Chapter 18
Feed intake in reproducing sows

A.V. Hansen
E-mail: a-varmloese@sol.dk

This chapter deals with:

- Feeding strategy and factors affecting feed intake during gestation
- Feeding strategy and factors affecting feed intake during lactation
- Feeding strategy during weaning-to-oestrus interval
- Carry-over effects between reproductive cycles
- Effect of water intake on feed intake during gestation and lactation
- Modelling of feed intake

1. Introduction

An adequate feed intake is crucial for the health, performance, reproduction and longevity of the sow. Feeding strategies for gestating and lactating sows are very different, because the gestating and lactating sows are fed restrictedly and semi ad libitum, respectively. This big difference in feeding strategies means that only during lactation can the feed intake be classified as voluntary or something close to ad libitum feeding. The aim of this chapter is to give an overview of feed intake and factors regulating it in the reproducing sow.

2. Gestation

During gestation, the feed intake must provide energy and nutrients for foetal development, maternal growth, and growth to reach mature size.

2.1. Feeding strategy during gestation

In Denmark, sows are fed restrictedly during gestation as a way to control the body condition. The gestation period is also the most important period for rebuilding body tissues and at the same time avoiding the sows becoming too fat before parturition. Sows that are over-fat (e.g. back fat thickness above 25 mm) at parturition may be more predisposed to agalactia, mastitis, dystocia and metritis than lean sows, and may have a less developed mammary tissue [86], [87]. On the other hand, it is also important that the feed allowance is at a level where foetal growth is not compromised and under Danish conditions most sows do not become as fat as in the abovementioned studies.

In general, sows are fed according to a curve where the allowance is increased around day 60-80 of gestation, because the nutrient and energy requirements for of foetal growth accelerate at this time [50]. McPherson et al. [50] looked at growth and compositional changes in different tissues of foetuses and found that foetal weight gain accelerated from day 60 of gestation. For fat and protein accretion, they found a breakpoint at day 69 when protein and fat gain increased from 0.25 g/day to 4.63 g/day and from 0.06 g/day to 1.09 g/day, respectively (per foetus).The Danish recommendations for gestating sows are shown in Figure 18.1, and the allowance should depend on the parity and body condition of the sow [83].

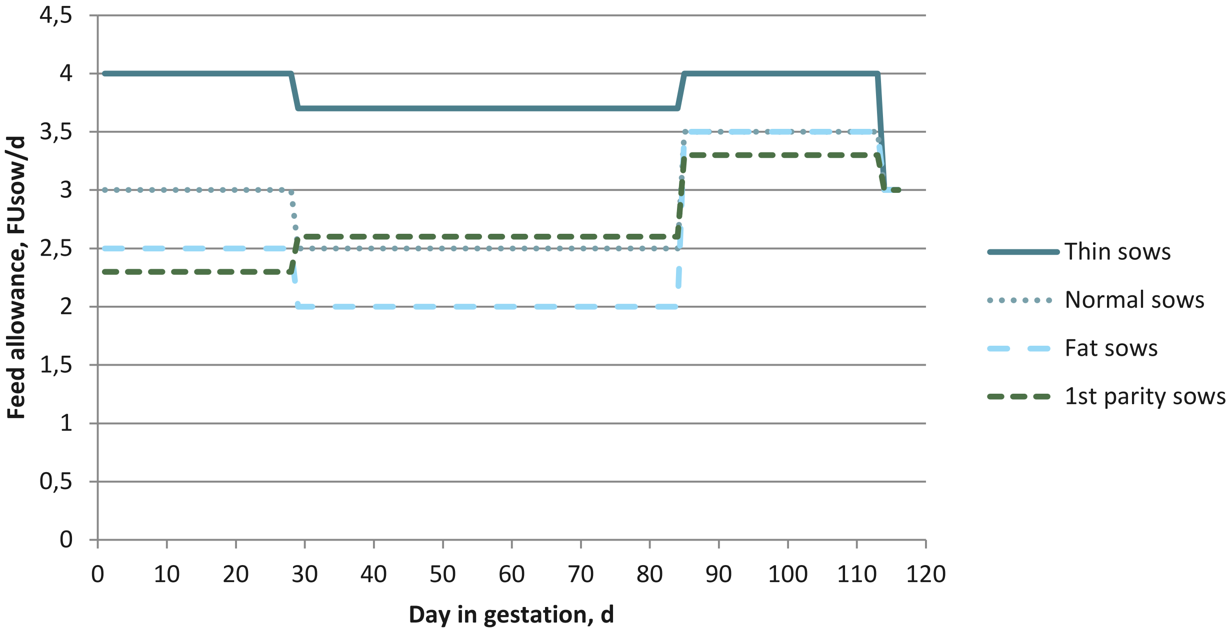

Figure 18.1. Danish recommendations for feed allowance during gestation for thin sows, normal sows, fat sows and 1st parity sows, respectively (FU = FUsow = Feed Unit for sow) [83].

The curves shown in Figure 18.1 vary depending on the body condition of the sow as sows generally should be fed according to their body condition, ie. thin sows are fed at a higher level and fat sows at a lower level than the curve.

2.2. Effects of housing and feeding system

In the European Union, all non-lactating sows must be housed loose from four weeks post-mating from January 2013. When sows are housed in large or small groups, different feeding systems can be applied. Indeed, group-housed sows can be fed in groups or individually.

Group-housing reduces the behavioural problems associated with confinement and this is of course an improvement of animal welfare [27] because of the freedom of movement and it allows social interactions between the sows [71]. However, at the same time group-housing might increase the risk of aggression from mixing unfamiliar animals, low space allowance and competition for resources in the pen [12], [27]. A major reason for aggression in gestating sows is the competition for feed as sows are motivated to eat during most of the day and maybe have to compete for small amounts of feed with a high energy concentration [12]. Electronic sow feeding (ESF), feeding in individual eating-spaces, and group-feeding on the floor or in troughs are common ways to feed group-housed sows.

When using ESF, it is very important to train the young sows to use the feeder before they are introduced to the group in the gestation unit. ESF enables the farmer to control and monitor the daily intake of individual sows, and thereby control the body condition of the sow and detect disease. In production systems with ESF, the feeder is not open for feeding 24 hours a day as it is important with some "silent time" in the pens. It is also important to consider if all sows in the pen have enough time to eat during the open period to avoid frustration and aggression amongst the sows. Studies have shown that the best time to start feeding after the closed period is between 22.00 and 01.00, because the dominant sows then will start eating during the night leaving more time for low-ranking sows to eat during the day. The systems are either programmed to close when all sows have eaten their ration to avoid sows visiting the station repeatedly without getting any feed or to close after 16 to 18 hours. If the station is programmed incorrectly, stress levels, aggression and injuries - particularly to legs because of fights - will increase [67]. Jensen et al. [27] investigated the activity and aggressive behaviour in sows in dynamic groups fed by ESF in four Danish herds. In the study, aggressive behaviour was generally seen from and following the time of feeding start (22.00) in the entire pen, but the level of aggression was lower in herds using straw as bedding as straw may increase other behaviours such as rooting.

In pens with one eating space per sow, it is important that the variation in body condition between the sows in the pen is as small as possible, because all sows are fed the same amount of feed. The advantage of this system is that all sows have the same access to feed; they will not have to fight to get into the feeding stall; and the sow decides how long it wants to stay in the feeding stall without being disturbed by other sows. It can be very difficult to control the body condition of the individual sow if the sows in a group are very dissimilar; in this type of feeding system it is therefore an advantage to group the sows according to feed requirement or size.

Group-feeding on the floor or in troughs can cause great differences in intake between sows, because the low-ranking sows generally have to eat last at every feeding. This type of feeding system can also cause aggression between the sows, because they have to compete for a limited amount of feed distributed in a small area [85]. It is very difficult to detect the actual individual feed intake in floor fed sows, but the changes in body weight and back fat thickness can be a good indicator of how the intake differs in a group of sows. The lower ranking sows typically gain less weight and back fat than the higher ranking sows, and they may even lose back fat. Whittaker et al. [85] investigated if provision of straw in the pen or a high-fibre diet could decrease the level of aggression in pens with floor feeding. The sows provided with straw did not exert a lower level of aggression during foraging, but the straw did decrease manipulation with pen inventory (e.g. bar biting) and oral behaviours (e.g. sham chewing or biting other sows in tail or ear); instead the sows were manipulating and eating the straw. The overall level of aggression was not reduced by feeding a high-fibre diet, but the level of non-contact aggression (threats) was higher in sows fed a high-fibre diet, which could be explained by the prolongation of time spent eating the high fibre diet compared to the standard diet [85]. The high-fibre diet did result in less vulva biting, which implies that it could have a positive effect on some types of behaviours that are related to satiety [85]. In another study, Brouns and Edwards [11] compared two groups of sows, where one group was floor-fed restrictedly once a day (3 kg/day) and the other group was fed ad libitum from a feeder with shoulder-length partitions. In this study, it was investigated how the social rank of the sows affected feed intake and weight gain. In the group with floor-fed sows, the low-ranking sows gained less weight than high-ranking sows (25 vs. 45 kg), whereas this effect was not seen in the group fed ad libitum. This implies that low-ranking sows have a great disadvantage in floor-feeding systems because often they have to wait before they can eat, and they lose when they have to compete with high-ranking sows for the limited amount of feed [11].

2.3. Satiety and hunger

Restricted feeding of gestating sows is practised to control the body condition of the sow, but it may cause periods with hunger, which in turn may cause stereotypic behaviour and welfare problems for the sows.

Under natural conditions, behaviour such as rooting, chewing and smelling is closely related to foraging, and it seems that sows may have a need for carrying out this type of behaviour as sows in intensive systems are seen to do rooting and chewing motions or something similar [28]. Hunger can make the sows try to compensate by redirecting the foraging activity towards another activity that can be related to foraging as, for instance, bar biting and sham chewing, which can be characterized as stereotypic behaviours [17]. Generally, the level of stereotypic behaviour increases with increasing restriction of feed intake [12], [6].

