UNIVERSIDADE DE LISBOA

FACULDADE DE MEDICINA VETERINÁRIA

ELECTRONIC SOW FEEDING:
MAKING SENSE OF FEEDING DATA TO SUPPORT SOW MANAGEMENT

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Acknowledgements

I wish to express my sincere gratitude to Dr Maria Costa for the consistent guidance, for sharing her enormous knowledge and for trusting me to take part in several projects. Thanks to her, I was able to learn invaluable lessons, develop useful skills and meet amazing people, things I will never forget. Thank you for being an outstanding person.

I would also like to thank Dr Yolanda Vaz for co-supervising my internship and providing helpful contributions that helped me writing this dissertation.

Special thanks to teacher Telmo Nunes for introducing me to the exciting world of data analysis applied to veterinary epidemiology and without whom this project would not have been possible.

I would like to acknowledge the Erasmus+ programme which helped to fund my internship.

Many thanks to Teagasc for receiving me and to everyone I met through this organisation, who somehow contributed to the success of this project. Thanks to Edgar, Lorcan, Martyna and Thomas.

While in Ireland I had the great pleasure of meeting several people who very kindly welcomed me to this astonishing country. I wish to thank every one of them, especially Anna and Maria.

Finally, I must thank my family and friends, especially my parents, for the priceless support they gave me throughout this journey.

ELECTRONIC SOW FEEDING:
MAKING SENSE OF FEEDING DATA TO SUPPORT SOW MANAGEMENT

Abstract

This study aimed to address the knowledge gaps concerning how group-housed gestating sows interact with modern electronic sow feeding (ESF) stations and to explore the potential of data recorded by these systems to enhance farm management. ESF records of 276 sow-gestations, from a dynamic group of c. 120 individuals were investigated. Data was analysed to identify patterns in the use of feeding stations by animals, and associations between feeding patterns and reproductive performance.

Throughout the approximate 15 weeks that each sow spent on the dry sow house during a gestation, the total number of visits to the feeding stations varied greatly among individuals (367.7 ± 282.8) most of which were non-feeding visits (60.01 ± 19.8%). Feeding activity was highly concentrated within the first 12 h of feeding cycles (23 h) and sows ate their daily rations predominantly on a single feeding station visit (98.3 ± 1.7%).

A mixed effects model revealed a weak effect of time on the number of feeding station visits, and a negative relationship between parity and total number of visits ($b = -0.230$, $SE = 0.022$, $p < 0.001$). Sows kept feeding order relatively stable across gestation, especially among those who fed first. Additionally, results suggested that with every additional parity, the odds of a sow being among the first 15% group members to feed increased by a factor of 2.16 [OR: 2.16, $p<0.010$].

Statistically significant associations were found between feeding patterns and pre-weaning piglet mortality, but not with number of piglets born alive nor average birth weight. Median piglet mortality was lower for sows feeding last compared to those feeding first (4.5% vs 14.3%, $p = 0.025$) and with a middle position in the feeding order (4.5% vs 11.8%, $p = 0.045$). Individuals with a regular feeding time showed higher piglet mortality rates than those with moderately regular (14.3% vs 10.6%, $p = 0.029$) and irregular (14.3% vs 9.5%, $p = 0.047$) feeding times. Median piglet mortality was superior in fast feeding sows compared to those feeding slower (13.3% vs 9.1%, $p = 0.053$).

This work enhances current understanding of how gestating sows interact with ESF stations and highlights the potential of ESF data to support sow management.

Keywords: electronic sow feeding; feeding records; gestating sow; precision livestock farming; reproductive performance

ALIMENTAÇÃO ELETRÓNICA DE PORCAS: UTILIZAÇÃO DOS SEUS REGISTOS COMO SUPORTE AO MANEIO DA PORCA REPRODUTORA

Resumo

Em suinicultura, o sucesso dos sistemas produtivos é influenciado em larga escala pelo desempenho do efetivo reprodutor. O maneio alimentar assume, a esse respeito, um papel decisivo na performance reprodutiva a médio e longo prazos e deve ter presentes as diferentes necessidades de cada animal. A alimentação eletrónica permite que porcas gestantes sejam alimentadas de forma individual estando alojadas em grupos, conforme previsto na legislação europeia. Ao passo que a adoção deste sistema tem vindo a crescer ao longo dos anos, a valorização dos seus registos tem recebido pouca atenção. Não obstante, alguns estudos sugerem que a informação recolhida automaticamente pelas estações de alimentação eletrónica (EAE) pode constituir uma ferramenta de monitorização, capaz de fomentar o maneio individual da porca gestante.

Este trabalho visa enriquecer a compreensão do modo como as porcas em gestação em grupo interagem com EAE e avaliar a utilidade dos registos gerados por este sistema para apoiar o maneio da porca reprodutora. Para o efeito, analisaram-se registos de 276 gestações pertencentes a um grupo dinâmico de cerca de 120 porcas com acesso a duas EAE. A análise focou-se na identificação de padrões de utilização das EAE e no estudo de relações entre padrões de alimentação e performance reprodutiva.

Numa primeira fase, estudou-se, ao longo de cada gestação, a forma como variaram o número de visitas às EAE, as horas de alimentação, o tipo de visitas (alimentarares vs não alimentares), a ordem pela qual os animais se alimentaram durante cada ciclo de alimentação e o ritmo de alimentação (kg/min). De modo a avaliar de que forma o número de visitas não alimentares evoluiu com o decorrer da gestação e em função da paridade, recorreu-se a um modelo misto considerando o indivíduo como efeito aleatório e o número de visitas por ciclo como variável resposta. O mesmo modelo, baseado numa distribuição de Poisson, inclui a semana de gestação e a paridade como efeitos fixos. Relativamente à ordem de alimentação, determinou-se o número de vezes que cada indivíduo esteve entre os primeiros e os últimos 15% a se alimentar, identificando-se, posteriormente, as 18 porcas que se encontraram mais frequentemente em cada um destes dois grupos. Estudaram-se ainda, através de uma regressão logística, eventuais diferenças entre os referidos grupos, em termos de paridade, número de visitas às estações e ritmo de alimentação.

À investigação de padrões de alimentação sucedeu-se a classificação de cada animal, no que respeita à ordem de alimentação (primeiras 15%, últimas 15% ou posição intermédia), horário de alimentação (regular, irregular ou moderadamente regular) e ritmo de alimentação (rápidas ou lentas). Enquanto a classificação consoante o ritmo de alimentação teve por

referência a média do grupo, o critério utilizado para o horário de alimentação consistiu na percentagem de refeições consumidas num intervalo de 5 horas (hora média de alimentação ± 2,5 horas): superior a 90%, inferior a 70% ou entre estes intervalos, respetivamente. Os indivíduos pertencentes a diferentes classes foram comparados entre si quanto à performance reprodutiva, nomeadamente número de leitões nascidos vivos, peso médio à nascença e mortalidade pré-desmame (MPD) dos leitões. As diferenças entre indicadores foram analisadas da seguinte forma: para o número de leitões nascidos vivos e peso médio à nascença utilizaram-se testes de Kruswal-Wallis para a ordem de alimentação, análises de variância (ANOVA) para o horário de alimentação e testes de Wilcoxon para o ritmo de alimentação. As taxas de MPD foram comparadas com recurso a testes de Kruswal-Wallis para a ordem de alimentação e horário de alimentação e testes de Wilcoxon para o ritmo de alimentação.

No decurso das cerca de 15 semanas (104,8 ± 0,9 dias) que cada porca passou no parque coletivo (período correspondente a uma gestação), o número total de visitas às EAE variou amplamente entre indivíduos (367,7 ± 282,8) e a maioria dessas visitas foram do tipo “não alimentar” (60,01 ± 19,8%). A alimentação concentrou-se marcadamente nas primeiras 12 h dos ciclos de alimentação (23 h), com início logo após o começo de cada ciclo, e os animais ingeriram a ração diária predominantemente numa única visita (98,3 ± 1,7%) a um ritmo consistente (0,19 ± 0,03 kg/min).

Dada a escassa variabilidade entre indivíduos em relação ao número de visitas alimentares realizadas por dia, este aspeto não foi aprofundado. Em vez disso, estudou-se de que forma as visitas não alimentares variaram em número e horas. Através de um modelo misto foi possível observar um efeito fraco do fator tempo (semana de gestação) no número de visitas não alimentares às EAE ($b = -0,067$; $SE = 0,004$; $p < 0,001$) e uma relação negativa entre paridade das porcas e número de visitas realizadas ($b = -0,230$; $SE = 0,022$; $p < 0,001$). Por outras palavras, os animais tinham tendência a fazer menos visitas à medida que a gestação avançava e quanto mais baixa a paridade maior o número de visitas. Constatou-se ainda que as visitas não alimentares do grupo apresentaram uma forte concentração entre as 4 e as 8 horas da madrugada e durante a última hora dos ciclos de alimentação (15:00 - 16:00).

A ordem pela qual os animais se alimentaram manteve-se relativamente estável ao longo do período de estudo, sobretudo entre aqueles que se alimentaram primeiro. Os resultados indicam ainda que por cada paridade adicional, a probabilidade de uma porca estar entre as primeiras 15% do grupo a alimentar-se aumenta 2,16 vezes [OR: 2,16; $p < 0,010$]. Contrariamente à paridade, o número total de visitas e o ritmo de alimentação não diferiram de forma significativa entre os primeiros e os últimos indivíduos a se alimentar. Para além disso, observou-se que enquanto as primeiras 18 porcas na ordem de alimentação

consumiram a ração diária nas primeiras 2 horas do ciclo de alimentação (17:00 - 19:00), as últimas 18 fizeram-no em horário noturno, exibindo um pico de atividade alimentar às 5 horas da madrugada.

Alguns padrões de alimentação demonstraram associações estatisticamente significativas com a MPD dos leitões. A MPD mediana foi inferior nas porcas que se alimentaram em último lugar em comparação com aquelas que o fizeram primeiro (4,5% vs 14,3%; p = 0,025) e com uma posição intermédia na ordem de alimentação (4,5% vs 11,8%; p = 0,045). Os indivíduos com um horário de alimentação regular apresentaram uma MPD superior àquela dos que tiveram um horário moderadamente regular (14,3% vs 10,6%; p = 0,029) e irregular (14,3% vs 9,5%; p = 0,047). A MPD mediana foi superior nas porcas que se alimentaram rapidamente relativamente às que o fizeram de forma mais lenta (13,3% vs 9,1%). Em contrapartida, não foram encontradas diferenças significativas no número de leitões nascidos vivos nem no peso médio à nascença de porcas com diferentes padrões de alimentação. As diferenças relativas às taxas de MPD observadas podem resultar do stress social, associado à competição pela entrada nas EAE, a que algumas porcas terão estado expostas, de forma constante, ao longo da gestação.

Os resultados confirmam a existência de padrões de alimentação em EAE e contribuem, nesse sentido, para reforçar a ideia de que o valor da alimentação eletrónica para porcas gestantes não está limitado à sua capacidade em proporcionar uma alimentação individual. O estudo permitiu elucidar alguns aspetos do modo como as porcas gestantes utilizam as EAE e realçou o potencial dos registos de alimentação eletrónica para enriquecer o maneio individual da porca reprodutora.

Palavras-chave: alimentação eletrónica de porcas; registos de alimentação; porca gestante; zootecnia de precisão; performance reprodutiva

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List of abbreviations

AST - Antimicrobial Susceptibility Testing

BCS - body condition scoring

DGAV - Direção-Geral de Alimentação e Veterinária

EAE - estações de alimentação eletrónica

ESF - electronic sow feeding

EU - European Union

FB - feeding behaviour

h - hour

ID - identification

IUHS - in utero heat stress

kg/min - kilograms per minute

LPS - lipopolysaccharide

MPD - mortalidade pré-desmame

NFV - non-feeding visit(s)

OR - odds ratio

PF - precision feeding

PIC - Pig Improvement Company

PISC - Primary Industries Standing Committee

PLF - precision livestock farming

PWM - pre-weaning mortality

RP - reproductive performance

SD - standard deviation

SE - standard error

1. INTRODUCTION

The nature and objectives of pig production have been changing over the years (Whittemore 2006a). Following the end of World War II, a shift from small sized extensive farms towards large-scale intensive units was observed, as a result of ever-increasing demands for animal protein. Consequently, for several decades sows were maintained in individual crates during most of their lives. As concerns about animal welfare emerged throughout the years, some countries banned gestation crates, thereafter demanding gestating sows to be housed in groups. This requirement was harmonized across the European Union (EU) with the implementation of Council Directive 2008/120/EC - laying down minimum standards for the protection of pigs - which took effect in 2013.

