Voluntary feed intake by lactating sows’ *Livestock Production Science*, Vol. 12 (1985) pp. 355–365. https://doi.org/10.1016/0301-6226(85)90134-4.

Passillé, A. de and Robert, S. ‘Behaviour of lactating sows: Influence of stage of lactation and husbandry practices at weaning’ *Applied Animal Behaviour Science*, Vol. 23 (1989) pp. 315–329. https://doi.org/10.1016/0168-1591(89)90100-7.

Peng, J. J., Somes, S. A. and Rozeboom, D. W. ‘Effect of system of feeding and watering on performance of lactating sows’ *Journal of animal science*, Vol. 85 (2007) pp. 853–860. https://doi.org/10.2527/jas.2006-474.

Petersen, V. 'The development of feeding and investigatory behaviour in free-ranging domestic pigs during their first 18 weeks of life' *Applied Animal Behaviour Science* (1994) pp. 87–98.

Planckh, C. and Fuchs, P. Landwirtschaft und Klimawandel. Available at: https://www.landschafftleben.at/hintergruende/landwirtschaftundklima (last accessed 25 November 2021).

Poulopoulou, I., Eggemann, A., Moors, E., Lambertz, C. and Gauly, M. 'Does feeding frequency during lactation affect sows' body condition, reproduction and production performance?' *Animal science journal = Nihon chikusan Gakkaiho*, Vol. 89 (2018) pp. 1591–1598. https://doi.org/10.1111/asj.13103.

Quiggin, J. and Horowitz, J. K. 'The impact of global warming on agriculture: A Ricardian analysis: Comment' *The American Economic Review* (1999) pp. 1044–1045.

Quiniou, N., Dubois, S., Le Cozler, Y., Bernier, J.-F. and Noblet, J. 'Effect of growth potential (body weight and breed/ castration combination) on the feeding behaviour of individually kept growing pigs' *Livestock Production Science* (1999) pp. 13–22.

Quiniou, N., Renaudeau, D., Dubois, S. and Noblet, J. 'Effect of diurnally fluctuating high ambient temperatures on performance and feeding behaviour of multiparous lactating sows' *Animal Science*, Vol. 71 (2000a) pp. 571–575. https://doi.org/10.1017/S135772980005534X.

Quiniou, N., Renaudeau, D., Dubois, S. and Noblet, J. 'Influence of high ambient temperatures on food intake and feeding behaviour of multiparous lactating sows' *Animal Science*, Vol. 70 (2000b) pp. 471–479. https://doi.org/10.1017/S1357729800051821.

Rauw, W. M., Soler, J., Tibau, J., Reixach, J. and Gomez Raya, L. 'Feeding time and feeding rate and its relationship with feed intake, feed efficiency, growth rate, and rate of fat deposition in growing Duroc barrows' *Journal of animal science*, Vol. 84 (2006) pp. 3404–3409. https://doi.org/10.2527/jas.2006-209.

Renaudeau, D., Quiniou, N., Dubois, S. and Noblet, J. 'Effects of high ambient temperature and dietary protein level on feeding behavior of multiparous lactating sows' *Animal Research*, Vol. 51 (2002) pp. 227–243. https://doi.org/10.1051/animres:2002020.

Renaudeau, D., Weisbecker, J.-L. and Noblet, J. 'Effect of season and dietary fibre on feeding behaviour of lactating sows in a tropical climate' *Animal Science*, Vol. 77 (2003) pp. 429–437. https://doi.org/10.1017/S1357729800054370.

Rivero, M. J., Rodríguez-Estévez, V., Pietrosemoli, S., Carballo, C., Cooke, A. S. and Kongsted, A. G. 'Forage Consumption and Its Effects on the Performance of Growing Swine-Discussed in Relation to European Wild Boar (Sus scrofa L.) in Semi-Extensive Systems: A Review' *Animals an open access journal from MDPI*, Vol. 9 (2019). https://doi.org/10.3390/ani9070457.

Rodríguez-Estévez, V., García, A., Peña, F. and Gómez, A. G. 'Foraging of Iberian fattening pigs grazing natural pasture in the dehesa' *Livestock Science*, Vol. 120 (2009) pp. 135–143. https://doi.org/10.1016/j.livsci.2008.05.006.

Russo, L., Massei, G. and Genov, P. V. 'Daily home range and activity of wild boar in a Mediterranean area free from hunting' *Ethology Ecology & Evolution*, Vol. 9 (1997) pp. 287–294. https://doi.org/10.1080/08927014.1997.9522888.

Schauer Agrotronic. MamaDos Sauenfütterung. Available at: schauer-agrotronic.com (last accessed 13 January 2022).

Seedorf, J., Hartung, J., Schröder, M., Linkert, K. H., Pedersen, S., Takai, H., Johnsen, J. O., Metz, J., Groot Koerkamp, P., Uenk, G. H., Phillips, V. R., Holden, M. R., Sneath, R. W., Short, J. L., White, R. P. and Wathes, C. M. 'Temperature and Moisture Conditions in Livestock Buildings in Northern Europe' *Journal of Agricultural Engineering Research*, Vol. 70 (1998) pp. 49–57. https://doi.org/10.1006/jaer.1997.0284.

Silva, B., Oliveira, R., Donzele, J. L., Fernandes, H. C., Abreu, M., Noblet, J. and Nunes, C. 'Effect of floor cooling on performance of lactating sows during summer' *Livestock Science*, Vol. 105 (2006) pp. 176–184. https://doi.org/10.1016/j.livsci.2006.06.007.