Appetite in reproducing sows is generally controlled in the same way as in growing pigs (see Chapter 19 for details about general physical and hormonal regulation), but some differences will appear. The reproducing or adult sow is larger than the growing pig, and naturally has a more developed digestive tract and a higher capacity to digest and ferment nutrients [77], [30]. The increased fermentative capacity of sows makes diets high in dietary fibre more suitable for sows than growing pigs, because these diets can be used to control energy intake and hunger at the same time and the sows can still utilize energy from the fibre, whereas growing pigs could be limited in their growth when fed too much fibre [73]. Table 8.7 in Chapter 8 provides a comparison of the digestion and absorption of carbohydrates in growing pigs and sows.

Differences in blood metabolites related to hunger and satiety will be discussed further when discussing the effect of high-fibre diets.

Satiety and hunger are very subjective terms and it is therefore difficult directly to measure if an animal is hungry or not. When measuring hunger and satiety is important to define what the terms mean, which in itself can be a difficult task. In a review paper by D'Eath et al. [17], hunger was defined as "a negative subjective state experienced by an animal that is chronically undernourished", so in this case it is related to a long-term restriction and not the short-term regulation of appetite and diurnal pattern of satiety and hunger. It is important to stress that sows can experience hunger between meals during the day without being directly undernourished.

Behavioural observations, behavioural tests and physical parameters are used as indirect indicators for their relationship with the animal's subjective view of hunger and satiety [17]. Some measurements and tests will be discussed below.

2.3.1. Testing of feeding motivation

Measures of feeding motivation are seen as a very valuable tool when testing how hungry an animal is, because it is seen as a direct and quantitative measure of the animal's state of hunger [17]. The feeding motivation can, for instance, be measured by feeding rate or operant conditioning.

Feeding rate is used to measure feeding motivation when a limited amount of feed or feeding time is offered. Generally, an increased feed restriction will increase the feeding rate, but there are some problems related to this type of measurements. When diet quality is low or when high-fibre diets are fed, feeding rates may decrease [64], [65]. Low-quality diets and certain fibre sources can be unpalatable to the sows and high-fibre diets can also lead to increased water consumption during the meal, which could lower the feeding rate.

Operant conditioning is used to measure how much the sows are willing to work for the feed, which is a measure of the feeding motivation and hunger. The sows must press a switch a number of times to get a reward. The sows can either be given the individual diets that are being compared in the experiment or they can all be given the same diet during the test with operant conditioning. When the treatment diet is released as a reward, the diet is familiar to the animal, but the treatments can be difficult to compare as the rewards may differ in energy density. This can be a problem because energy-dense diets are generally more palatable. If all sows are tested using the same feed, which usually is a high-quality diet, it is easier to compare the number of rewards across treatment groups. A high-quality diet is a greater contrast for an animal fed, for instance, a high-fibre diet during the experiment than for an animal fed this diet both during the experiment and the test with operant conditioning [42], [69], [66]. When the sows are either very familiar or unfamiliar with the feed fed during the test, this could also affect the outcome.

In a 3 x 3 latin-square design, Ramonet et al. [66] investigated the effect on feeding motivation of three different diets (all sows were allotted to all three diets):

- Basal diet (B)
- Basal diet + sugar beet pulp (SB)
- Basal diet + wheat bran (WB)

The daily energy intake was the same (33.4 MJ ME/d), but the daily intake was 2.44, 2.74 and 2.90 kg for diets B, SB and WB, respectively, which shows how the fibre sources are used to dilute the energy content of the diet and making it more bulky. The sows had to push a switch close to the trough in order to get 8 g of a standard diet, and the number of times the sow had to push the switch was increased by five until the end of the 45-minute test. There was no difference in the number of rewards between the three dietary groups, which could imply that all the sows were equally hungry. It could also be that the sows on SB and WB diets were less hungry, but worked harder because of the greater contrast between the high-fibre diets (SB and WB) and the standard diet received in the test with operant conditioning.

In a study by Jensen et al. [29] the feeding motivation was also tested using operant conditioning in gestating sows, but in this study the sows were fed the designated experimental diets during the test. The sows were allotted to one of five diets (Table 18.1). Four of the diets were fed restrictedly (fed once or twice daily) and one diet was fed semi ad libitum (fed six times daily). The control diet was a low-fibre diet and the other diets had a higher content of dietary fibre.

Table 18.1. Results from a study by Jensen et al. [29] using operant conditioning to test feeding motivation.

	Control	Pectin residue	Potato pulp	Sugar beet pulp	Semi ad libitum[1]
Intake, kg/d	2.6	3.0	2.5	2.6	4.9
Energy intake, MJ ME/d	37.9	40.9	36.5	38.4	70.2
Dietary fibre intake, g/d	425	935	992	917	1,679
Number of rewards	34.9	32.4	30.3	34.5	12.1
Responses for last reward	85.5	79.3	74.3	84.4	27.7

[1] A mixture of pectin residue diet, potato pulp diet, and sugar beet pulp diet.

The semi ad libitum fed sows had a higher intake than the sows in the other groups (Table 18.1). The test of feeding motivation by operant conditioning showed no difference between the restrictedly fed groups, and the sows in these groups had similar number of rewards and number of responses for the last reward (Table 18.1), which implies that the high-fibre diets did not decrease the feeding motivation compared to the control diet. The semi ad libitum fed sows had a lower feeding motivation than the restrictedly fed sows (Table 18.1), which indicates that these sows were less hungry. Consequently, a high-fibre diet - when fed restrictedly - does not necessarily exert metabolic, physicochemical and gastrointestinal effects large enough to reduce feeding motivation (Jensen et al. 2012). It was also tested at what time after the morning feeding the feeding motivation was highest, and results revealed that the restricted fed sows showed increasing motivation with increased hours after morning feeding. The number of feedings also had an effect on feeding motivation. The sows fed only once daily had a higher feeding motivation than the sows fed twice daily [29]. This is consistent with results of Robert et al. [70], but sows fed twice daily had an increased level of stereotypic behaviour and activity before the meal compared to sows fed once a day.

2.3.2. Palatability and preference tests

The palatability (see Chapter 19) of a diet can influence sows' feed intake. Preference tests are used to investigate which diets or specific ingredients sows prefer when given the option to choose. These tests give information on whether sows like a diet or ingredient more or less than another, but because the diets or ingredients tested are chosen by humans, it does not necessarily reveal the favourite meal of the sow. Animals generally prefer energy-dense diets compared to diets with a lower energy concentration [17].

Guillemet et al. [25] tested three diets with different levels of crude fibre (CF), crude protein (CP) and digestible energy (DE):

- Control gestation diet (C),
- High-fibre gestation diet (F), and
- Lactation diet (L).

The three experimental diets (see Table 18.2) were only fed during the preference test, and for all other meals sows were fed a standard diet, which gives a direct measurement of the animals' preferences in relation to the feed characteristics (e.g. taste and ease of ingestion).

Table 18.2. Composition of diets used in the study by Guillemet et al. [25].

	Crude fibre (CF), %	Crude protein (CP), %	Digestible energy (DE), MJ/kg DM
Control gestation diet (C)	3.3	16.8	13.8
High-fibre gestation diet (F)	9.3	16.8	12.4
Lactation diet (L)	3.8	20.3	13.9
Standard diet	5.1	15.8	13.3

The sows were given the choice of two diets at a time in two adjacent troughs (right and left), and all combinations of the diets were tested (C+F, C+L, F+L) twice to eliminate the effect of right or left trough. In the study, the amount of each diet ingested, first trough visited, and number of trough changes were recorded. Forty three per cent of the sows preferred diet C being the diet that they consumed most of. Forty two and 15 per cent preferred the L and F diets, respectively. Diets C and L were consumed at a higher rate than diet F (210 vs. 168 g/min). When the sows had to choose between diets C and L, there was no specific preference for one of the diets. In this study, the sows preferred the more energy-dense diets (C and L) compared to the high-fibre diet (F). Some fibre sources have high contents of unpalatable substances, such as pectin, tannins or alkaloids, but this is generally only a problem if the fibre source is included in very high levels (10-15%) in the diet. Diet F could just have been less palatable than the other two diets, but in this study only the short-term preferences were tested. Diets C and L were very similar to the standard diet, so the preference for these two diets could also be associated with a neophobic (neophobia = fear of new things or experiences) response to diet F.

2.3.3. Physiological measurements

Besides the behavioural observations as a measure of the level of hunger, physiological measures can also be used [17]. Generally, this type of measurements can be related to feeding physiology or stress physiology. Many hormones, metabolites and neuropeptides (see Chapter 19) are involved in the regulation of feed intake, and the interplay between them is highly complex and it can therefore be difficult to relate them directly to the satiety of an animal. Plasma concentrations of glucose, NEFA, insulin and glucagon have often been measured in sows, but not related directly to the sows' subjective experience of hunger. Since the experience of hunger can cause stereotypic behaviour and stress in the sow, parameters related to stress such as, for instance, cortisol can also be measured. Cortisol might not be the best measure of hunger, because cortisol can also reflect that the sow is excited before the meal [69]. In addition, cortisol is probably not the best measure of chronic stress as feed restriction would be, because the hypothalamic-pituitary-adrenal axis will adapt, and cortisol has various metabolic effects and is therefore hard to interpret [17]. The results of studies trying to relate physiological measurements to hunger are not very consistent and more knowledge is needed before it can be related reliably to level of hunger.

2.4. Controlling hunger with high-fibre diets

According to Danish and European legislation, gestating sows must be provided with enough bulky or high-fibre feed to improve satiety and meet their need for chewing [1]. To comply with this legislation, gestating sows are often fed a diet containing a source of fibre as for instance sugar beet pulp, pectin residue, potato pulp, or oats.

High-fibre diets have shown to reduce stereotypic behaviour by signalling satiety for a longer period than traditional, high-starch gestation diets without concomitantly providing too much energy [6]. High-fibre diets have other properties than high-starch diets and may promote satiety by changes in its physical (e.g. water binding capacity) properties in the intestine as well as by changing the diurnal patterns of absorbed nutrients (e.g. short chain fatty acids (SCFA)). High-fibre diets increase fermentation in the hindgut and thereby increase microbial production of SCFA, which are absorbed and can be used as energy source by the sow [18], 76].