While group-housing gestating sows improved their welfare standards, namely the freedom of movement, the aggressive interactions necessary to establish hierarchies within each group gave rise to divergent opinions. Likewise, providing individual attention to animals became less practical, especially in large herds. This trade-off assumes particular relevance when considering the high extent to which these animals can influence the success of a pig production system, along with the importance of having full focus on feeding management of each individual. Thankfully, the development of electronic sow feeding (ESF) systems has contributed to overcoming these issues, by ensuring that every sow is housed in a group but fed and monitored as an individual.

Even though the adoption rates of ESF have increased over the years, little attention has been given to the potential that records automatically generated by these systems have to provide useful information to enhance farm management. In addition to this, current knowledge on how animals interact with modern ESF stations is based on very limited data. Understanding this interaction by identifying patterns is of interest, as monitoring for deviations from such patterns may be a powerful tool to detect disease, oestrus, reproductive and other problems. The aim of this work was 1) to investigate the existence of patterns in the use of ESF stations by sows, and 2) to study relations between feeding patterns and reproductive performance, using data retrieved from an ESF system.

2. INTERNSHIP REPORT

The main part of the curricular internship took place in Ireland at the Animal and Grassland Research and Innovation Centre of Teagasc - Agriculture and Food Development Authority, from January 13th to May 29th, 2020. Prior to that, a 14-week internship was undertaken at the Faculty of Veterinary Medicine - University of Lisbon, from September 9th to December 18th 2020, under the guidance of Professors Telmo Nunes and Yolanda Vaz. During that period, in Lisbon, R programming skills were acquired by carrying out several data handling tasks. These were primarily focused on statistical data analysis, data transformation and data visualization, in the context of veterinary epidemiology and included:

- Describing the Portuguese national pig herd in terms of farm production system, herd size, housing conditions and geographical distribution;
- Contributing to the testing and implementation of a new pig health and movement management informatic system;
- Studying the effects of climate change in mortality of pigs;
- Cooperating with the Portuguese veterinary services (DGAV), as part of a project regarding an official antimicrobial resistance surveillance system, where the resistance profiles of different species to different substances were analysed and graphically represented on a shiny application.

In Ireland, a wide range of activities were followed concerning pig health and welfare and pig management, both on farm and at slaughter, under the supervision of Dr Maria Costa. This included accompanying the daily events on a pig farm, where clinical cases were discussed, practical training was received on euthanasia, necropsy and farm biosecurity assessment, as well as participating in ongoing investigation projects. The latter involved visiting multiple farms and slaughterhouses, collecting faecal samples on farm and colon and caecum samples at slaughter, hence practicing in sample harvesting, handling and preservation. Further tasks included laboratorial processing of the samples for microbiological culture, isolation and AST analysis of *E. coli* and *Salmonella*.

Topics related to pig health and husbandry and farm management were discussed on regular meetings with the supervisor. Moreover, several scientific papers with relevance to the dissertation were presented and other pig related scientific articles were discussed on a weekly Journal Club. Additional training was received on data management, with particular emphasis being given to data retrieved from Electronic Sow Feeding systems and their value as a Precision Livestock Farming component. Following the onset of a national lockdown, work was carried on remotely, from March 13th until the end of the traineeship.

3. LITERATURE REVIEW

3.1. Modern intensive pig production

3.1.1. Role of the sow

One of the main factors responsible for improving pig production efficiency has been the increase of average litter size (Baxter et al. 2013; Quesnel et al. 2015). Following the introduction of hyper-prolific breeding lines, obtaining litters exceeding 15 piglets born became a common scenario in many countries (Friendship and O'Sullivan 2015; Quesnel et al. 2015). For example, this increased sow output brought the average number of piglets weaned per sow per year from 27.2 in 2009 to 33.3 in 2017 in Denmark (SEGES 2018) (Figure 1). In Ireland, the average number of pigs produced per sow per year evolved from 23.9 in 2010 to 26.8 in 2019 (Teagasc 2011, 2020).

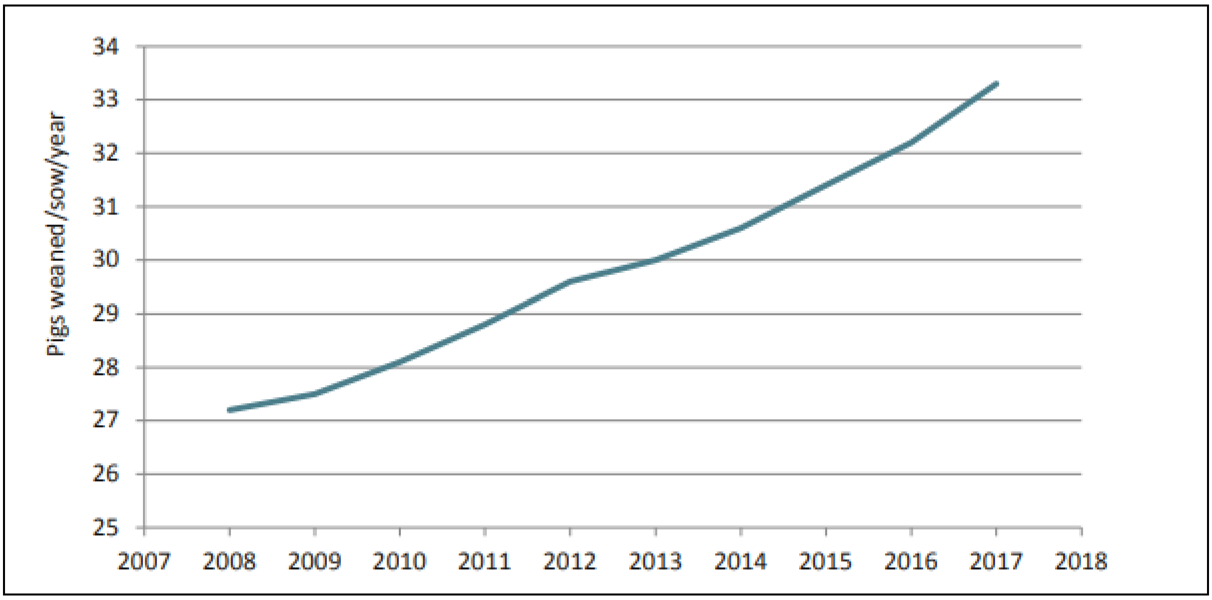


Figure 1. Evolution in the efficiency of sows in Denmark expressed as weaned pigs/sow/year (Source: SEGES 2018).

Likewise, the performance of a (breeding) pig herd is often evaluated based on indicators which directly involve the sow (Whittemore 2006b; Gaines et al. 2012), where a positive correlation between farm productivity and sow longevity has been demonstrated (Anil et al. 2008; Sevilla et al. 2009). Poor herd management often results in sows being replaced by gilts at a higher rate than that of an economically sustainable system (Gaines et al. 2012). Aside from the direct costs and sanitary risks that arise from such replacements, gilts produce smaller litters and their progeny are less efficient and have higher mortality rates and disease susceptibility compared to sow progeny (Miller et al. 2008; Craig et al. 2017).

From a sanitary point of view, the position of the sow as the starting point of the production chain makes it a key element regarding disease control and prevention. Vaccination of reproducing females, aimed at increasing passive immunity or decreasing embryo or foetal losses, is a common strategy to mitigate the spread of several diseases and maximize herd performance (Matías et al. 2017).

The success of a pig production system relies greatly on performance of the breeding herd and that might explain why the sow can be referred to as the most valuable animal on the herd (Schenck et al. 2008). It is therefore of utmost importance that close attention is paid to these individuals during all stages of production, including breeding, gestation, farrowing and lactation. However, the intensive nature of modern production poses a significant challenge for individual sow monitoring, especially with European legislation requiring sows to be group-housed from four weeks after service until a week before farrowing (Council Directive 2008/120/EC).

3.1.2. Feeding management of the gestating sow

As a consequence of larger litters, sows need to be fitter and high performing to endure longer farrowing processes and to nurse their offspring. For this reason, it is paramount to have full focus on their nutrient requirements. Due to the close relation between all stages of the reproductive cycle, sow feeding not only affects current performance but will influence long-term productivity (Stender 2012; Trottier et al. 2015). In fact, even small nutritional deficiencies should not be overlooked considering the cumulative effect they can have on herd performance (Trottier et al. 2015). Despite this, sow feeding remains a subject of great debate and with a vast potential to improve production efficiency (Goodband et al. 2013).

An adequate gestation feeding program is one which fulfils the sow’s nutritional demands, allowing for optimal development of the conceptus while preparing the sow for the upcoming lactation (Aherne 2006), and prevents excessive body weight gain and fat deposition (Meunier and Bolhuis 2015). The latter is usually accomplished by providing the animals with a restricted amount of feed, that is, a fraction of their potential voluntary feed intake (Trottier et al. 2015; D’Eath et al. 2018).

Overfeeding during gestation is associated with decreased lactation feed intake, increasing tissue catabolism and impairing future reproductive performance (Trottier et al. 2015), as well as excessive fat accumulation in the mammary glands which compromises milk and colostrum production and litter growth (Woodworth 2007). Further implications include farrowing difficulties, lameness and higher culling rates (Trottier et al. 2015; D’Eath et al. 2018).

Moreover, in addition to the direct feed costs involved, an increased body weight implies higher nutritional requirements (Trottier et al. 2015), raising feed costs.

Recent studies questioned whether increasing feed intake in late gestation could result in better litter performance. A literature review by Goodband et al. (2013) revealed lack of evidence supporting this theory, presenting several studies in which raising the feeding level in late gestation had no significant outcome with regard to litter performance. An equally important matter, especially under restricted feeding conditions, is making sure every sow eats her daily feed allowance, avoiding maternal undernutrition and subsequent repercussions (Trottier et al. 2015).

Considering the aforementioned, regular monitoring of body condition and body weight should be central elements to a sow herd management protocol. Most farms, however, lack the necessary conditions to weigh sows (Aherne 2006), relying on visual inspection of body condition score (BCS) to adjust feeding level. Indeed, Young et al. (2004) found no differences on lactation performance between sows fed according to target body weight and those fed simply based on visual inspection. In this study, while the results showed that the more targeted approach managed to reduce the incidence of overweight sows, only a single production cycle was studied meaning that any long-term treatment effects on reproductive performance, such as weaning-oestrus interval, were not reported.

Considering how nutritional requirements vary according to gestation phase and parity (Trottier et al. 2015), a feeding program using the same feed across all gestation is not the most suitable, although practical from a management standpoint. Thanks to the development of modern feed delivery systems, this issue can be overcome, and parity segregated phase-feeding programs may benefit sow feeding management in the future (Trottier et al. 2015).

3.2. Precision livestock farming

A major consequence of intensification of livestock production is that, in comparison to the last decades, farmers now have to look after a much larger number of animals. The resulting higher animals per stockperson ratio poses a significant challenge for modern production, given the reduced time available to care for each animal, which conflicts with society’s pressure to provide individual animal attention (Guarino et al. 2017). These and other production related concerns, such as animal health and welfare and environmental issues, gave rise to the development of automated monitoring systems, which are part of a tool generally known as precision livestock farming (PLF) (Figure 2).

Mostly developed for pigs, poultry and dairy cattle (Stevenson 2017), PLF technology takes advantage of sensors to carry out continuous automated monitoring of animal productivity, health and welfare, providing farmers with real-time accurate information to support daily management decisions (Kamphuis et al. 2015). On-farm sensors can gather simple but valuable measures like feed intake or body weight, without requiring any labour, and they can be centred on either the animal or its surrounding environment. More sophisticated approaches collect and analyse image, sound, accelerometer data, temperature measurements, etc. A great advantage of many PLF applications is their potential to generate early warnings when measurements fall outside pre-defined ranges, enabling rapid problem detection and resolution (Tullo et al. 2019).

With a view to optimizing labour costs, a system that is fully automated is preferred. Furthermore, by not requiring animal handling, automation prevents disease spread while avoiding human error (Berckmans 2017). Because some animal responses can be very fast and/or sporadic, like oestrus behaviour, monitoring devices should collect information on a continuous way, thus avoiding data gaps (Berckmans 2017) and generating big amounts of precise data, otherwise unattainable by any human observer (Berckmans 2015).

