The effect of flush feeding during lactation on sow reproductive efficiency, litter size, birth weight and with-in litter variation

by

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Declaration

I, Jancke Krynauw hereby declare that this thesis, submitted for the MSc(Agric) Animal Science: Production Physiology and Product Quality degree at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at any other University.

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Date

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Abstract

The aim of the experiment was to determine the effect of feed- and energy intake by adapting a feeding curve and change in energy source during lactation, on reproduction functions in sows and the effect on the subsequent litter. In this experiment, 252 lactating sows were randomly divided into three groups of 84 each. To remove sow variation between groups and within a treatment group, Topigs Norsvin, purebred Z-Line sows, were inseminated with pooled A-line semen, and randomly assigned to a specific treatment group. All sows were fed to the same feed intake curve until day 13 of lactation. From day 14 the sows were fed according to a specific treatment group. Group 1 (Control) received a lactation diet during lactation, following the standard feed curve (maximum level of 2kg plus 500 g per piglet). Group 2 (Ad Lib) was fed with the same lactation diet with an increase in feed level (ad lib) on day 14 to 21. Group 3 received the same lactation diet and followed the standard feed curve with a dextrose top-up (500g/day) from day 14 to day 21.

There was no significant effect of group on the sow efficiency (WSI; P>0,41) and the subsequent litter's total number born (P>0.36), although there was a trend seen of the effect of dextrose top-up on the subsequent litter's total number born (P>0.16).

The sows with a high total number born before treatment, also had a high total born after treatment (P<0.01). Energy intake (P<0.01) during the last week of lactation, before weaning had a significant effect on the following total number born, as well as the feed intake (P<0.05). The higher lactation feed intake (P<0.05) and energy intake (P=0.07) before weaning had a positive effect on their WSI interval. For every 1kg increase in feed intake per day during the last week of lactation, the WSI reduced with 1 hour and 37 minutes. For every 100 MJ NE increase in energy intake in the last week of lactation, the WSI was reduced by 2 hours and 16 minutes. Empty body weight loss also contributed to a difference in WSI, where a lower weight loss during lactation, reduced the WSI (P>0.1).

Empty body weight loss during lactation was affected by parity (P<0.01), where younger sows lost more weight during lactation. Sows having a smaller litter size at farrowing, exhibited a greater weight loss during lactation (P<0.0001). Feed intake during the last week of lactation had a significant effect on weight loss (P<0.05). For every 1kg feed intake per day during the last week of lactation, the weight loss % decreased with 0.91%. For every 100 MJ NE increase in energy intake during the last week of lactation, the sow lost 1.15% less empty body weight loss during lactation.

For every 100MJ NE increase in energy intake during the last week of lactation, results in a 0.41 increase in total number born in the following farrowing. For every 1kg increase in feed intake, the total born increased with 0.23 piglets. The subsequent average birth weight of a piglet was significantly influenced by the total number born (P<0.0001) and litter weight (P<0.0001) of the following litter. Litter weight was significantly influenced by gestation gain (P<0.0001) and the total number born (P<0.0001) of the following litter. The within litter variation was influenced by the parity of the sow (P<0.01)

Together these results indicate that having a high energy or feed intake before weaning, will benefit the sow's reproductive performance and the subsequent litter.

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Chapter 1: Introduction

1.1 Introduction

There is increasing evidence about the effects of nutrition on the reproductive performance of a lactating sow. The heritability of reproductive traits is low. With a low heritability, it is important to optimise the environment to express genetic potential. Nutrition, along with temperature, has a major impact on reproductive performance (Den Hartog, 1984). Reproductive performance is not only influenced by nutrition, but also by the metabolic state of a sow during lactation (Van den Brand, *et al.*, 2000 & Tauson, 2012). Nutritional supplementation alters the concentration of specific metabolic - and reproductive hormones in the blood (Scaramuzzi, et al., 2006). The nutrients available, along with the hormones, determines the hormonal signalling to the reproductive hormone axis, which can have a central and local ovarian effect (Zak, *et al.*, 1997 & Tauson 2012). It systemically impacts reproduction via the hypothalamic-pituitary-ovarian axis and at the ovarian level, it regulates folliculogenesis (Garcia-Garcia, 2012).
The metabolic state at a given time will affect the metabolic – and reproductive hormones available. The relationship between nutrition and reproduction is the energy balance of an animal. This will ultimately determine the metabolic state of a sow. A sow is in a positive energy balance if the nutrient intake is more than the nutrients required. The metabolic state of a sow during a positive energy balance is an anabolic state. A negative energy balance is when the nutrient intake is less than the nutrient requirements and results in a catabolic state. When an animal is in a positive energy balance, or in a relatively less catabolic state, the metabolic consequences are increased plasma insulin, leptin and IGF-1. The central effect of this metabolic state on reproduction is an increase in Gonadotropin Releasing Hormone (GnRH) secretion by the hypothalamus, which increases Luteinizing Hormone (LH) pulses and Follicular Stimulating Hormone (FSH) concentration, and then lastly enhances folliculogenesis and ovulation rate at the ovarian level (Scaramuzzi, et al., 2006).
The state of a lactating sow will mostly be catabolic, due to the partitioning of nutrient towards milk production (Zak, et al., 1997). Although the severity can be altered by either changing the feeding level or changing the energy source. By increasing the energy levels during lactation (feeding level or energy source), there will be more energy available for a longer period (Scaramuzzi, et al., 2006). It will stimulate the hypothalamic-pituitary-ovarian axis and release FSH and LH. The higher levels of LH will result in larger, more uniform follicles being developed and matured. The quality of embryos produced are higher, there is less variation in birth weight, there is an increase in litter size and a lower pre-wean mortality (Van den Brand, et al., 2009).
To maintain a high rate of productive- and reproductive performance, the sows should be efficient. The sows should be able to produce sufficient milk to support piglet growth to wean a viable piglet at the end of lactation. Also keeping in mind that while a sow is in lactation, the follicles for the following litter already starts to develop. After weaning the period up to oestrous should be within a short period (Tauson, 2012). Wean-to-estrus interval (WEI) is not influenced by the energy state of a sow after weaning but is more dependent on the state during lactation (Zak, et al., 1998).

1.2 Aim and hypothesis

The aim of the experiment is to determine the effect of feed and energy intake by adapting a feeding curve and change in energy source during lactation, on reproduction functions in sows and the effect on the subsequent litter.
Based on this information, the hypothesis is that feeding the sow higher levels of feed or energy during the last week of lactation, it will shorten the WEI, the sow will be in a better condition during insemination, there will be an increase in total number born and an improvement in litter characteristics (increase total number born, increase litter weight and a lower within litter birth weight variation).

Chapter 2: Literature Review

2.1 Introduction

There is increasing evidence about the effects of nutrition on the reproductive performance of a lactating sow. The heritability of reproductive traits are low and there is a negative correlation between reproductive traits and productive traits. With a low heritability, it is important to optimise the environment to express genetic potential. Nutrition, along with temperature, has a major impact on reproductive performance (Den Hartog, 1984). Reproductive performance is not only influenced by nutrition, but also by the metabolic state of a sow during lactation (Van den Brand, *et al.*, 2000 & Tauson, 2012). Nutritional supplementation alters the concentration of specific metabolic - and reproductive hormones in the blood (Scaramuzzi, et al., 2006). The nutrients available, along with the hormones, determines the hormonal signalling to the reproductive hormone axis, which can have a central and local ovarian effect (Zak, *et al.*, 1997 & Tauson 2012). It systemically impacts reproduction via the hypothalamic-pituitary-ovarian axis and at the ovarian level, it regulates folliculogenesis (Garcia-Garcia, 2012).
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2.2 Endocrine control

The endocrine system consist of glands that secrete specific hormones, acting as messengers throughout the body to have a physiological response. Certain target organs can recognize, bind and respond to a specific hormone via hormone receptors. Some hormones have multiple target organs. This study focus on the effect of nutrition on reproduction and Table 2.1 shows all the endocrine glands and hormones involved, as well as the action of the specific hormone (Frandson, et al., 2009).
The effect of a hormone depends on the concentration available in the body fluids to bind to receptors. The concentration is determined by the rate the hormone is released and the rate by which it is eliminated from the body fluids. The plasma concentration of hormones is regulated by a negative feedback system. This means that an increase in a hormone leads to a response which inhibits any further release of the specific hormone. The opposite of this situation is a positive feedback regulation. In this case the hormone causes an increase in the concentration of that specific hormone (Frandson, et al., 2009).

Table 2.1 The endocrine glands involved in the reproductive system (Frandson, et al., 2009).

Endocrine gland	Hormone	Action (target tissue or organ)
Hypothalamus	GnRH	Stimulates FSH and LH production (anterior pituitary)
Anterior pituitary	FSH	Stimulates follicular development (ovary)
	LH	Stimulates ovulation, development of the CL, secretion by the CL (ovary)
	PRL	Promotes lactation (mammary gland) and maternal behaviour
Pancreatic islets (Beta-cells)	Insulin	Promotes glucose uptake; protein, lipid synthesis by various tissues and organs
Ovaries	Estradiol	Initiate puberty
	Progesterone	Maintain pregnancy

GnRH – Gonadotropin Releasing Hormone. FSH – Follicular Stimulating Hormone. LH – Luteinizing Hormone. PRL – Prolactin. CL – Corpus Luteum

The hypothalamus controls the endocrine changes of the pituitary gland, as a result of sensory information it receives from the rest of the body. The hormones released by the hypothalamus are neurotransmitters and has a releasing- or inhibiting effect on a specific target organ. It is carried via the hypothalamo-hypophysial portal system from the hypothalamus to the anterior pituitary. This is known as the hypothalamo-pituitary axis. These neurotransmitters act on the anterior pituitary to stimulate or inhibit the release of a specific hormone (Frandson, et al., 2009).