After ingesting a low-fibre diet, glucose is rapidly absorbed and the blood glucose increases, and as response insulin secretion also increases. Insulin works as a feeding inhibitor, so the increase in insulin after ingesting a high-starch diet results in signals being sent to the hunger centre of the brain. and other molecules (e.g. melanocyte-stimulating hormone and neuropeptide Y) are released. The release will decrease the sensation of hunger and inhibit the feed intake (See Chapter 19 for further details). In contrast to low-fibre diets, high-fibre diets increase SCFA absorption from the large intestine. The fermentation process in the hindgut is slower than the enzymatic degradation of carbohydrates in the small intestine, which means that the absorption of nutrients when given a high-fibre diet will be slower and the diurnal variations in blood metabolites will be fewer than those observed when fed a low-fibre diet.

High-fibre or bulky diets differ substantially in physicochemical properties (water binding capacity, solubility, viscosity, swelling) from low-fibre diets, and different fibre sources also differ, and therefore they can affect the feeling of satiety in different ways. The solubility of the dietary fibre will affect the rate of gastric emptying; the more soluble the fibres are, the lower is the rate of emptying, because a higher solubility increases the viscosity and water binding capacity [31]. The slower rate of gastric emptying is thought to cause a prolonged feeling of satiety, because the gut is filled for a longer period (See Chapter 19 for more about physical factors in the stomach affecting hunger). On the other hand, a high content of insoluble fibre increases faecal excretion because of the lower fermentability of these fibres [74]. The intestines contain stretch receptors like the stomach, and these are activated by increasing distension resulting from water that is moved into the lumen of the gut. When the receptors are activated, signals are sent to the central nervous system and feed intake is inhibited [92]. Aside from the stomach, the large intestine is also a major site of retention of solids and fluids, and the passage rates through the large intestine will therefore be more affected than the passage rate through the small intestine when comparing different diets [2]. Danielsen and Vestergaard [16] compared gestating sows fed diets with contrasting levels of soluble and insoluble fibre, and results shows that the diet containing sugar beet pulp had the highest content of soluble fibre and the sows in this group exhibited less aggressive behaviour compared to the other groups fed diets low in fibre or diets high in insoluble fibre. This suggests that these sows felt less hungry.

Figure 8.4 in Chapter 8 compares the composition of the fibre fraction in some feedstuffs. Sugar beet pulp and potato pulp are characterized by having a high content of soluble dietary fibre; pectin residue and pea hull medium content of soluble dietary fibre; and brewers spent grain and seed residues are high in insoluble dietary fibre [73]. These ingredients were used in experiments by Serena et al. [74], [75], [76] to investigate how the contrasting physicochemical properties of the dietary fibre affected digestion, absorption and energy utilization of the diets. One low-fibre diet (wheat and barley) and two high-fibre diets (high in soluble fibre, sugar beet, pectin residue and potato pulp; high in insoluble fibre sugar beet, pectin residue, potato pulp, seed residue, pea hulls, and brewers spent grain) were formulated [74], [75]. The ileal and total tract digestibility of organic matter and carbohydrates were higher for the low-fibre diet than the high-fibre diets. The flow of digesta at the terminal ileum was twice as high in sows fed the high-fibre diets compared to the low-fibre diet. The high-fibre diets had an increased flow of undigested carbohydrates to the large intestine, and the disappearance of carbohydrate from the large intestine was 393 g/d for the diet high in soluble fibre; 303 g/d for the diet high in insoluble fibre; and 58 g/d for the low-fibre diet. This implies that the diet high in insoluble fibre reduces the microbial fermentation in the large intestine [74]. The study also showed that sows fed the diet high in soluble fibre had a decreased level of activity compared to the other diets, which could indicate that these sows were less hungry. Table 18.3 provides an overview of how the different levels and types of fibre affect the passage rate through the GI tract.

Table 18.3. The dietary effect on passage rate[1] out of the stomach and intestines. The plus signs indicate how much the diet affects (increases) the passage rate.

	Stomach	Terminal ileum	Terminal colon[2]
Diet high in insoluble fibre (HFI)	++	+++	+++
Diet high in soluble fibre (HFS)	+	++	++
Low-fibre diet (LF)	+++	+	+

[1]Rate of emptying: +++ = fast, ++ = medium fast, + = slow
[2]Faecal excretion

In the study by Serena et al. [76], a low-fibre diet, a diet high in soluble fibre, and a diet high in insoluble fibre were compared to investigate the effects on the diurnal variation in concentrations and absorption of some blood metabolites. The main differences between the diets were the starch content and type and content of dietary fibre. Figure 18.2 shows how the glucose concentration (Figure 18.2A) and absorption (Figure 18.2B) changed after a meal (time = zero). When sows were fed the low-fibre diet, an increase in glucose concentration and absorption was seen right after the meal. The diet high in insoluble fibre also resulted in a less steep, but still rapid, increase in glucose concentration one hour after the meal, whereas for the diet high in soluble fibre the response was slower and the peak was not very pronounced. The insulin concentrations showed similar patterns as for glucose. The diet high in soluble fibre had the most stable glucose concentration throughout the day compared to the two other diets, which could be explained by the delayed glucose absorption. The concentration and absorption of SCFA were lowest for the low-fibre diet, intermediate for the diet high in insoluble fibre and highest for the diet high in soluble fibre (Figures 18.2C and 18.2D).

The LF and HFI diets had very similar patterns for concentration and absorption profiles, but the HFI diet was lower because of the lower starch content. Glucose was the main energy source out of the total absorbed energy 0 to 10 hours post-feeding for sows on LF and HDI diets, whereas the main absorbed energy for sows on HFS was from SCFA. The glucose concentrations were measured at the portal vein, which means that the differences in concentrations correspond to differences in absorbed glucose originating from the dietary starch. The contrasting starch contents and the properties of the fibre sources were the major factors regulating glucose absorption into the portal vein. The insulin response to the increase in blood glucose after the meal was seen as a peak in LF and HFI diets to stabilize the blood glucose, whereas the HFS diet had a stabilizing effect on insulin concentrations. The sows fed LF and HFI diets would experience a feeling of satiety for a short period after the meal, because the period of glucose absorption and insulin secretion has a short duration. In contrast, the HFS diet resulted in a lower, but more stable, absorption of glucose over time following the meal, and these sows would have a longer lasting feeling of satiety, because insulin is secreted in the same pattern as the glucose absorption [76].

It was concluded that the content of insoluble dietary fibre did not have a great effect on gastric emptying and movement of digested products in the small intestine. However, the later peak in concentration and net absorption of glucose in sows fed HFS could be attributed to delayed gastric emptying and a more bulky content in the intestinal lumen, which may have slowed the enzymatic degradation of starch to glucose and movement of digested products [75], [76].

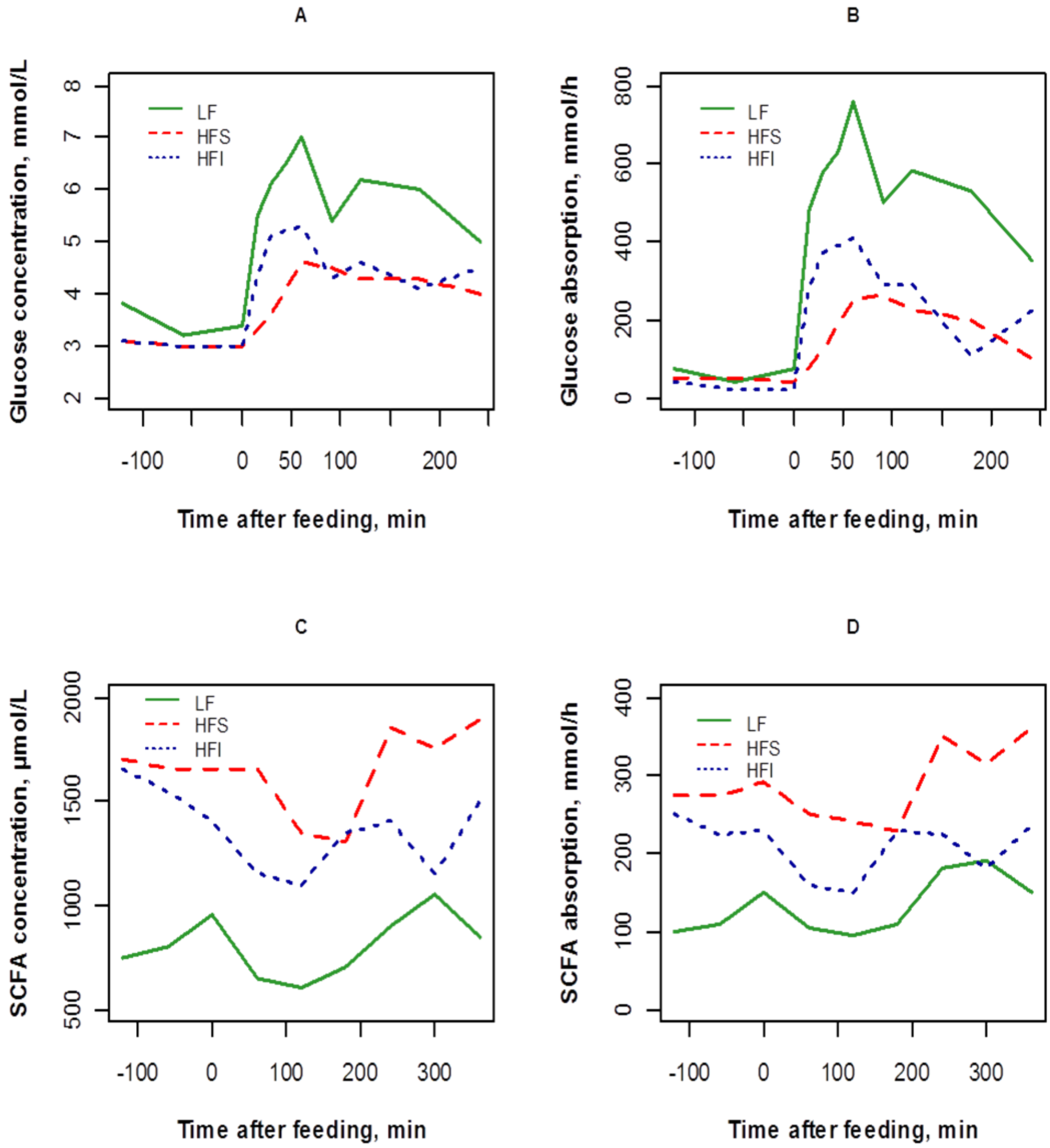

Figure 18.2. Concentrations (portal vein) of glucose (A) and SCFA (C) and net portal absorption of glucose (B) and SCFA (D) after a meal in sows fed diets low in dietary fibre (LF), high in insoluble fibre (HFI) or high in soluble fibre (HFS). Time zero is time of the meal [76].