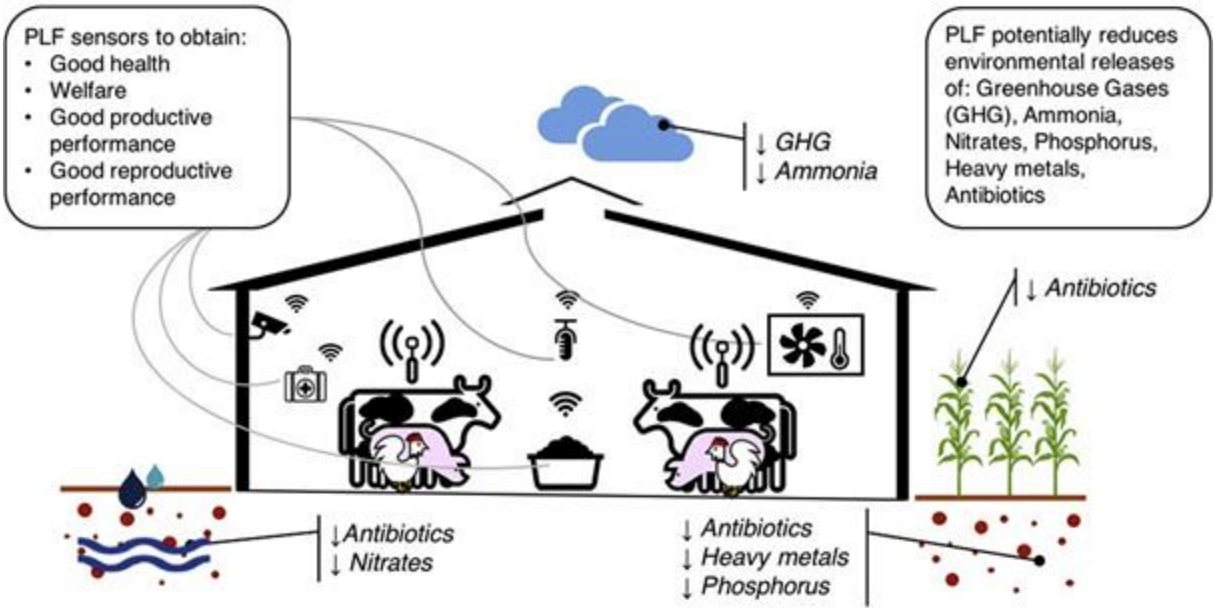


Figure 2. Example of how PLF can be incorporated in food production systems (Source: Tullo et al. 2019).

Among the main focus areas of PLF applications, animal health and welfare monitoring have received a great deal of attention. One example is the use of pedometers for measuring activity of dairy cattle, widely adopted in some countries (Steeneveld and Hogeveen 2015). These devices, usually attached to a leg band or neck collar, record indicators such as number of steps or lying time, described as pedometric activity, which not only differ between healthy and sick individuals but may also work as an early indicator of lameness (Mazrier et al. 2006; Shepley et al. 2017) and heat detection tool (Galon 2010). More specific biomarkers can be analysed when monitoring for a particular group of diseases. For instance, sound monitors, which are able to detect cough when coupled with sound analysis systems, have been shown to accurately assess porcine respiratory health (Hemeryck and Berckmans 2015) and predict lung lesions at slaughter (Pessoa et al. 2020).

Another purpose of PLF is to reduce farmers' dependence on human labour (Berckmans 2015). Otherwise time consuming and labour-intensive tasks like weighing animals or distributing feed can be performed by fully automated and precise systems. Furthermore, a lower labour demand combined with an increased production efficiency result in increased farm profitability. These economic benefits are supported by several studies (Kamphuis et al. 2015; Steeneveld and Hogeveen 2015), but are frequently underestimated due to lacking of data on PLF day-to-day integration and use in the routine management of livestock farming.

Even though PLF applications are not conventionally developed to directly minimize the environmental load of animal production, there is great potential for this modern technology to increase the environmental sustainability of animal production systems (Tullo et al. 2019). Although literature on this issue is not abundant, farm ventilation control as a mean to reduce NH3 emissions or precision feeding, meeting the animal's nutritional requirements at each stage of its development, among others, have been suggested as effective tools to increase environmental sustainability of animal production (Tullo et al. 2019). Perhaps a more relatable example is, for instance, the lower and more directed use of medication to treat sick animals in each individual pen as opposed to medicating the whole batch. This is made possible through real time and directed management systems, thus reducing antibiotic use and mitigating the threat of antimicrobial resistance.

While increasing attention has been given to PLF as an emerging and necessary research field, adoption rates by farmers are still low (Halachmi et al. 2015; Kamphuis et al. 2015). The lack of perception of its practical and economic value seem to justify this tendency (Kamphuis et al. 2015). In fact, a system that generates large quantities of accurate data will only serve the farmer if these data can be translated into management supporting actions. High investment costs, use licenses, and absence of clear cost-benefit data are additional unappealing factors (Kamphuis et al. 2015). Moreover, in many family-owned farms old farming facilities can be a limiting factor for PLF implementation along with other factors like farmer's age and education level. Nevertheless, PLF has been shown to give added value to the livestock industry, providing farmers with a wide range of efficient management enhancing tools (Kamphuis et al. 2015). Vranken and Berckmans (2017) have also suggested that PLF is the only realistic way to support livestock production in the foreseeable future.

3.2.1. Precision feeding

Feeding costs are a major concern, especially in the pig industry where they account for 60% - 75% of total production costs (Pomar et al. 2019; Thomas et al. 2020). Over the last decades, the improvement of pig production efficiency was possible, in part, thanks to new insights on animal nutrition and growth (Whittemore 2006a). For some of these findings, however, implementation at farm level can be difficult. On the other hand, several examples of modern technology-based approaches, under the designation of precision feeding (PF), have demonstrated how PLF can be a promising tool towards better meeting individual nutritional requirements and maximising growth, benefiting both animals and the environment (Tullo et al. 2019).

As an animal grows, its nutritional demands will vary, forcing farm managers to adapt feeding strategies throughout the production cycle. Accordingly, growing pigs are normally kept in fairly homogenous groups, in terms of growing phase, and the same feed is used within each group (phase) (Andretta et al. 2016). This practice is referred to as phase feeding. Although far from ideal, this strategy contributes for a more efficient use of feed (Hazzledine and Whittemore 2006), and the reduction of feeding costs. The main downsides here are overfeeding and the fact that individual requirements can vary considerably within a group, not to mention the farm logistics (i.e. number of silos) necessary to supply many different diets from weaning to slaughter.

An automatic feeding system that promotes optimal growth of every animal involves estimation of each individual’s nutritional demands, which, as already mentioned, vary continually. In an attempt to overcome these issues, advanced feed delivery systems able to estimate real-time individual requirements (through body weight gain and feed intake) were developed for growing-finishing pigs (Pomar et al. 2019; Pomar and Remus 2019). Further knowledge on animal growth and nutrition, as well as developing more practical and accessible systems, are necessary to enhance these PF applications and encourage their on-farm adoption. Similar applications for gestating sows have been in place for a longer time.

Although still an emerging topic, PF is regarded as a promising way of minimizing the environmental impact of livestock production (Tullo et al. 2019; Pomar and Remus 2019). Improved feed efficiency results in lower nutrient excretion, reducing water pollution, and decreased greenhouse gas emissions. By promoting a better use of costly resources, PF is able to convert livestock farming into a more sustainable activity from both environmental and economic standpoints.

3.2.2. Feeding behaviour monitoring

The study of animal feeding behaviour (FB) has taken place over the past five decades on account of its contributions to animal performance, nutrition, health and welfare (Maselyne et al. 2015; Andretta et al. 2016) with continuous automated monitoring devices facilitating the collection of high-quality data at farm level. Among the main studied FB variables are feed intake, feeding time, time spent feeding, feed consumption rate, feeder occupancy rate and number of feeder visits.

Some of these variables are influenced by health status, especially in the early stages of disease (Maselyne et al. 2015). Reduced feed intake, for instance, may indicate illness and/or inadequate housing conditions, such as excessive heat, insufficient water supply, very high stocking densities and improper feeding system. Applications that record individual feed intake can therefore be of great value for farmers. González (2008) investigated the value of FB monitoring as an early indicator of disease in dairy cows. The authors reported that time spent feeding decreased prior to confirmation of ketosis and lameness, while feeding rate increased before lameness was diagnosed. They recognize time spent feeding as a superior indicator in terms of on-farm application.

FB of growing pigs was recently studied in its relation to growth performance and carcass characteristics (Carcò et al. 2018). Pigs with higher feeding rates had better performance on both studied variables, but not on feed efficiency, compared to those eating slower, suggesting that selection for this trait can be advantageous. A study concerning tail biting influence on FB of growing pigs, fed *ad libitum*, suggests that an outbreak can be predicted by a decreasing number of feeder visits up to nine weeks before the event (Wallenbeck and Keeling 2013), despite the highly multifactorial nature of the disease. This variable can also be used to evaluate how severely a disease affects an animal, as concluded by Brown-Brandl et al. (2013).

When analysing different studies involving feeding variables, it is imperative to be aware of the strongly varying conditions between experiments (diet composition, housing conditions, feeding system, between-animal differences, genetics, etc.), before generalizing results (Wallenbeck and Keeling 2013). Another relevant aspect, regarding pig production, is that advanced feeding systems which monitor and treat animals at an individual level do not yet represent the reality of commercial farm production. Exceptions to this are gestating sow herds, for which more sophisticated feeding systems have been adopted, as will be discussed later.

3.2.2.1. Feeding order

When raised under certain feeding systems and management conditions, animals develop feeding orders. This is the case for group housed sows and cattle individually fed through electronic stations where animals sharing the same space outnumber feeding places (Spoolder and Vermeer 2015; Kelly et al. 2020). Some authors studied the feeding order of sows throughout gestation and concluded it was not random nor fixed, but rather relatively stable (Edwards 1988; Hunter 1988; Chapinal et al. 2008). Additionally, correlations between feeding order and parity (Hunter et al. 1988; Strawford et al. 2008) and social rank (O'Connell 2003; Chapinal et al. 2008) have been reported with younger and low-ranked individuals being among the last group members to feed.

The daily feeding order of sows can be recorded by automatic feeding stations and some authors have investigated whether this information could be useful to monitor an animal's health status. Kratz et al (2013) followed 150 sows over two weeks and observed that animals feeding within the last decile of the feeding order were more likely to be lame and present skin lesions, in comparison with the rest of the group. Authors suggested that determining the time it takes for 90% of a sow herd to feed can help to detect group members in need of special attention among the last 10% of sows to feed.

Hinrichs and Hoy (2011) compared the position in the feeding order of non-medicated sows and medicated sows on the day of treatment, reporting the latter to feed later. Such results resemble those of a study by Littooij and Butterworth (2018) regarding the milking order of dairy cattle. Cows with a higher medical treatment history entered the milking parlour later than those less frequently treated. Cornou et al. (2008) proposed using sow feeding order monitoring as a tool to automatically detect oestrus and health disorders. Their method, based on individual feeding behaviour modelling, showed a detection sensitivity ranging from 59% to 75% for oestrus and from 0% to 75% for health disorders, despite the high number of false alarms.

3.2.3. Electronic sow feeding

The transition from individual stalls to group housing facilities during gestation, legally required in Europe since 2013 (Council Directive 2008/120/EC), several US states (Pairis-Garcia 2016) and Australia (Primary Industries Standing Committee [PISC] 2008), has fostered the development of new feeding systems able to accommodate the individual needs of every sow within a group. Among them, electronic sow feeding (ESF) has made it possible not only to feed sows at an individual level but also to monitor feeding behaviour and to decrease human labour, while ensuring adequate levels of herd performance and animal welfare (Brooks 2003; Spoolder and Vermeer 2015). An ESF system consists of one or more computer-controlled feeding stations, capable of automatically identifying and delivering a predetermined amount of feed to one animal at a time. Feeding level can thereby be set to vary between individuals and throughout gestation of each individual.

Systems used nowadays are the result of decades of improving the first models developed in the early 1980s (Brooks 2003, Olsson et al. 2011). Consequently, modern ESF stations are fully protected and equipped with entrance and exit gates, allowing each user to feed without being disturbed by other group members (Figure 3). Upon approaching an available station entrance, a sow is identified through a transponder usually carried in an ear tag and, once inside the feeding station, the entrance gate is locked. A restricted amount of feed with or without water is then dispensed on a bowl or trough and the animal is given a certain amount of time to feed. Having finished feeding, the sow leaves the station by a forward exit making it accessible for another individual.