The relationship between the endocrine system and reproduction is the hypothalamic-pituitary-ovarian axis. The key hormones for reproduction are LH and FSH. The hormones secreted by the ovaries (estradiol and progesterone) stimulates or inhibit the release of GnRH. GnRH secreted by the hypothalamus, stimulates the release of FSH and LH from the anterior pituitary, which in turn stimulates the release of estradiol or progesterone at the ovaries. The hormone secreted on the ovarian level depends on the stage of the oestrous cycle (Frandson, et al., 2009).

Endocrine control also regulates nutritional changes and determines the concentration of a metabolite present in blood plasma. The response is controlled by the metabolic state of the animal, whether anabolic or catabolic. For example, when an animal consumes energy, glucose concentrations in the blood increases. This stimulates the release of insulin via the pancreas. Insulin stimulates the absorption of glucose to maintain an energy balance in the body (Frandson, et al., 2009).

2.3 Folliculogenesis and Ovulation

A sow is a polyoestous breeder, which means that she has more than one oestrous cycle per year. The oestrous cycle of a sow is 21 days and is divided into a follicular phase and luteal phase. During the follicular phase, the follicles develop and mature in the ovary. After the follicles matured, ovulation occurs. A Corpus Lutea (CL) is formed at the ovary after ovulation. This is known as the luteal phase (Tauson, 2012).

To complete one oestrous cycle, four stages need to be completed to start a new cycle. It is known, in order, as Pro-Oestrous (3days), Oestrous (2days), Met-Oestrous (4-5 days) and Di-Oestrous (10-12 days). During Oestrous, the sow is sexually receptive to be fertilized. One will notice a change in behaviour, feed intake and standing reflex. Ovulation occurs 36-42 hours after the onset of oestrous (Tauson, 2012).

The number of oocytes a mammal produces during its lifetime, is determined before birth. As the animal approach puberty, the follicles starts to develop and continue with meiotic cells division. Folliculogenesis is divided into two stages. Firstly, the hormone-independent stage, followed by hormone-dependent stage. During the hormone-independent stage, the follicle increase in size and activity (±0.40 mm). Oocytes are initially surrounded by follicular cells. These cells start to grow and divide to form granulose cells. After this transformation, the zona pellucida is formed, serving as a glycoprotein layer around the oocyte. Theca cells around the developed follicle are supplied with blood and supply nutrients to the granulosa cells and oocyte. Theca cells form part of the outside layer of the follicle (Tauson, 2012).

At the start of the hormone-dependent stage, the developed follicles synthesize receptors, which is sensitive for a specific hormone. The granulosa cells have receptors which are sensitive for FSH and oestrogen. The theca cells have receptors sensitive to LH. Theca cells produce androgens under the influence of LH, which is converted to oestrogen at the granulosa cells. This can only take place if FSH is present to stimulate the granulosa cells. The oocyte with supporting cells surrounding it, is now known as an antral follicle (Tauson, 2012).

Initially, follicles can continue with development or undergo atresia. The determining factors are recruitment and selection. The recruited follicles present on the surface of the ovary (±50 follicles from 1-6 mm) are selected 5 – 7 days before oestrous. The reason for variation in size is because all the recruited follicles are in different stages of development. Only a small number will eventually mature and ovulate.

Follicles are selected during the luteal phase in the presence of the CL. During this phase, the follicles are still small to medium sizes. After regression of the CL, the number of large (>6.5mm) follicles starts to increase. Before ovulation, a number are selected and their dependence shifts from FSH to LH. This is made possible by the change in receptors on the granulosa cells from sensitive to FSH to LH. Small follicle will undergo atresia, as well as most of the medium size follicles (Tauson, 2012).

For ovulation to occur, a pre-ovulatory LH surge needs to be initiated by GnRH stimulation. LH surge stimulates the last stage of follicle maturation. Lastly, it stimulates the production of intrafollicular substances to support the rupture of a follicle. 36 - 42 hours after the onset of oestrous, ovulation occurs and several follicles are released (Tauson, 2012).

Follicle development is influenced by lactation. Due to the sudden decrease in progesterone concentration at parturition, the LH secretion immediately increases. After 2-3 days, LH concentration decreases as a result of suckling stimulation form the sow's piglets. Prolactin is the hormone regulating lactation and inhibits the release of GnRH. After 2 weeks of lactation, the suckling intensity decreases and the anterior pituitary is more responsive to GnRH, resulting in a gradual increase in LH concentration. With this slight increase in LH, follicle development continue, initially at a lower rate. As the LH pulse frequencies increases, follicular growth and maturation continues. During lactation, the follicle diameter hardly become more than 5 mm (Tauson, 2012).

2.4 Flush feeding

Oocyte quality is affected by the age of a sow, breed, environment and nutrition. The main nutritional influence is energy supply. When an animal is flush fed, it is introduced to a sudden increase in starch and sugar for a short period. Sugars are directly used to supply energy to the body and contains glucose. Starches consist primarily of glucose and is readily available as an energy source. This is an acute effect on the sow because the animal's body weight is not altered, it is only to recover after lactation. It is one of the feeding strategies introduced to improve reproductive performance after weaning. It directly affects the hypothalamic-pituitary-ovarian axis, as a result of changes in metabolic – and reproductive hormones (Tauson, 2012).

During lactation, the nutrients that the sow consume, as well as her body reserves, are partitioned towards milk production. This is a high energy demanding period in any animal's life and due to this, the animal is in a catabolic state (negative energy balance) during lactation. Because of the lack of energy, folliculogenesis is impaired. It causes an increase in Growth Hormone (GH) and nonesterified fatty acid (NEFA) and a decrease in IGF-1, insulin, glucose and leptin. These changes alter the intrafollicular fluid and decrease preovulatory follicle function through changes in the growth pattern of the follicle. It has a direct effect on oocyte quality and can lead to a prolonged WEI, a lower total born and increase variation within the litter (Tauson, 2012).

After weaning, the suckling stimulus is removed and the number of LH surges increase. By flush feeding the sow, it gives the sow time to recover after lactation. The sudden increase in readily available energy stimulates follicle recruitment and growth, because the elevated concentration of glucose has a positive effect on reproduction. Thus, more sows come onto heat (Den Hartog, 1984). It is important to remember that flush feeding after weaning, only recovers ovulation rate and not enhance it. However, according to Garcia-Garcia, 2012, it only has a significant effect on animals with a low body condition after lactation.

The advantage of supplying energy for a longer period, starting in lactation, is that the sow will be in a less catabolic state, will have a longer period to recover and be in a better condition at the following ovulation. It also has a positive effect on the hypothalamic-pituitary-ovarian axis, by stimulation of LH and FSH production during lactation. Thus, the follicles will be stimulated for a longer period, removing or suppressing the factors limiting folliculogenesis during lactation.

Van den Brand, *et al.*, did a study where he compared two sources of dietary energy to each other during lactation and postweaning. He used starch and fat as the energy sources in the diets and examined the effect on glucose, insulin and LH concentrations, as well as follicle development, weaning-to-estrus interval and ovulation rate. Sows fed on the starch diet had higher glucose and insulin concentration during lactation. LH pulses were not affected by the energy sources, but is correlated to lower feeding levels and weight loss during lactation. Higher number of LH pulses occurred if the sow received higher levels of feed and less weight loss. Follicle diameter tends to be larger for starch diets compared to a fat diet (3.8mm vs 3.1mm). The duration of estrus was 54 hours for sows on a starch diet and 47 hours for those on a fat diet. The rest of his findings was not influenced by energy sources, but were by the feeding levels. With higher feeding levels during lactation, the follicle diameter was higher, 94% of the sows returned to estrus, had a shorter WEI and a higher ovulation rate (Van den Brand, et al., 2000).

2.5 Metabolic Hormones

Nutrition can have a central or local effect, as a response to metabolic- and intraovarian changes. The relationship between nutrition and follicle development is the glucose-insulin system, IGF system and leptin system. The metabolites produced with an increase in energy are increased glucose, insulin, IGF-1, leptin and lower non-esterified free fatty acids (NFFA). These metabolic hormones send signals to the hypothalamus, stimulating GnRH release. This, in turn, stimulates FSH and LH release and because the metabolic status can be altered, LH pulses are modified. Locally, there is an effect on the ovary and the most important event regulated by energy balance is folliculogenesis. Intra-follicular alterations are made as a result of changes in metabolites and the higher concentration of FSH and LH secreted, enhance folliculogenesis (Scaramuzzi, *et al.*, 2006; Garcia-Garcia, 2012; Tauson, 2012).
Glucose-insulin system. Follicle development is stimulated by energy, mainly glucose. Insulin increase glucose uptake, which serves as an energy source to the body, including the follicles that are developing. Glucose increases the number of large follicles maturing during folliculogenesis. There is an increase expression of GLUT-1 and GLUT-4 proteins (glucose transporters) in the granulosa and theca cells, which regulates glucose uptake in the ovary. Insulin increases the responsiveness to LH in the ovary. During a period of restricted energy, the lower level of insulin at the ovarian level reduces androgen and estradiol production, which results in less LH receptors acquired by the follicle. Insulin regulates follicular atresia during folliculogenesis. It reduces the number of small – and medium-size follicles, maintaining more good quality pre-ovulatory follicles (Garcia-Garcia, 2012 & Tauson, 2012).
Leptin system. Leptin is present in the intra-follicular fluid. It inhibits the secretion of oestradiol by stimulating theca cell steroidogenesis, meaning that the follicle will be exposed longer to higher levels of LH during folliculogenesis. Thus it will affect follicle development, follicle rupture and the CL being formed after ovulation.
IGF system. High level of IGF-1 in the follicular fluid stimulates folliculogenesis, follicular proliferation, steroid secretion, oocyte maturation and increases ovulation rate. Because, like insulin, IGF-1 increases the responsiveness of LH in the ovary (Tauson, 2012). Thus, changes in the IGF system due to nutrition will alter the quality of the oocyte being produced (Clowes, et al., 1994).