When using high-fibre diets as a way to control hunger and body condition of gestating sows, it is very important to realize that different types of dietary fibres have different properties and may not all be good at controlling hunger. Another problem is the significant individual variation among sows (to be discussed later). It is also important to emphasize that the dietary fibre content in many experiments is very high compared to that applied in practice.

3. Carry-over effects from gestation to lactation

A good body condition at parturition is important for the lactation performance (Chapter 17), but it is known that increasing intake during gestation can decrease intake during lactation [68]. The decreased lactational intake is associated with accumulation of body lipid during gestation [21], so the fatter the sow is at parturition, the lower is the feed intake in the following lactation.

Revell et al. [68] compared the performance of primiparous sows with different body composition (lean and fat, see Table 18.4), but similar body weight, at parturition to test the hypothesis that feed intake depended both on body fatness and the supply of substrates for milk production. The different levels of body fatness were obtained by feeding two dietary levels of protein (5.8 and 15.6 %) during gestation.

Table 18.4. Body composition, changes in body composition, dietary composition and feed intake for lean and fat sows fed a high or low-protein diet during lactation [68].

	Lactation diet			
	Low protein, fat sows	Low protein, lean sows	High protein, fat sows	High protein, lean sows
Dietary crude protein, %	7.9	7.9	19.0	19.0
Digestible energy, MJ/kg	15.5	15.5	15.6	15.6
Av. feed intake during lactation, kg/day	3.59	5.15	3.59	5.15
Back fat thickness at parturition, mm	25.3	18.2	23.6	17.7
Back fat loss during lactation, mm	3.7	1.4	3.0	0.8
Fat gain during lactation, kg	-17.4	-10.6	-8.7	-3.1
Lean tissue gain during lactation, kg	-16.0	-16.5	1.4	0.8

Lean sows had a lower back fat thickness and body fat mass, and a higher lean tissue mass at parturition than the fat sows. Sows were fed either a high or low-protein diet (see Table 18.4) ad libitum during lactation.

On average, the sows in the fat group had a 30% lower feed intake than the lean sows during lactation (see Table 18.4), which indicates a negative association between body fatness and voluntary feed intake. It was hypothesized that the feed intake could be regulated by the insulin concentration, but fat and lean sows had the same concentrations. Instead it was proposed that the fat sows were less sensitive to insulin or had fewer insulin receptors than the lean sows. An increased insulin resistance could lead to increased mobilization from body reserves, which could explain that fat sows also had the largest loss of back fat during lactation [68].

The differences in loss of body tissues between the fat and the lean group were largest in the first and second weeks of lactation and decreased throughout lactation. The composition of body weight loss did not depend on the body condition at parturition, but on the protein intake during lactation. Sows fed the high-protein diet had a lower loss of body fat and lean tissue than sows fed the low- protein diet. The conclusion of the study was that the voluntary feed intake is controlled in a very complex way, and during the first two weeks of lactation the intake mainly depended on body fatness and not the protein content of the diet. Later in lactation, the intake was more affected by the protein intake, which could be because the sows fed a high-protein diet had a higher milk production and the higher protein intake also prevented excessive loss of lean tissue [68], see Table 18.4.

The mechanism for how gestational intake affects the intake during the following lactation is not totally understood, but several things may control it. Several studies have been investigating the connection between body condition, feed intake, blood metabolites and hormones. In the periods pre- and post-partum, a lot of metabolic changes occur, because of the transition from gestation to lactation. The changes in hormones related to reproduction are described in Chapter 16. Insulin and leptin are known to have anorexigenic effects (see Chapter 19), and leptin is associated with the amount of body lipid, whereas insulin is secreted from pancreas after a meal as a response to increased blood glucose. It has been hypothesized that sows fed at a high feeding level during gestation, and therefore were fatter a parturition, had decreased feed intake during lactation because of a higher basal level of leptin and insulin in the plasma [22].

During the last third of gestation, insulin resistance increases, and this is an adaptation in the sow's metabolism to spare glucose for the developing foetuses and during lactation for milk production. Insulin resistance is characterized by increased plasma insulin concentrations after a meal, glucose half-life is increased and return of insulin to basal levels is delayed after a glucose load (glucose tolerance test). The occurrence of this gestation related insulin resistance is common in many species, and it is also seen in sows, though less pronounced [59], and some studies suggest that primiparous sows may be more resistant to insulin than multiparous sows [59], [58]. Pere and Etienne [58] showed that the insulin resistance developed during gestation resulted in delayed insulin secretion in glucose tolerance tests during lactation. If sows are fed at a high feeding level during gestation, they may also develop insensitivity to insulin by affecting the number of insulin receptors and/or the affinity, which results in decreased glucose clearance from the blood after a load of glucose [84]. It has been shown that sows with high back fat thickness at parturition have a lower glucose clearance indicating that the negative effect of back fat thickness on lactational feed intake could be associated with increased insulin resistance [84], [43], [82]. Increased insulin resistance means that cells fail to respond to the insulin leading to a drop in the normal response to insulin as for instance uptake of glucose by cells or glycogen synthesis in the liver.

A high gestational feeding level may also cause glucose intolerance by decreasing the number of receptors and making the beta-cells of the pancreas less sensitive to glucose [84], which results in persistence of high blood glucose and insulin concentrations and this may delay the intake as it lowers the appetite and thereby the total feed intake decreased. The lower plasma insulin concentrations caused by the glucose intolerance could also enhance mobilization and oxidation of body lipid depressing the oxidation of NEFA. The increased blood concentrations of NEFA can also have a negative impact on feed intake.

In a study [59] on multiparous sows, it was investigated if the feeding level during gestation affected the glucose metabolism and development of insulin resistance. The sows were fed either 4 kg/d (High) or 2.5 kg/d (Low) of the same diet during gestation to investigate the effect on metabolite concentration in the blood at day 10, 59, 87, 97, 101 and 110 of gestation. The pre-meal plasma glucose concentration was slightly higher in the sows fed a low feeding level than sows fed a high feeding level, and following the meal the Low sows also had slightly higher glucose concentrations. The increase in insulin concentrations induced by the meal was highest in the High sows, but sows in both groups returned to the same basal level after 120 minutes. The differences between sows on high or low feeding level were not very large, which could indicate that the dietary effect on the insulin resistance was not very pronounced in this study. However, the study did also compare gestating with non-gestating sows, and found that the insulin and glucose concentrations following a meal were higher in gestating compared to dry sows, which indicates that the gestating sows developed an insulin resistance. The half-life of glucose after a glucose injection was also higher in the gestating sows and increased during gestation. This was also seen for insulin concentrations, though it was not affected by stage of gestation. Xue et al. [89] found that sows were more glucose intolerant during late gestation, which resulted in higher glucose and lower insulin concentrations in fat sows after a glucose infusion compared to lean sows. However, in the study by Revell et al. [68] no differences were seen in insulin and glucose concentrations between fat and lean sows. In the study by Revell et al. [68], the fat sows had higher plasma NEFA concentrations both before and after parturition, which could indicate that the fat sows were more resistant to insulin.

Mosnier et al. [52] found that plasma insulin concentrations were increased the first six days postpartum compared to gestation and the following days during lactation. The average daily feed intake was 6.3, 8.4 and 8.5 kg/d during the first, second and third week postpartum, respectively. The average back fat thickness at parturition was 13.7 mm, which is a relatively low back fat thickness compared to other studies also looking at relations between feed intake and body condition in multiparous sows [82],[93]. The high feed intake observed by Mosnier et al. [52] could be associated with the low back fat thickness at parturition, because a high back fat thickness is associated with increased insulin resistance. The study was done on multiparous sows and because of a relatively high feed intake during the study the sows generally did not lose weight and back fat during lactation. The glucose concentration increased during the last 35 days pre-partum [52]. The insulin-to-glucose ratio was increased during the first week postpartum compared to prepartum and 14 to 21 days postpartum, which indicates that the insulin resistance developed in late gestation is accentuated during lactation. This could explain the observed increase in glucose concentration after parturition while insulin concentrations and feed intake did not change. The average daily feed intake during weeks 1, 2 and 3 postpartum was negatively correlated with the insulin-to-glucose ratio measured the last week before parturition, which implies that the insulin resistance during late gestation may affect the feed intake and energy balance during lactation [52]. The NEFA concentration following a meal during the first week postpartum was negatively correlated with feed intake showing that sows with a low intake mobilize more from body fat. The leptin concentration during gestation was also negatively correlated with feed intake during lactation, which could indicate that sows with a high fat gain during lactation have a lower intake during lactation. The conclusion of the study is that the increased insulin resistance in late gestation induced mobilization of body reserves, which has a negative impact on feed intake during lactation.

Leptin is secreted by adipocytes and the leptin receptors are located within the area of hypothalamus associated with appetite regulation [44]. Leptin is secreted in response to the energy balance: a positive energy balance induces secretion of leptin and decreases feed intake, and a negative energy balance decreases the level of plasma leptin and increases feed intake [5]. It is also well established that there is a positive correlation between leptin concentrations and adiposity [4].

Estienne et al. [24] studied the effect of body condition at parturition on plasma concentrations in leptin. Generally, fat sows had higher levels of leptin compared to thin sows, and the leptin concentration was correlated with the back fat thickness. Table 18.5 shows the results from the experiment. The lower adiposity and leptin concentrations in thin sows could have caused the significantly higher intake in this group compared to the other two groups.