ESF systems are set to work according to consecutive 24 h cycles, each comprising a period shorter than or equal to 24 h, commonly called feeding cycle, during which feeding stations can be accessed. Over the course of a feeding cycle, animals can get their allotment from a feeding station in an unlimited number of feeding station visits. Not only can a sow eat its allotment in several visits, but it can also do it in different ESF stations, if present in the pen, as every station is controlled by the same computer. Once a sow has consumed its ration, it will not be provided additional feed before the subsequent feeding cycle, despite still being able to go through the feeding station.

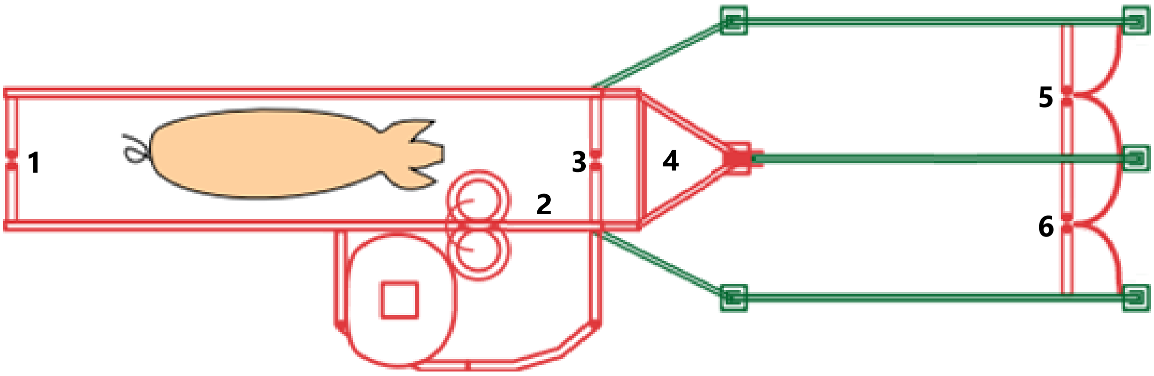


Figure 3. Example of a modern electronic sow feeding station (adapted from: Automated Production [Internet]).

Legend: 1 - Entrance gate; 2 - Retractable feed bowl; 3 - Intermediate gate; 4 - Sorting area; 5 and 6 - forward exit gates

Although suited for a wide range of group sizes, ESF is frequently used for large groups that may reach 500 individuals (Spoolder and Vermeer 2015, Pedersen 2018), in which case multiple stations are placed in the pen. The number of sows per feeding station should consider the time it takes each animal to feed along with station revisits performed by sows who have already eaten their allotment. Different sources indicate capacities of 40 to 60 sows (Spoolder and Vermeer 2015) and 70 sows (Algers 2012; Pedersen 2018) per feeding station. Some companies even advertise models capable of feeding up to 80 individuals. Feeding station capacity, however, is influenced by station settings and design as well as pen layout (Brooks 2003, Olsson et al. 2011).

While numerous companies keep improving ESF stations as the market for this technology expands, different models share some essential aspects in terms of station design. In modern stations, a sow is totally protected from other group members while inside the station and walks out through a forward exit gate, as opposed to the older unprotected and back-out exit models which led to more aggressive encounters. Animals should be given the option to eat their allotment in more than a single visit and enter an available station at any time during a feeding cycle, regardless of whether or not they have finished their ration, according to Brooks (2003). The same author suggested that the feeding bowl or trough should remain inaccessible once a sow finishes its' allotment until the next cycle. This would inform the sow it will not get additional feed and another individual would be able to soon enter the station. This feature promotes a lower total number of station visits, hence allowing more members to feed and contributing for a quieter environment. An additional option to reduce feeder activity is the installation of physical barriers preventing sows to (re)enter feeding stations immediately after having exited them (Brooks 2003).

The precision feeding attributes of ESF go beyond defining the feed allowance of each feeding cycle for every sow. Although rarely reported, automatic animal weighing (Thomas et al. 2018) and blending of different diets are available with some models. Further settings make it possible to determine the amount of feed dropped at a time as well as the interval between consecutive feed droppings, during each station visit (Olsson et al. 2011). The combination of these two variables will set the available time each animal has to feed, therefore influencing station capacity. The time of start and the duration of feeding cycles can be changed. For example, setting a cycle to start at late afternoon may result in most sows having fed by the next morning when animal manipulations take place (Brooks 2003). A remarkably useful function of many ESF systems is automatic sorting of specific individuals to a separate pen by means of a sorting gate, located after the feeding bowl (Spoolder and Vermeer 2015). This facilitates selecting animals for vaccination, pregnancy scanning, inspection, treatment, culling or for drafting sows due to farrow. An alternative setting capable of serving the same purpose is the automatic colour marking of selected sows with spray markers integrated in feeding stations (Brooks 2003). This is common in farms without a sorting pen.

Being a sequential feeding system (only allows one animal to feed at a time), ESF gives rise to some level of competition over access to feeding stations which represents the main limitation of this feeding system. Aggressive interactions are frequent among sows queuing at the entrance of a station (Jensen et al. 2000, Olsson et al. 2011) and, as a result, the prevalence of vulva lesions may be high for sows fed through this system. Mitigation strategies include adopting the already mentioned measures to reduce feeder activity along with providing straw as bedding material and setting the feeding cycle to start late in the evening (Jensen et al. 2000, Brooks 2003). Prior to start using an ESF system, individuals have to be trained (Spoolder and Vermeer 2015). This usually takes place on a separate pen with a training station for gilts.

3.2.3.1 Feeding behaviour monitoring

Besides enabling high control over individual feed intake, ESF enables individual FB monitoring through continuous recording of real time data concerning each feeding station visit, namely animal identification, time and length of visit and feed intake. The ESF computer software generally provides a daily list of animals which have not fed (Cornou et al. 2008) which, as mentioned earlier, can be a powerful management supporting tool. Other information to be retrieved from ESF systems are feeding order, preferred time of feeding, feed consumption rate and number and type (feeding or non-feeding) of station visits. These are seldom used.

Cornou et al (2008) studied several groups of sows, both dynamic and static, from three herds with approximately one ESF station per 60 sows, over a one-year period. In every herd the vast majority of sows ate their daily allotment on a single visit and most visits registered at feeding stations were non-feeding visits (NFV). Similar findings had been reported by Sollested (2001) regarding two dynamic groups of around 150 individuals with access to either two or three ESF stations each, whose records were analysed across three consecutive 70-day periods. With the aim of investigating how ESF settings influence sow interactions and agonistic behaviours' prevalence at feeding stations, Olsson et al (2011) studied three sow herds each with different ESF capacities. In all three situations, one third of the sows queuing at the entrance of a feeding station had already eaten their daily ration, while approximately one third of feeding visits were preceded by attacks directed to the sow entering the station. Authors also reported that over 50% of ESF visits were NFV and, when comparing different station settings, the herd with the highest ESF capacity had greater numbers of sows queuing and severe vulva lesions.

Since animal interaction with ESF is influenced by station settings and design along with group composition and management factors, monitoring FB helps estimating the degree of suitability of the feeding system for a particular sow population. In spite of this, little research has been published describing sow FB under modern ESF systems. Even though experimental conditions may vary significantly among studies, these reports are crucial to better understand animal interaction with ESF and how this can be enhanced, with a focus on improving individual sow care and productivity.

4. ELECTRONIC SOW FEEDING: MAKING SENSE OF FEEDING DATA TO SUPPORT SOW MANAGEMENT

4.1. Material and methods

4.1.1. Farm management aspects

The study took place in a 200-sow farrow-to-finish Irish pig farm with a 3-week farrowing batch system. All sows were PIC Large White x Landrace and gilts were purchased from the same source, which populated the farm in 2016 with the same genetics. The dry sows (gestating sows) were kept as one dynamic group of around 120 individuals with access to two fully protected forward-exit electronic sow feeding stations.

Every three weeks a batch of 20-30 sows was introduced to the dynamic group, four days after the first insemination. With the same frequency, another batch was relocated to individual farrowing crates, one week before the expected date of parturition as illustrated in Figure 4. After being scanned to detect pregnancy, sows either stayed in the group (positive pregnancy diagnosis) or were drafted out to the service house to be inseminated again. In addition to natural daylight, sows were exposed to full artificial lighting from 08.30h to 16.30h. A map of the dry sow house where the study took place can be found in Annex 1.

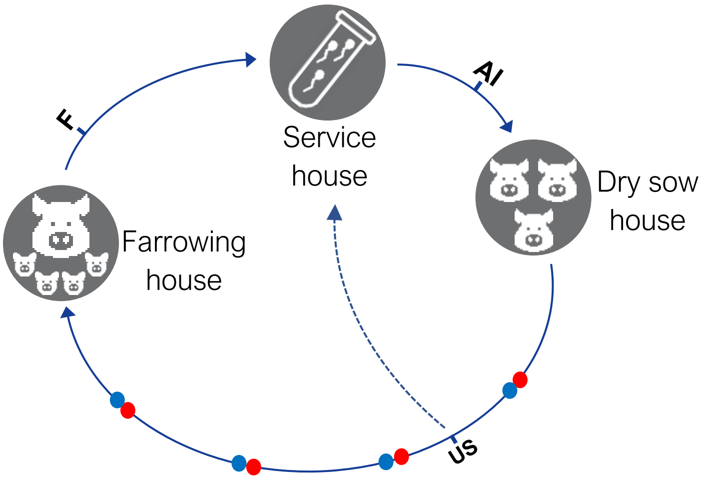


Figure 4. Sow production cycle (Original)

Legend: F - expected farrowing date; AI - artificial insemination; US – (ultrasound) pregnancy scanning; Blue dots - new batch entering the dry sow house; Red dots - batch exiting the dry sow house.

4.1.1.1. Feeding management of gestating sows

Feeding cycles comprehended a 23-hour interval, set to start at 17.00h. During this period, the feeders were accessible and any sow was allowed to enter either station and get its daily ration in one or several visits. After eating its daily allotment, an individual could still enter a station despite not receiving additional feed prior to the next feeding cycle. Feeding level was restricted. Each animal was assigned to one of the following feeding schemes:

a) 2.2 kg/day until day 90 of gestation and 2.6 kg/day thereafter;

b) 2 kg/day throughout the whole gestation.

Apart from a small quantity mixed with feed, water was always available through multiple wall mounted nipple drinkers at the pen. Following the end of each feeding cycle, at 16.00h, stations remained closed for 1 hour, disallowing any visits. The ESF station’s model was Schauer COMPIDENT VI. Diets’ composition is shown in Annex 2.

4.1.2. Dataset and data pre-processing

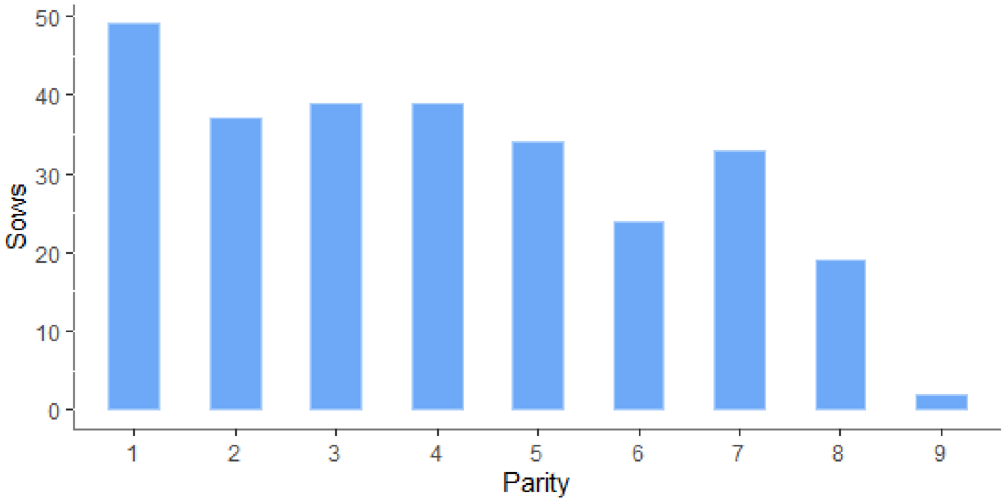
Data consists of ESF records from this farm for a one-year period (from 2019-03-14 to 2020-03-12). Each record corresponds to a feeding station visit and it includes feeding station ID, sow ID, feed intake value, date, time of entry and time of exit. According to the intake values (amount eaten at each feeding station visit, presented in kg), ESF visits were classified as ’Non-Feeding’ (NFV; intake = 0 kg) or ‘Feeding’. Intake was calculated as the total amount eaten per sow for every feeding cycle. In order to facilitate time series analysis, days were adjusted to the ESF cycle, starting at 17.00h rather than 00.00h, and visit duration was obtained by calculating the time difference between station entry and exit times.

