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Weaning practices and culling policy

Critical steps for optimal reproductive performance of female breeding pigs

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"Anyone who has never made a mistake,

has never tried anything new."

~ Albert Einstein

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ACTH	Adrenocorticotropic Hormone
Ad lib	*Ad libitum*
AI	Artificial Insemination
BW	Birth Weight
Ca	*Corpora albicantia*
Ca	Calcium
CI	Confidence Interval
Cl	*Corpora lutea*
COF	Cystic Ovarian Follicles
Cr	*Corpora rubra*
CV	Coefficient of Variation
E2	Estradiol
eCG	equine Chorionic Gonadotropin
E. coli	*Escherichia coli*
ED	Estrus Duration
e.g.	*exempli gratia* (for example)
ER	Estrus Rate
E. rhusiopathiae	*Erysipelotrix rhusiopathiae*
et al.	*et alii* (and others)
etc.	*et cetera* (and other things)
EU	European Union
FS	Follicle Size
FSH	Follicle Stimulating Hormone
GnRH	Gonadotropin-Releasing Hormone
H	Herlopers
hCG	human Chorionic Gonadotropin
i.e.	*id est* (that is)
IGF-1	Insulin Growth Factor-1
IU	International Unit
LB	Live Born piglets
l-GnRH-III	Lamprey- Gonadotropin Releasing Hormone - III
LH	Luteinizing Hormone
ME	Metabolisable Energy

MJ	Mega Joule
MR	Mortality Rate
Mu	Mummified piglets
NPD	Non Productive Days
OP	Ovulation Points
OR	Odds Ratio
P	Phosphor
P4	Progesterone
PGF2α	Prostaglandin F2α
PMSG	Pregnant Mare Serum Gonadotropin
PR	Pregnancy Rate
Pw	post weaning
PW	Piglets Weaned
RIA	RadioImmunoAssay
RB	Repeat Breeders
SB	Stillborn Piglets
SBI	Spenen-Bronst Interval
SD	Standard Deviation
sFTI	single Fixed Time Insemination
S. scabiei	*Sarcoptes scabiei*
TB	Total Born Piglets
USA	United States of America
WEI	Weaning-to-Estrus Interval
WW	Weaning Weight

Chapter 1

General Introduction

1 General Introduction

Pig producers and breeders have made major efforts to improve sow productivity through genetic selection for increased litter size. This is partly because litter size is easily recorded and partly because some studies in the early eighties have indicated that it is the most important economic component of sow reproductive performance (Bichard et al., 1983; Smith et al., 1983; Tess et al., 1983). The pork industry has achieved tremendous gains in litter size through the introduction of hyperprolific dam lines into commercial production (Beaulieu et al., 2010). Nevertheless, it has been shown that productivity of sows measured as number of produced pigs per year is also dependent on their capacity to give birth to piglets that survive and have high vitality at weaning (Damgaard et al., 2003). Rapid increases in litter size and annual sow productivity have, however, resulted in increased numbers of stillborn piglets and light-birth-weight piglets, limiting the overall effectiveness of selection for increased litter size (Canario et al., 2006; Distl 2007; Rosendo et al., 2007; Beaulieu et al., 2010).

To improve the number of litters per sow per year and the number of piglets weaned per sow per year, it is critical that sows cycle fairly quickly after weaning. In the 1980s, females with lactation lengths of five weeks presented weaning to estrus intervals (WEI) between eleven and a half and twenty and a half days (Vesseur, 1997). As swine production has been intensified in the last years, this interval reduced to approximately five to seven days (Koketsu and Dial, 1997; Behan and Watson, 2005). In most modern sow farms, females commonly show estrus between three and five days postweaning (Vesseur, 1997), with more than 90% returning to estrus by day seven after weaning (Belstra et al., 2004; Behan and Watson, 2005). There is evidence that reproductive performance is influenced by WEI (Poleze et al., 2006). The WEI has namely been shown to be a key driver for improving farrowing rate and increasing litter sizes of the subsequent litters (Wilson and Dewey, 1993; Vesseur, 1997).

In the following literature review the normal reproductive cycle of the sow is described, followed by a synopsis of the different factors influencing the reproductive performance of the gilts and sows, *i.e.* the WEI, the number of regular repeat breeders and the litter performance. The review concludes with an overview of the reasons for culling, the influencing factors for sow removal and the macroscopical examination of the reproductive organs of gilts and sows.

1.1 Reproductive cycle of the sow

1.1.1 Changes in the ovary during the reproductive cycle

1.1.1.1 Development of the antral follicle pool

Ovaries of the sow have a large number of primordial follicles, which are already present before birth. These follicles contain immature oocytes in the first meiotic phase and are surrounded by flat, squamous granulosa cells that are segregated from the oocyte's environment by the basal lamina. When the gilt reaches puberty, the ovaries contain about 420.000 primordial follicles which are about 0.03-0.05 mm in diameter. The exact mechanisms behind the development of these different groups of primordial follicles are yet unknown. It is clear that Follicle Stimulating Hormone (FSH) and Luteinizing Hormone (LH), the so-called gonadotropins, from the hypothalamo-pituitary-axis have no influence on this process. Most probably, some intra-ovarial products play a role. Already long before puberty, some primordial follicles start to develop into primary, secondary and tertiary follicles. Primary follicles contain mitotic cells in the oocyte and cuboidal granulosa cells, with a diameter of approximately 0.1 mm. Secondary follicles are characterized by the presence of theca cells and multiple layers of granulosa cells. They have a diameter of 0.2 mm. Tertiary or antral follicles, also called *Graafian follicles,* contain a fluid-filled cavity adjacent to the oocyte: the antrum. Tertiary or *Graafian* follicles have a diameter of two to five millimeter (Dyck and Swierstra, 1983). In the tertiary follicle, the basic structure of the mature follicle has formed. As puberty approaches, granulosa and theca cells continue to undergo mitosis concomitant with an increase in antrum volume. For antrum-formation, an increased pulsatile release of FSH and LH is necessary, which is present at puberty. The size of tertiary follicles is dependent on FSH. Receptors to FSH start to develop in the primary follicles, but they are gonadotropin-independent until the antral stage. Theca cells express receptors for LH. Binding to LH induces the production of androgens by the theca cells, most notably androstendione. Androgens are aromatized by granulosa cells to produce estrogens, primarily estradiol (E2). Consequently, estrogen levels begin to rise (Esbenshade et al., 1982; Karlblom et al., 1982).

During the development of primordial follicles into tertiary follicles, the oocytes undergo maturation. A glycoprotein polymer capsule, called the *zona pellucida,* is formed and separates the oocyte from the surrounding granulosa cells. The *zona pellucida* remains with the oocyte until after ovulation and contains enzymes that are important for sperm penetration.

Activation and growth of primordial follicles occur continuously throughout the sow's life. The development from the primordial phase to ovulation requires between 80 to 100 days (Fig. 1; Morbeck et al., 1992). Because of the continuous development of little groups of primordial follicles to antral follicles, an antral follicle pool arises. During the normal reproductive cycle, follicles are recruited from this antral follicle pool.

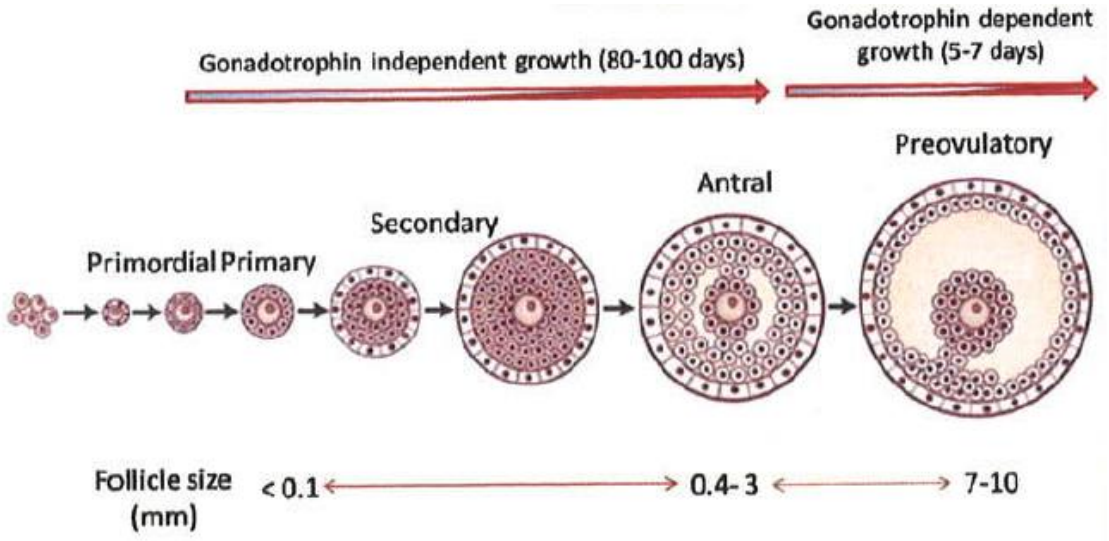

Figure 1. Follicle growth in the porcine ovary (Morbeck et al., 1992).

1.1.1.2 Recruitment and selection of the follicles

During the normal estrus cycle, the population of ovulatory follicles grow between day 14 and 16. Between day 16 and estrus, approximately 50% of the medium-sized follicles become atretic (Ryan et al., 1994; Almond et al., 2006). Follicular growth and development are complex and involve numerous factors, including hormones. The influences on the hypothalamus-pituitary-ovarian axis and gonadotropin release are important in follicular growth (Kemp et al., 1995a).

The follicular phase starts with the recruitment of follicles. This process is initiated by high-frequency, low-amplitude pulses of Gonadotropins Releasing Hormones (GnRH) from the hypothalamus. The pituitary gland generally reacts to this secretion with a same pulse wise secretion of LH (Fig. 2) and a continuous release of FSH (Fig. 4(a)). This contributes to the maturation of the developing follicles. Small follicles have FSH-receptors on the granulosa cells. The continuous release of FSH stimulates the growth of these follicles and the production of estrogen. As the follicles grow, LH-receptors are developing. The further growth of these larger follicles into pre-ovulatory follicles is called the selection of the follicles and is now dependent on both hormones, LH and FSH. In response to the rise of FSH, mature follicles are associated with an increase in E2 and inhibin production (Fig. 4(b)). The latter two hormones suppress the release of FSH. Only follicles with sufficient LH-receptors can continue to grow and the decreased FSH-release causes smaller follicles to stop developing and to become atretic. The elevated E2 concentration elicits namely a prolonged release of GnRH via the hypothalamus, which triggers a massive release of LH (Fig. 4(c); Elsaesser and Foxcroft, 1978). The surge in LH is necessary to induce ovulation and onset of estrus usually coincides with this pre-ovulatory LH surge (Fig. 3; Almond et al., 2006; Cassar, 2009). Only in the follicular phase, follicles can escape atresia, grow to a pre-ovulatory size and ovulate with subsequently the release of 15 to 25 ova in the female pig (Quesnel and Prunier, 1995; Prunier et al., 2003). This takes about five to seven days. Tertiary follicles grow from approximately four to five millimeter in diameter, to an ovulatory diameter of eight to twelve millimeter in five to six days (Knox and Althouse, 1999; Waberski et al., 1999). In general, sows ovulate when approximately 70% of the estrus has passed (Soede et al., 1995a), which is about 30 to 50 hours after the LH surge. The follicular phase ends with this LH surge.