Table 18.5. Body weight, back fat thickness and leptin concentrations of sows at parturition and lactational feed intake [24].

	Fat sows	Medium sows	Thin sows
Body weight, kg	263	220	203
Back fat, mm	28.1	22.4	15.5
Leptin, ng/ml	4.9	3.7	2.8
Feed intake, kg/d	4.3	4.5	5.4

These results are in accordance with findings in other studies [61], [19], which showed that sows that were fatter at parturition and had high gestational feed intake had a higher level of leptin throughout lactation.

Clearly, gestational feed intake and body condition at parturition, and thereby also changes in metabolite and hormone concentrations, affect feed intake during lactation. The mechanisms by which metabolite and hormonal concentrations regulates the intake are complicated and many factors remain unclear and need further investigation.

4. Lactation

The major sources of energy and nutrients during lactation are feed intake and mobilized body tissues (lipid and protein). The feed intake is very important during lactation to ensure maximal performance of the sow (milk production/piglet growth) and to avoid excessive weight loss.

4.1. Feeding strategy during lactation

During lactation, sows are fed semi ad libitum, which means that they are fed very close to ad libitum to ensure a high feed intake and avoid excessive mobilization from body tissues, and at the same time minimize feed waste. Figure 18.3 shows the Danish recommendations for lactating sows. It is recommended to increase the intake gradually during the first 1-2 weeks post-partum, and hereafter staying on a plateau.

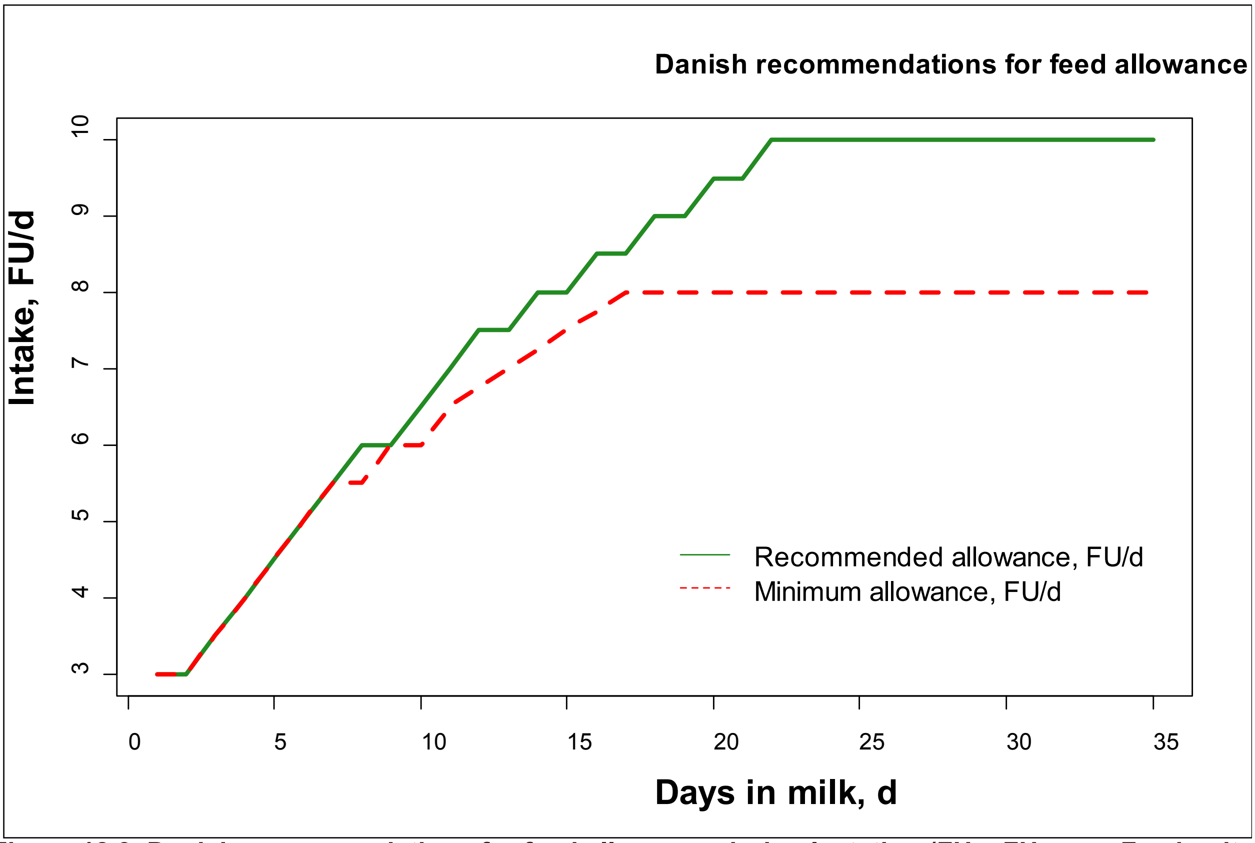

Figure 18.3. Danish recommendations for feed allowance during lactation (FU = FUsow = Feed unit for sow). The green line indicates the recommended feeding level and the red line the minimum feed level [14].

4.2. Pattern of lactational feed intake

The individual feed intake patterns in lactating sows can vary a lot, because sows have different levels of production and may also differ in feed intake capacity. The feed intake is often low the first days post-partum, but increases during the first week of lactation and reaches a maximum during the second or third week. In some sows, intake will decrease after reaching the maximum capacity and others will stay at a plateau throughout lactation. Koketsu et al. [35] recorded daily feed intake in 20,000 sows on 30 commercial farms in the US.

The feed intake was categorized as follows:

- RAPID, rapid increase in intake,
- MAJOR, major drop in intake,
- MINOR, minor drop in intake,
- LLL, low intake throughout lactation,
- LHH, low intake during the first week postpartum and then increase during the rest of the lactation period, and
- GRADUAL, gradual increase in intake.

The different patterns of intake resulted in average daily intakes of 5.9, 5.1, 5.4, 3.2, 4.0, and 5.9 for RAPID, MAJOR, MINOR, LLL, LHH and GRADUAL, respectively.

Lactation length varied from 10 to 28 days, and the average daily intake increased with increasing length of lactation [35]. The weaning-to-service interval was increased and the litter weight at weaning was slightly lower in the groups with the lowest intake (LLL and LHH), but litter size at weaning was not affected by feed intake pattern [36]. The average daily feed intake in this study is generally lower than in modern Danish sows, but it shows the huge variation between individual sows in feed intake patterns during lactation.

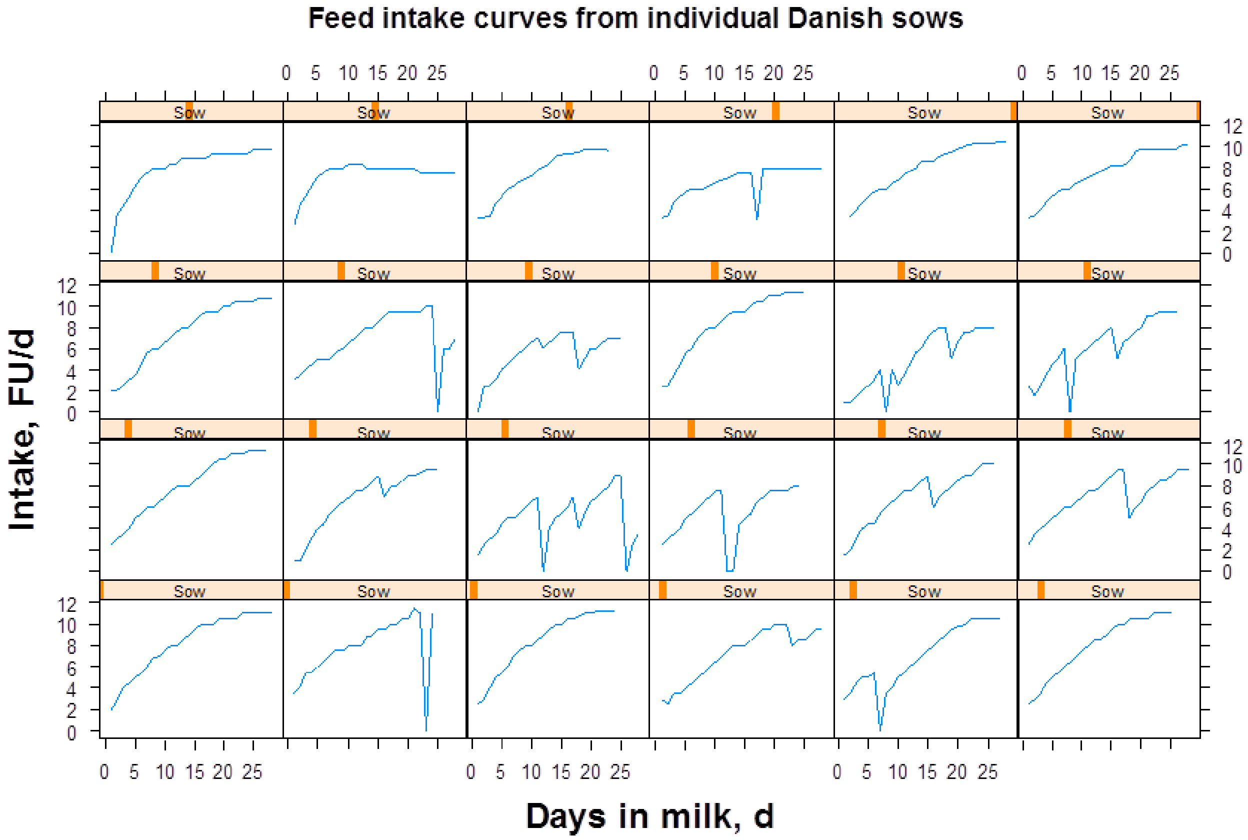

Figure 18.4. Individual feed intake (FU = FEsow = Feed unit for sow) in lactating sows from different Danish herds [14].