Figure 2.1 shows a schematic representation of how metabolites influence reproduction.

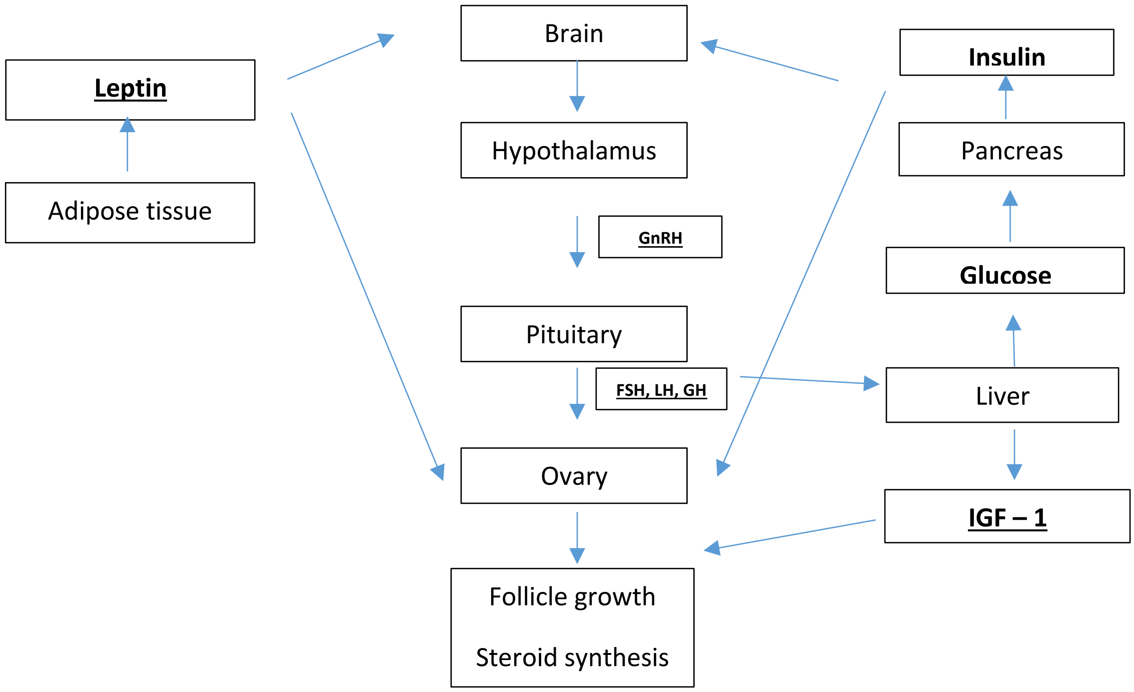


Fig. 2.1 Schematic representation of how metabolites influences reproduction. (Garcia-Garcia, 2012)

2.6 Reproductive Hormones

Reproductive hormones are regulated by the hypothalamic-pituitary-ovarian axis. GnRH is secreted by the hypothalamus, which stimulates the anterior pituitary, secreting LH and FSH. The female reproductive processes depends on them. These hormones ultimately stimulate the ovaries to release estradiol or progesterone. (Tauson, 2012)
LH and FSH each have their own main functions in the reproductive axis. Even though each has their own functions, LH and FSH interact with each other to complete an oestrous cycle. LH regulates ovulation and the formation of the CL, while FSH stimulates follicle growth. (Tauson, 2012)
Estradiol production occurs in the granulosa cells of a follicle and is controlled by FSH and LH. Progesterone is released by the CL and is controlled by LH concentrations. Prolactin maintain lactation after parturition and is produced by the anterior pituitary. Both these hormones have important roles in the reproductive activities of an animal. Estradiol initiates puberty by regulating GnRH release stimulating the LH surge to trigger ovulation. It improves the survival of oocytes and spermatozoa in the Fallopian tube of the uterine horn, it stimulates secretory activity. It also stimulates the development of the endometrial glands to ensure that a zygote is maintained before implantation, as well as the growth of ducts in the mammary gland. Progesterone acts synergistically with oestrogen. It stimulates endometrial gland to grow as well as the secretory activity to supply the zygote with nutrients before implantation. It maintains pregnancy by preventing contractions of the uterus. It also promotes the growth of lobuloalveolar in the mammary gland (Tauson, 2012).
With the reproductive axis, it states that there is a connection between the hypothalamus, anterior pituitary and ovaries. Thus to be able to regulate the concentration of hormones in the blood system, Estradiol and Progesterone can also stimulate the hypothalamus to either release GnRH or not. The hypothalamus is not only influenced by metabolic hormones. This system works through a positive or negative feedback system. Estradiol usually stimulates the release of GnRH. High concentrations of estradiol has a positive feedback to the hypothalamus, stimulating GnRH release, resulting in a pre-ovulatory LH surge. In contrast, high levels of progesterone send a negative feedback signal to the hypothalamus, inhibiting the release of GnRH. (Tauson, 2012). Thus, for folliculogenesis, the negative feedback signalling is critically important, because as long as there is not an LH surge, the follicle has a longer period to develop and increase in size (Scaramuzzi, et al., 2006).
During lactation, there is interference with the normal oestrous cycle. As mentioned above, it influences follicle development. The pituitary is stimulated to secrete prolactin (PRL), Growth Hormone (GH), Adrenocorticotropin (ACTH), Thyroid-Stimulating Hormone (TSH) and Oxytocin. The release of these hormones stimulates the secretion of IGF-1, cortisol and thyroid hormones. While all these hormones are associated with milk production, they also have a metabolic effect. GH has a repartitioning effect on glucose and lipids towards the mammary gland. IGF-1 minimize catabolism of body protein. Protein synthesis in the mammary gland is stimulated by thyroid hormone and the energy supply from body stores are directed towards the mammary gland due to the release of cortisol. (Tauson, 2012)

2.7 Wean-to-Estrus Interval (WEI)

By characterizing the factors influencing WEI of sows, has resulted in procedures to detect estrus and ovulation more effectively to improve the reproductive performance. The reason why it is important to know these factors is because it directly influence sow efficiency. In WEI, it is the ability to accurately determine the onset of oestrous (Knox & Rodriguez Zas, 2001). The lactation length, metabolic status, number of piglets suckling and weight loss during lactation will determine the WEI (Wilson & Dewey, 1993 & Tauson, 2012).
These factors can either cause ovulation to occur too early (less than 3 days) or too late (more than 7 days). According to Knox *et al*., if a sow returns to oestrus in less than 3 days, its chances to ovulate is 80% and if it is 4 days or more, the ovulation rate increases to 92%. The optimal time for inseminations are shown to be between 3 to 6 days after weaning. It resulted in a higher ovulation rate, farrow rate and litter size. Keeping the WEI in mind, the timing of insemination is also important. Ovulation occurs 38 to 48 hours after onset of estrus and the optimal time to inseminate a sow is 24 hours before ovulation. Thus, by regular heat checks and boar stimulation, the onset of estrus can be determined more accurately (Wilson & Dewey, 1993).
There is a correlation between energy levels and ovulation rate. If a sow is in a severe catabolic state during lactation, due to limited feed, low energy levels in feed or milk production, it will delay the onset of oestrous (Zak, *et al.*, 1998 & Tauson, 2012). WEI is not influenced by the energy state after weaning, but is more dependent on the state during lactation. (Zak, et al., 1998). Reason being, if the LH concentration is higher before weaning, the WEI is shorter. An anabolic state or a less severe catabolic state during lactation will have a positive effect on postweaning fertility, because more energy is available for reproductive purposes. The catabolic state results in a loss in body condition. According to Wilson and Dewey (1993), the second parity

dip is due to a loss in body condition, because, during their first lactation, they have to maintain milk production and growth. 23% of the first parity sows will return to estrus later, compared to 8.2% of the older sows.
To monitor the metabolic state during lactation is challenging. The only way to measure it effectively is to weigh the sows at farrowing and weaning. Because weight loss is positively correlated to WEI and weight and condition at insemination is negatively correlated to WEI (Den Hartog, 1984).
WEI ultimately will determine the sow efficiency of the herd. According to Wilson and Dewey (1993), the less efficient period is 7 – 10 days after weaning. If a sow returns to estrus during this period, the chances of a sow not to farrow is 3 times more likely, the number of pigs produced per mated sow decreases by 30% and it also resulted in a lower born alive per sow (Wilson & Dewey, 1993).

2.8 Litter characteristics

Selection intensity on litter size has been improved over the past decades. The increase in litter size led to an increase within litter variation. Birth weight is an important trait in pig production and due to the higher variation, there are more piglets born with a lower birth weight. This is a result of intrauterine crowding causing a decrease in nutrient and oxygen supply to some piglets in the large litter, affecting their development and growth. Low birth weights have a negative effect on piglet viability and growth rates, resulting in higher mortality rates and lower daily gains. Table 2.2 shows the effect of birth weight on live weight at different ages in a pig's life, as well as on average daily gain (Vaclavkova, et al., 2012).

Table 2.2 The effect of birth weight on live weight and average daily gain (ADG) (Vaclavkova, et al., 2012).