1.1.1.3 Formation of *corpora lutea* (luteal phase)

Following ovulation, blood rapidly fills the central cavity of the follicles. Luteinization of the theca interna and the granulosa cells of the follicle results in the formation of *corpora lutea (cl).* The early *cl* are capable of producing low levels of progesterone (P4) within a few hours. In concert with low levels of estrogen, P4 inhibits the secretion of FSH and LH from the pituitary gland and thus inhibits follicular growth (Fig. 4(d)). The production of P4 increases until a maximum is achieved by day 10 to 15 (Fig. 3; luteal phase). Sows are not sexually receptive during this period of P4 production (Almond et al., 2006; Cassar, 2009).

Hormonal events associated with the first 14 days of the estrus cycle and pregnancy are essentially identical. After that time, however, functional *cl* must be maintained in the pig for the continuation of pregnancy (Bazer and First, 1983). If pregnancy has not been initiated, the *cl* regress, resulting in a decline of serum P4 concentrations and a return to estrus. From day eleven onwards, the *cl* form receptors for prostaglandin F2α (PGF2α). Degeneration of the *cl* starts approximately at day 13-15, together with an increased endocrine secretion of PGF2α, a luteolysin, by the endometrium (Marengo et al., 1986; Fig. 4(e)). At the same time, follicular recruitment starts all over again, caused by an increase of FSH, and concomitant with regression of the *cl*, follicles continue to grow (start of a new follicular phase; Almond et al., 2006).

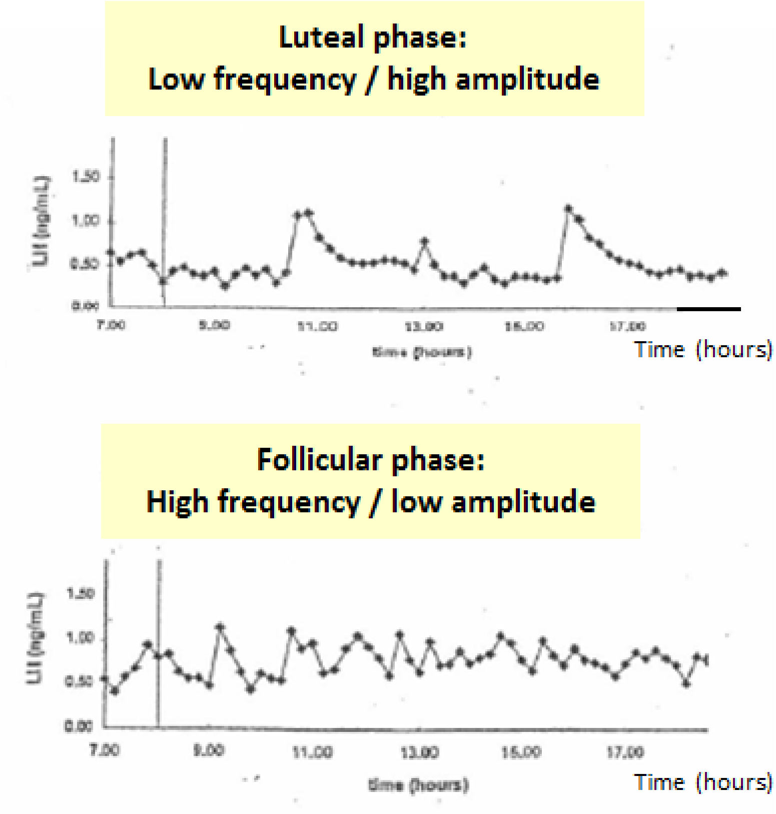

Figure 2. Change in pulsatile LH-release from luteal phase (upper graph) to follicular phase (lower graph) during the reproductive cycle of the sow (adapted from Kemp et al., 2013a).

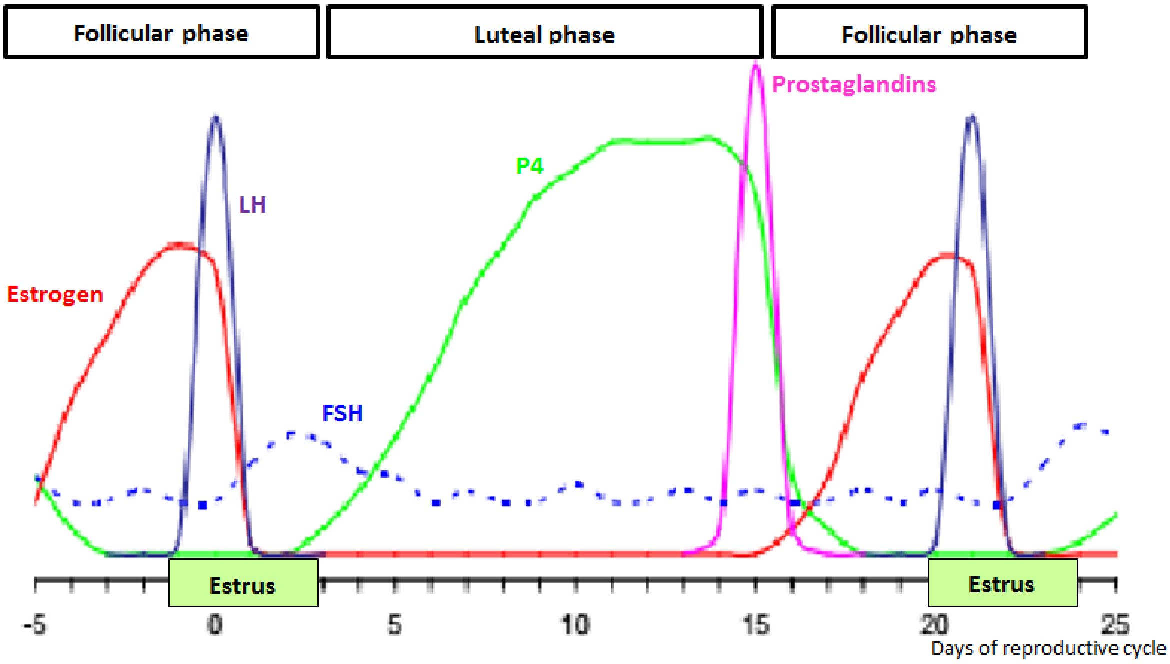

Figure 3. A diagram of the hormone profiles during the reproductive cycle of the pig (with LH = Luteinizing Hormone, FSH = Follicle Stimulating Hormone and P4 = Progesterone; adapted from Kemp et al., 2013a).

1.1.2 Estrus

1.1.2.1 Definition of estrus

Estrus is defined as a period of sexual excitement during which the female will accept the male, ovulates and is thus capable of conceiving. A sow is defined to be in estrus, when she shows a standing behavior to back pressure from a boar, another sow or a person. In most commercial pig herds, the farmer mimics the tactile stimulation of the boar by pushing the sow in the flanks and rubbing or pressing the sow’s back: back pressure. In a typical standing response, the sow reacts with a frozen stance, arched back and cocked ears (Soede et al., 2013).

1.1.2.2 Estrus behavior

The first signs of approaching estrus in sows are increased activity and vocalizations. Sows in pens will attempt to mount or ride other females. Soon after the increased activity, reddening and swelling of the vulva is seen. The size of the vulva and color change are most pronounced just prior to onset of the standing reflex. In older parity sows, it is possible that swelling and eventually reddening do not occur as this is masked by the loose, flabby skin around the vulva caused by repeated deliveries. The presence of a sticky discharge and enlargement of the clitoris usually occur immediately before and during the standing reflex (Almond et al., 2006). The standing reflex is the most common behavior associated with sexual receptivity and serves as the reference point upon which most breeding regimens are based (Almond et al., 2006). The expression of the standing reflex is influenced by a number of environmental factors (Hemsworth and Barnett, 1990) and depends on interactions between internal and external stimuli. High concentrations of E2 produced by pre-ovulatory follicles are the internal, while pheromones (5-alpha androstenone) produced by a (teaser) boar serve as the external cues (Almond et al., 2006). Besides male pheromones, female ones may also be involved, as the presence of sows in estrus has been shown to stimulate and synchronize estrus behavior in weaned sows and peripubertal gilts (Pearce and Pearce, 1992; Kemp et al., 2005).

1.1.2.3 Ovulation

An increase in the LH-secretion by the pituitary gland of the sow leads to ovulation. Ovulation in pigs begins 36-44 hours after the onset of estrus and lasts one to three hours (Soede et al., 1992; Almond et al., 2006). In general, ovulation occurs at about 70% of estrus duration (Soede et al., 1992; Weitze et al., 1994; Soede et al., 1995a; Kemp and Soede, 1996). More than 95% of the follicles ovulate over a short period of time, *e.g.* within two hours after onset of ovulation, while a minority ovulates over a longer interval. Nevertheless, onset and duration of ovulation are extremely variable within and among herds (Flowers and Esbenshade, 1993). After ovulation, the oocytes are transported to the place of fertilization (in the transition from the isthmus to the ampulla in the oviduct) within one hour, through movement of the cilia in the oviduct and the contraction of the smooth muscle cells.

Regarding procedures of artificial insemination (AI), especially the timing of insemination relative to the time of ovulation is critical. The ideal insemination time is 0-24 hours before ovulation, then fertilization results are higher than 90% (Soede et al., 1995a; Nissen et al., 1997). As female pigs ovulate when estrus duration is about 70% completed, the timing of insemination needs to be based on the onset of estrus.

1.1.2.4 Estrus duration

The estrus duration is defined as the time interval between the first and last standing-reflex. Sows initially only show standing behavior in the presence of a boar, and not when backpressure is executed by the pig producer. This short period is often not observed by the pig owners. Therefore, first standing-reflex throughout this thesis refers to the first ‘observed’ standing reflex when backpressure is induced by the pig farmer. Duration of the standing reflex has been reported to be between 46 and 53 hours for sows and 36 to 48 hours for gilts (Kemp and Soede, 1996).

However, the estrus duration is influenced by factors such as the individual sow, WEI, boar effects, housing/stress and herd (Kemp and Soede, 1996; Steverink et al., 1999). Gilts and repeat-breeders have on average a shorter estrus duration than sows bred at the first estrus after weaning (Nissen et al., 1997; Steverink et al. 1999). Steverink et al. (1999) showed that the average estrus duration on farms was consistent from month to month, with a repeatability of 86%, but it varied considerably within a farm. This variation is partly the result of different WEI. A prolongation of the WEI from three to six days was accompanied with a decrease of estrus duration from 55 hours to 37 hours (Kemp and Soede, 1996). This decrease follows a linear pattern and was also accompanied by an acceleration of the onset of ovulation (Steverink et al., 1999). In general, the longer the WEI, the shorter the estrus duration and the sooner the sow will ovulate and *vice versa.*

Boar stimuli have substantial effects on estrus expression in sows. Langendijk et al. (2000a) showed that the more stimuli for estrus stimulation and detection were used, the longer the estrus duration was. Bringing sows into a mating area with four boars increased the estrus duration with ten hours, compared to only the back pressure test performed by a person, or bringing the boar in front of the sows. Soede et al. (1996) found that average estrus duration with estrus detection in presence of a boar lasted 24 hours, which was twice as long in comparison to the duration assessed in absence of a boar. Contradictory, Langendijk et al. (2000b) noted an estrus duration in primiparous sows of about 39 hours if no boar contact was applied after weaning, which was the same as in pluriparous sows having boar contact from day one after weaning. Dyck (1998) indicated that the estrus duration is shorter in sows housed adjacent to boars as compared to sows having short daily boar contacts, indicating that habituation might occur. The duration of standing reflex depends also on the quality of the individual boar.

Variations in estrus duration between farms is not only breed dependent, but could probably also be explained by different housing of weaned sows. Comparing tethered sows to sows roaming freely in a pen alone, resulted in a shorter estrus duration in tethered sows (24 - 60 hours vs. 52 - 76 hours; Soede and Kemp, 1997). This could possibly be attributed to the chronic stress situation the tethered sows were exposed to. Housing factors contributing to a shorter WEI, will also have an influence on the estrus duration. Weaned sows need to be housed in a dry cool environment (18°C) with sufficient light in a fixed circadian rythm *e.g.* 16 to 18 hours per day (Stevenson et al., 1983) to shorten the WEI and increase the estrus duration. Finally, variation in estrus duration could also be explained by the specific factors that may influence the WEI. These factors are discussed in the following chapter.