Figure 18.4 shows different patterns of feed intake for individual sows in different parities. The sows originate from different Danish herds that employ different feeding strategies (e.g. dry or wet feed) and management (e.g. fast or slow increase in feed allowance). Some sows may from a practical point of view be categorized as difficult sows because of several drops in feed intake.

These drops could be caused by disease or other factors affecting the intake such as high temperatures.

4.3. Factors affecting feed intake

Many factors affect feed intake during lactation, and factors specifically related to lactating sows will be discussed further below. The general metabolic and hormonal regulation of feed intake will not be described in detail as this is already discussed in Chapters 16 and 19.

4.3.1. Stage of lactation and milk production

Sows nursing large litters generally have a higher milk production and therefore a higher requirement for nutrients, which increases the feed intake [22]. This effect is called a pull effect. It is suggested by Mackenzie and Revell [45] that a high feed intake cannot increase the milk production, but a low feed intake can inhibit the milk production, because sows will mobilize from body tissues if the intake is inadequate to cover the requirement. It could be hypothesized that a push effect, which is increased milk yield due to higher feed intake, is seen during the first week postpartum when feed intake is usually inadequate, and when feed intake reaches a maximum, it changes to a pull effect.

Eissen et al. [23] evaluated the effect of litter size on feed intake using three different genotypes (one purebred Landrace line, and two lines of crossbreds of Landrace and Yorkshire). Litter size varied from 7 to 14 piglets, but only for one of the genotypes an effect of litter size was seen. In this group, the sows reached a maximum feed intake at 10.8 piglets, which probably shows that these sows have reached their maximum feed intake capacity. The back fat loss in the same group of sows increased from a litter size of 10 piglets, which shows how the sows compensate for the inadequate intake by mobilizing from body reserves [23]. The study showed that a higher feed intake decreased body weight loss and back fat loss, but the effect was reduced at higher litter sizes. An increase of 1 kg in daily feed intake reduced the body weight loss by 0.130 kg/d at a litter size of 10 piglets, whereas the weight loss was only reduced by 0.015 kg/d at a litter size of 14 piglets. It was concluded that sows nursing large litters were less efficient in utilizing the extra feed for reducing weight loss and instead the extra nutrients were probably excreted in the milk [23]. This implies that the interactions between feed intake, body tissue mobilization and milk productions need further investigation to clarify the mechanisms.

4.3.2. Number of daily feedings

It has been proposed that offering feed more frequently will make the sows eat more, but research results are contradicting. In a Danish study [79], the sows were fed either 1) restrictedly (107 FU_{sow}/100 kg feed); 2) ad libitum (107 FU_{sow}/100 kg feed); or 3) ad libitum (115 FU_{sow}/ 100 kg feed). Sows that were fed ad libitum had free access to feed 24 hours a day. Feed intake averaged 6.5 (7.0 FU/d), 6.9 (7.4 FU/d) and 7.0 kg/d (8.1 FU/d) for groups 1, 2 and 3, respectively, ie. the sows with free access to feed had a slightly higher intake than the restrictedly fed sows. The difference in intake was not very large, but due to a higher energy density in diet 3, the sows in this group had a higher energy intake than sows in the other groups. Other studies have shown that free access to feed decreases the intake. Another Danish study investigated the effect of increasing the number of daily feedings from 3 to 5-8. Here it was found that sows that had more daily feedings had a lower incidence of shoulder lesions, but there was no effect on the total daily feed intake [80]. The decrease in shoulder lesions may therefore be attributed to the fact that the sows with more feedings had to get up more times during the day. Sows have a diurnal pattern of feed intake, and have the highest intake in the interval from 5.00 in the morning to 8.00 in the night [10], which indicates that most feedings should be in this time interval. However, it is unclear if an increased frequency of feedings will increase the intake substantially as sows prefer to eat at certain times of the day and if they are prevented to eat at these specific times they might not compensate by eating more at other times - even if they are given access to feed [88].

4.3.3 Dietary effects

A common way to increase energy or nutrient intake in lactating sows is to increase the energy or nutrient density of the diet to prevent the physical capacity of the gastrointestinal tract from limiting the intake (see Chapter 19). However, as described in Chapter 19, dietary energy, protein and fat content might affect feed intake. The results are contradicting regarding inclusion of higher concentration of fat or protein, but generally a higher energy density decreases the intake (kg/day) [55].

Dourmad [20] reviewed the literature and estimated that daily intake decreased by 150 g when the energy density was increased by 1 MJ ME/kg. Table 18.6 gives an example of how an increase in energy density by 4 MJ ME/kg decreases the intake (kg/d), but the total energy intake actually increases.

Table 18.6. Example of how dietary energy density (MJ ME/kg) changes feed intake (kg/d) using estimates from Dourmad [20].

MJ ME/kg	Intake, kg/d	Total ME intake, MJ/d
13	5.0	65.0
17	4.4	74.8

In a study by Schoenherr et al. [72], it was tested how three different energy sources (fibre, starch and fat) affected the feed and energy intake. The diets with fibre, starch and fat were formulated to contain 12.3, 13.2 and 15.1 MJ ME/kg, respectively. The energy density affected the feed intake: sows fed the fat diet had a lower intake (- 600 g/d) than the sows fed the fibre or starch diets. The total energy intake was also affected by the energy density, and sows fed fibre, starch and fat had an energy intake of 70, 81 and 83 MJ ME/d, respectively. In contrast, Coffey et al. [15] did not find any difference in feed intake when energy density was increased from 13.6 to 15.1 MJ ME/kg. Similar results was obtained in a Danish study where the energy density was increased from 13.3 to 14.4 MJ ME/kg in ad libitum fed sows, but the sows on high-energy diet did not reduce their intake significantly compared to the low energy diet (7.5 vs. 7.8 kg/d) [57]. The contradicting results regarding the effect of energy density on feed intake could be the result of differences in the total energy requirement of the sows in the studies. If the sows are easily able to consume enough feed to cover their energy requirement, the diet with the highest energy density might inhibit feed intake before the low energy density diets. On the other hand, modern high-prolific sows often lose weight during lactation, because they cannot consume enough feed to cover their requirement for milk production, and in this case the intake might not be affected by energy density. A way to increase the energy intake is then to increase the energy density of the diet.

The effect of high (56 g/d), medium (36 g/d) or low (16 g/d) lysine levels fed to sows during an 18-day lactation period was studied by Yang et al. [90]. The average feed intake was slightly decreased (3.9 vs. 3.4 kg/d) in the sows fed high lysine (1.6 %) compared to low lysine (0.4 %). In another study by Yang et al. [91], the same pattern was seen when the lysine concentration was increased from 0.6 to 1.6 % (5.4 vs. 4.6 kg/d). The effect of protein on feed intake could be explained by the positive relationship between lysine/protein intake and plasma urea nitrogen. Urea nitrogen must be excreted in urine, so when the nitrogen intake reaches the level of maximum capacity for excreting nitrogen via urea, the intake is decreased to avoid toxic levels of plasma urea [91]. Another explanation could be an increasing ratio between tryptophan and branched-chain amino acid (BCAA) with increasing dietary protein. Tryptophan is precursor for serotonin, which decreases the appetite. Tryptophan and BCAA compete for the same carrier to cross the blood-brain barrier, and increasing the tryptophan intake could decrease the feed intake because of the increased serotonin synthesis [91]. Trottier and Easter [81] evaluated how the tryptophan-to-BCAA ratio affected feed intake. Dietary addition of BCAA did not increase feed intake as expected but rather the intake was decreased in the second week of lactation. Mateo et al. [48] studied the effect of increasing the protein concentration from 17.9 to 19.1 %, but there was no effect of dietary treatments on feed intake.

4.3.4. Ambient temperature and heat stress

When the temperature is above or below the thermo neutral zone of the sow, the sow must maintain the body temperature by heat loss or production. During periods with high outdoor temperatures, the ambient temperature in the pig house can be harder to control. Furthermore, the thermal comfort zone of the sow ranges from 12 to 22 °C, but for the piglets it is between 30 and 37 °C, and the temperature is therefore generally kept in between the two thermal comfort zones, which means that the temperature is above the sows comfort zone [47]. High temperatures can cause heat stress in the sow, and one effect of this can be decreased feed intake [8], [51], [63], [7] to lower the heat production associated with digestion, absorption and utilization of nutrients. To compensate for the lower feed intake during heat stress, the sow will mobilize from body tissues and in severe cases milk production will be compromised. The feed intake decreased 40 and 43% in lactating sows when the ambient temperature was raised from 18 to 28 °C and from 20 to 30 °C, respectively [8], [51]. It is suggested that the decrease in milk production is caused by an increased blood flow to the skin at the expense of the blood flow and thereby nutrients to the mammary gland and other organs [8], and Messias de Braganca et al. [51] found that sows kept at 20°C and fed the same amount of feed as sows kept at 30°C had a significantly higher litter weight gain during the first three weeks of lactation.

The selection for high productivity in a non-limiting environment in the presence of an interaction between genotype and environment may have a negative impact on how sensitive the sows are to the environment [34] as for instance temperature and humidity. Bergsma and Hermesch [7] investigated the effects of temperature and humidity on feed intake and found that when the outside temperature increased from 22.4 to 35.4°C, there was only a minor decrease in intake by 53g/d. The highest feed intake was at a relative humidity of 80%. The feed intake was 145g/d lower at a humidity of 40 %, but only 37 and 35 g/d less at 60 and 100%, respectively. In this study, an interaction between sow line and temperature was seen, and the sows reacted differently to changes in temperature. Another study showed that sow lines bred in tropical countries were more resistant to heat than lines bred in a temperate climate (The Netherlands). The more heat resistant sows had a higher feed intake at high temperatures than less heat resistant sows at the same temperature [9]. It will be possible to select for reduced thermal sensitivity, but the effects on feed intake will probably be small [9], [7], because of the already very controlled environment in farrowing units in the temperate climate zone (Denmark). The effects of heat stress on feed intake can also be decreased by different cooling techniques as, for instance, water drips, snout coolers [49], [13] and floor cooling [78]. Silva et al. [78] found that floor cooling increased the average feed intake during a 21-day lactation to 5.5 kg/d compared to 4.7 kg/d in sows without floor cooling. Body weight loss from parturition to weaning was decreased (6.9 vs. 12.2 kg) and piglet gain increased (264 vs. 200 g/d) with floor cooling, which indicates that the extra intake is partitioned towards milk production and thereby decreases the mobilization from body tissues.