Traits	**Birth weights**			
	<1000g	**1001 – 1200g**	**1201 – 1500g**	**1501g>**
Live Weight at 21 days	6.57 ± 0.41	6.84 ± 0.42	7.02 ± 0.44	8.12 ± 0.78
Live weight at 28 days	6.77 ± 0.74	7.4 ± 0.81	8.01 ± 0.78	8.67 ± 1.12
Live weight 2 weeks before slaughter	86.33 ± 4.99	95.17 ± 12.18	109.47 ± 8.32	116.33 ± 7.23
Live weight at slaughter	98.83 ± 6.41	108.58 ± 12.18	122.06 ± 7.35	132.50 ± 7.27
ADG pre-wean	241.67 ± 26.30	264.29 ± 28.79	286.13 ± 27.96	309.52 ± 39.86
ADG birth to slaughter	546.04 ± 35.44	599.91 ± 67.27	674.36 ± 40.62	732.04 ± 40.19

Birth weight is an indication of how the piglet is going to perform for the rest of its life. As seen in Table 2, the piglets with higher birth weight, grew faster and had a higher average daily gain. From an economic point of view, faster-growing pigs are more profitable, because the pigs reach the target slaughter weight at an earlier age. The difference between a higher birth weight and lower birth weight, is more or less 30 kg at slaughter. A piglet is considered viable at birth if its birth weight is higher than 1.2 kg. The chances of this piglet to survive is higher and they will reach the maximum of its production efficiency up to slaughter (Vaclavkova, et al., 2012).
With nutritionally induced changes, the litter variation decreases and there is an increase in birth weight with 80g. By reducing the variation, the piglet survive and perform better and sows with a previously lower born alive, had a higher born alive in the subsequent litter. At the end, it influences the number of piglets weaned per sow. (Van den Brand, et al., 2009)
The subsequent litter is also parity related. There tends to be a higher birth weight in 4th parity and older, as well as the total number stillborn. With flush feeding after lactation, the total number born increase with 0.31 and the live born with 0.51.

2.9 Conclusion

For a sow to be reproductively efficient, it is important to ensure that the sow is in a good state at weaning. Increasing the lactation energy intake will limit the losses during lactation. Thus the sow will be in a better condition at insemination. A higher energy intake during lactation will also lead to a lower WEI, influencing the sow's productivity. A lower WEI is correlated with a higher total number born in the following litter.

Chapter 3: Materials and Methods

3.1 Introduction

The experiment was conducted in Villiers, South Africa, from June 2019 to November 2019. Before the experiment could start, it was important to receive ethical clearance from the animal ethics committee first, which was approved in February 2019. The aim of the experiment is to determine the effect of feed and energy intake by adapting a feeding curve and change in energy source during the last week of lactation, on reproduction functions in sows and the effect on the subsequent litter.

3.1.1 Materials

In this experiment, 252 lactating sows were randomly divided into three groups of 84 each. To remove sow variation between groups and within a treatment group, Topigs Norsvin, purebred Z-Line sows, were inseminated with pooled A-line semen, and randomly assigned to a specific treatment group. To reduce the variation between parities, lactating first, second, third and fourth parity sows were treated. To reduce variation of the influence of the number of piglets suckling the sow, all the sows had 12 piglets at the beginning of lactation. This was regulated by cross-fostering, up to 48 hours after farrowing.

3.1.2 Methods

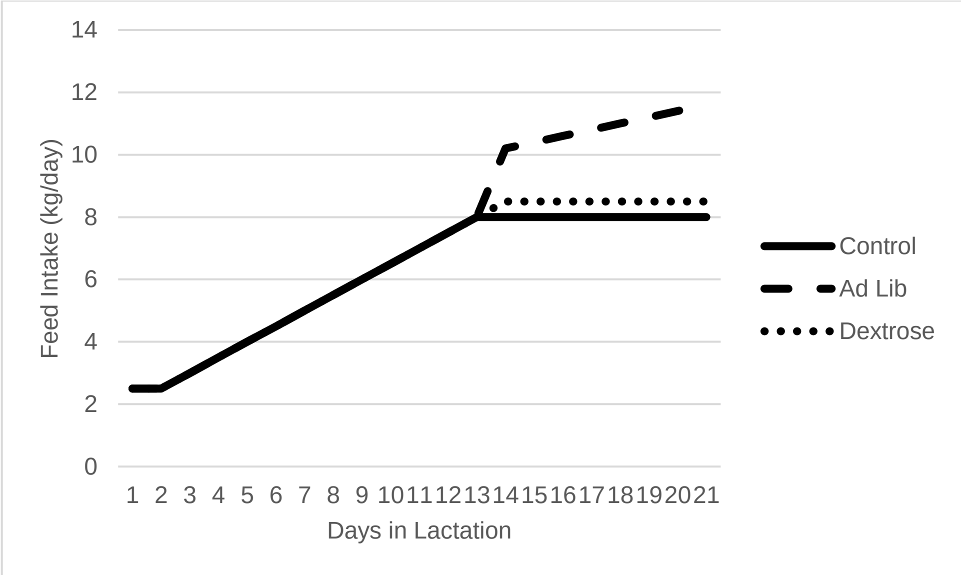
The diets on the farm is corn-soya based diets. Table 3.1 shows the nutrients of the different diets which the sows ate during the duration of the experiment. See Addendum A for feed composition of the different diets.

Table 3.1 Calculated contents of the lactation diet, dextrose, wean-to-service (WSI) diet and gestation diet.

		Diets			
Nutrients	**Unit**	**Lactation**	**Dextrose**	**WSI**	**Gestation**
Crude Protein	%	15,9	0,00	14,00	13,00
Crude Fat	%	2,87	0,00	3,20	2,87
Crude Fibre	%	3,9	0,00	3,9	5,66
Calcium	%	0,95	0,00	0,65	0,70
Phosphorus	%	0,59	0,00	0,62	0,54
Sodium	%	0,22	0,00	0,23	0,26
NE	MJNE/kg	9,7	16,74	9,6	9,3
SID Lys	g	8,8	0,00	6,7	5,7
SID Lys/NE	ratio	0,91	0,00	0,70	0,61

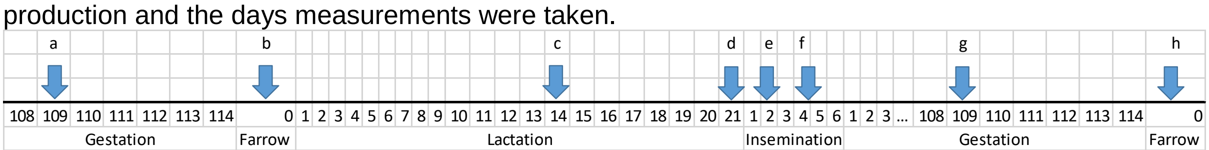
A standard feeding curve can be seen in Fig. 3.1, with the added treatment groups. All sows were fed to the same feed intake curve until day 13 of lactation. From day 14 the sows were fed according to a specific treatment group. Group 1 (Control) received a lactation diet during lactation, following the standard feed curve (maximum level of 2kg plus 500 g per piglet). Group 2 (Ad Lib) was fed with the same lactation diet with an increase in feed level (ad lib) on day 14 to 21. Group 3 received the same lactation diet and followed the standard feed curve with a dextrose top-up (500g/day) from day 14 to day 21. After weaning all groups received a standard wean-to-service diet of 4kg per day until they moved to the gestation houses. During lactation, total feed intake per sow per day was calculated to determine the feed- and energy intake during lactation.

Fig. 3.1 Schematic illustration of a standard feeding curve during lactation, including the treatment groups.



The randomly selected sows were weighed before they were moved into the farrowing house and after weaning, to determine weight loss. The weight loss was determined with the equations formulated by Rob Bergsma (Bergsma, 2011). The farrow date, number of piglets born and their individual birth weight was recorded at farrowing. The farrow date was used to determine the lactation length of each sow.
After weaning, sows entered the insemination house where they received the standard wean-to-service diet (4kg per day, 38,4 MJ NE/day) and daily boar stimulation. During this period, heat detection and insemination dates were recorded daily. At 48 hours after insemination, follicle size was measure with a trans-rectal scanner. See Addendum B explaining the procedure of insemination.
After insemination, sows were relocated to the gestation pens where they stay for 16 weeks. See Addendum C on how sows are grouped and fed during gestation. Sows that returned to oestrous, not pregnant after the pregnancy scans, abortions and mortalities were recorded, with the number of sows that farrow to determine the farrowing rate for each treatment group. The subsequent litter size and their individual piglet birth weights were recorded to determine the effects of the different treatment groups.

Fig. 3.2 Illustrates the timeline of the sows randomly selected for the experiment, including the stage of production and the days measurements were taken.



[a] Farrow Weight
[b] Farrow date and litter information (born alive, total born, individual birth weight)
[c] Treatment of sows according to the assigned group
[d] Sows were weaned. Weaning weight was taken
[e] Follicle size was measured
[f] Insemination date
[g] Farrow Weight
[h] Farrow date and litter information (born alive, total born, individual birth weight)

3.1.2.1 Data editing

Table 3.2 Outliers that were removed from the data set

Sow Number	Tag Nr.	Reason to remove
1	SK0327	High number of mummies in subsequent litter
2	SK1351	High number of mummies in litter before treatment
		Low birth weight before treatment
		>25% empty body weight loss
		Prolonged WSI [a]
3	SI4577	Prolonged WSI [a]
4	SL6198	Prolonged WSI [a]
5	SK1354	Prolonged WSI [a]
6	SL6987	Prolonged WSI [a]
7	SK3106	Wrong pedigree
8	SH6278	Culled
9	SI4103	Died - stomach ulcer
10	SJ7875	Wrong pedigree

[a] WSI of more than 8 days.

A prolonged WSI will influence the outcome of the results and can give the wrong impressions. Firstly, the sow has a longer time to recover, leading to a better condition at insemination. Secondly, it will influence the subsequent litter characteristics (Clowes, et al., 1994).

3.1.2.2 Statistical analysis

Data manipulation, visualization and treatment were conducted using the R Studio software. Records equal to the mean ± 2 STD were considered outliers and removed from the dataset. Abnormal situations, records or sows were removed after careful scatterplot analyses. R Studio was also used to determine the normality of all the variables.