1.1.3 Pregnancy

Initial attachment of the embryo to the uterine surface occurs around day 12 after fertilization and is well established by day 18 to 24 (Senger, 2005). The embryonic period is characterized by rapid growth and differentiation, during which major tissues, organs and systems are formed. The fetal period begins from day 35, coinciding with the skeletal calcification.

For the continuation of pregnancy, functional *cl* must be maintained in the pig (Bazer and First, 1983) and estrogen is the primary factor triggering a series of events to establish this (Almond et al., 2006). The feto-placental unit is the major source of estrogen production during pregnancy. The concentrations of P4 in blood increase to peak values by day 12 after fertilization and remain elevated, causing myometrial quiescence (Anderson, 1987). The levels of E2, however, increase from day 60 onwards and reach peak values just before parturition. Estrogens in late gestation prepare the uterus for the massive contractile activity and encourage maternal behavior, such as nest building (Baldwin and Stabenfeldt, 1975; Ashworth, 2006).

As this thesis does not focus on pregnant sows, the described information has been restricted to the minimum. More information on this topic can be found in literature (Martinat-Botté et al., 2000; Almond et al., 2006).

1.1.4 Parturition

One of the clearest behavioral signals of approaching farrowing is the increased activity of the sow due to nest-building behavior. However, this symptom is easily overseen in the farrowing units used in the commercial pig husbandries nowadays. Also some physiological parameters are signals for impending parturition, such as the rise in body temperature and in respiratory rate (Hendrix et al., 1978). These changes occur 24 to 36 hours before onset of farrowing.

The overriding factor initiating parturition is the decrease in concentration of P4 in the maternal circulation (Senger, 2005). The fetal hypothalamo-pituitary-adrenal axis plays a central role in the initiation. As fetal mass approaches the inherent space limitation of the uterus, the fetus becomes stressed, stimulating the fetal anterior pituitary to release adrenocorticotropic hormone (ACTH). High levels of ACTH lead to increased secretion of glucocorticoids by the fetal adrenal cortex, initiating the release of PGF2α from the gravid uterus, which promotes luteolysis of the *cl* and thereby decreases the concentration of P4 (Molokwu and Wagner, 1973). This facilitates an increased frequency of uterine contractions and the initiation of parturition (First et al., 1982; Bazer and First, 1983).

1.1.5 Lactation

After parturition, the *cl* regress to *corpora albicantia.* These *corpora* gradually regress further during lactation and are less than two millimeter in diameter at the time of weaning.

Already during the last few days of gestation, follicles start to develop again on the ovaries. Pre-ovulatory sized follicles are seen at the first two days of lactation, together with elevated LH and FSH concentrations and declined estrogen and P4. During lactation however, sows massively produce milk for their litter, leading in most cases to a negative energy balance in the sow. Along with this, the GnRH secretion is inhibited due to suckling and the release of prolactin (Fig. 4(f)), leading to a decrease of LH and FSH. Finally the large follicles regress within a few days after farrowing (Almond et al., 2006). As lactation progresses, the GnRH- and subsequently LH-pulsatility is restored (Kemp et al., 1995a), follicle growth continues and the proportion of atretic follicles decreases (Britt et al., 1985).

The uterine involution is rapid during the first week *post partum*, but is only completely achieved within 21 to 28 days *post partum* in lactating sows (Palmer et al., 1965; Prunier et al., 2003). In early-weaned sows (four days *post partum*), the complete involution is still slower (Prunier et al., 2003).

1.1.6 Weaning-to-estrus interval

Sows are normally in anestrus during lactation. At weaning, suckling disappears and the LH-production increases dramatically with the typical low amplitude and high frequency pulse secretion. This induces the recruitment of the present population of two to five millimeter follicles (Kemp, 1998). The final maturation of follicles begins, antral follicles grow out to ovulatory sizes, resulting in post-weaning estrus and ovulation. The WEI in sows takes generally about four to seven days (Kemp et al., 2005) and is equivalent for the follicular phase of the estrous cycle in gilts (Kirkwood, 1999).

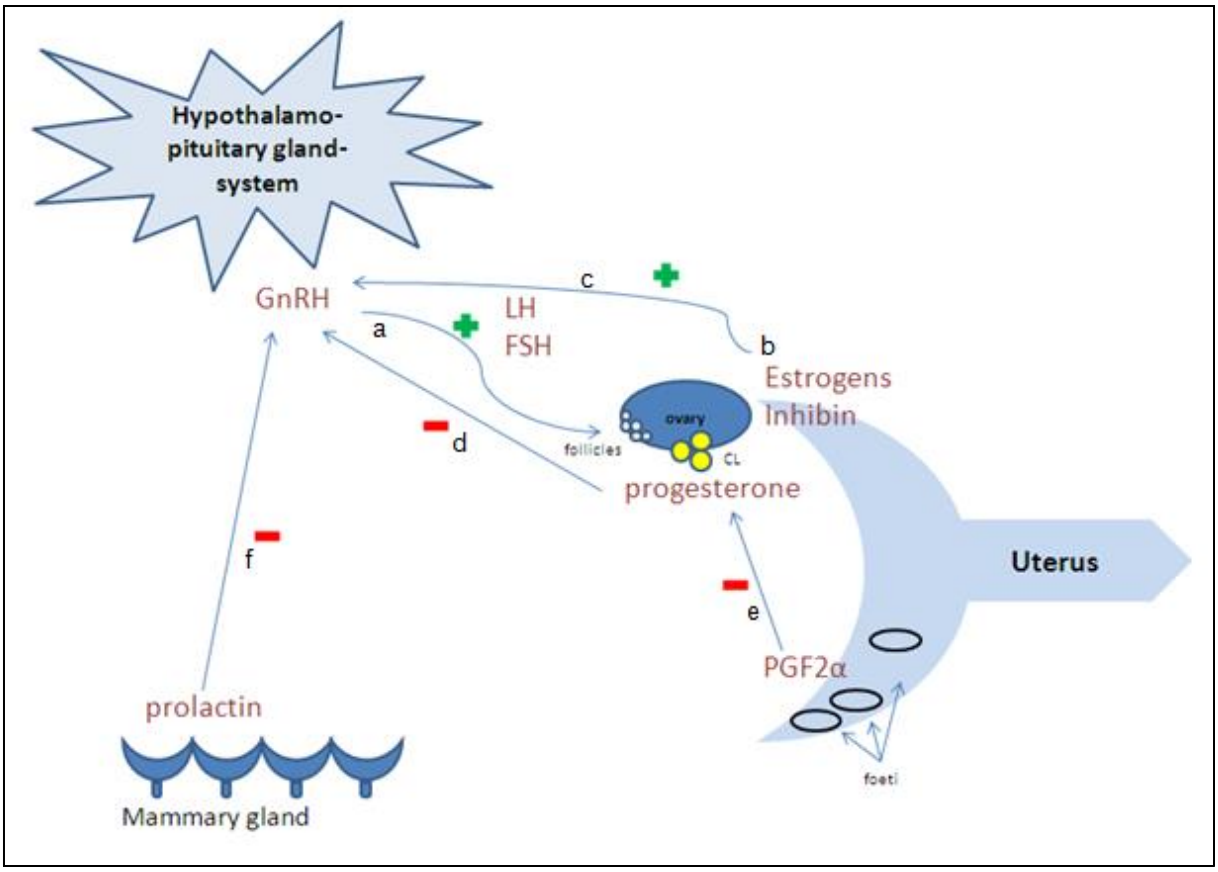

Figure 4. A diagram of the hormonal interactions between brains and reproductive tract of the female pig (with GnRH = Gonadotropin Releasing Hormones, LH = Luteinizing Hormone, FSH = Follicle Stimulating Hormone, PGF2α = Prostaglandin F2α and CL = *corpora lutea*): (a) secretion of LH and FSH by the pituitary gland, (b) production of estrogens and inhibin by mature follicles, (c) increased estrogen release prolonged GnRH, resulting in pre-ovulatory LH-surge (d) production of progesterone by *cl*, inhibiting release of LH and FSH, (e) endocrine production of PGF2α in the endometrium if pregnancy is not initiated, followed by luteolysis, (f) production of prolactin, due to suckling of piglets, inhibiting the GnRH concentration.

1.2 Prolonged Weaning-to-estrus interval

1.2.1 Physiology of prolonged WEI

Several physiological systems have to be restored after weaning to allow good reproductive performance of the sow: the pulse release of gonadotropins by the hypothalamic-pituitary system with subsequently the follicle growth on the ovaries to antral follicle sizes and the ability to mount a good pre-ovulatory LH-surge, leading to ovulation (Kemp et al., 2013a). If the GnRH pulse generator somehow fails to induce the typical high frequency/low amplitude LH release from the pituitary gland after weaning, sows will show a prolonged WEI (Shaw and Foxcroft, 1985).

The study of Van den Brand et al. (2000) showed a linear plateau relationship between LH pulse frequency at the day of weaning and WEI. The lower the number of LH pulses, the longer the WEI. Some studies revealed that LH levels and LH-pulsatility directly after weaning are related to the restoration of the LH levels and pulsatility during lactation (Tokach et al., 1992; Kemp et al., 1995b; Van den Brand, 2000). If these are not restored properly during lactation, the WEI is prolonged.

There are several reasons of an increased WEI:

1.2.1.1 Lactation estrus

Sows normally do not show estrus during lactation, because of the suppression of LH, induced by suckling. In some sows this suppression is not enough to maintain anestrus during lactation. This occurs particularly at the end of lactation, in pluriparous sows from specific prolific breeds, with a good body condition and with good appetite, in sows with a low number of suckling piglets or a high feed intake during lactation. Many other and yet undefined reasons may also influence the appearance of lactation estrus, *e.g.* seasonal influence (Hultén et al., 2006; Kongsted and Hermansen, 2009). Some management measures stimulate the occurrence of lactation estrus, like for example limited nursing, preweaning of a part of the litter or intermittent suckling. In the latter, sows are separated from their offspring for a couple of hours per day, mostly in the second half of lactation. This stimulates the LH-release, the follicle development and ovulation during lactation (Kemp et al., 2013a). Another current practice is the use of nurse mothers. These are young sows in good condition, with sufficient available teats and which had taken good care of their own piglets. Nurse sows have a longer lactation period, therefore estrus during their lactation occurs frequently. Lactation estrus is often not detected and consequently these sows will be marked as sows with a delayed estrus and a prolonged WEI (Kemp et al., 2011).

1.2.1.2 Subestrus

Sows in subestrus have normal follicular activity on the ovaries and mainly also ovulate, but they fail to show standing behavior and other estrus symptoms. Few is known about the hormonal background of subestrus, also called missed or silent estrus (Soede et al., 1994). The cause for missed estrus can mainly be attributed to a failed estrus detection: the farmer did not notice the symptoms of heat. The causes for silent estrus can mainly be attributed to fear for the boar or the pig farmer or submissive sows that are dominated by other sows (Pedersen et al., 1993; Kemp and Soede, 2011).

1.2.1.3 Anestrus

In contrast to sows in subestrus, sows in anestrus mostly do not have any follicular development nor ovulation. Sows with a prolonged WEI due to anestrus have lower LH-production and pulsatility restoration two weeks after farrowing in comparison to sows with a short WEI (Tokach et al., 1992). Therefore, the final follicle growth and maturation begins more slowly or only at a later stage. Anestrus is mainly caused by factors during lactation: the length of lactation, the feeding strategies and body condition and some aspects of weaning management (Kemp et al., 2011).