4.3.5. Genetic selection for feed intake and breed effects

The common breeding objectives for sows do not focus directly on feed intake, but indirectly selection for traits related to feed intake may increase or decrease the intake capacity of the sow [22].

Kerr and Cameron [32] reported a large variation in feed intake in Large White sows after seven generations with selection for lean growth. The line bred to have a high lean growth rate had the highest feed intake compared to the line with lower lean growth rate. The same group found that sows bred for low feed intake during the growth phase had a significantly lower intake during lactation than sows selected for high intake during rearing. It is suggested that lactation feed intake depends on the difference between the actual body fatness of the sow at parturition and the potential fatness at parturition. The actual body fatness depends on the intake during gestation, while the potential fatness depends on the genotype [22]. A smaller difference between the actual and potential fatness results in a lower intake during lactation, which could explain why the sows selected for low feed intake during the growth phase had a low intake during lactation in spite of a leaner body. When compared to their genetic potential for body fatness, they were relatively fatter than the sows selected for high feed intake during rearing.

Several studies show that daily feed intake in lactating sows is a heritable trait with heritabilities ranging from 0.14 to 0.27, so the feed intake during lactation may also be changed by directly selecting for the feed intake trait [22], [7], [9].

4.3.6. Effect of parity

Very few studies have investigated how parity affects the daily feed intake. Inadequate feed intake is usually more pronounced in primiparous sows compared to multiparous sows. Primiparous sows have a smaller body size and thereby fewer body reserves to mobilize from. Besides the requirement for maintenance and milk production, these sows also need energy and nutrients for growth to reach mature size. Primiparous sows often have a lower milk production than multiparous sows because they are partitioning a greater part of the dietary energy and nutrients towards growth instead of milk production [60]. Body weight increases with increasing parity, and therefore multiparous sows have a higher requirement for maintenance.

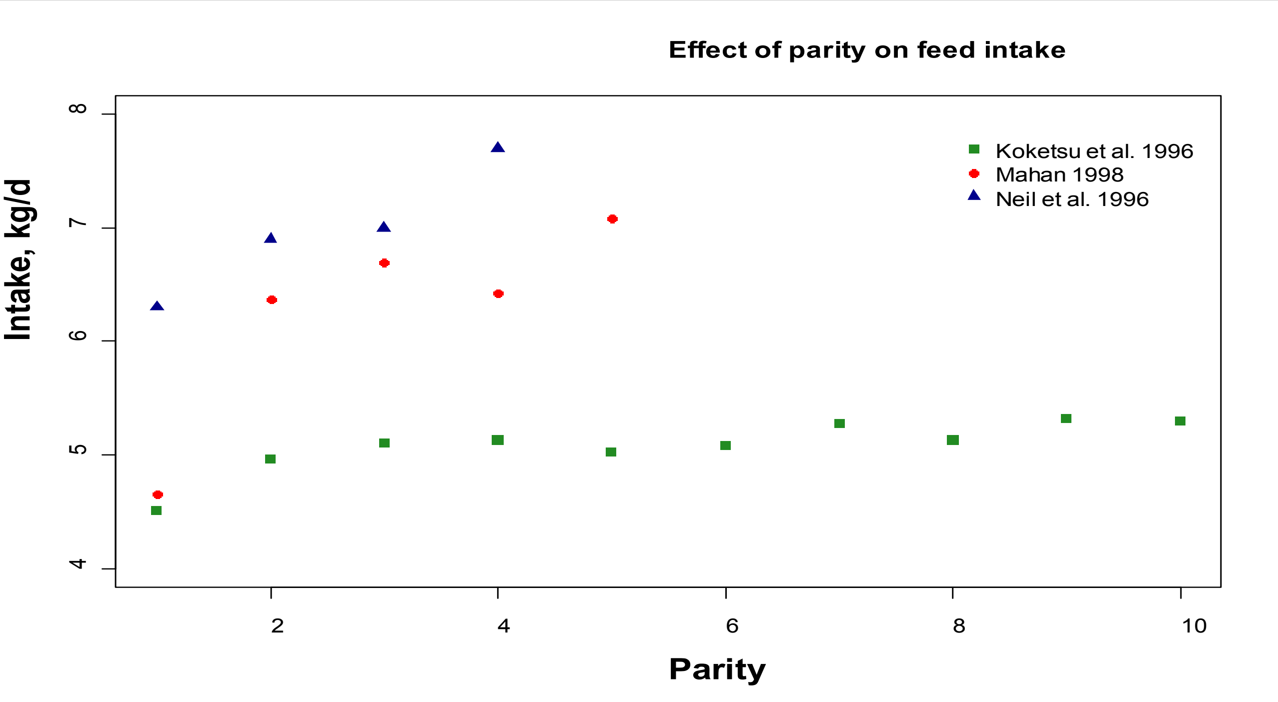

Figure 18.5. Results from three studies [35], [46], [54] showing the effect of parity on average voluntary daily feed intake (kg/d).

Generally multiparous sows have a higher voluntary intake during lactation than primiparous sows (Figure 18.5), but in most studies the increase is most pronounced from first to second parity [55]. Neil et al. [54] showed that sows fed a conventional diet ad libitum increased the intake from 6.2 to 7.8 kg/d with increasing parity from one to four. Koketsu et al. [35] demonstrated a similar pattern with increasing feed intake from 4.5 to 5.3 kg/d when parity increased from one to nine. The increased intake with increasing parity seems to be consistent with the increase in the requirement for maintenance [56], [36], but some studies [54], [53] indicated that the extra feed intake is higher than the additional requirement, which could explain why first parity sows often have a higher weight loss and higher occurrence of reproductive problems [55].

4.3.7. Feeding management and hygiene

As described above the palatability of the feed can play an important role for a sow's feed intake. The feeding method (e.g. dry or wet feed) can affect the feed intake, and many diets will be eaten in a greater amount if presented wet instead of dry. Feed refusals should be removed from the trough to ensure that the hygiene is good as old feed mixed with new feed may be unpalatable to the sow.

5. Weaning-to-oestrus interval

The interval from weaning to oestrus is important and the sow should be rebred as soon as possible after weaning, because the weaning-to-oestrus interval (WOI) represents a non-productive phase of the reproductive cycle. Generally, sows are in anoestrus during lactation, but will return to oestrus within 4-6 days of weaning. Some sows divert from this and come into oestrus during lactation, while other sows have very long WOI [62]. It is typically sows with a positive energy balance or sows nursing small litters that come into lactational oestrus.

5.1. Effect of lactational feed intake and body condition at weaning on WOI

During lactation, many sows turn catabolic and mobilize from body tissues to maintain milk production, because of an insufficient feed intake. This nutritional deficit may decrease plasma concentrations of insulin and IGF-1, which could have a negative effect on folliculogenesis and thereby affect the WOI and delay the return to oestrus [62]. There seem to be a connection between the body condition at weaning, which is related to lactational feed intake, and the return to oestrus.

King and Williams [33] investigated the effect of energy and protein intake during lactation on WEI. In the experiment, 68 Large White gilts were fed four diets with contrasting levels of energy and protein:

- Diet 1) high energy and high protein (HEHP),
- Diet 2) high energy and low protein (HELP),
- Diet 3) low energy and high protein (LEHP), and
- Diet 4) low energy and low protein (LELP).

Energy and protein intake for the four groups are shown in Table 18.7.

Table 18.7. Energy and protein intake, body weight and back fat thickness at weaning and weaning-to-oestrus interval of sows in a study by King and Williams [33].

	Diet 1: HEHP	Diet 2: HELP	Diet 3: LEHP	Diet 4: LELP
Daily intake of digestible energy, MJ/d	59.5	53.1	27.1	25.4
Daily intake of crude protein, g/d	745	302	550	318
Body weight at weaning, kg	142	121	118	113
Back fat thickness at weaning, mm	23.0	20.7	15.2	17.3
Weaning-to-oestrus interval, d	6.9	18.5	15.3	21.5

Diet 1) high energy and high protein; diet 2) high energy and low protein; diet 3) low energy and high protein; and diet 4) low energy and low protein.

All the sows had same body weight (167-172 kg) and back fat thickness (22.1-22.7 mm) one day before parturition, but because of different energy and protein intakes body weight and back fat thickness varied greatly at weaning (Table 18.7). The sows fed HEHP had a significant lower WOI than sows on the other three treatments (Table 18.7). It was concluded that both a high energy and protein intake was required to minimize loss of body tissues and WOI, because when either protein or energy intake was restricted, onset of oestrus after weaning was delayed [33].

Other authors [3], [38] also found an effect of lactational feed intake on WOI. In these studies, a low intake during lactation was associated with lower plasma concentrations of glucose, insulin, and a lower luteinizing hormone pulse frequency before weaning, which could be the reason for a prolonged WOI.

5.2. Feeding strategy

The effect of feeding during the WOI is thoroughly described in Chapters 16 and17. In Denmark, sows are generally fed 4.5 to 5.5 FU_{sow}/d in the WOI. In some herds, the feed level is gradually decreased from 7 FU_{sow}/d during the first 4-5 days post-weaning, and in other herds the feed intake is kept at same level from weaning to mating.

6. Water intake

The water intake is just as important as the feed intake for the general health and production of the sow [54], [37]. Water intake is closely related to feed intake, but only few studies have measured water intake in gestating and lactating sows.

Kruse et al. [39] showed that multiparous sows had a higher water intake than primiparous sows, and the intake slightly increased during late gestation. In this study, the water intake varied from 11 to 16 l/d. The water-to-feed ratio was not significantly affected by parity of the sows, but first, second and multiparous sows had an average water-to-feed ratio of 5.2, 6.5 and 8.5 L/d, respectively.