For each of the dependent variables, WSI (days), empty body weight loss during lactation (%), subsequent total number born, subsequent individual birth weight (g), subsequent litter weight (kg) and subsequent within litter birth weight standard deviation (g) of each litter, a mixed linear model was used. Models were analysed through the MIXED procedure of the University Edition of the Statistical Analysis System (SAS System, Inc., Cary, NC, USA). The model assumed was

$$y_{ijklm}=\mu+group_i+parity_j+MI_k\ \ +LL_l+FI_m+e_{ijklm}$$

where y is the dependent variable for each sow, µ is the mean across sows, group is the treatment (i = control, ad libitum or dextrose), and parity (j = 1, 2, 3 or 4), MI is the month of insemination (l = June, July, August, September, October or November), LL is the lactation length, FI is the feed intake in kilograms or energy intake in MJ NE, and e is the residual term. Least square means were computed and separated by Tukey test. P values lower or equal to 0.05 were considered significant.

Chapter 4: Results

The descriptive statistics of the sows included in the analyses per group are shown in Table 4.1.

Table 4.1 Descriptive statistics of the parity, feed intake, body weight change during lactation and the following gestation, and pre-and post-treatment litter characteristics of sows analysed per group (means±STD).

	Group		
Variables	**Control**	**Ad Lib**	**Dextrose**
n	80	71	81
Farrowing			
Parity	2,29±1,03	2,39±1,06	2,31±1,06
Total Number Born	16,05±3,17	16,34±3,80	16,21±3,08
Average Birth Weight, g	1348,38±224	1345,73±161	1342,98±209
Litter Weight, kg	21,25±3,96	21,77±4,83	21,57±4,49
Litter Variation, STD g	276,79±68	276,23±74	269,88±76
Last week of lactation			
Feed intake, kg per day [a]	6,62±1,55	7,86±1,82	6,49±1,40
Energy Intake, MJ NE [b]	449,75±105	533,46±123	498,99±95
Weaning			
Lactation days [c]	22,03±1,62	22,11±1,57	21,99±1,77
Empty body weight loss, %[d]	7,45±6,27	7,66±7,17	8,99±5,66
Insemination			
Month of insemination [e]	9,09±1,43	9,17±1,39	9,14±1,38
WSI	4,57±0,64	4,53±0,73	4,67±0,55
Gestation			
Gestation Gain, kg	66±22,10	60±21,89	76±19,23
Subsequent farrowing			
Total Number Born	17,16±3,53	17,48±4,19	17,73±3,09
Average Birth Weight, g	1416,93±217	1376±135	1379±201
Litter Weight, kg	23,78±4,36	23,91±5,56	24,33±4,09
Litter Variation, STD g	304,30±72	291,53±59	298,78±65

[a] Feed intake per day (kg) during the last week of lactation.
[b] Total energy intake (MJ NE) during the last week of lactation.
[c] Difference between farrowing date and weaning date.
[d] Estimated according to the equations of Rob Bergsma (Bergsma, 2011).
[e] Month of insemination is calculated as a number, where June is month 6 to November is month 11.

There was no significant effect of group on the sow efficiency (WSI; P>0,41) and the subsequent litter's total number born (P>0.36), although there was a trend seen of the effect of dextrose top-up on the subsequent litter's total number born (P>0.16).

Although the average feed intake per day and the total energy intake during the last week of lactation, varied between groups, there was more variation within the groups with regards to feed- and energy intake. These observations affect the effect of energy on sow efficiency and subsequent litter. Instead of analysing the different groups, Table 4.2.1 shows a descriptive table of the sows grouped by their energy intake during the last week of lactation, where the energy intake was ranked from a low to high intake and divided into 3 equal groups. The rest of the tables are also grouped in this way throughout the chapter.

Table 4.2.1 Descriptive statistics of the parity, feed intake, body weight change during lactation and the following gestation, and pre-and post-treatment litter characteristics of sows that had a low, medium and high total energy intake (MJ NE) during the last week of lactation (means±STD).

Variables	Group: Low Energy Intake (135,8-452,41)	Group: Medium Energy Intake (454,93-522,83)	Group: High Energy Intake (529,62-746,9)
n	75	71	82
Average energy intake per group (MJ NE)	373	491	602
Farrowing			
Parity	1,93±1,09	2,35±0,96	2,70±0,94
Total Number Born	15,73±3,13	15,97±3,44	16,83±3,35
Average Birth Weight, g	1306,68±207	1369,52±191	1364,85±200
Litter Weight, kg	20,33±4,49	21,58±4,35	22,64±4,14
Litter Variation, STD g	265,27±73	273,78±71	283,57±75
Last week of lactation			
Max feed intake, kg per day [a]	5,20±1,17	6,93±0,48	8,56±1,06
Weaning			
Lactation days [b]	21,7±1,93	22,01±1,42	22,32±1,54
Empty body weight loss, % [c]	9,51±6,56	8,20±5,71	6,38±6,31
Insemination			
Month of insemination [d]	9,09±1,43	9,17±1,39	9,14±1,38
WSI	4,73±0,65	4,57±0,58	4,48±0,66
Gestation			
Gestation Gain, kg	64,06±20,22	63,66±21,16	57,21±20,76
Subsequent farrowing			
Total Number Born	16,53 [x] ±3,35	16,91 [y] ±4,01	18,79 [z] ±3,09
Average Birth Weight, g	1441,32±215	1380±193	1358,34±159
Litter Weight, kg	23,03±4,11	23,32±5,86	25,60±3,41
Litter Variation, STD g	283,93±73	311,09±71	301,78±52

[a] Feed intake per day (kg) during the last week of lactation.
[b] Difference between farrowing date and weaning date.
[c] Estimated according to the equations of Rob Bergsma.
[d] Month of insemination is calculated as a number, where June is month 6 to November is month 11. (P<0.05)
[x,y,z] Effect of total energy intake during the last week of lactation on the subsequent total number born (P<0.01)

Table 4.2.2 Percentage of each treatment group per energy group according to Table 4.2.1

	Energy intake group: Low	Energy intake group: Medium	Energy intake group: High
Treatment Group			
Control	45,30%	40,80%	20,70%
Ad lib	21,30%	23,90%	43,90%
Dextrose	33,30%	35,20%	35,40%

At the high energy intake group, the sows were older and had a higher total number born before treatment and the same sows loss less empty body weight during lactation. The sows with a high total number born before treatment, also had a high total born after treatment (P<0.01). It is important to note that the energy intake (P<0.01) during the last week of lactation, before weaning had a more significant effect on the following total number born than the feed intake (P<0.05) before weaning. The higher lactation feed intake (P<0.05) and energy intake (P=0.07) before weaning had a positive effect on their WSI interval. Together these results

indicate that having a high energy or feed intake before weaning, will lead to a better metabolic condition at weaning, i.e. less catabolic, as well as during the period of insemination.
The body weight gain during gestation was less when the empty body weight loss during lactation was lower, due to the management system on farm (See Addendum B). Body weight gain was significantly influenced by the total energy intake during the last week of lactation in 1st parity sows ($p<0.05$), total born in the previous farrowing ($p<0.01$), farrowing weight from previous farrowing ($p<0.001$), empty body weight loss during lactation ($p<0.001$) and month of insemination ($p<0.05$).
When comparing between low energy intake to high energy intake there was a 2.26 significant difference ($P<0.01$) in total number born in the following litter. There was a 2.57 kg increase ($P>0.7$) in litter weight between the low energy intake and high energy intake, whereas the individual piglet birth weight for the lower energy intake group was higher ($P>0.86$), but it was not significantly different. When comparing between medium energy intake to high energy intake there was a further increase in total number born of 1.88 piglets.

Factors affecting wean-to-service interval

Factors influencing wean to service interval (WSI) are described in Table 4.3. WSI was influenced by the total energy intake during the last week of lactation ($P=0.07$) and feed intake per day ($P<0.05$), whereby the WSI was shorter in the sows which consumed a higher level of energy or feed intake. For every 100 MJ NE increase in energy intake in the last week of lactation, the WSI was reduced by 2 hours and 16 minutes. From Figure 4.1, the difference in WSI between the lowest energy intakes to the maximum energy intake, was 13 hours and 12 minutes. Referring to Figure 4.2, for every 1kg increase in feed intake per day during the last week of lactation, the WSI is reduced by 1 hour and 37 minutes. Empty body weight loss also contributed to a difference in WSI, where a lower weight loss during lactation, reduced the WSI ($P>0.1$).

Table 4.3 The means of different variables as a result of wean to service interval (WSI).

	WSI		
Variables	**4**	**5**	**6**
n	95	110	11
Parity [a]	2,36	2,33	1,64
Total Number Born [b]	16,57	16,12	14,55
Energy Intake, MJ [c]	499,95	193,65	377,08
Empty body weight loss, % [d]	6,93	8,33	13,40
Month of insemination [e]	8,94	9,21	9,73

[a] Parity of the sow before treatment
[b] Total number born of the sow before treatment
[c] Total energy intake (MJ NE) during the last week of lactation.
[d] Estimated according to the equations of Rob Bergsma (Bergsma, 2011).
[e] Month of insemination is calculated as a number, where June is month 6 to November is month 11.

Figure 4.1 Scatter plot with a regression line, predicting the WSI at a specific total energy intake consumed during the last week of lactation.