1.2.1.4 Ovarian cysts

Ovarian cysts are an important cause of reduced reproductive performance in gilts and sows. Sows with cystic ovarian follicles (COF) are mainly in anestrus (Castagna et al., 2004), although the signs and behavior depend on the type and the number of cysts present. A distinction can be made between follicular, which originate from unovulated follicles and luteinized cysts, originating from developed *cl*. Ovarian cysts vary in size and in number, can be single or multiple and can be present on one or both ovaries (Kauffold and Althouse, 2007; Beek et al., 2011).The formation of COF is associated with a deficiency in LH release and the continuous growth of follicles (Almond et al., 2006). An insufficient P4 concentration, which is necessary to suppress the follicular cycle, could also lead to continuous growth of follicles without ovulation (Beek et al., 2011). Sows can either have large or small cysts. During lactation, estrogens produced by the pre-ovulatory follicles progressively induce the pre-ovulatory LH-surge, which subsequently results in ovulation after weaning (Bevers et al., 1981; Sesti and Britt, 1993). An insufficient restored system may result in small cystic ovaries (Gerritsen, 2008). The more cysts are observed, the less *cl* can be found, eventually leading to infertility (Heinonen et al., 1998). Most of the sows with multiple large cysts show intermittent or permanent anestrus, because of luteinization and considerable P4 production. In contrast, multiple small cysts often produce estrogen, and these sows may have irregular estrus cycles (Ebbert and Bostedt, 1993; Ebbert et al., 1993). The incidence of COF is herd dependent and no equivocal results have been found considering parity prevalence (Gherpelli and Tarocco, 1996; Castagna et al., 2004; Kauffold et al., 2004; Beek et al., 2011).

1.2.2 Consequences of prolonged WEI

Sows with a prolonged WEI increase the number of non-productive days (NPD) in a herd. NPD are defined as all the days in the production cycle of a sow when she is not pregnant or lactating. The WEI automatically creates NPD as sows are not immediately inseminated the day after weaning. A non-productive sow still requires feed, water, housing, care, etc. resulting in an estimated cost of €2.5 per sow per day (Kirkwood, 2002).

Besides the increase in NPD, a prolonged WEI has also other negative consequences. When the WEI increases from 4 days to 9 - 12 days, a decrease in farrowing rate from 88% to 59% and in litter size, from 11.7 to 10.6 piglets, can be found (Vesseur et al., 1994; Steverink et al., 1999). This increase in WEI is accompanied by a decrease in ED and a decrease in insemination-ovulation interval. Therefore, the origin for the decrease in reproduction results could be found in the timing of insemination relative to ovulation (Kemp and Soede, 1996; Soede and Kemp, 1997). Another cause for the decrease in litter size could be a decrease in ovulation rate with an increasing WEI. Several studies have reported a decrease in ovulation rate from 21.6 to 19.7 oocytes, when WEI increased from three to six days (Soede et al., 1995 a,b; Steverink et al., 1999).

The use of batch production systems in sow herds has increased the last decades, because of advantages in labor planning, batch sizes of piglets, all-in all-out practices and health management (Vangroenweghe et al., 2009). Sows are weaned together, are all inseminated within two to three days and have approximately the same parturition date. However, sows with a prolonged WEI interfere with the strict time frame of batch production systems, as they fall in between two batches. Such sows are often treated *off label* with altrenogest to delay estrus until the next batch of weaned sows, resulting in a further increase of number of NPD, or they should be culled.

1.2.3 Diagnosis of prolonged WEI

Analysis of the WEI and return to estrus intervals of all sows in the record system of a herd can be a helpful tool. In case of lactation estrus, the WEI will be very irregular, between 10 and 20 days after weaning. In case of subestrus, the return to estrus interval shows a peak at day 24 to 28, approximately 21 days after the expected estrus. A high percentage of sows with a long WEI or with an irregular return to estrus interval points towards anestrus or large COF.

If the year average WEI of a herd is prolonged, *i.e.* more than ten days, slaughterhouse examination can give some clarity in the problems. In sows culled due to reproductive failure, inactivity of the ovaries and large COF are frequently found (up to 28 respectively 15%) (Dalin et al., 1997).

The most effective way to diagnose the cause of a prolonged WEI in an individual sow is the use of ultrasonography. Using the ultrasound, the ovaries can be visualized, the time of ovulation and subsequently the timing of insemination can be determined, or ovarian dysfunctions can be diagnosed (Vigo et al., 1996; Kemp et al., 1998; Knox and Althouse, 1999; Waberski et al., 1999; Bracken et al., 2003; Kauffold et al., 2004). Little black spots, with a diameter of three to ten millimeter on the ovary are identified as follicles (Fig. 5). Sows with a short WEI have several follicles of seven millimeter in diameter on their ovaries at day two or three after weaning. Smaller follicles (five to six millimeter) are associated with a prolonged WEI (Bracken et al., 2003). Blood vessels may erroneously be considered as follicles. Distinction can be made based on the thickness of the walls, as blood vessels often have thicker walls and are clearly delimited. When applying a longitudinal image, blood vessels will be seen as long black tubules, while follicles will stay round (Martinat-Botté et al., 2000).

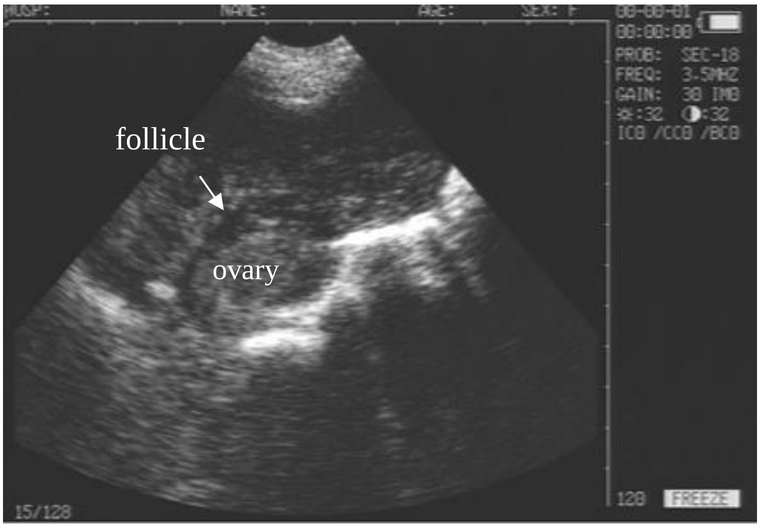

Figure 5. Ultrasound image of the right ovary in a sow in estrus.

In sows with lactation estrus, *cl* can be detected on the ovaries after weaning. *Corpora lutea* however, are sometimes difficult to visualize as the density of *cl* is the same of that of the ovarian stroma. Only experienced investigators can find them, with proper ultrasound equipment(Waberski et al., 1999; Kauffold et al., 2004). Sows that have had a silent estrus do not have *cl* after weaning, but they have a normal evolution to pre-ovulatory follicles with *cl* at day ten after weaning. The latter is comparable with normal estrus. In sows in anestrus, only small follicles can be detected in the ovaries (Knox and Rodriguez Zas, 2001). Ovarian cysts are fluid-filled thin-sided round black structures (Fig. 6; Waberski et al., 1999; Kauffold et al., 2004). A differentiation should be made with early pregnancy, a delayed ovulation or para-ovarian cysts. Measuring the structure is important for the final diagnosis. A pre-ovulatory follicle has a diameter of 8-10 mm, whereas large COF can reach in some cases 80-100 mm. Frequent scannings, resulting in the same image is also conclusive.

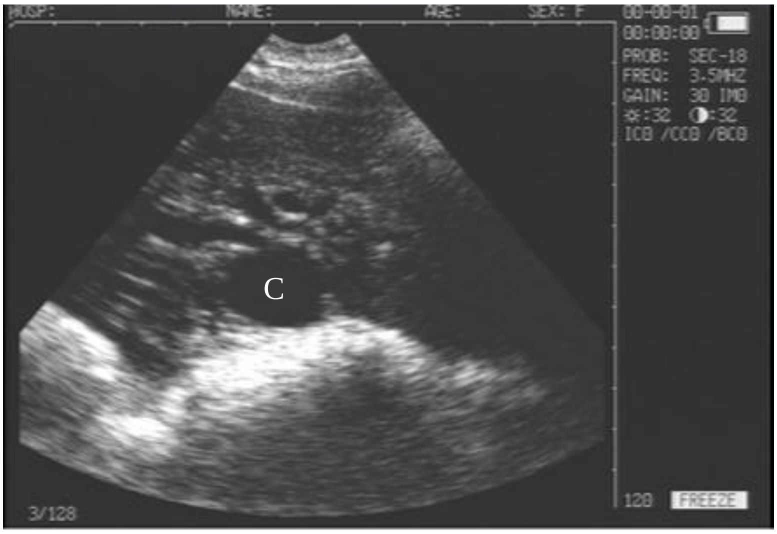

Figure 6. Ultrasound image of an ovarian cyst (C).

Finally, if sows do not react with estrus after induction with exogenous administered hormonal products (for example PG600®) between day 7 and 14 after weaning, this is distinctive for subestrus (Kirkwood, 1999). If they still do not react after a second administration 10 days after the first treatment, they will likely be in anestrus, or have large COF.

1.2.4 Factors influencing WEI

1.2.4.1 Genetics

The genotype is considered an important cause of variation in WEI in sows (ten Napel et al., 1995a) and some genetic markers for WEI have been described (Suwanasopee and Koonawootrittriron, 2011). A high genetic correlation was obtained in the study of Leite et al. (2011) between the first and third WEI of sows, suggesting that most genes, acting during the first interval, also operate during the third. This fact suggests that selection based on the first WEI could be done, which would possibly cause a decrease in WEI in the subsequent cycles. But, the heritability was low, indicating that genetic selection for decreasing incidence of prolonged WEI may be useful, but it may not be very efficient (ten Napel et al., 1995a; Leite et al., 2011). Also according to the observations of Poleze et al. (2006) and Leite et al. (2011), there was no effect of genetic line on the WEI, but the genotype indirectly interferes through genetic variation in susceptibility of the factors that may prolong this interval.

1.2.4.2 Parity and body condition of the sow

Young sows have in general a longer WEI and a shorter ED than older sows (Kemp and Soede, 1996). Management of the gilts is a very important starting point. First insemination at 250-260 days is common practice in Europe (Kemp et al., 2013b) and depending on the breed, 17-20 mm back fat thickness (P2) and 175-185 kg body weight at first parturition are recommended (Yang et al., 1989; Aherne and Williams, 1992; Clowes et al., 2003). Prolonged WEI, caused by anestrus is frequently seen in first parity sows. Besides nutrient need for milk production, primiparous sows also need extra nutrients for growth during lactation. They have a lower feed intake capacity than older sows and they lack substantial reserves of fat and protein (ten Napel et al., 1995b). Therefore, they generally loose more bodyweight during lactation, what makes them more susceptible to impaired reproductive performance, *i.e.* prolonged WEI. Suboptimal reproduction of these sows post-weaning and in the next litter commonly occurs in many pig herds, and is referred to as the “second litter syndrome” (Morrow et al., 1992).

To limit body weight loss during lactation, split-weaning (*i.e.* a permanent removal of part of the litter a few days before complete weaning) or intermittent suckling (*i.e.* a daily temporary removal of part of or the whole litter) could be an option (Kuller et al., 2004; Prunier et al., 2003). These strategies reduce the milk production, and thus the energy demand for the sow. But they may also reduce the inhibition of the suckling induced suppression of LH release. Also limiting the number of suckling piglets for the first parity sows during the second part of the lactation can be a solution, however piglets in smaller litters will consume more milk per piglet. A drawback of the use of these techniques is the increasing risk of occurrence of lactation estrus (Kemp and Soede, 2011).