The study unit consisted of one sow-gestation, as opposed to one sow, and hence individuals with two gestations counted as two study units. A time series of feeding records was computed for each animal to identify the consecutive days it spent on the dry sow house. Farrowing dates were used to validate complete gestations, and the length of gestation was estimated using the (first) insemination date as day 0. There were records for a total of 391 sow-gestations, amongst which 276 were considered complete (with 100-107 days of feeding records) and included in the study. Of these, 95 sows had two gestations and 86 sows had one gestation.

Gestations with missing records (including 89 returns to oestrus) and sows with feeding records ranging from 124 to 145 consecutive days in the dynamic group (or dry sow house; n=7) were not included in the analysis. Gilts were also excluded from the study once they were housed on a different pen and were subjected to a training process on ESF utilization before being introduced to the dynamic group.

Parity information (Graph 1) and individual sow performance were retrieved from the farm's herd management software (PigCHAMP (513) Copyright © PigCHAMP 2006-2010) and collated to the ESF records. Farrowing information for each sow, including the number of piglets born alive, average litter birthweight, and litter mortality was characterized and studied. These records were available for 268 sow-gestations, with the exception of litter mortality, which accounted for 247 out of the 276 sow-gestations.

Graph 1. Parity distribution of the study group (n= 276 sows).



4.1.3. Descriptive analysis and statistical analysis

All data was processed using Microsoft Excel® and further analysis were performed using R, including R packages Dplyr, Ggplot2, Lme4 and Shiny. The number and type of feeding station visits across gestation were computed and analysed for every sow-gestation, along with feed intake, meal duration and feeding times. As an exploratory data analysis tool, an interactive web-based application was developed on Shiny, aimed at finding patterns and detecting irregularities on sow feeding records (Annexes 3 and 4). All levels of statistical significance were determined for $P < 0.05$. Results are expressed as Mean ± Standard deviation (SD).

4.1.3.1. Number of non-feeding visits

For the purpose of studying how the number of ESF station NFV varied as gestation progressed, a generalized linear mixed effects model was conducted using gestation week and parity as fixed effects. As random effects there were intercepts for subjects and by-subject random slopes for the effect of gestation week. Once the response variable (the number of feeding station visits in one day) is a discrete variable, the model is based on a Poisson distribution.

4.1.3.2. Analysis of reproductive performance by feeding patterns

With a focus on the possible links between feeding patterns and reproductive performance, animals were classified based on their feeding order, feeding rate and on how feeding time evolved through gestation. The differences on performance indicators according to the feeding patterns were analysed as follows: for the number of piglets born alive and average litter birth weight a Kruskal-Wallis test was used for feeding order, a one-way between-subjects ANOVA for feeding time and Wilcoxon signed-rank tests for feeding rate. To study the effect on litter mortality, Kruskal-Wallis tests were carried out for feeding order and feeding time and Wilcoxon signed-rank tests were performed for feeding rate. Regarding post-hoc analysis, a significant Kruskal-Wallis test was followed by a Dunn’s test.

4.1.3.2.1. Feeding Order

As the total number of sows present at the dry sow house at any day fluctuated slightly around 120, the first and last 15% animals in the feeding order were determined by filtering the first and last 18 to eat, respectively, on each feeding cycle. For every sow-gestation, the number of days among the first and last 15% positions was calculated and the 18 individuals with the highest number of records on each of these two groups were selected. These were designated “early feeders” and “late feeders”. Those who didn’t fall in any group were included in a middle category. Two animals classified as early feeders and one classified as late feeder were excluded from the analysis on account of missing data.

4.1.3.2.2. Feeding times

Feeding times were classified on the basis of their regularity across gestation, which relied on the percentage of meals eaten within a timeframe of 5 h, for every sow-gestation. Animals with percentages greater than or equal to 90% (n = 67), not exceeding 70% (n = 61) or between these 2 ranges (n = 140) were considered regular, irregular or moderately regular, respectively. This indicator also reflects the regularity of a sow’s position on the feeding order over time.

4.1.3.2.3. Feeding rate

Once animals were not fed *ad libitum* and feeding strategy differed among individuals, comparisons based solely on feed intake or meal duration were not conducted. Instead, individual feeding rate was calculated by dividing the sums of amount eaten, in kilograms, and meal duration, in minutes, during gestation. Group mean was used as a reference, with ratios above that reference value being fast eaters (n = 113 sows) and the ones below that reference being slow eaters (n = 155 sows).

4.1.3.3. Feeding order

To explore the relationships between feeding order and use of feeding stations, a logistic regression model was carried out with feeding position, first 18 or last 18, as the dependent variable. It included parity, feeding rate and total number of feeding station visits as continuous predictors of the binary outcome. Grouping by feeding order was performed according to the criteria already mentioned while feeding rate was obtained by dividing the total amount eaten during gestation (kg) by total time (minutes) spent feeding.

4.2. Results

4.2.1. Use of ESF stations - main aspects

Over the length of 364 feeding cycles, 101,493 ESF station visits were recorded from the 276 studied sows, which corresponded to 28,931 individual feeding cycles (Table 1). While there was only a small variation on total feeding visits between individuals (mean = 103.9, SD = 2.2), total non-feeding visits differed significantly (mean = 263.8, SD = 282.6). The vast majority of sows ate the daily allotment on a single visit (98.3% of the individual cycles) and did so at a fairly stable feeding rate (mean = 0.19 kg/min, SD = 0.03).

Table 1. Individual use of ESF stations

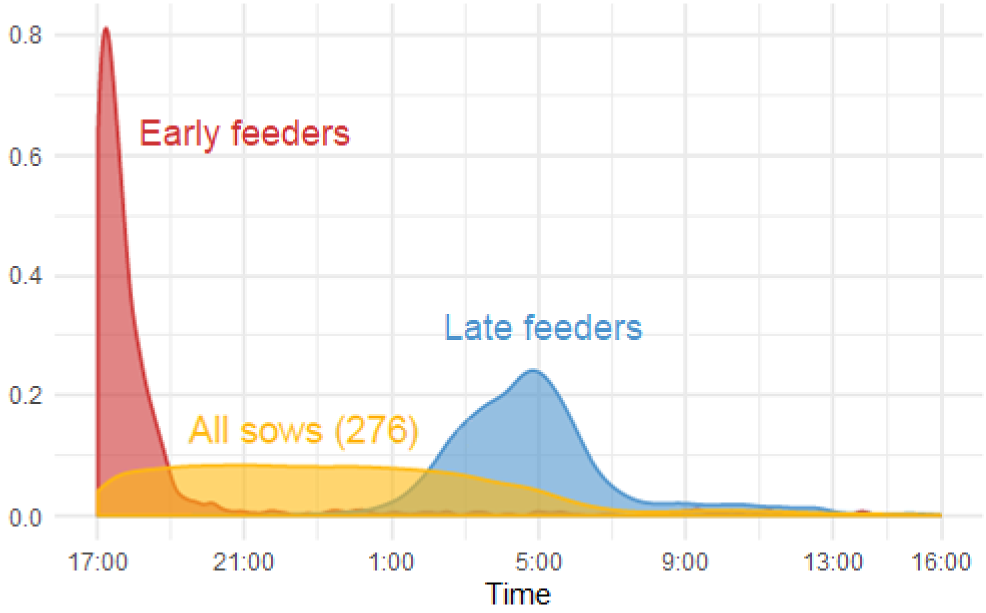
Parameter	**Values per sow Mean (SD)**
Available feeding cycles of data	104.8 (0.9)
Total ESF visits - of which feeding visits (%)	367.7 (282.8) 39.9 (19.8)
Perc. of daily meals eaten in a single visit	98.3 (1.7)
Feeding rate (kg/min)	0.19 (0.03)

Legend: ESF – Electronic sow feeding

4.2.2. Feeding times

Feeding activity took place almost entirely within the first half of the feeding cycles and when focusing on the feeding order, distinct patterns were detected (Graph 2). Most early feeders had already eaten their meal two hours after the cycle started whereas those feeding last displayed a wider distribution. This last group fed mainly during the night time, approximately 9 to 14 h succeeding the cycle starting time (after the rest of the herd had eaten). For animals making several feeding visits in a cycle, only the first visit was considered.

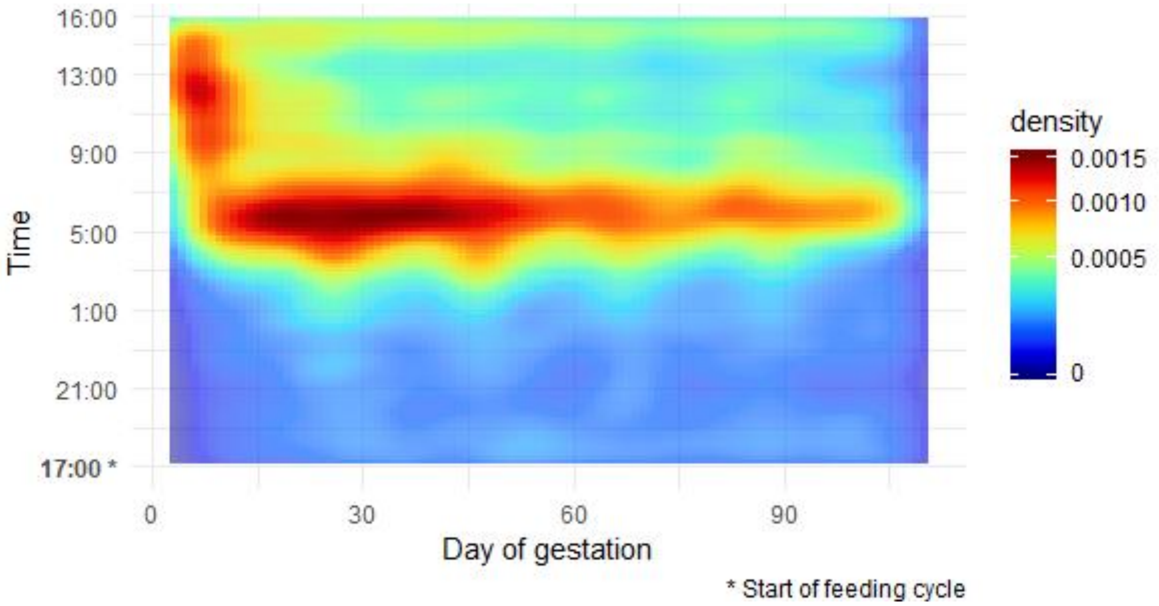
Graph 2. Feeding times of three groups (Kernel density estimation) (Note: 'All sows (276)' includes 'Early feeders' and 'Late feeders').



4.2.3. Number and time of non-feeding visits

Two major patterns were recognized when studying NFV across gestation of the whole study group. As gestation advanced, visits decreased in number and there was a time span of nearly 4 h (0400 – 0800h) during which most of the visits occurred (Graph 3).

Graph 3. Distribution of Non-feeding visits by time of the entire study group (Kernel density estimation)



4.2.4. Evolution of the number of ESF station visits

When modelling NFV, adding by-subject random slopes for gestation week made it possible to model the number of visits as a function of gestation week, assuming that this relationship may vary among sows. Poisson regression estimates for gestation week and parity were -0.067 and -0.230, respectively, and both were significant predictors of the number of NFV (Table 2). That means that, for a one unit increase in gestation week, the log number of visits was expected to decrease by 0.067 units. In other words, sows tended to make less visits to the feeding stations as gestation progressed, whereas the younger the sow was the likelier it was to pay more visits.

Table 2. Poisson modelling estimates for the number of ESF station visits depending on gestation week and parity.

	Estimate	SE	p
Intercept	1.894	0.102	<0.001
Gestation week	-0.067	0.004	<0.001
Parity	-0.230	0.022	<0.001

4.2.5. Feeding order

Due to the dynamic nature of the group, the feeding order of the sows was not stagnant. However, early feeders were among the first 18 to feed during 89.7 ± 4.27% of the days and late feeders fed within the last 18 during 69.8 ± 10.2% of their stay (Table 3). According to a logistic model (Table 4), the log of the odds of a sow being among the first 15% to feed was positively related to parity, which had an estimate of 0.772 and was the only significant predictor. The higher the parity the more likely it was that a sow was among the first to eat.

Table 3. Percentage of days each sow from the first 18 (early feeders) and last 18 (late feeders) to feed spent on their respective groups.