Silva, B., Oliveira, R., Donzele, J. L., Fernandes, H. C., Lima, A. L., Renaudeau, D. and Noblet, J. 'Effect of floor cooling and dietary amino acids content on performance and behaviour of lactating primiparous sows during summer'

Livestock Science, Vol. 120 (2009) pp. 25–34. https://doi.org/10.1016/j.livsci.2008.04.015.

Simitzis, P. E., Veis, D., Demiris, N., Charismiadou, M. A., Ayoutanti, A. and Deligeorgis, S. G. ‘The effects of the light regimen imposed during lactation on the performance and behaviour of sows and their litters’ *Applied Animal Behaviour Science*, Vol. 144 (2013) pp. 116–120. https://doi.org/10.1016/j.applanim.2013.01.014.

Skuce, P. J., Morgan, E. R., van Dijk, J. and Mitchell, M. ‘Animal health aspects of adaptation to climate change: beating the heat and parasites in a warming Europe’ *Animal an international journal of animal bioscience*, 7 Suppl 2 (2013) pp. 333–345. https://doi.org/10.1017/S175173111300075X.

Stolba, A. and Wood-Gush, D. G. M. ‘The behaviour of pigs in a semi-natural environment’ *Animal Science*, Vol. 48 (1989) pp. 419–425. https://doi.org/10.1017/S0003356100040411.

Studnitz, M., Jensen, M. B. and Pedersen, L. J. ‘Why do pigs root and in what will they root? A review on the exploratory behaviour of pigs in relation to environmental enrichment’ *Applied Animal Behaviour Science*, Vol. 107 (2007) pp. 183–197. https://doi.org/10.1016/j.applanim.2006.11.013.

Sulabo, R. C., Jacela, J. Y., Tokach, M. D., Dritz, S. S., Goodband, R. D., DeRouchey, J. M. and Nelssen, J. L. ‘Effects of lactation feed intake and creep feeding on sow and piglet performance’ *Journal of animal science*, Vol. 88 (2010) pp. 3145–3153. https://doi.org/10.2527/jas.2009-2131.

Taylor, N., Prescott, N., Perry, G., Potter, M., Le Sueur, C. and Wathes, C. ‘Preference of growing pigs for illuminance’ *Applied Animal Behaviour Science*, Vol. 96 (2006) pp. 19–31. https://doi.org/10.1016/j.applanim.2005.04.016.

van Erp, R. J. J., Vries, S. de, van Kempen, T. A. T. G., Hartog, L. A. den and Gerrits, W. J. J. ‘Circadian misalignment imposed by nocturnal feeding tends to increase fat deposition in pigs’ *The British journal of nutrition*, Vol. 123 (2020) pp. 529–536. https://doi.org/10.1017/S0007114519003052.

‘Verordnung der Bundesministerin für Gesundheit und Frauen über die Mindestanforderungen für die Haltung von Pferden und Pferdeartigen, Schweinen, Rindern, Schafen, Ziegen, Schalenwild, Lamas, Kaninchen, Hausgeflügel, Straußen und Nutzfischen (1. Tierhaltungsverordnung). 1. Tierhaltungsverordnung', in *BGBl. II Nr 485* pp. 1–34.

Villagrá, A., Althaus, R. L., Lainez, M., Martinez, A. B. and Torres, A. G. 'Modelling of daily rhythms of behavioural patterns in growing pigs on two commercial farms' *Biological Rhythm Research*, Vol. 38 (2007) pp. 347–354. https://doi.org/10.1080/09291010600950131.

Xin, H. and DeShazer, J. A. 'Swine responses to constant and modified diurnal cyclic temperatures' *Transactions of the ASAE*, Vol. 34 (1991) pp. 2533–2540. https://doi.org/10.13031/2013.31903.

Yang, A., Huang, H., Zheng, B., Li, S., Gan, H., Chen, C., Yang, X. and Xue, Y. 'An automatic recognition framework for sow daily behaviours based on motion and image analyses' *Biosystems Engineering*, Vol. 192 (2020) pp. 56–71. https://doi.org/10.1016/j.biosystemseng.2020.01.016.

Yoder, C. L., Schwab, C. R., Fix, J. S., Duttlinger, V. M. and Baas, T. J. 'Lactation feed intake in purebred and F1 sows and its relationship with reproductive performance' *Livestock Science*, Vol. 150 (2012) pp. 187–199. https://doi.org/10.1016/j.livsci.2012.08.019.

Young, J. M., Cai, W. and Dekkers, J. C. M. 'Effect of selection for residual feed intake on feeding behavior and daily feed intake patterns in Yorkshire swine' *Journal of animal science*, Vol. 89 (2011) pp. 639–647. https://doi.org/10.2527/jas.2010-2892.

Zheng, C., Zhu, X., Yang, X., Wang, L., Tu, S. and Xue, Y. 'Automatic recognition of lactating sow postures from depth images by deep learning detector' *Computers and Electronics in Agriculture*, Vol. 147 (2018) pp. 51–63. https://doi.org/10.1016/j.compag.2018.01.023.

Zheng, P., Zhang, J., Liu, H., Bao, J., Xie, Q. and Teng, X. 'A wireless intelligent thermal control and management system for piglet in large-scale pig farms' *Information Processing in Agriculture*, Vol. 8 (2021) pp. 341–349. https://doi.org/10.1016/j.inpa.2020.09.001.

Ziron, M. Dr. ‘DLG – Merkblatt 359 Fütterungstechnik in der Sauenhaltung’ (2010) pp. 1–22.