1.2.4.3 Feeding strategies during lactation and WEI

An inadequate nutrient and energy intake during lactation will result in extended WEI and lower percentage of sows in estrus within seven days of weaning, but also in reduced pregnancy rate, and reduced embryo survival (Quesnel et al., 1998). The average daily protein and energy intake affects mean LH concentration during lactation (King and Martin, 1989; Quesnel and Prunier, 1998; Van den Brand et al., 2000). Also restrictions of the amino acid lysine intake during lactation causes a lower LH-concentration on day 21 (Tokach et al., 1992). The lactation diet should contain at least 1.3% and 0.8% of total lysine for primiparous and pluriparous sows, respectively (Yang et al., 2000; Kongsted, 2005). Willis et al. (2003) found an optimum in WEI with a protein concentration of at least 18% during lactation.

As stated before, the issue of body weight loss is particularly important for primiparous sows, which represent 15% to 17% of the sow population of a pig herd with an optimal parity distribution (Muirhead and Alexander, 1997). Sufficient feed intake in lactation can only be accomplished in case of a good appetite. Excessive feed intake during pregnancy decreases the voluntary feed intake during lactation (Yang et al., 1989). On the contrary, in first litter sows, insufficient feed intake during pregnancy, resulting in thin sows at parturition, cannot be compensated by increased voluntary intake during lactation, and thus may also result in prolonged WEI (Yang et al., 1989). The following factors should be considered: a good body condition at the time of parturition and a gradual increase of feed intake post-farrowing (Koketsu et al., 1996a, b). Therefore, gilts, but also other sows, should be fed according to their requirements for maintenance, reproduction and growth. Everts et al. (1994, 1995) and Noblet et al. (1997) advised an energy intake of 24.8 to 28.6 MJ at the beginning and 34.6 MJ to 39.5 MJ metabolisable energy (ME) per day at the end of gestation, respectively (Tabellenboek Veevoeding, 2010). After parturition, 2kg of a lactation diet is recommended and a stepwise increase of feed intake of 0.5 kg a day until the maximum feed intake is reached (1% of the body weight plus 0.5kg per piglet, with an energy of 14.1 MJ ME/kg) (Kuller et al., 2004). Other recommended measures for a good feed intake during lactation are: tasty feed that is offered several times per day, removing uneaten feed from the trough once daily to prevent the feed to become sour and mouldy, good quality of the drinking water, providing extra drinking water in addition to the *ad lib* and an optimal stable climate (*e.g.* temperature) in the farrowing unit.

During the interval between weaning and insemination, sows can be fed to appetite. Feeding carbohydrate rich diets instead of fat rich diets resulted in a shorter WEI in the study of Van den Brand et al. (2001) and the percentage of first litter sows in estrus within 9 days after weaning increased from 52 to 67%. Carbohydrate rich diets stimulate insulin release and insulin is believed to stimulate LH release from the pituitary gland and thus to stimulate the growth of follicles (Kemp, 1998).

1.2.4.4 Estrus stimulation and estrus detection

Intensive boar contact is very important to stimulate onset of estrus. Research in the eighties already demonstrated that in weaned sows daily boar exposure resulted in shorter WEI and a higher percentage of sows showing estrus within ten days (Hemsworth et al., 1982; Walton, 1986; Pearce and Pearce, 1992). Langendijk et al. (2000b) performed an experiment to validate the effect of the boar contact after weaning on weaning to ovulation intervals in 94 primiparous sows, which usually showed a prolonged WEI. Half of the sows had boar contact three times daily from day two after weaning, half did not have any boar contact. The presence of the boar resulted in a significant increased number of sows ovulating within ten days after weaning: 51 vs. 30%. These data suggest that boar stimuli may be particularly important in sows with expected longer WEI, such as primiparous sows.

The stimulatory role of the boar on onset of estrus after weaning can be explained by a stimulatory effect on LH release from the pituitary gland leading to follicle growth and ovulation. Boar introduction to sows in anestrus resulted in an increase in pulsatile LH release lasting from three to at least seven hours after boar introduction (Van de Wiel and Boorman, 1993). However, in some sows, boar contact may be insufficient to sufficiently stimulate LH release and these sows remain in anestrus. When sows are exposed to different combinations of stimuli (olfactory, tactile, visual) their estrous expression adapts to the highest magnitude of stimuli (Langendijk et al., 2000a). At lower stimuli levels, the expression of estrus becomes suppressed. Mainly the tactile and olfactory stimuli, *i.e.* the pheromones, produced by boars are the most potent and effective inducers of the standing reflex (Signoret, 1970). Gerritsen et al. (2005) reported that the standing response in sows, at any time during estrus, was not present in case of boar presence without tactile stimulation or, in case of olfactory bulbectomy in sows or, removal of salivary glands in boars. The presence of a life intact boar is more effective for estrus detection than a combination of artificial olfactory, visual, auditory and tactile stimuli (*e.g.* a robot) (Gerritsen et al., 2005).

Detection of estrus is also easier if the sow’s behavior is observed in the presence of a boar, particularly when there is physical contact between boar and female. Ideally, sows should be taken in small groups to the boar’s pen for fence line contact *e.g.* twice a day for approximately 20 minutes (Kemp et al., 2005). This should preferably not be done too close to feeding time. In many herds, the boar is moved in front of the females, while a breeding technician applies back pressure, because this is more practical (Kemp et al., 2005). As sows showing standing behavior are very difficult to move, bringing them in front of the boar’s pen, gives problems to lead them back to their own box. The boar should have contact with only a limited number of sows, *e.g.* five sows maximum at a time. Habituation occurs commonly in situations where sows have continual fence-line contact with boars. Females are then no longer able to exhibit their normal immobilization reflex. This can be prevented and the standing reflex can be enhanced by providing short, daily periods of boar exposure or by physical separation of at least one meter (Hemsworth and Barnett, 1990).

Finally, a teaser boar needs to be sufficiently mature, *i.e.* at least eleven months old, and needs to have enough libido: be active and *smelly* (Kemp et al., 2005). To ensure a sufficient libido, a non-vasectomized boar could be allowed from time to time to mate a sow just before she is culled. Approximately one boar per 20 weaned sows is advisable.

1.2.4.5 Lactation length

The data of Xue et al. (1993) showed that WEI rapidly increased as lactation length was shorter than 17 days, but that it was relatively unaffected by lactation lengths of 17 to 30 days. These data also emphasized that the percentage of sows inseminated within six days after weaning was significantly reduced for short lactation lengths (Xue et al., 1993). Besides increasing WEI, Koketsu et al. (1997) also reported lower farrowing rates (91.4%) if lactations are shorter than three weeks (17-19 days), compared to sows weaned at 25 or more days (94.4%). There are several ways to explain the negative effects of short lactations. First, early weaned sows may experience an endocrine dysfunction, preventing them from returning to service and conceiving normally after weaning. The height of the pre-ovulatory LH-surge is decreased, causing a failure of normal luteinization (Varley and Foxcroft, 1990). Second, involution of uterus may be incomplete during the first three weeks of lactation (Palmer et al., 1965), causing higher rates of embryonic mortality (Varley and Cole, 1976). As a minimum lactation period of three weeks is compulsory in the EU (Commission Directive 2001/93/EC of 9 November 2001), the possible negative influence of a short lactation length is less important than *e.g.* in the USA.

Clowes et al. (2003) indicated that also extended lactations (> 30d) may negatively influence fertility post-weaning, because it can cause catabolism of the sow body tissues. This in turn may negatively influence the WEI, the quality of the follicles, the ovulation number and litter size in the next farrowing.

1.2.4.6 Housing of weaned sows

Weaned sows are preferably housed in a dry environment, at 18°C ambient temperature and with sufficient light intensity in a fixed circadian rythm *e.g.* 16 to 18 hours per day (Stevenson et al., 1983). Insufficient light intensity may be due to inappropriate height of the lighting, too few lamps, fly feces and dust on lamps, or high walls surrounding animals or automatic feeders in front of sows producing shadows (Muirhead and Alexander, 1997; Tast et al., 2005).

In general, group housing of sows after weaning has a negative effect on onset of estrus (Langendijk et al., 2000a), compared to individual housing. The differences in reproductive state of the sows in the group are probably a good explanation. Housing weaned sows adjacent to an anestrous ovariectomized sow compared to an ovariectomized sow where estrus was induced, showed an increase in WEI (Pearce and Pearce, 1992). This could be partly explained by the release of pheromones by estrous sows, as is suggested for boars, and by the aggression during daily contact with the anestrous sow, causing elevated levels of ACTH and corticosteroids related to stress (Pearce and Pearce, 1992; Arey and Edwards, 1998), which has a negative influence on the WEI.

Other management factors that interfere with the expression and the detection of estrus include housing submissive sows in groups with dominant sows, the group size and the space allowance. Subordinate sows show fear related behavior in response to boar stimulation, even if they are in estrus (Pedersen et al., 1993). Group size and space allowance seem to have little effect on estrus (Knox et al., 2004). Estrus detection is more difficult in very small (< 3 sows) and very large groups (> 8 sows), and only one square meter per gilt seems to affect estrus detection adversely (Hemsworth and Barnett, 1990). In general, group housing systems that are in accordance with EU legislation are sufficient to alleviate the social stress experienced by submissive sows in a group (Kemp et al., 2005).

1.2.4.7 Seasonal effects

During late summer and early autumn, reproductive parameters (onset of puberty, WEI, farrowing rate) are consistently worse (Peltoniemi et al., 1999). The origin of this seasonal infertility in the northern hemisphere, seems to lie in the suppression of GnRH/LH release resulting from increased melatonin levels. Melatonin is produced during darker periods, and thus increases during autumn and winter (Spoolder et al., 2009). The seasonal infertility period of the domestic sow coincides with the non-breeding season in the European wild boar. The ancestral wild pig is a short day length seasonal breeder (Love et al., 1993). Although selection over many generations has almost totally eliminated any seasonality of reproduction in domesticated pigs, some traces still remain.

1.2.5 Treatment of prolonged WEI

Problems with a prolonged WEI should be controlled primarily by optimizing management practices. Therefore, it is important to understand the current weaning management practices on commercial sow herds. It is necessary to identify factors at herd-level that prevent problems of prolonged WEI and that can be easily implemented by the farmer. If, however, deficiencies in management are not identifiable or if they are difficult to be corrected, treatment with the use of hormonal products can be considered.

The combination of Pregnant Mare Serum Gonadotropin (PMSG) or equine Chorionic Gonadotropin (eCG) and human Chorionic Gonadotropin (hCG) augment the normal endogenous secretion of gonadotropins and can be used to reduce the incidence of anestrus (Bates et al., 1991; Benaglia et al., 2012; Krejci et al., 2012). The influence of PMSG is similar to that of FSH and LH, namely stimulating the development and maturation of follicles and inducing ovulation, hCG has an LH-effect and causes ovulation.

A combination of 400 IU PMSG or eCG and 200 IU hCG is very well known and widely used in pig production (*e.g.* PG600®, Fertipig® or Gestavet®). Some preparations containing only eCG (*e.g.* Folligon® or Prolosan®) are also used to induce estrus. However, higher doses (*e.g.* 900 vs. 600 IU) are needed to improve the response of gilts and first parity sows (Lucia et al., 1999). Kirkwood (1999) as well as Breen et al. (2006) described an increase of cystic ovaries caused by the misusage of hormonal products in gilts, *e.g.* administration of gonadotropins at an unknown cycle stage or an underdosed administration of progestagens (< 13 mg per day) and in weaned sows, *e.g.* higher doses of PG600®.