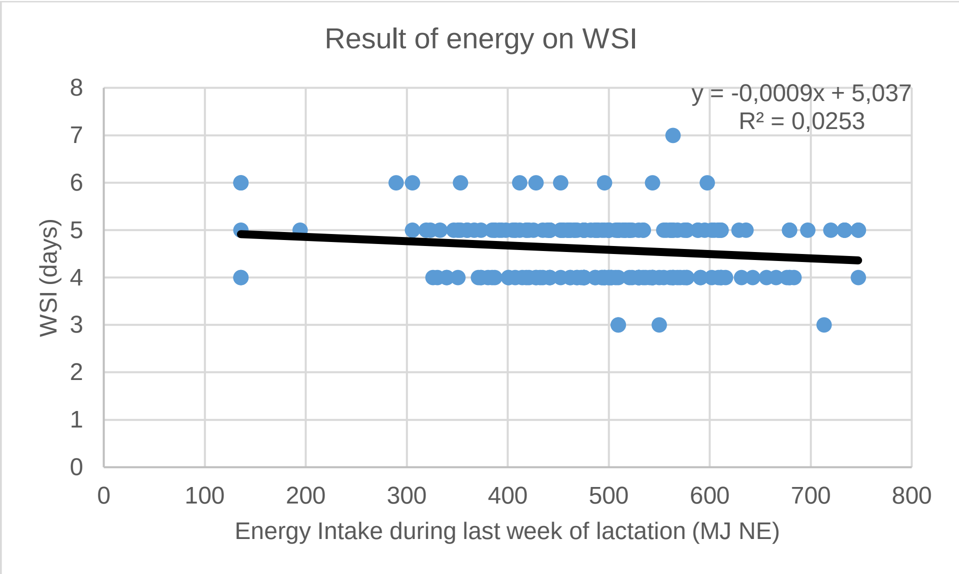
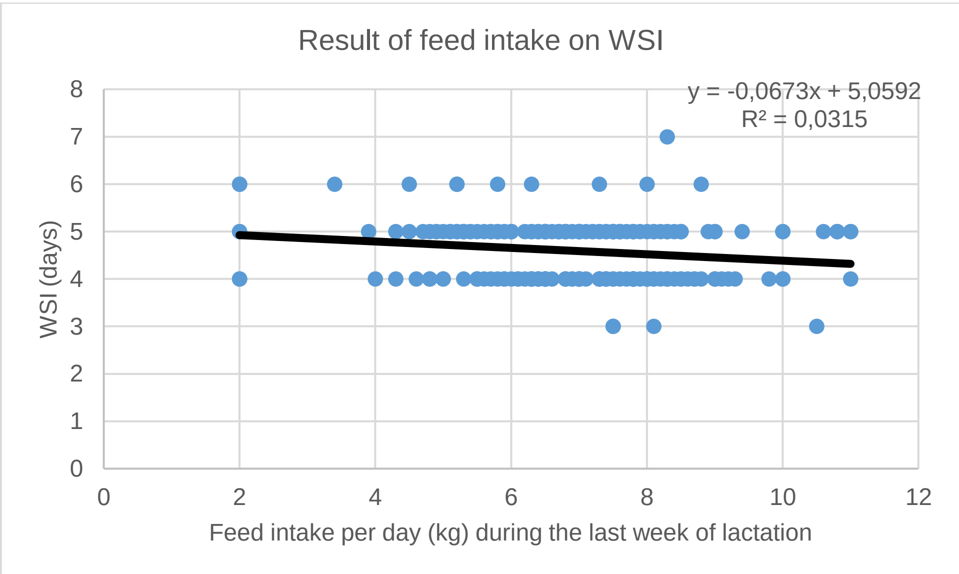


Figure 4.2 Scatter plot with a regression line, predicting the WSI at a specific daily feed intake consumed during the last week of lactation.



Factors affecting empty body weight loss during lactation

Empty body weight loss during lactation was affected by parity (P<0.01), whereby younger sows lost more weight during lactation. Sows having a smaller litter size at farrowing, exhibited a greater weight loss during lactation (P<0.0001). Sows whom consumed more energy during the last week of lactation, lost less weight (P=0.06) during lactation. Refer to Table 4.4 for details. Daily feed intake during the last week of lactation had a significant effect on weight loss (P<0.05). For every 1kg feed intake per day during the last week of lactation, the weight loss % decreases with 0.91% (Fig. 4.3). Dextrose tended to reduce the weight loss during lactation (P<0.1). For every 100 MJ NE increase in total energy intake, the sow lost 1.15% less empty body weight loss during lactation (see Figure 4.3).

Table 4.4 The means of different variables as a result of empty body weight loss during lactation.

	Empty body weight loss, %		
Variables	**Low (-9,67-4,9)**	**Medium (5,1-11,4)**	**High (11,5-24,4)**
n	75	75	73
Parity [a]	2,47	2,51	2,00
Total Number Born [b]	16,49	16,48	15,47
Energy Intake, MJ [c]	510,20	515,33	452,80
Lactation days [d]	21,93	22,11	22,08

[a] Parity of the sow before treatment
[b] Total number born of the sow before treatment
[c] Total energy intake (MJ NE) during the last week of lactation.
[d] Difference between farrowing date and weaning date.

Figure 4.3 Scatter plot with a regression line, illustrating the effect of total energy intake during the last week of lactation on empty body weight loss % during lactation.

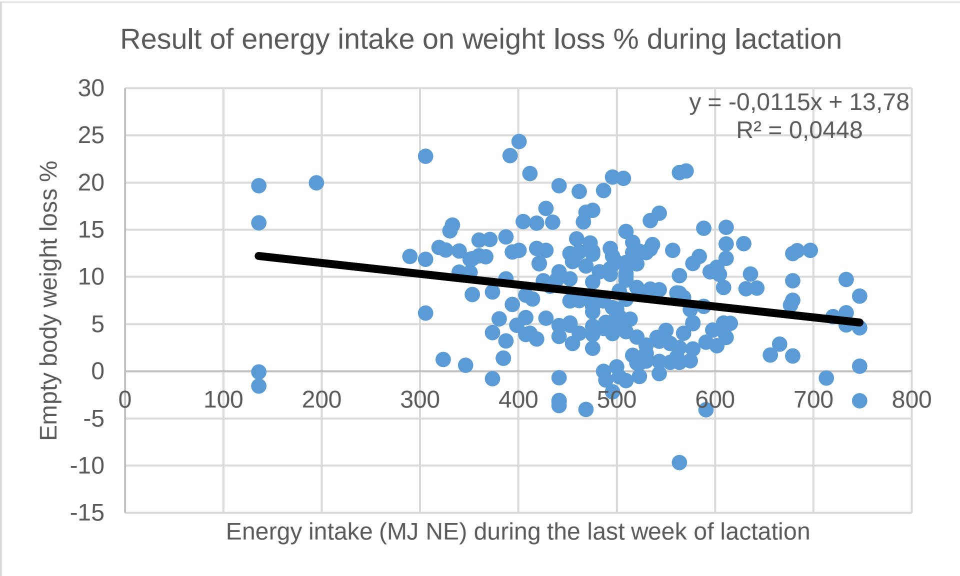
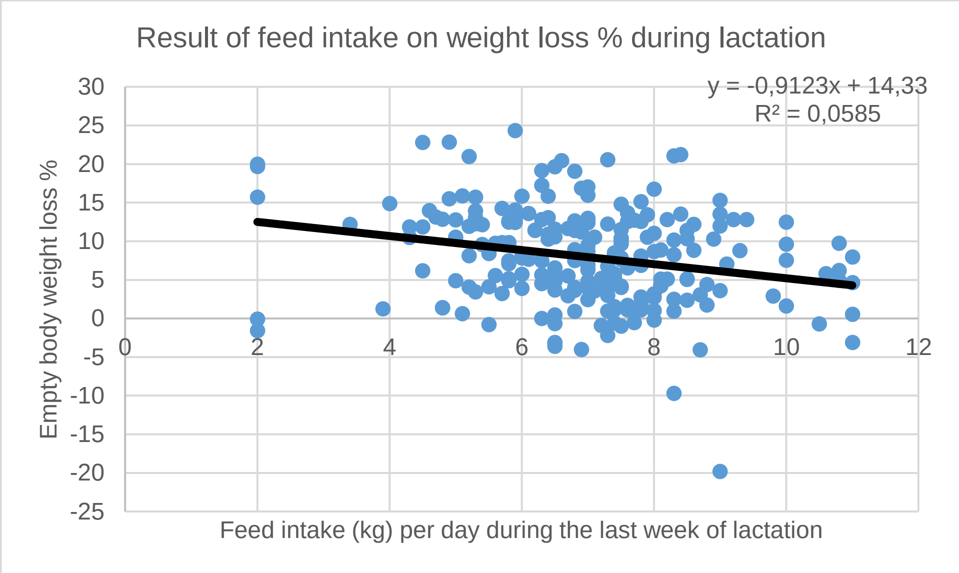


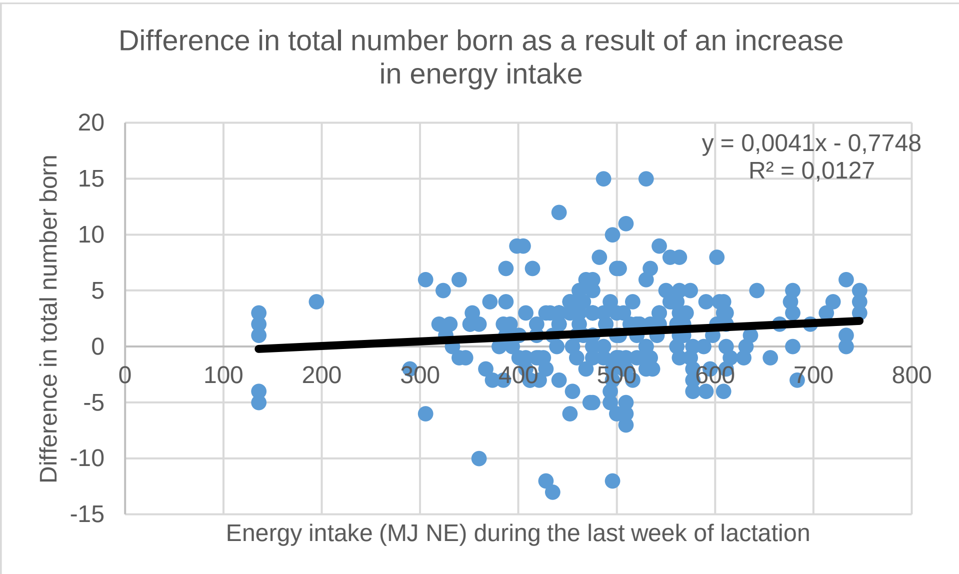
Figure 4.4 Scatter plot with a regression line, illustrating the effect of daily feed intake during the last week of lactation on empty body weight loss % during lactation.