Early feeders		Late feeders	
Sow	Days (%)	Sow	Days (%)
T1	96.15	B1	90.20
T2	95.19	B2	82.86
T3	95.15	B3	79.05
T4	93.40	B4	76.19
T5	93.33	B5	76.19
T6	93.27	B6	75.73
T7	91.43	B7	72.64
T8	91.35	B8	72.38
T9	90.48	B9	72.38
T10	90.00	B10	70.48
T11	88.57	B11	69.52
T12	88.46	B12	67.62
T13	85.71	B13	66.67
T14	85.71	B14	65.71
T15	85.71	B15	57.14
T16	85.44	B16	55.24
T17	83.96	B17	54.29
T18	81.90	B18	51.89

Table 4. Logistic regression estimates regarding the feeding order

	Estimate	**SE**	**p**
Intercept	-9.296	4.778	0.051
Parity	0.772	0.264	0.004
Feeding rate	31.343	21.868	0.151
Total NFV	0.001	0.001	0.424

4.2.6. Sow reproductive performance

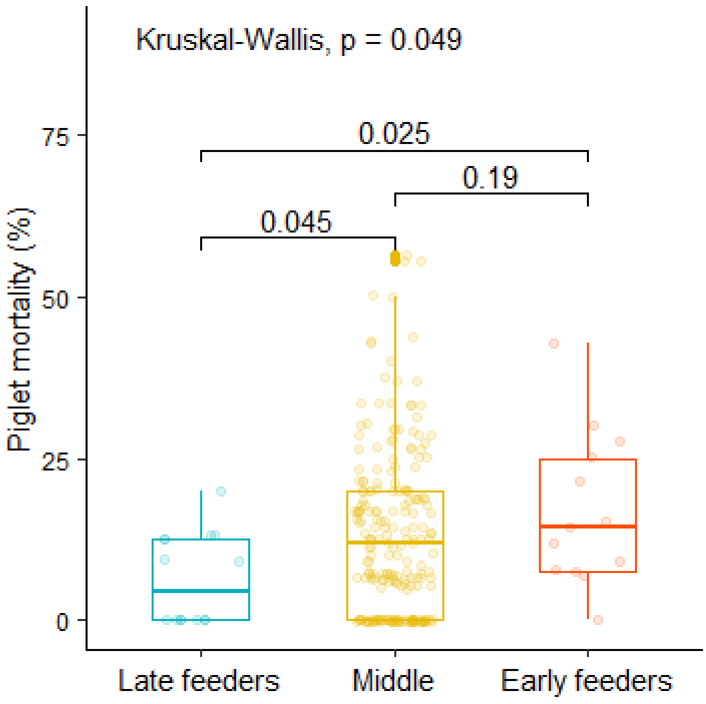
The number of sows in each class according to the availability of reproductive performance data is shown in Table 5. A Kruskal-Wallis test showed that there was a statistically significant difference in median litter mortality between sows from different feeding order classes, with those feeding last displaying lower values than the ones doing so first (4.5% vs 14.3%; p = 0.025) or with a middle position (4.5% vs 11.8%; p = 0.045) (Graph 4). The same test revealed a significant difference in piglet mortality between certain feeding time patterns: sows with a regular feeding time had higher median piglet mortality than those with a moderately regular (14.3% vs 10.6%; p=0.029) and an irregular (14.3% vs 9.5%; p=0.047) pattern (Graph 5). Wilcoxon signed-rank tests indicated that mortality was lower in sows that fed slower (Median = 9.1%) compared with sows feeding faster (Median = 13.3%; p = 0.05) (Graph 6). Number of piglets born alive and average birth weight did not differ significantly between each class of feeding order, feeding time nor feeding rate (Graphs 7 - 12).

Table 5. Number of sows with available reproductive performance (RP) data in each class of feeding order, feeding time and feeding rate.

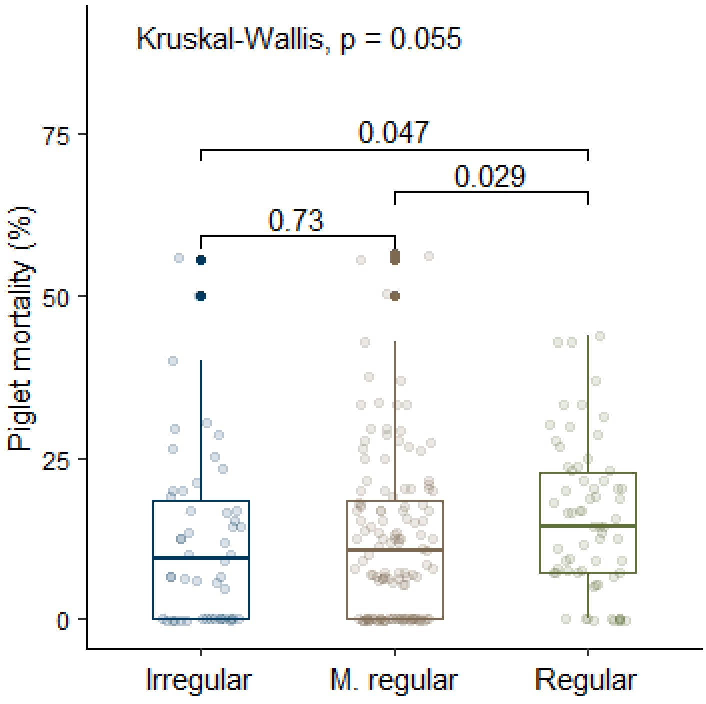
	Feeding order			Feeding time			Feeding rate	
	First	Middle	Last	Regular	M. regular	Irregular	Fast	Slow
Sows with RP data								
. litter size (n=268)	16	235	17	67	140	61	113	155
. birth weight (n=268)	16	235	17	67	140	61	113	155
. litter mort. (n=247)*	14	219	14	66	131	50	103	144

* litter mort. – pre-weaning mortality rate; M. regular – moderately regular

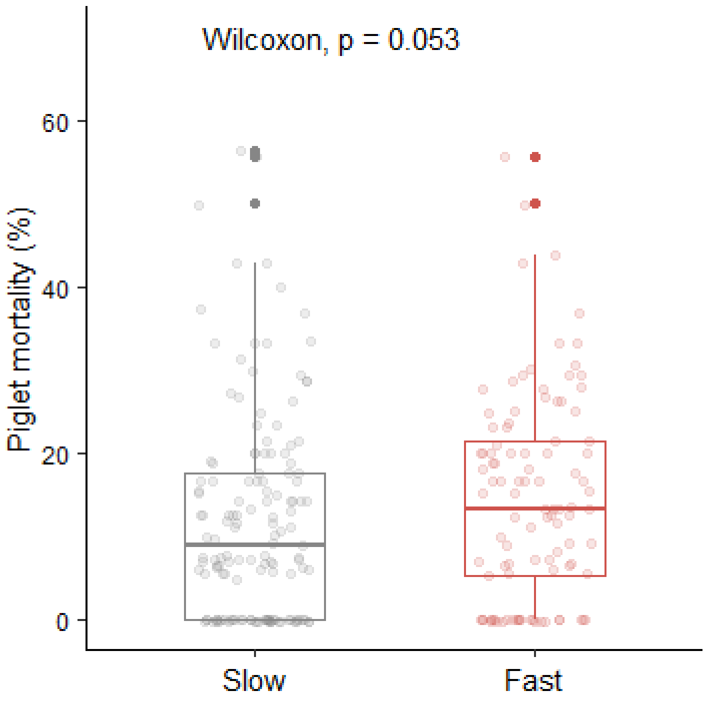
Graph 4: Pre-weaning piglet mortality rate according to sow's feeding order position



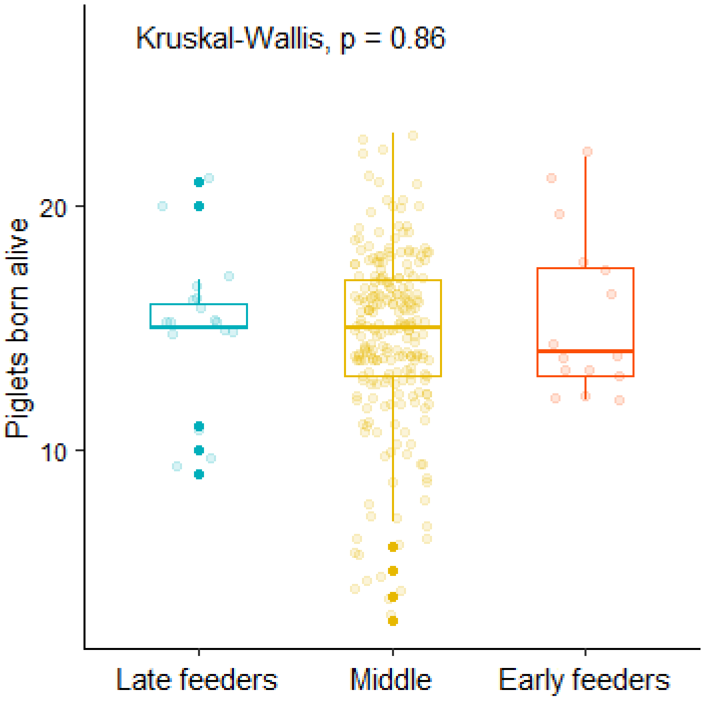
Graph 5: Pre-weaning piglet mortality rate according to sow's feeding time



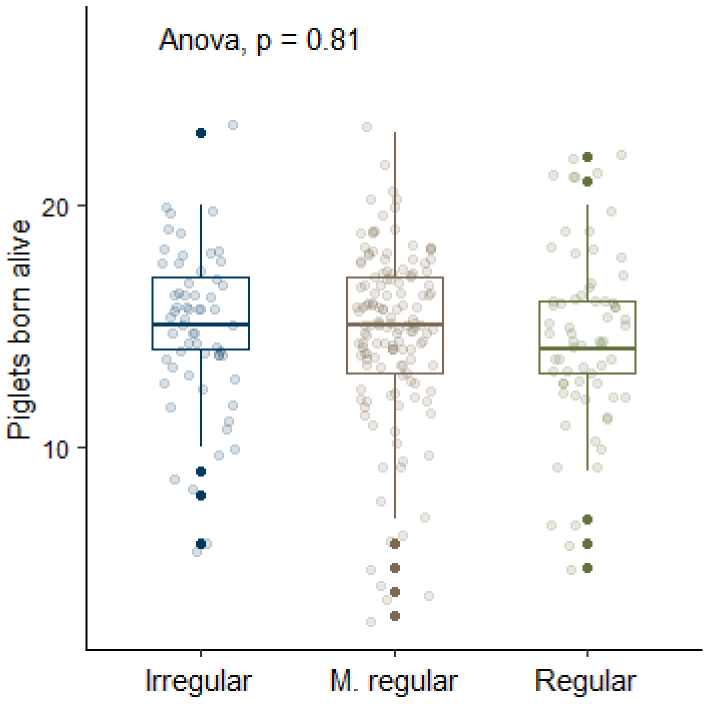
Graph 6: Pre-weaning piglet mortality rate according to sow's feeding rate



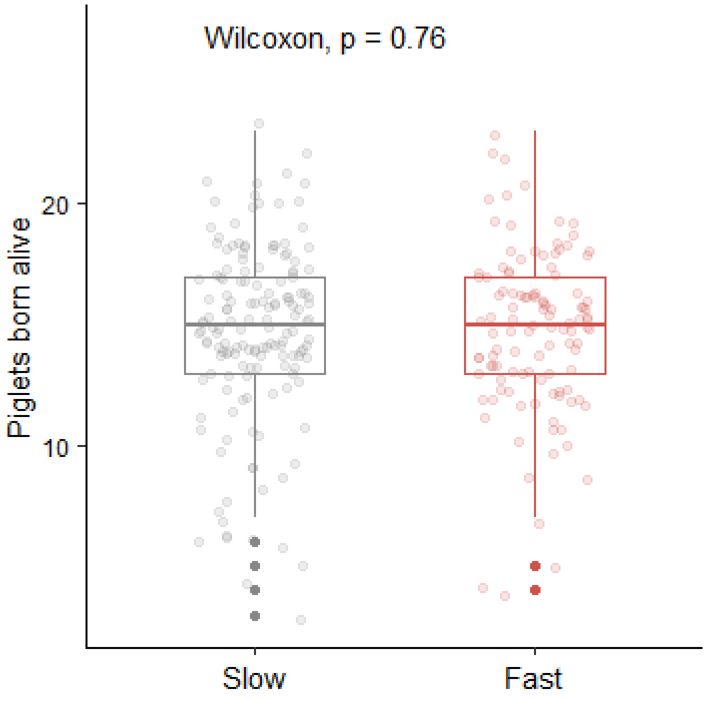
Graph 7: Number of piglets born alive according to sow's feeding order position