Treatment strategies with the hormonal products mentioned above are very variable depending on the use of the product, the problems and the herd situation. In general, injection at weaning or the day after weaning seems only be dictated by ease of the management and does not affect the response obtained (Kirkwood and Giebelhaus, 1998; Kirkwood, 1999). It is also possible to treat all sows not showing estrus by day seven or ten after weaning with PMSG or eCG and hCG (Britt, 1996; Mao et al., 1999). This strategy involves less treatment costs and also leads to higher estrus rates (Krejci et al., 2012).

Treated gilts or sows show estrus three to seven days after treatment. Sows will not show estrus upon treatment with PMSG or eCG and hCG in case of silent estrus, insufficient follicular activity or the presence of large COF. But also sows in the luteal phase of their cycle will not show estrus upon treatment. The administration of prostaglandins to induce luteolysis has not been shown to be of any economical value (Kirkwood, 1999).

Sows with large COF are difficult to treat effectively. A field experiment including 177 sows with ovarian cysts, showed positive results after double treatment with 100 µg GnRH with an interval of 12 hours. Within 6 weeks after treatment, the insemination rate was 84% compared to 17% in the control group and the final pregnancy rate was 44% compared to only 7% in the control group (Cech and Dolezel, 2007). However, these results are unsatisfactory under practical conditions, and therefore, sows with ovarian cysts are mostly culled.

In the past ten years, GnRH analogues such as peforelin (*e.g.* Maprelin®), GnRH-A (*e.g.* Gonavet®), buserelin (*e.g.* Receptal®, Porceptal® or Veterelin®) and triptorelin (*e.g.* OvuGel®) have been introduced. Peforelin is mainly used for the induction of estrus and the shortening of the WEI in gilts, primi- and pluriparous sows (Engl, 2006; Engl et al., 2010a, b, c). Up till now, little information is available on the effect of peforelin on the subsequent reproductive performance of gilts and sows in commercial pig herds and which effects it has on the litter parameters of treated females. The other products are primarily used as part of a strict breeding regime for the induction and synchronization of ovulation (Kauffold et al., 2007; Martinat-Botté et al., 2010; Knox et al., 2011). The latter can be used in a single Fixed Time Insemination (sFTI) Program, decreasing the labor of the farmer and the costs of two or three semen doses, with similar reproductive performance (Swarts et al., 2012; Kauffold and Sigmarsson, 2014; Sallé et al., 2014; Webel et al., 2014). The use of a sFTI advances the proportion of sows ovulating, with an associated effect on reducing the mean WEI in a herd.

All the above mentioned factors can also be seen as the preventive measures that can be taken to avoid a prolonged WEI in a herd. To conclude this chapter, figure 7 gives a schematic overview of these factors.

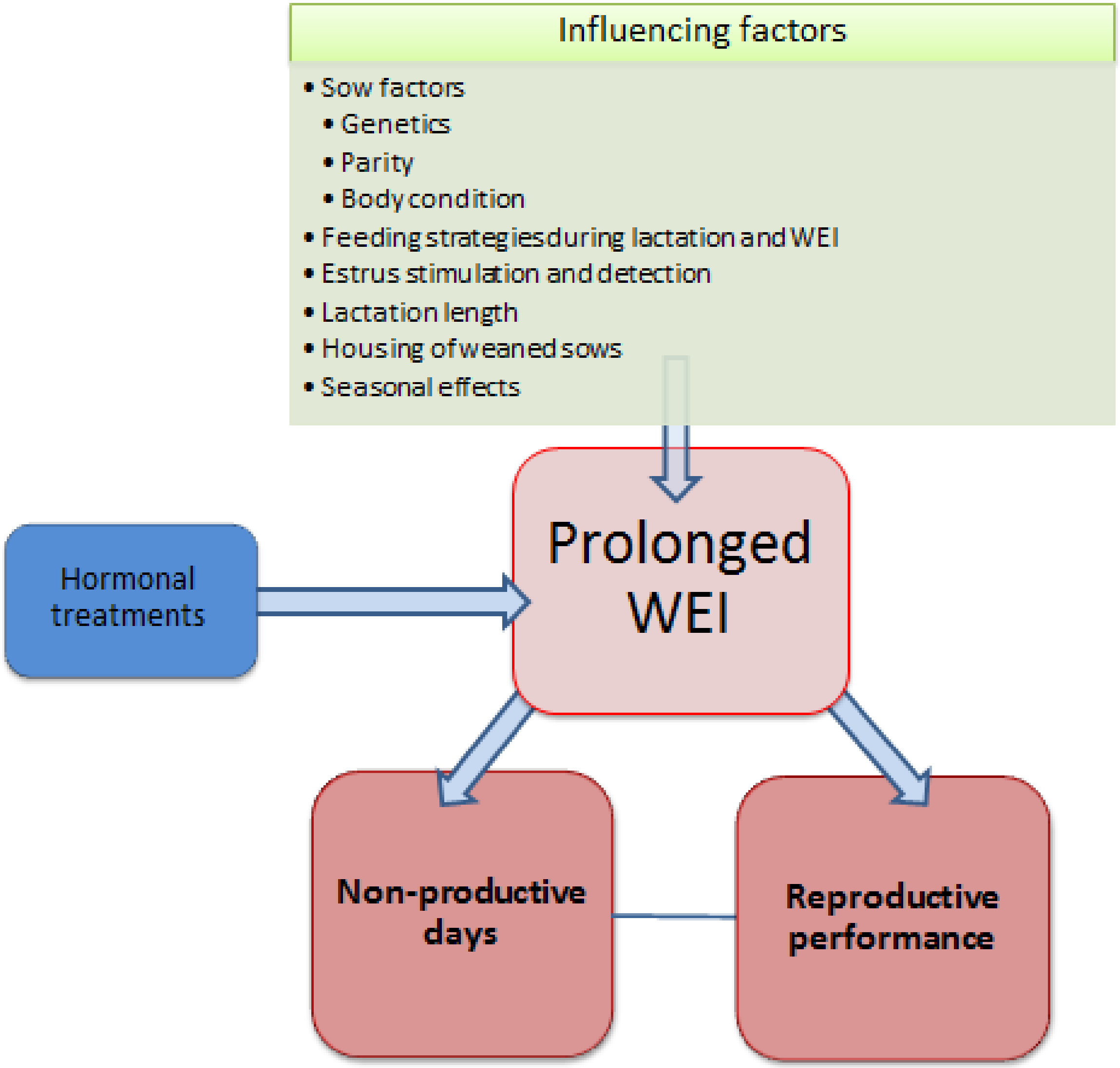

Figure 7. Schematic overview of chapter 1.2: factors influencing the Weaning-to-Estrus Interval (WEI).

1.3 Repeat breeding

Sows returning to estrus at regular intervals, *i.e.* regular repeat breeding, are likely to have experienced either conception failure or embryonic death of a critical portion of the litter before onset of implantation, such that pregnancy could not be maintained (Dial et al., 1992). At least four embryos are required at nidation, *i.e.* at day 12 after insemination, for pregnancy to be initiated (Maes, 2009). Otherwise, the sow will resume cyclicity and return to estrus 18 to 24 days after insemination.

Sows returning to estrus more than 24 days after insemination, *i.e.* irregular repeat breeding, may have (1) failed to conceive, but estrus was not detected at 21 days post-insemination, (2) failed to conceive, but the *cl* were maintained because of *e.g.* exposure to estrogenic mycotoxins (Young and King, 1986), or (3) lost pregnancy later than 12 days post-insemination, but before fetal calcification (35 days; Dial et al., 1992). Most of the sows returning at irregular intervals, return to estrus around days 25-30 after insemination.

In general, approximately two thirds of the sows returning to estrus after AI return at regular intervals, one third at irregular intervals (Maes, 2009). To fit in the scope of this thesis, this chapter will only focus on regular repeat breeding (RB).

1.3.1 Consequences of too many regular RB

The number of RB in a herd influences the herd productivity, because it has a direct negative effect on the number of farrowings per sow per year. Sows experiencing return to service or found non-pregnant negatively affect productivity through their contributions to the service-to-reservice component of annual NPD. The interval between the time a female is detected non-pregnant and rebreeding is an important component of the NPD in a herd. The impact of a NPD on a breeding herd is comparable with 0.05 to 0.08 pigs per sow per year. Consequently, a decrease in 20 NPD is comparable to 1 or 1.6 piglet more per sow per year (Almond et al., 2006). Moreover, failure to conceive is the most frequent observed reproductive disorder and represents up to 20% of the total of removals in a herd (Koketsu et al., 1997; Lucia et al., 2000a; Engblom et al., 2007).

The increase in RB is also of critical economic significance, because producers are unable to predict or maintain the production volume (Bertoldo et al., 2009). In addition, together with the prolonged WEI, repeat breeding can also derange the batch production systems, as sows returning to estrus, fall mostly in between two insemination batches and have to be treated with altrenogest until the next batch of weaned sows, again increasing the NPD, or have to be culled.

1.3.2 Diagnosis of RB

To verify whether sows are pregnant or will return to estrus after insemination, estrus detection with the teaser boar can be performed, starting from 18 days post insemination. Sows showing clear standing behavior will probably not have conceived and will regularly return to estrus. More reliable is the use of ultrasonography to determine if sows are pregnant or not. Pregnancy can be diagnosed quickly and reliably by one person from day 20-23 of gestation onwards (Kauffold et al., 1997; Maes et al., 2006; Kauffold and Althouse, 2007). Another possibility to differentiate between pregnant and non-pregnant females is the use of endocrine tests. Estrone sulfate, PGF2α and P4 are three hormones which have potential as pregnancy detection tests. Measuring these hormone concentrations in the blood for pregnancy diagnosis has an accuracy of 93%, 80% and 85%, respectively. Measurements should take place between day 25 and 30 of gestation for estrone sulfate, between day 13 and 15 for PGF2α and between day 17 and 20 for P4. However, the extra labor and costs for the blood sampling and the laboratory analyses make these tests less popular (Boma and Bilkei, 2008; Flowers and Knox, 2008).

Pregnancy diagnosis at an early stage can limit the number of NPD, however it will still take another three weeks before these sows can be inseminated again.

1.3.3 Factors influencing RB

Many of the factors influencing the WEI, also influence the percentage of RB on a herd (see figure 8). However, they are briefly mentioned again in this chapter.

1.3.3.1 Parity and previous reproductive cycle

In general, gilts and primiparous sows are associated with an increased percentage of repeat breeding (Koketsu et al., 1997; Vargas et al., 2009a; Iida and Koketsu, 2013). This can be explained by the fact that young sows (1) could suffer from ‘second litter syndrome’ (see chapter 1.2.4.2), (2) are susceptible to receive post-ovulatory inseminations, because of incorrect detection of the onset of estrus, as gilts have shorter ED than older females (see previous chapter; Kemp and Soede, 1996; Nissen et al., 1997), resulting in no conception or (3) have immature endocrine systems, making them less able to maintain pregnancy (Vargas et al., 2009a), resulting in regular returning to estrus.

Repeat breeding in the first parity did not significantly increase the risk of recurrence of repeat breeding in the second and third parities in the study of Elbers et al. (1996). But females with a pregnancy failure had 3.2 times higher odds of returning to estrus because of no pregnancy, than first service females according to the study of Vargas et al. (2009b).

1.3.3.2 AI procedures

Especially the timing of insemination relative to the time of ovulation is critical for AI-procedures. The ideal insemination time is 0-24 hours before ovulation (see 1.1.2.3). At least one mating should take place on each day of estrus (Almond et al., 2006). However, two inseminations during the 24-hour period prior to ovulation resulted in an improvement of the fertilization rate (Kemp and Soede, 1996). The positive results of a second insemination however depend largely on the percentage of animals that were inseminated too early for the first time, *i.e.* more than 24h before ovulation.