Factors affecting subsequent litter characteristics

Litter size at the subsequent farrowing was significantly influenced by the total energy intake during the last week of lactation (P<0.01). Figure 4.5 indicates that for every 100MJ NE increase in energy intake during the last week of lactation, results in a 0.41 difference in total number born in the following farrowing.

Figure 4.5 Scatter plot with a regression line, indicating the difference in total number born as a result of an increase in energy intake during the last week of lactation.



The importance of daily feed intake during the last week of lactation on the following total number born (P<0.05) is highlighted in Figure 4.6 and 4.7. For every 1kg increase in feed intake, the total born increases with 0.49 piglets.

Figure 4.6 Scatter plot with a regression line to predict the total number born for feed intake per day during the last week of lactation.

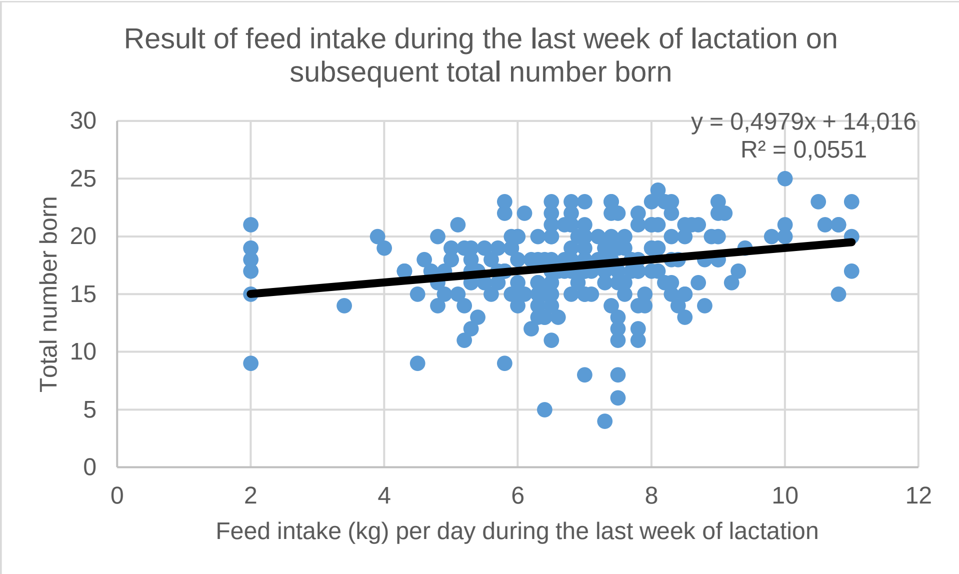
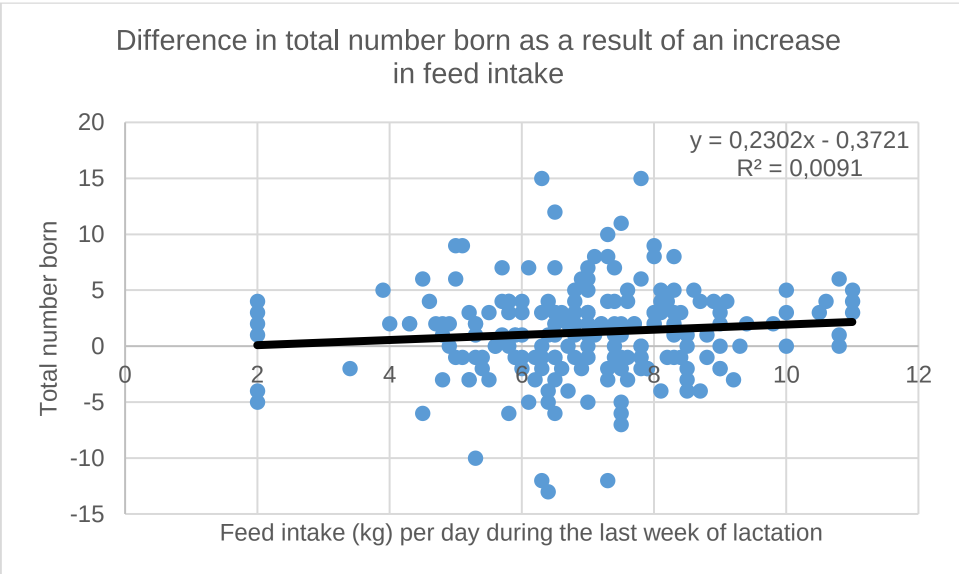


Figure 4.7 Scatter plot with a regression line, indicating the difference in total number born as a result of an increase in feed intake per day during the last week of lactation.



Average birth weight

The subsequent average birth of a piglet was significantly influenced by the total number born ($P<0.0001$) and litter weight ($P<0.0001$) of the following litter (Table 4.5). Litter weight was significantly influenced by gestation gain ($P<0.0001$) and the total number born ($P<0.0001$) of the following litter (Table 4.6).

Table 4.5 The means of different variables for sows that had a low, medium and high subsequent average piglet birth weight.

Variables	Subsequent average piglet birth weight, g Low (864-1300)	Medium (1302-1447)	High (1450-2058)
n	63	62	62
Parity 1 [a]	2,43	2,18	2,37
Parity 2 [b]	3,43	3,16	3,37
Gestation Gain, kg	57,84	64,57	68,57
Total Number Born [c]	18,84	18,24	15,40
Litter Weight, kg [d]	22,70	25,01	24,40
Energy Intake, MJ [e]	513,74	486,46	478,71

[a] Parity of the sow at the start of the experiment.
[b] Parity of the sow at the subsequent farrowing.
[c] Total number born of the sow at the subsequent farrowing
[d] Litter weight at the subsequent farrowing.
[e] Total energy intake (MJ NE) during the last week of lactation

Litter weight

Litter weight was significantly influenced by gestation gain (P<0.0001) and the total number born (P<0.0001), but not by the total energy intake in the last week of lactation on the following litter (Table 4.6).

Table 4.6 The means of different variables for sows that had a low, medium and high subsequent litter weight.

Variables	**Subsequent litter weight, kg** **Low (4,4-22,8)**	**Medium (22,9-26,2)**	**High (26,4-35,3)**
n	62	63	62
Parity 1 [a]	2,13	2,22	2,63
Parity 2 [b]	3,11	3,22	3,63
Gestation Gain, kg	61,00	64,19	65,58
Total Number Born [c]	14,24	17,71	20,55
Energy Intake, MJ [d]	462,69	479,69	536,02

[a] Parity of the sow at the start of the experiment.
[b] Parity of the sow at the subsequent farrowing.
[c] Total number born of the sow at the subsequent farrowing
[d] Total energy intake (MJ NE) during the last week of lactation.

Uniformity of piglets within a litter

The within litter variation was influenced by the parity of the sow (P<0.01). Gestation gain, litter size at the subsequent litter, litter weight and the total energy intake at the end of lactation did not influence piglet uniformity within a litter.

Table 4.7 The means of different variables for sows that had a low, medium and high with-in litter birth weight variation.

	Subsequent variation, standard dev. g		
Variables	**Low 126-270**	**Medium 273-324**	**High 325-472**
n	64	63	60
Parity 1 [a]	2,11	2,48	2,40
Parity 2 [b]	3,11	3,48	3,38
Gestation Gain, kg	62,27	62,90	65,89
Total Number Born [c]	16,53	18,46	17,53
Litter Weight, kg [d]	22,89	24,85	24,37
Energy Intake, MJ [e]	482,03	494,71	502,89

[a] Parity of the sow at the start of the experiment.
[b] Parity of the sow at the subsequent farrowing.
[c] Total number born of the sow at the subsequent farrowing
[d] Litter weight at the subsequent farrowing.
[e] Total energy intake (MJ NE) during the last week of lactation.

Part of the experiment was to scan follicle size 48 hours after weaning. Due to a lack of experience, the data obtained from the scans, were not suitable to use in the results and to make any conclusions from. It was a great learning experience and I thank the University of Pretoria, Onderstepoort and VFT for the training and equipment.

Chapter 5: Discussion

The study shows that it is important to ensure that sows consume enough feed and energy during lactation, especially during the last stages of lactation. There is a clear link between feed- and energy intake during the last week of lactation and sow's subsequent reproductive efficiency and performance. In this study, two types of energy sources were used. The first kind of energy source was from the standard lactation diet, which has to be converted to glucose before the sow's body can absorb it. The second kind of energy source was a dextrose top-up. Dextrose is a readily available energy source to the sow's body (Tauson, 2012).

The initial analysis based on treatment groups, did not show a significant effect of a treatment group on sow reproductive efficiency and the subsequent litter, as the variation in feed intake was greater within a treatment group than between treatment groups. The variation of feed intake was caused by the number of piglets per sow, the parity of the sow and in the case of the top-up treatment group, the dextrose top-up seemed to have limit some of the sows feed intake per day. Keeping in mind that the dextrose group showed a trend on the subsequent total number born.

Highlighting the difference between feed intake and energy intake is important, because the effects of each has a significant effect on the sow and the litter characteristic, respectively. By increasing the energy intake, via feed intake or energy source, the concentration of available energy increases, whereas by increasing only the feed intake, all the nutrient's concentration increases. Referring to Table 4.2.2, by controlling the feed intake of a sow during lactation via a feeding curve, the sow's intake is limited, as the control group with a high energy intake had more piglets and was allowed more feed during lactation. By enabling a sow to eat ad libitum at the end of lactation, 23% more sows consumed more feed and energy when compared to animals fed to the lactation feed curve. Overall this resulted in almost 44% of sows eating high feed intake. The effect of increasing feed- and energy intake was less weight loss during lactation, a shorter WSI and more piglets at the next farrowing. The dextrose top-up seemed to have limited feed intake during lactation, as a third of the low, medium and high energy groups consisted of the dextrose group, although it increased the total energy intake of some of the groups. The variation in feed intake during gestation also affected the next litter size but to a lesser extent than the effect of lactation feed and energy intake.