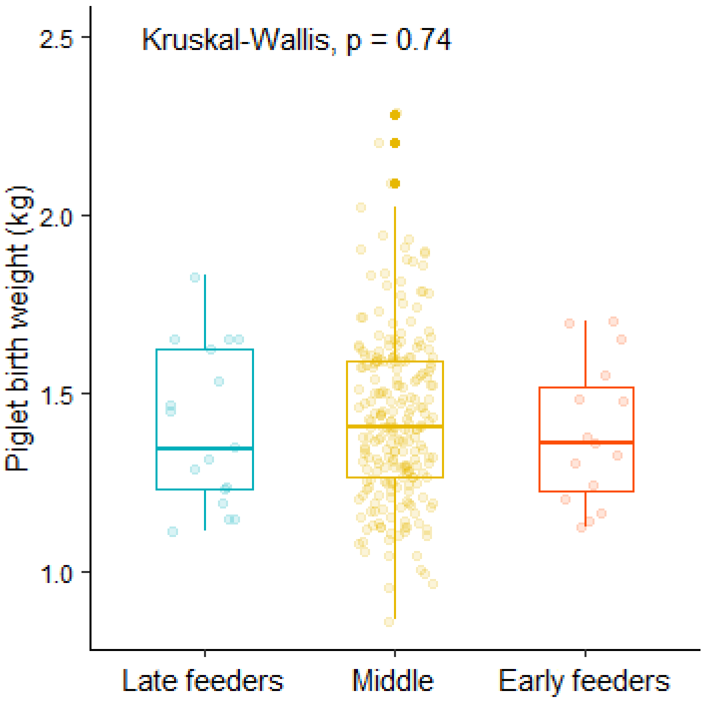
Graph 8: Number of piglets born alive according to sow's feeding time



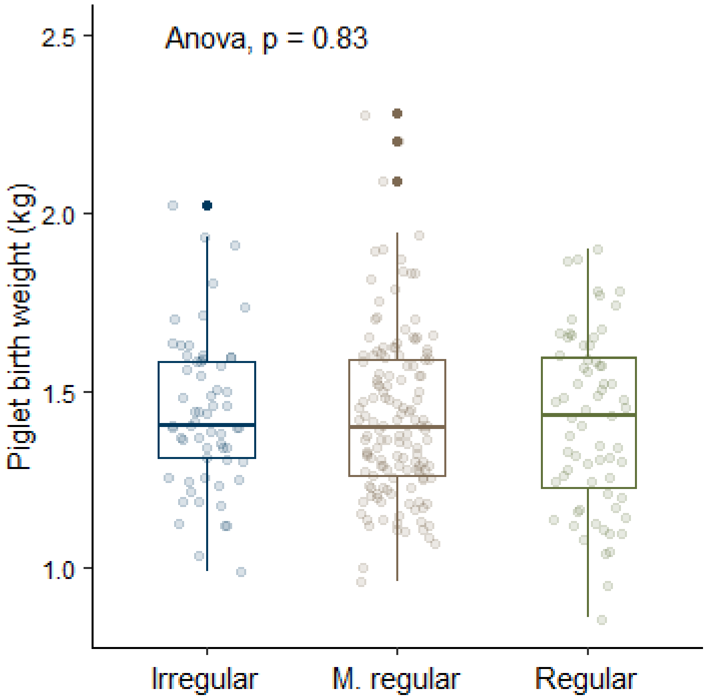
Graph 9: Number of piglets born alive according to sow's feeding rate



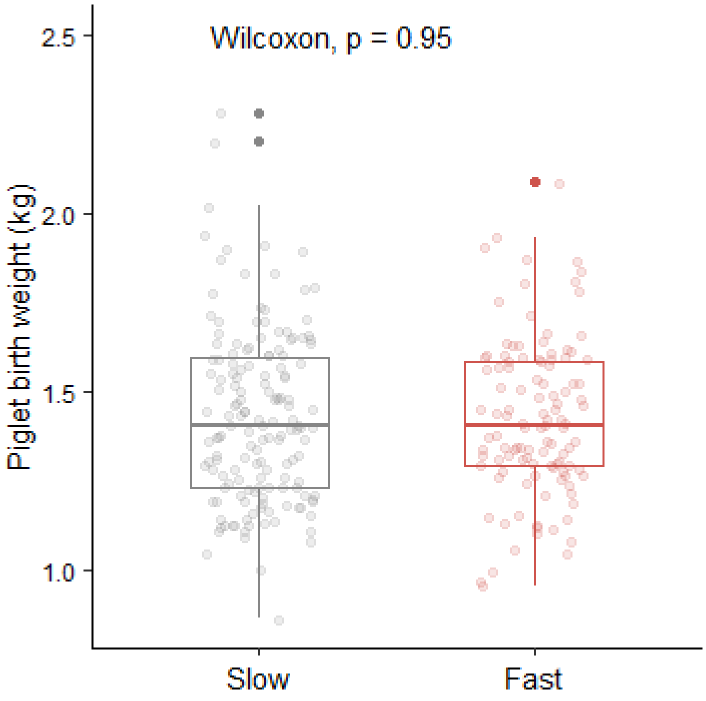
Graph 10: Average piglet birth weight (kg) according to sow's feeding order position



Graph 11: Average piglet birth weight (kg) according to sow's feeding time



Graph 12: Average piglet birth weight (kg) according to sow's feeding rate



4.3 Discussion

In this dissertation, ESF records of a sow herd were analysed, in an attempt to address the knowledge gaps concerning how gestating sows interact with ESF stations, and what are patterns of use of these feeding stations. A total of 276 sow-gestations were studied, with regard to number and type of feeding station visits, and how these evolved throughout gestation, as well as feeding times, feeding order and feeding rate. Each animal was classified according to its position in the feeding order, feeding time and feeding rate and the reproductive performance of individuals in different classes was compared.

During the approximate 15 weeks that each sow spent on the dry house, the mean number of total ESF station visits per sow was 367.7, most of which were NFV (60.01 ± 19.8%), yet this parameter differed considerably between individuals (SD: 282.8). On the other hand, the percentage of rations eaten in a single (first) visit (98.3 ± 1.7%) and the feeding rate (0.19 ± 0.03 kg/min) showed more consistency among animals. Similar high proportions of NFV under modern ESF systems have been reported by Cornou et al. (2008) regarding three herds, where 60.8% to 68.8% of all daily ESF visits were NFV. Even though the ESF stations used in the current study had retractable feed bowls, which contribute for a lower number of visits, the absence of physical barriers between stations' exits and entrances may have encouraged some individuals to perform station revisits after having fed, as suggested by Brooks (2003).

In addition, the fact that sows were provided a limited amount of feed might have motivated some group members to make several visits in search of additional feed. The large percentage of daily meals eaten in a single visit is in line with the reports of Søllested (2001) and Cornou et al (2008), where 72.25% - 83.88% and 79.5% - 95.3% of sows, respectively, ate their ration on a single visit. In both situations the number of animals per feeding station was similar to that of the present study.

Because the number of feeding visits was, to a large extent, homogenous between individuals, this parameter was not explored. Instead, number and time of NFV of the whole group were analysed. While most NFV were performed during the first half of gestation, the time at which they took place followed a narrower distribution, with the vast majority occurring between 04.00h and 08.00h. A less pronounced but still discernible proportion of visits was identified within the last hour of the feeding cycle (1500-1600) throughout the whole gestation, equivalently to what Chapinal et al. (2008) observed across three static groups of twenty sows each. However, the feeding stations used in that study were not fully protected and the authors do not differentiate feeding from non-feeding visits. Nevertheless, they report most feeding activity to take place during the first half of the feeding cycle and thus visits during the last hour are likely to be NFV. Jensen et. al (2000) studied the feeding times of sows from four dynamic groups, where feeding cycles were set to start at different times. As in the present work, they observed a rise in feeding activity following the start of feeding cycles, as expected, because at that time a considerable number of animals had not eaten for several hours.

According to a mixed effects model using sow as a random effect, as gestation advanced one week, the log of the number of NFV was expected to decrease 0.067 units ($b = 0.067$, $SE = 0.04$, $p < 0.001$), denoting a weak effect of time on the number of NFV. Parity, on the other hand, was a more expressive predictor ($b = - 0.230$, $SE = 0.022$, $p < 0.001$), indicating that older sows were more likely to make less visits, compared to younger group members. Søllested (2001) and Chapinal et al. (2008) did not find any significant effects of time on total number of feeding station visits but the latter reported that individual daily feeder occupation decreased over time. The relation between parity and total NFV, when considered together with the fact that different parities of the study group were represented by similar percentages (4.03 ± 2.26), may help explaining the high variability of total NFV observed between individuals.

The stability of the feeding order over time was analysed by investigating the first and last 15% individuals to feed each day, subsequently determining the 18 individuals more frequently observed in each of these two groups, referred to as early feeders and late feeders. The percentage of days each 18 individuals spent on each given group indicates that the feeding order is more stable among the early feeders (89.7 ± 4.27%) in comparison with the late feeders (69.8 ± 10.2%). Accordingly, the distribution of the feeding times among sows feeding last was visibly wider than that of those feeding first, which did so almost entirely within the first 2 hours of a feeding cycle. Although no studies using an equivalent method to assess the feeding order seem to have been published, some authors have described the feeding order of gestating sows using ESF stations to be relatively stable in both dynamic, even though for a short time (Bressers et al. 1993), and static (Edwards et al. 1988; Chapinal et al. 2008) groups. Regarding the dynamic nature of the study group, during the stay of each animal in the dry sow house, four batches of 20-30 sows were introduced to the group and another four batches were drafted out. These recurrent changes in the group composition may impact the feeding order of resident sows as they force the dominance hierarchy, which has been reached to influence the feeding order, to be constantly re-established. Hunter et al. (1988) studied the position in the feeding order of twenty sows for seven days and reported that individuals feeding in the bottom half of the order had higher standard deviations than those feeding earlier, which resembles what was found in the current work. It is worth mentioning the results presented by these authors account for a much shorter period of time than the present work. Likewise, group size and frequency of mixing, which can influence the feeding order, are dissimilar.

Differences in the use of feeding stations (total NFV and feeding rate) and parity of sows belonging to each feeding order class were investigated through a logistic regression. With every additional parity, the odds of being among the first 15% to feed increased by a factor of 2.16 [OR: 2.16, $p<0.010$], and this was the only significant predictor. Chapinal et al (2008) found feeding order not to be correlated to number of feeding station visits, as in the present study, but to be correlated to social rank. Because feeding level affected time spent on feeding stations and sows in the current study were assigned different feed allowances, feeding rate (kg/min) was studied instead of ESF station occupation. In 2015, Bøe and Cronin reported a relation between feed consumption rate and sow liveweight, with heavier sows eating faster than lighter ones. However, in the present work, older and presumably heavier early feeders did not show any statistically significant differences from late feeders regarding feeding rate. Conversely, the positive relation found between parity and feeding order is consistent with the findings of Hunter et al. (1988) and Strawford (2006).

A small number of works have been published studying possible relations between use of feeding stations by sows and occurrence of disease or oestrus. In the present dissertation, sows were grouped according to their feeding order, feeding times and feeding rate and the reproductive performance of different groups was compared, in terms of number of piglets born alive, average piglet birth weight and pre-weaning piglet mortality. Concerning the feeding order, no significant differences were found between median values of litter size or average piglet birth weight but median piglet mortality was lower in late feeders compared to both middle (4.5% vs 11.8%, p = 0.045) and early feeders (4.5% vs 14.3%, p = 0.025). Hoy et al. (2009) compared total piglets born between sows feeding in the first half of the feeding order and those doing so in the later half, describing the first group to have more born piglets (16.14 vs 14.83, p = 0.052), whereas no significant variation was observed when looking at the number of piglets born alive (13.45 vs 12.73). Nicholson et al. (1993) (cited by Strawford 2006) further reported that sows with a middle social rank had larger litters than higher and lower ranked ones. Social rank and feeding order, however, may not be associated (Hunter et al. 1988; Brooks 2003).