The timing of the first insemination in gilts is related with the percentage of regular repeat breeding. Insemination during *e.g.* the first estrus of puberty often results in higher embryonic deaths, caused by the worse quality of the oocytes and embryos and lower P4 secretion, compared to the 2nd or 3rd estrus (Archibong et al., 1992). This increases the number of gilts returning to estrus at regular intervals.

The time invested in estrus detection is important to reduce the percentage of repeat breeding in sows (Bortolozzo et al., 2005), as well as the use of a clearly defined breeding protocol, including the times for breeding, taking into account the impact of the WEI. A lower number of sows returning to estrus has been reported in herds where sows were inseminated twice or more per estrus, compared to herds in which sows were inseminated only once per estrus (Elbers et al., 1995). Timing is the single most important factor in achieving optimal pregnancy rates and multiple services appear to compensate for the inevitable inaccuracies in timing of AI. Recently the use of a single fixed AI-scheme, together with the use of exogenous GnRH treatment has been presented in several studies (see 1.2.5). With this method, estrus detection is no longer necessary and one insemination is at a fixed time after GnRH treatment, with similar results in pregnancy and farrowing rate (Swarts et al., 2012; Kauffold and Sigmarsson, 2014; Sallé et al., 2014; Webel et al., 2014).

1.3.3.3 Body condition and feeding strategies during lactation and in gestation

For each kg of increase in average daily feed intake during lactation a sow is 0.84 times less likely to have a regular return to estrus, according to Koketsu et al. (1997). Low feeding levels during lactation and the luteal phase is correlated with inferior quality of the oocytes (Zak et al., 1997a; Yang et al., 2000; Ferguson et al., 2003) and an increase in embryonic mortality (Zak et al., 1997b; Ashworth et al., 1999; Almeida et al., 2000). Sows can sustain a loss of nine to twelve percent of their body protein mass without adverse effects on piglet growth or ovarian function (Clowes et al., 2003). Nevertheless, if muscle protein loss in lactation exceeds twelve percent of the body protein mass at parturition, reproductive function is impaired, *e.g.* an increase in sows returning to service (Vargas et al., 2009a). In the latter study both primiparous sows and sows of second parity showed a higher risk of return to estrus (≥ 25%), indicating that huge losses in body condition during lactation not only have a negative influence on the conception rate of primiparous sows, but also on second parity sows (the 2nd litter syndrome, see chapter 1.2.4.2).

High feeding levels after weaning and before ovulation are beneficial for the quality of the oocytes and for the normal functioning of the uterus (see chapter 1.2.4.3). Controversely, going back to a normal feeding level after ovulation is important in order to ensure optimal processes during early pregnancy. High feeding levels during early pregnancy could increase the number of embryonic deaths, but, most likely only in gilts (Hazeleger, 2013). Studies comparing normal and high feeding levels showed respectively 21% and 30% embryonic deaths in gilts, whereas this was 25% respectively 26% in sows (Hazeleger, 2013). There seems to be an inverse relationship between level of nutrition and circulating P4 concentrations (Dyck et al., 1980; Prime et al., 1988). Feeding levels influence the P4 levels and certain studies strongly indicate that a distortion in the P4-dependent process, with a high metabolic clearance rate in liver and intestines, is the main cause of embryonic death (Ashworth, 1991; Pharazyn, 1992; Jindal et al., 1997). However, to the contrary, a more recent study (Quesnel et al., 2009) showed that a high feeding level (4 kg vs. 2 kg gestation feed per day) for prolific gilts did not reduce embryo survival, and had no beneficial nor detrimental effects on embryo size and variability at 27 days of gestation.

1.3.3.4 Lactation length

Herds applying short lactation lengths have in general more sows returning to service. Sows lactating during 15 to 19 days had a higher risk of return to estrus than those with longer lactations in the study of Vargas et al. (2009a), whereas Koketsu et al. (1997) detected no improvements in percentage RB once the lactation length was longer than ten days. It is clear that early weaned sows are associated with more embryonic deaths (Kiracofe, 1980; Koketsu et al., 1997; Willis et al., 2003; Gaustad-Aas et al., 2004; Vargas et al., 2009a), because of the reasons described in the previous chapter (1.2.4.5).

1.3.3.5 Housing inseminated sows

The housing of pregnant sows can induce stress in different ways, such as high stocking density, new social grouping, poor environments, thermal extremes and poor human-animal or animal-animal relationships (Varley and Stedman, 1994). Stress causes increased release of corticosteroids, subsequently suppressing the release of reproductive hormones (Einarrson et al., 1996).

The stress of regrouping sows in the beginning of gestation has a major influence on the incidence of repeat breeding (Love and Wilson, 1990). The lowest percentage of regular returns was found in sows grouped immediately after insemination (1.5%) in comparison to sows grouped later than two weeks post-insemination (4.7%; Van der Mheen et al., 2003; Kirkwood and Zanella, 2005). It seems therefore important to avoid stress in the period of implantation of embryos (Spoolder et al., 2009).

The effect of ambient temperature on the ovarian activity, conception and embryonic mortality before the maternal recognition is important. The study of Iida and Koketsu (2013) showed that an increase of maximum temperature in the post service period from 25°C to 30°C increased the percentage of RB (3.7% to 4.4%).

Fear for humans or dominant sows can also cause chronic stress, affecting the reproductive performance of the animals, as described in the previous chapter (1.2.4.6). This fear may negatively influence the estrus expression and thereby lower the insemination success, leading to increased repeat breeding rates (Spoolder et al., 2009).

1.3.3.6 Seasonal effects

The photoperiod in the European countries and the increasing temperatures in the southern hemisphere in late summer and early autumn not only affect the WEI (see previous chapter, 1.2.4.7), but also the ovarian activity, conception rate and pregnancy maintenance (Paterson et al., 1978; Koketsu et al., 1997; Peltoniemi et al., 1999).

1.3.3.7 Infections and toxins

Any (subclinical) disease of the sow could result in embryonic mortality and return to estrus. Infections and mycotoxins mainly result in an increase of the percentage of sows with irregular return to estrus.

In conclusion, the above mentioned factors can be considered as the preventive measures that can be taken to avoid too many regular repeat breeders in a herd.

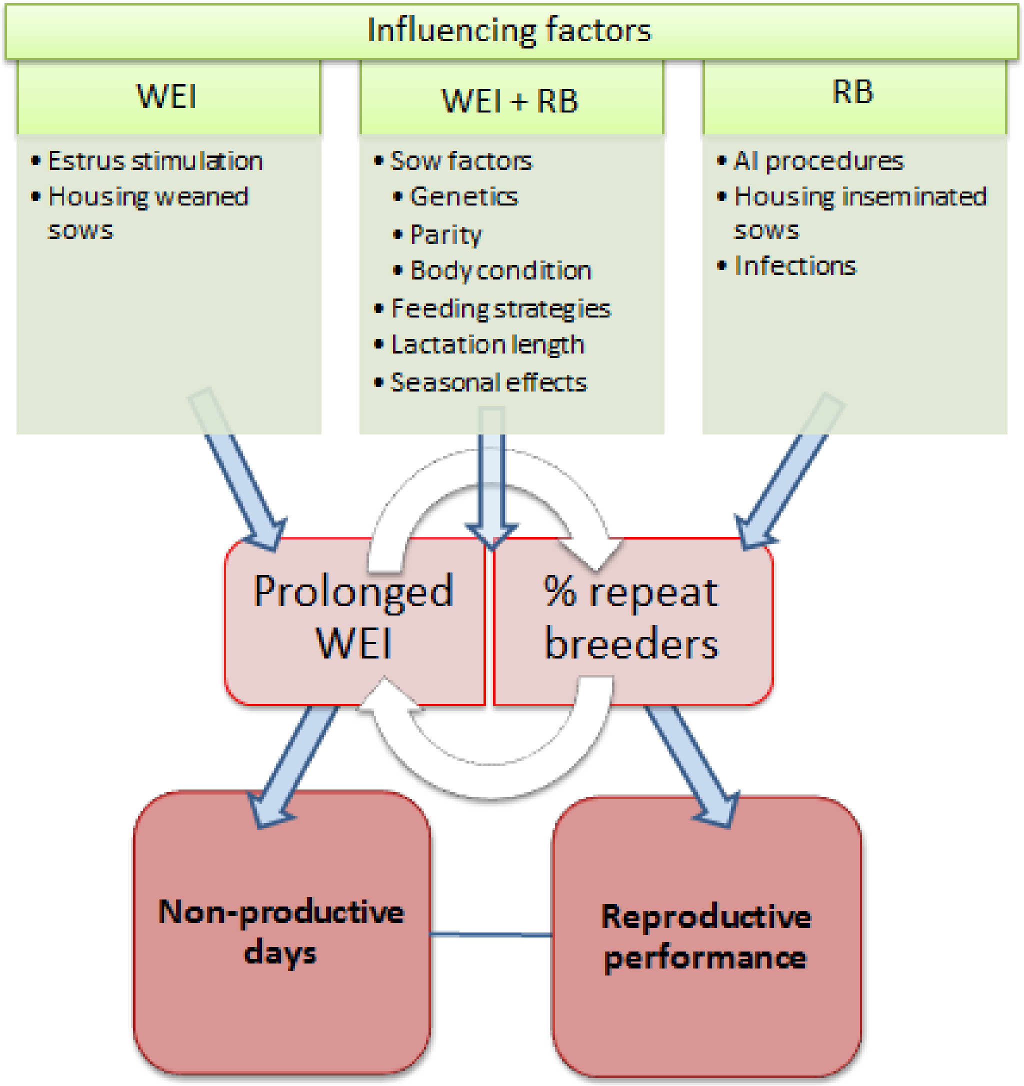

Figure 8. Schematic overview of chapter 1.2, enriched with the acquired knowledge of chapter 1.3: factors influencing the Weaning-to-Estrus Interval (WEI) and the percentage of regular Repeat Breeders (RB).

1.4 Litter performance

1.4.1 Parameters of litter performance

Litter performance includes litter size, number of stillborn piglets and the birth weight of the piglets.

Litter size is determined by the number of ovulations, the fertility rate (*i.e.* the percentage of fertilized oocytes) and the percentage of prenatal mortality (Blasco et al., 1995). Nowadays, the number of ovulations varies between 20 to 30 oocytes. The fertility rate is often assumed to be one hundred percent and therefore barely contributing to litter size. However, Steverink et al. (1999) demonstrated losses up till 10% due to partial fertilization. Prenatal mortality includes embryonic death until 35 days of pregnancy, and fetal mortality, from 35 days of pregnancy, in which embryonic death is the most influencing factor of litter size. The ability of the uterus to meet the nutritional demands to maintain fetuses during gestation until farrowing is defined as the uterine capacity (Bennet and Leymaster, 1989). The interaction between uterine, placental and fetal factors influences the survival of the fetus during pregnancy (Vallet et al., 2006). Uterine crowding, the phenomenon when too many fetuses are present in relation to the capacity of the uterus, is an important cause of fetal death.

Stillbirths generally account for three to eight percent of all pigs born (Zaleski and Hacker, 1993; Borges et al., 2005; Cutler et al., 2006). Stillborn piglets are defined as dead piglets, born later than day 109 of gestation. Survival before day 109 of gestation is limited, because the lung maturation has not been completed by this age (Curtis, 1974), therefore piglets born before day 109 are called aborted fetuses. Stillborn piglets can be classified into two categories, based on the time of death: type I, occurring before parturition, the cause of fetal death is generally attributed to intrauterine infection and type II, accounting for the major part of all stillbirths, occurring during parturition and generally associated with non-infectious etiologies such as intrauterine asphyxia and dystocia (Randall and Penny, 1967; Curtis, 1974; Sprecher et al., 1974; Leenhouwers et al, 1999; Alonso-Spilsbury et al., 2004).