In another study by Kruse et al. [40] the water and feed intake in lactating sows was investigated. The average daily water intake was 27.5 kg/d, but the intake varied from zero to 69.5 l/d. Some of the variation could be due to water wastage. During lactation, the water intake was generally higher than during gestation, because milk production requires a lot of water. The average water-to-feed ratio was 4.9. Second parity sows had significantly higher water and feed intakes compared to first and third parity sows, and these sows also had higher piglet weaning weight, so they probably had a higher milk production.

Water quality and access is important to make sure that the sows eat, and access is particularly important when feeding dry feed as then the feed will in these cases not be a major source of water as it could be when feeding wet feed.

7. Modelling of feed intake curves

Mathematical modelling can be a very useful tool to predict or describe feed intake and get a better understanding of how feed intake changes during lactation.

7.1. The importance of knowing the feed intake

When formulating a diet for a specific sow herd or group of sows within a herd, it is important to have knowledge about the feed intake capacity in this specific group of sows, because the diet is formulated to contain certain concentrations of nutrients and energy, which should cover the requirement of that particular group of sows.

Energy and nutrient requirements can be calculated using a factorial approach. In this approach, the sum of requirements for maintenance, growth, and production (foetuses or milk) is the total requirement of energy or a given nutrient. The requirement for digestible protein is used as an example, but energy or other nutrients could also be used.

In Table 18.8 two cases for lactating sows are given, where the sows vary in litter size, milk production and feed intake capacity. The requirement for digestible protein varies because of the different milk production for low (case 1) and high (case 2) producing sows.

Table 18.8. Example of how knowledge about feed intake and protein requirement can be used to calculate the dietary protein concentration for lactating sows. Milk production and requirement for a sow in the third week of lactation.

	Case 1	Case 2
Litter size	8	13
Feed intake capacity, kg/d	8	8
Milk production, kg	8.1	13.4
Digestible protein requirement[1], g/d	540	880
Dietary protein (digestible) concentration, g/kg	78	126

1) Dietary digestible protein/ nitrogen is used for milk protein/ nitrogen with an efficiency of approximately 75%.

In these cases, it is assumed that the diet should cover the entire protein required by the sows. In case 1, the sow has a low milk production and a high feed intake capacity, so the dietary concentration of digestible protein is low compared to the sow in case 2 with a higher milk production.

7.2. Modelling feed intake in lactating sows

For lactating sows, it can be very useful to be able to describe the feed intake throughout lactation by generating a curve describing the intake on each day, because the intake changes from early to late lactation. The feed intake can be modelled or predicted in many ways depending on the nature of the data [41]. As an example, the daily feed intake data from a Danish study [26] in 48 high-prolific lactating sows fed semi ad libitum (with an upper limit of 2 FU + ½ FU for each suckling piglet) was modelled using a Mitscherlich function that has three parameters (ϕ_1, ϕ_2, ϕ_3):

$$\text{Intake, kg/d} = \phi_1 + (\phi_2 - \phi_1) \cdot \exp(-\exp(\phi_3) \cdot t)$$

Where t is the day in milk and the three parameters can be expressed as follows:

$$\phi_1 = 9.14 + 0.7 \cdot (LS - 11.3)$$

$$\phi_2 = 2.14 + 0.59 \cdot (LS - 11.3)$$

$$\phi_3 = -2.45 - 0.31 \cdot (LS - 11.3)$$

Where litter size (LS) was used as an input and LS of the sows in the dataset averaged 11.3. ϕ_1 is the maximum feed intake during lactation (the asymptote of the curve); ϕ_2 is the intake at day 1 postpartum; and ϕ_3 is a curvature coefficient. Figure 18.6 shows the individual feed intake (kg/d) for the sows and the fitted model for the entire group of sows.

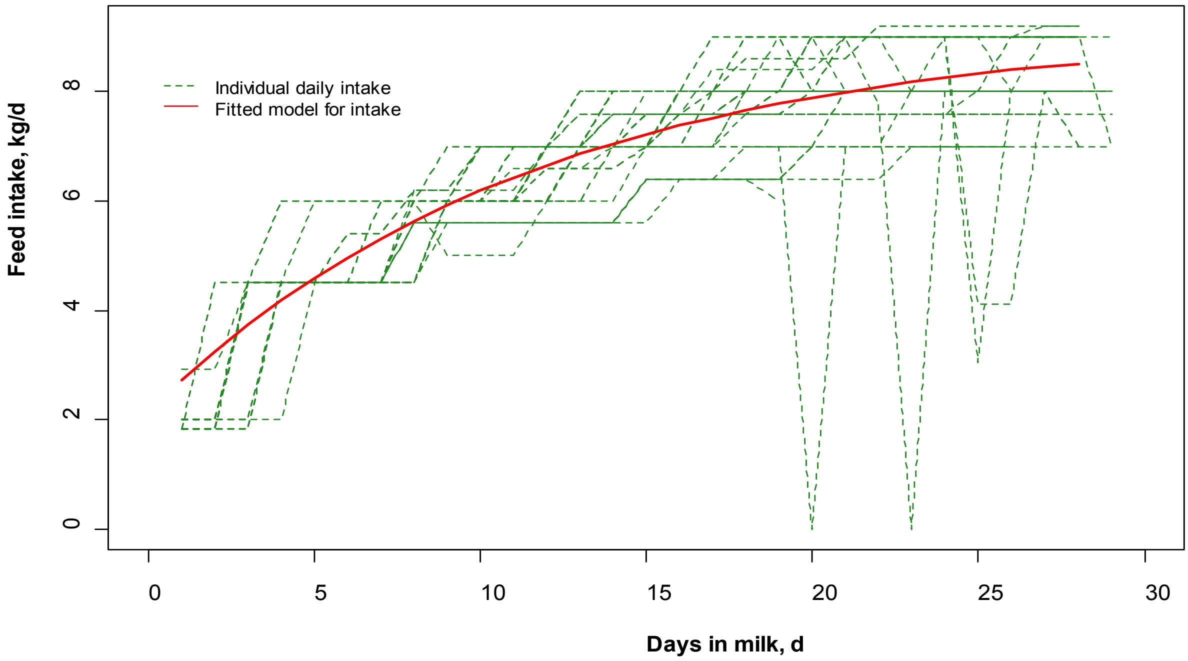

Figure 18.6.The green dashed lines are daily feed intake curves for 48 sows [26] and the solid red line is the Mitscherlich function fitted to the feed intake data.

In the example above, a function was fitted to the specific data, but the model could also be used to predict the feed intake curve for other groups of sows if it is assumed that the sows in this group have similar feed intake patterns. If it is used to predict intake of other sows, ϕ_1 and ϕ_2 are set to other values.

Figure 18.7 shows how the model was used to predict feed intake curves for sows with different intake on day 1 postpartum (ϕ_2) and different maximum feed intake (ϕ_1).

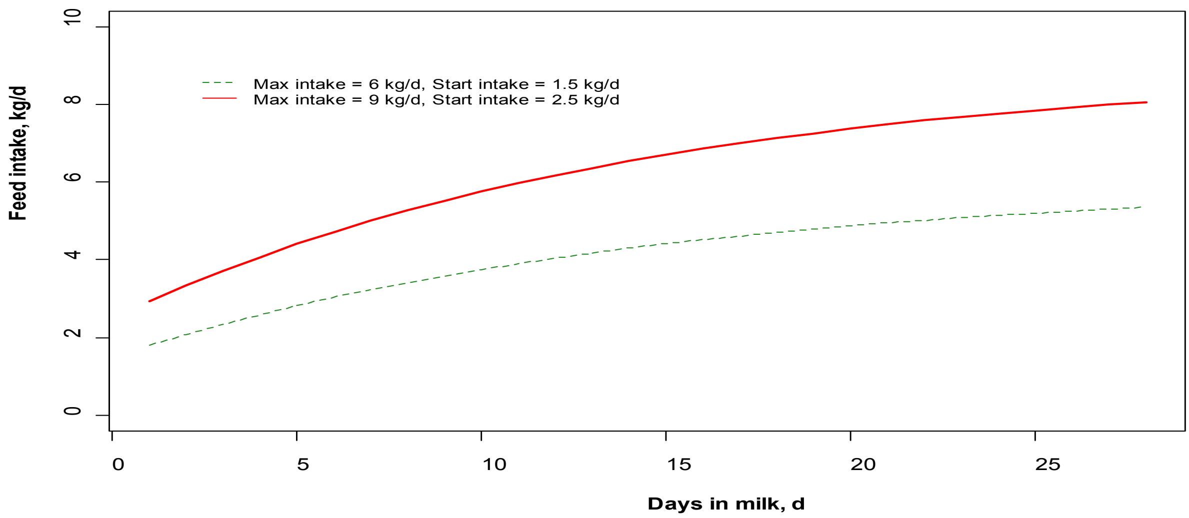

Figure 18.7.The Mitscherlich function fitted to the data from Hansen et al. [26] was used to predict feed intake curves by changing the maximum feed intake (ϕ1) and the start intake (ϕ2).

This is just an example of how a mathematical function can be used to model and predict a feed intake curve - in this case describing the maximum intake of a sow with a given litter size - but other functions could also be suitable depending on the nature of data. Prediction of feed intake in lactating sows can generally be difficult because the between-sow variation can be very large. This means that two sows with same BW and milk production can have very different feed intakes because of different potentials both for intake and body mobilization. Consequently, the model will only describe the average sow in a group.

8. Conclusion

Feed intake is very important in the reproducing sow, but the regulation of intake and satiety is highly complex. The factors affecting feed intake are physical (e.g. gut fill), chemical (e.g. hormones and blood metabolites), environmental (e.g. ambient temperature) and feed characteristic (e.g. energy density). During gestation, sows are fed restrictedly to avoid them becoming too fat; to avoid farrowing complications; and to ensure a high feed intake during the following lactation. Feeding high-fibre diets is a way of controlling body condition and reducing hunger in gestating sows. During lactation, sows are generally fed close to ad libitum to ensure a high milk production, high piglet growth and reduce body mobilization. During lactation, the sows can have difficulties ingesting enough energy and nutrients to cover the requirement, which emphasizes the importance of knowing the factors controlling feed intake to optimize the production and longevity of the sow and to develop new feeding strategies.

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