For a sow to be productively- and reproductively efficient, the sow should be able to perform in terms of economical measurements, such as a high number of piglets weaned per year and a lower number of non-productive days. During lactation a series of events occurs which can influence the sow negatively. Firstly, milk production is a highly demanding phase, in which the metabolic challenges of the sow are met through mobilization of body reserves and to some extent lactation feed intake (Strathe, et al., 2017). Costermans, et al., 2020 recently reported that milk production during lactation is independent of feed intake during lactation, indicating that mobilization of a sow's body reserves is a critical aspect of milk production. This repartitioning of body reserves and nutrients towards milk production, leads to a catabolic metabolic state which it influences the availability of metabolites and hormones for reproductive purposes. There is a decrease plasma insulin, leptin and IGF-1. The hormone driving milk production, prolactin, is stimulated by the suckling intensity of piglets suckling the sow. The hormone inhibits the release of GnRH, meaning that there is a low concentration of FSH and LH available. The low availability of certain metabolites and reproductive hormones, negatively impacts the sow centrally (catabolic state) and locally (impairs folliculogenesis).

Flush feeding is used as a management tool to repair the sow after lactation. During this stage, the follicles that where developing during lactation now has a greater chance of remaining optimal or repairing and to increase in size. In this study, the same idea was kept in mind, but the timing of flushing was different and also for a longer period. Instead of repairing the follicles after weaning, by suppling the sow with extra energy during the last week of lactation seemed to have had a positive effect on the total number of follicles developing during lactation, as seen in the results that there was an increase in total number born.

The timing of increasing the energy uptake is also critical. During lactation, the suckling intensity of the piglets only starts to decrease after 14 days in lactation. As the suckling intensity decreases, the concentration of prolactin also decrease. Thus, the anterior pituitary is more responsive to GnRH. Even if the energy intake was high at a high suckling intensity, all the nutrients would have been partitioned towards milk production. At a lower suckling intensity, and less milk production, more metabolites and reproductive hormones are available for the metabolic state of the sow and for folliculogenesis.

The factors influencing WSI is parity, season, lactation length, weight loss, metabolic status and the number of piglets suckling the sow. From the results of the study, the feed intake of a sow during the last week of lactation had a significant effect on the length of the WSI. Energy intake also affected but was not significant. Weight loss during lactation is driven by parity of the sow and the feed intake during lactation, where energy intake seemed to have had a trend. Younger sows lost more weight during lactation, this is because they have a poor appetite and they are still growing. Leading to the conclusion of a higher feed intake, the sow is in a

less severe catabolic state and in a better condition at weaning and the subsequent insemination. This has a positive effect on the WSI. This confirms the results of L. Zak et al, 1998, Lopes et al, 2020, to name a few.
A recent study done by Lopes et al, 2020, concluded that follicle size at weaning influences the post-weaning performances of a sow in means of the WSI and the quality of the follicles which are ovulated. More follicles are ovulated and because of the better quality and size of the follicles, more embryos have the ability to survive. The subsequent total number born was significantly influenced by the energy intake during the last week of lactation in this study. Supporting the findings of Lopes et al, 2020.
By increasing the energy intake, more plasma insulin, leptin and IGF-1 is available. These metabolites are essential for reproductive purposes on a central and local level. Centrally, it stimulates the production of GnRH, leading to the secretion of FSH and LH. Locally, the metabolites are present in the intra-follicular fluid, enhancing follicle growth, thus affecting the size and quality of the follicles (Hunter, et al., 2004). Before ovulation, follicles are recruited at the ovary. This cluster of follicles consist of small, medium and large follicles. With an increase in energy, the number of small follicles decreases and there are more medium to large follicle available to ovulate. At this point, the medium and large follicles are selected to be ovulated and the small follicles undergo atresia. Thus, there are less small follicles, meaning that less follicles will be lost before ovulation and more follicles are ovulated.
The month of insemination influenced the subsequent total number born. If the sows were inseminated during the warmer months, the chances of having a smaller subsequent litter, increased. This is due to heat stress and loss of appetite during lactation.
This study did not show that feed – or energy intake had a significant influence on the subsequent litter weight, average individual birth weight and with-in litter birth weight variation. These litter characteristics were significantly influenced by factors after insemination. The subsequent individual birth weight was negatively affected by the subsequent total number born and litter weight. The subsequent litter weight was positively affected by gestation gain and the subsequent total number born. The with-in litter birth weight variation was influenced by the age of the sow, indicating that the younger sows had less with-in litter birth weight variation.

Chapter 6: Conclusion

It can be concluded that by managing a sow's feed intake and energy intake during late lactation, will economically benefit the sow herd. By ensuring that the feed intake is sufficient, the sow will lose less condition during lactation. The WSI will be shortened and reduce the number of non-productive days. By increasing the energy intake during late lactation, the sow will be in a better metabolic state. By increasing the energy intake, it will benefit the piglet litter in terms of total number born, which will ultimately increase the number weaned piglets per sow per year.

6.1. Implications

Optimal management of a sow during lactation is complex. During lactation, it is important to feed the sow to support milk production, litter weights and the subsequent reproductive efficiency, as follicles for the following litter starts to develop during lactation. This management starts in lactation, before breeding. By giving sows the opportunity to consume high levels of feed and energy intake during late lactation, the WSI is reduced and the number of piglets born in the next litter is increased.

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Addendum A

Table A.1 Feed composition of the lactation diet, wean-to-service (WSI) diet and gestation diet.

Item	Lactation diet	WSI diet	Gestation diet
Ingredient (g/kg)			
Maize	640	586	625
Soya Oilcake	87	62	20
Full Fat Soya	50	50	-
Wheat Bran	109	130	200
Lucerne	20	-	50
Fishmeal	30	-	-
Sunflower Oilcake	20	60	71
Limestone	15	14	10
MDCP [a]	6	10	4
Salt	4	4	4
L-lysine HCl	3	2	3
L-Threonine	1	1	1
MHA-Methionine	3	2	2
L-Tryptophan	1	-	-
Premix gestation	-	-	7
Premix lactation	5	-	-
Premix flush	-	10	-
Magnesium Oxide	2	-	1
Ecobiol	1	1	1
Sodium Bicarbonate	2	3	3
Mycofix Plus	3	1	1
Mycosorb	2	2	2
Dextrose	-	65	-
Total, g	1004	1003	1005

[a] Mono-Dicalcium Phosphate

Addendum B

After weaning sows are moved to the insemination room, where they stay in individual crates for 6 days. They are fed 4 kg of wean-to-service diet per day.
Heat detection is done on a daily basis. To determine if a sow is in oestrous, a man test is done before they are exposed to the boar. A man test is where a person applies pressure to the back of the sow and the sow stands to be inseminated. If the sow stands for the man, she is marked with a marker on the right side of her tail. After this, the boar enters the room. All the sows standing for the boar, are marked on the left side of the tail. This process starts at 9 AM and is done to determine if the sow is in oestrous and also to determine if the sow is approaching the peak of ovulation (to inseminate the sow at the optimal time).

Table B.1 Heat detection time, time of insemination and the standing reflex of the sow.

Day	WSI	Time of heat detection	Time of insemination	Standing reflex
Thursday	0	9:30 AM	11:00 AM	Sow stands for the man and the boar
Friday	1	9:00 AM	11:00 AM	1. Sow stands for the man and the boar 2. Sow stood for the boar the previous day and is standing for the man/boar today
Saturday	2	9:00 AM	11:00 AM	1. Sow stands for the man and the boar 2. Sow stood for the boar the previous day and is standing for the man/boar today
Sunday	3	9:00 AM	11:00 AM	1. Sow stands for the man and the boar 2. Sow stood for the boar the previous day and is standing for the man/boar today
Monday - AM	4	9:00 AM	11:00 AM	Sow stood for the boar the previous day and is standing for the man/boar today
Monday - PM	4,5		15:00 PM	Sow stood for the man and the boar at Monday AM
Tuesday	5	9:00 AM	11:00 AM	1. Sow stands for the man and the boar 2. Sow stood for the boar the previous day and is standing for the man/boar today
Wednesday	6	9:00 AM	11:00 AM	1. Sow stands for the man and the boar 2. Sow stood for the boar the previous day and is standing for the man/boar today
Thursday	7	9:00 AM	11:00 AM	1. Sow stands for the man and the boar 2. Sow stood for the boar the previous day and is standing for the man/boar today

Addendum C

After insemination sows are grouped into pens of 6-7 sows per group. The sows are grouped according to their back fat, body condition and age. Table C.1 illustrates how the sows are fed during gestation and Figure C.1 demonstrates the feeding curve up to farrowing. It is known as a 3 phase feeding curve. The diet is not changed, but the intake per day is changed to feed them on 3 different levels during gestation. Feed intake levels are changed on day 34 and 90 of gestation.

Table C.1 Feed intake of gestating sows.

Parity 2 & 3	Back fat at insemination (mm)			
Days in Gestation	<11	12-14	15-16	>17
0-33	3,2	2,8	2,7	2,6
34-89	2,9	2,6	2,5	2,4
90-108	3,1	3	2,9	2,8

Sows > 4	Back fat at insemination (mm)			
Days in Gestation	<11	12-14	15-16	>17
0-33	3,1	2,8	2,7	2,6
34-89	2,8	2,5	2,4	2,4
90-108	3,1	3	2,9	2,8

Figure. C.1 Feed curve of sows during gestation.