As previously mentioned, sows classified as early feeders fed at the start of a feeding cycle for the most part of their gestation. This period has been characterized as of great activity near feeding stations and increased aggressive interactions (Weber et al. 1993 (cited by Strawford 2006); Jensen 2000). Such environment is likely to expose animals to certain levels of stress, as opposed to that when late feeders usually feed, during night time, since most of the group has fed by then. The extent to which stress in gestating sows may affect the development of the conceptus has been debated, with conclusions varying across studies. While some authors suggest social stress during early gestation to negatively affect reproductive performance (Knox et al. 2014), others found a different (Mheen et al. 2003) (cited by Spoolder and Vermeer 2015) or the absence of relation between these two factors (Cassar et al. 2008). Kranendonk et al. (2007) studied if sow social rank (estimated through displacement rates at the feeder) could affect offspring performance. The authors reported that animals more frequently displaced at the feeder gave birth to progeny which performed worse, in terms of weight gain and carcass characteristics, and suggest a negative impact of social stress on reproductive performance. Recently, Johnson et al. (2020) evaluated the impact of in utero heat stress (IUHS), from day 6 to 59 of gestation, on the innate immunity of progeny from primiparous sows. They concluded that when subjecting gestating females to certain levels of heat stress, long-term implications were observed on the immune, metabolic and stress response of their offspring, likely compromising the innate immune response. Pre-weaning mortality was not studied on that paper. Despite this, IUHS has been shown to increase the post-natal energy requirements of pigs (Maskal et al. 2020) and Omtvedt et al. (1971) found that sows exposed to heat during late pregnancy had lower litter survival rates in comparison with those kept under thermoneutral conditions (71.7% vs 88.5%).

Regarding the feeding times, individuals with a regular feeding time showed higher piglet mortality rates than those with moderately regular (14.3% vs 10.6%, p = 0.029) and irregular (14.3% vs 9.5%, p = 0.047) feeding times. Considering the existence of a relatively stable order in which animals feed, the time at which an individual feeds is influenced by its position in that order. Because in dynamic groups, group composition, and consequently dominance hierarchy, change frequently, in order to keep a regular feeding time throughout gestation a sow must consistently overcome eventual displacement attempts from group members. An exception to this would be the few individuals regularly feeding later in the feeding cycle, when competition is lower. Therefore, and similarly to what has been suggested for sows feeding first, maintaining a regular feeding time across gestation may give rise to increased stress levels, with increased litter mortality as a possible outcome. In terms of feeding rate, sows classified as fast feeders had higher median piglet mortality rates than those feeding at a lower rate (13.3% vs 9.1%). This parameter and its associations with performance, have not yet been studied for gestating sows using ESF systems.

There are some limitations in this study and thus caution should be taken when interpreting the results. Firstly, eventual health impairments of the study group, which may influence the use of feeding stations as well as reproductive performance, were not accounted for. Similarly, considering the different feeding levels among sows when conducting statistical analyses could have enriched this work, given the possible effect that feed intake during gestation can have on reproductive performance, as already mentioned, and perhaps to study the relationship between feed allowance and use of feeding stations.

While data recorded automatically by ESF systems provide real-time precise information regarding animal-machine interactions, the suitability of these records to evaluate between-animal interactions is less evident. Despite involving additional labour/costs, direct observation of animals (Olsson et al. 2011) or video recording (Jensen et al. 2000) constitute effective methods of estimating animal aggression levels. Therefore, if included in the current work, these tools could have been helpful to address the hypothesis that some sows were repeatedly exposed to a stressful environment. Further benefits would be, for instance, understanding if some sows fed during night-time because their access to feed is blocked by other group members or if that is their preferred time of feeding. Despite its limitations, this work enhances current understanding of how gestating sows interact with ESF stations, comprising a representative study period for each individual, and may lay the groundwork for future research.

Based on the results of this work, some recommendations could be made for stakeholders using ESF systems. Because high competition over access to feeding stations may negatively affect sow health (Olsson et al. 2011) and performance, as suggested by the present study, adopting certain management strategies to minimize this factor might improve herd productivity. While reducing the number of sows per ESF station is not practical, setting the feeding cycle to start at late evening (Jensen et al. 2000), or displaying stations in a way that sows walking out cannot promptly approach the same or another station's entrance, may decrease competition levels. This study supports the idea that manipulating the starting time of the feeding cycle is an effective method of concentrating feeding activity in a particular period. Such strategy can be useful if, for instance, management tasks are to be performed at the dry sow house on specific times without disrupting the natural feeding routine of animals.

A limitation of ESF systems that became evident with this work is that despite gathering large amounts of records, much of this information is presented to farmers as raw data. This problem could be solved at source (ESF system providers) by developing a dashboard with a user-friendly interface to effectively convey information to the farmer, or locally, through the services of farm advisors whose role includes the collation and interpretation of the multiple sources of farm data. In both options, the transformation of data into information should materialize the potential of ESF stations to support farm management.

4.4. Conclusion

The study of ESF records from 276 sow-gestations revealed some results consistent with previous findings. These include the preference of sows to eat their ration on a single ESF station visit, rather than dividing it through multiple visits, along with their tendency to use feeding stations mostly for non-feeding visits. The theory that gestating sows develop a relatively stable feeding order, even in dynamic groups, is supported by this work. While the proneness of older sows to be among the first group members to feed is in line with prior investigation, the inclination of younger individuals to make more visits to ESF stations had not been reported.

Prior to this study, relations between feeding patterns at ESF stations and reproductive performance had not been explored. For sows eating first and/or displaying regular feeding times throughout gestation, pre-weaning piglet mortality was higher. These findings may reflect the high competition over access to feeding stations, characteristic of this feeding system, that some animals are constantly exposed to.

When considered together, the benefits of exploring ESF records and the fact that collection of these data is automatic, thus avoiding any additional labour or costs, suggest that there is more to ESF systems than simply feeding animals at an individual level. Although further research is needed to confirm the hypothesis discussed above, the present work contributes to a growing body of evidence suggesting that ESF records can be used as a component of precision livestock farming, supporting decision making concerning sow management.

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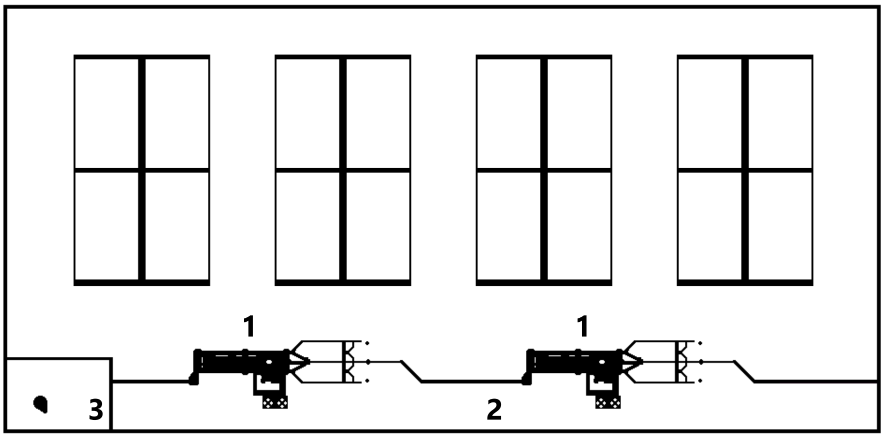
6. ANNEXES

Annex 1. Map of dry sow house with capacity for 140 sows at 2.025 m^2 each.

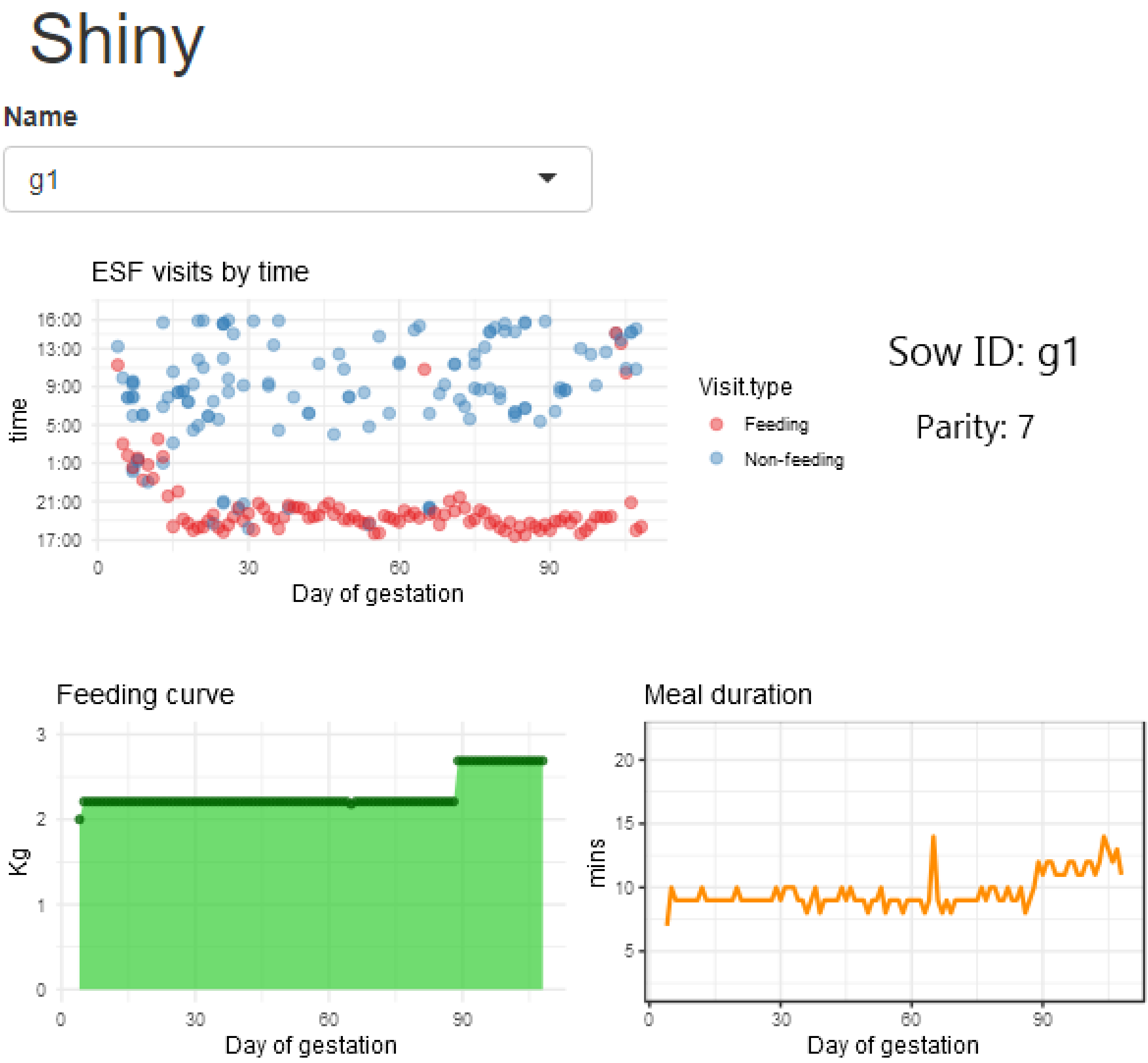


Legend: 1 - Electronic sow feeding station; 2 - Sorting pen; 3 - Boar pen

Annex 2. Composition of Gestation and Lactation diets.

Diet Analysis	Gestation diet	Lactation diet
Indredient (%)		
Wheat	—	42.95
Barley	75.30	26.88
Soyahulls	12.18	—
Soya	8.96	19.67
Soya oil	1.10	6.60
Limestone flour	0.91	1.15
Mono Dicalcium phosphate	0.65	0.85
Salt feed grade	0.40	0.50
Lysine HCl	0.22	0.45
Vitamin-mineral premix	0.15	0.15
L-Threonine	0.06	0.25
L-Valine	—	0.23
DL-Methionine	0.06	0.14
Phytase	0.01	0.01
L-Tryptophan	—	0.07
Sepiolite	—	0.10
Chemical analysis (g/kg)		
Dry matter	873.27	876.96
Crude protein	140.00	157.57
Ash	47.34	48.31
Crude fat	31.44	79.76
Crude fibre	80.00	33.32
Sugar	25.82	31.09
Starch	399.94	422.66
Neutral Detergent Fibre	213.41	122.73
Acid Detergent Fibre	108.59	43.53
Digestible energy (MJ/kg)	13.20	15.10
Lysine	8.20	10.80
Methionine	2.70	3.00
Threonine	5.50	6.90
Tryptophan	1.70	—
Calcium	7.20	8.10
Phosphorus	5.00	5.50

Annex 3. Shiny application showing sow “g1”.



Shiny

Name

g1

Sow ID: g1

Parity: 7

Annex 4. Shiny application showing sow “g2”.

Shiny

Name

g2

Sow ID: g2

Parity: 3