The optimum birth weight is discussed by several authors and it is desirable within the range of 1.2 to 1.8 kg (Cechova, 2006).

1.4.2 Factors influencing litter performance

Factors influencing litter performance are presented in figure 9.

1.4.2.1 Litter size and birth weight

Litter size itself has an influence on the different parameters of litter performance, *i.e.* on birth weight and the number of stillborn piglets, as well as birth weight has an influence on the prevalence of the number of stillbirths.

A positive association between litter size and stillbirth is well documented (Zaleski and Hacker, 1993; Leenhouwers et al., 1999; Knol et al., 2002; Lucia et al., 2002; Arango et al., 2005; Borges et al., 2005; Canario et al., 2006; Wolf et al., 2008; Vanderhaeghe et al., 2010a). Large litters are mostly associated with longer farrowings (van Rens and van der Lende, 2004) and subsequently greater risks of hypoxia (Herpin et al., 2001). On the opposite, Knol et al. (2002) and Canario et al. (2006) found a greater probability of stillbirth in small litters, possibly because of oversized piglets which have a relatively large size compared to the maternal pelvis with subsequently greater difficulties in farrowing and more risk for hypoxia. The latter is also the reason why some authors found an increase in proportion of stillborn piglets, when sows were selected for producing higher mean birth weights (Knol et al., 2002; Leenhouwers et al., 2002; Damgaard et al., 2003; Holm et al., 2004). On the contrary, a low individual birth weight as well as the decrease in average litter birth weight increased the probability of stillbirth (Zaleski and Hacker, 1993; Leenhouwers et al., 1999; Le Cozler et al., 2002; Canario et al., 2006).

Quesnel et al. (2008) reported a decrease of 180 g in birth weight over the past ten years, due to increasing litter sizes. Indeed, several studies documented negative associations between litter size and individual birth weight (Lush et al., 1933; Kerr and Cameron, 1995; Roehe, 1999; Sorensen et al., 2000; Czechova, 2006; Akdag et al., 2009; Beaulieu et al., 2010), with an average decline of 35 to 43 g for each additional piglet born (Quiniou et al., 2002; Beaulieu et al., 2010). This can mainly be affected by changing the intensity of competition among the developing fetuses for the available blood supply, oxygen, space, etc. (Lush et al., 1933) and consequently the reduced utero-placental blood flow per fetus (Reynolds and Redmer, 2001). Despite the unfavorable correlation that was found between within-litter birth weight variation and number of piglets born alive in the study of Damgaard et al. (2003), an increase in litter size did not result in an increase in within-litter variability of birth weight in a more recent study of Beaulieu et al. (2010).

1.4.2.2 Genetic factors

As a result of heterosis, litter size of crossbred sows is on average 0.25 to 0.5 piglets larger than that of purebred sows (Aherne, 2002). The between-breed variation in relation to stillborn piglets is a dominant factor. Leenhouwers et al. (1999) observed significantly more stillbirths per litter in purebred than in crossbred lines and Vanderhaeghe et al. (2010b) even observed signifant differences between crossbred lines, with Danbred sows having nearly twice as many stillbirths compared to others. Canario et al. (2006) mentioned a lower risk of stillbirths in Meishan sows compared to European breeds, probably due to a shorter farrowing duration and birth interval (see further: 1.4.2.5 and 1.4.2.6; van Dijk et al., 2005). Also birth weight differs between breeds: Cechova (2006) compared different hybrid combinations with purebreds and as well as the highest as the lowest average birth weights occurred in the hybrid combinations, with 1339 g and 1227 g, respectively.

A review of 85 published results documented a heritability for total number of piglets born per litter of 0.11, ranging from 0.0 to 0.76 (Rothshild and Bidanel, 1998). Tummaruk et al. (2001a) reported that an increase of one piglet in the litter in which a gilt was born, resulted in an increase of her own litter size with between 0.07 and 0.1 piglets. The heritability of number of live-born piglets was 0.07 (Holm et al., 2004), and that of stillborn piglets between 0.02 and 0.05 (Hanenberg et al., 2001; Holm et al., 2004). The heritability of within litter variation in birth weight is low, but significant (0.08 - 0.11), indicating that genetic improvement of within litter variation by selective breeding can be successful (Högberg and Rydhmer, 2000; Hermesch et al., 2001; Damgaard et al., 2003). The maternal effect explains most of the genetic variation in birth weight (Hermesch et al., 2001; Arango et al., 2006). But the boar also has some effects on the birth weight of his progeny, with a heritability of 0.08 (Lush et al., 1933). The genetic improvement over the past ten years, resulted in an increase of 1.8 piglets per litter in commercial sows, but also in a reduction of the mean birth weight (Quesnel et al., 2008).

Selection for increased uterine capacity and, in particular, selection for reduced placental size and increased placental efficiency may also lead to increases in litter size (Ford et al., 2002; Wu et al., 2006). The uterine capacity is characteristic of the genotype and thus also the breed of the animal (Pere and Etienne, 2000; Campos et al., 2012). The uterine capacity is influenced by the uterine space, the uterine circulation, the synthetic capacity and the folding of the endometrium, which are all genetically determined. As an example, the Chinese

Meishan breed is known for its prolificacy and higher litter size compared to the commercial European breeds (Christenson, 1993). The Meishan is suggested to have slower fetal growth rates, resulting in improved homogeneity and a higher uterine capacity, thanks to an increased uterine size and placental efficiency (Ford, 1997; Ford et al., 2002).

1.4.2.3 Parity

Litter size is usually smallest in the first litter, increases to a maximum between the third and fifth parity and then remains constant or tends to decline as sows get older (Aherne and Kirkwood, 2001). The number of stillborn piglets increases with age (Leenhouwers et al., 1999; Le Cozler et al., 2002; Canario et al., 2006; Vanderhaeghe et al., 2010a). This could be attributed to a poor uterine muscle tone, leading to less efficient labor and prolonged farrowings in older parity sows (Vanderhaeghe et al., 2010a). An exception occurs in first parity sows, which can have a relatively high number of stillborn piglets, caused by a too narrow birth canal (Borges et al., 2005; Cutler et al., 2006; Canario et al., 2006).

Parity also influences birth weight, and generally, primiparous sows have lower birth weight yields than pluriparous sows (Milligan et al., 2002). Cechova (2006) found a positive trend in birth weights of piglets with increasing parity. Birth weights reached a maximum in the fifth parity (1337 g) and thereafter gradually decreased to 1111 g on the tenth parity (Cechova, 2006). On the contrary, Milligan et al. (2001) and Akdag et al. (2009) observed the highest birth weights in piglets originating from second litters.

1.4.2.4 Body condition

A longer period between two successive parturitions allows for better restorage of the body condition and metabolic status of the sow. This is mainly important for primiparous sows, who suffer from the consequences of the lactational catabolism (2nd litter syndrome, see 1.2.4.2; Tummaruk et al., 2001b). A possibility to allow the sow more time to regain a decent body condition after weaning is for example *skipping a heat*. It can improve pregnancy rates by 15% and subsequent litter sizes by 1.3 to 2.5 piglets (Clowes et al., 1994; Vesseur, 1997; Santos et al., 2004). Unfortunately, this leads to a significant increase in the number of NPD, because of the increase of the WEI. Also altrenogest, a synthetic progestagen of which the physiological effects mimic the biological activity of the sow’s own P4, can be used. Its activity lies in the suppression of the secretion of gonadotropins and consequently, inhibition of the growth of follicles on the ovaries. By administering 20 mg a day, the reproductive cycle of the sow is blocked at the end of the luteal phase. Application of altrenogest from one day before weaning has been shown to increase the ovulation rate with 2%, the embryo survival (77% versus 68% in the control group; Koutsotheodores et al., 1998) but also the pregnancy rate from 5.6% to 15.7% and litter size with 0.2 to 0.8 piglets per litter (Johnston et al., 1992; Forgerit et al., 1995). This may be explained by restoration of follicle development under altrenogest treatment after lactation (Van Leeuwen et al., 2009). However, the costs of an extended WEI should be weighed against the benefits of improved pregnancy rates and litter sizes. In order to limit body weight losses, primiparous sows can be weaned three to five days earlier than older sows, and receive a post-weaning treatment with altrenogest for 4 to 6 days (Everaert et al., 2007).

Where some studies found a positive association between a high body condition score of the sow at farrowing, determined by visual scoring, and stillbirth rate (Bilkei, 1992; Le Cozler et al., 2002), others found no association (Lucia et al., 2002; Borges et al., 2005). Maes et al. (2004) and Vanderhaeghe et al. (2010a) showed that sows with lower amounts of back fat at the end of gestation (< 16 mm) had significantly higher numbers of stillborn piglets, whereas back fat levels approaching 20 mm did not have detrimental effects on the stillbirth rate. Although, this is breed dependent (Vanderhaeghe et al., 2010a).

1.4.2.5 Gestation length and farrowing duration

Several studies found more stillborn piglets with a decreasing gestation length, *i.e.* less than 113 days (Leenhouwers et al., 1999; Hanenberg et al., 2001; Sasaki and Koketsu, 2007; Rydhmer et al., 2008; Vanderhaeghe et al., 2011). This could be linked to the immaturity of the piglets, born too early (Zaleski and Hacker, 1993), or a significant increase in farrowing duration with a decrease in gestation length (Van Dijk et al., 2005). A direct relationship is documented between farrowing duration and stillbirth rate (Borges et al., 2005; Van Dijk et al., 2005; Canario et al., 2006). Farrowings taking more than three hours and piglets being born late in the farrowing process increase the probability of stillbirth (Zaleski and Hacker, 1993), due to a higher risk of asphyxia of piglets because of detachment of placenta or rupture of the umbilical cord (Herpin et al., 1996).

1.4.2.6 Birth interval and birth order

The time interval between the expulsions of two successive piglets is on average 12 to 18 minutes (Sprecher et al., 1974; Alonso-Spilsbury et al., 2004). A longer birth interval is seen with stillborn piglets (Zaleski and Hacker, 1993; Van Dijk et al., 2005). Furthermore, a longer interval and a higher stillbirth rate are also associated with piglets with posterior presentation at birth (van Dijk et al., 2005). Piglets in the middle rank of the litter are born after the shortest birth interval (van Rens and van der Lende, 2004; Van Dijk et al., 2005) and the frequency of premature umbilical cord rupture increases towards the last third of the litter (Mota-Rojas et al., 2006).

Data on the effect of birth order on birth weight are rather scarce, but there is an indication that birth weight is related to birth order, with heavier piglets born earlier (Friend and Cunningham, 1966; Motsi et al., 2006).

1.4.2.7 Rearing of gilts

Rearing conditions during the first weeks in life can have a permanent effect on the reproductive capacity of the mature gilt and sow. Tummaruk et al. (2001a) found an influence of the growth rate in the finishing period: an increase in growth rate in gilts of 100 g a day resulted in an increase of between 0.3 and 0.4 piglets in their first litter. However, the recent study of Almeida et al. (2014a, b) revealed that, although birth weight affects the postnatal growth, the influence of the gilts' birth weight on the ovarian development and the development of the reproductive tract is minor.

A high back fat level in gilts of 100 kg, *i.e.* more than 10 mm, increases also the litter size in parity two (Tummaruk et al., 2001a). However, the sexual maturity, or the number of reproductive cycles, has a stronger influence on the first litter size, than the age or weight of the gilts at breeding. Serving gilts at their second estrus rather than at puberty can increase litter size by about 0.7 piglets (Aherne and Kirkwood, 2001).

1.4.2.8 WEI

An increase of WEI from four to ten days is associated with a decline in subsequent litter size by about one pig (Tummaruk et al., 2000). This seems to be a combined effect of ovulation rate, fertilization rate and embryo survival. The relative importance of these effects is not known (Prunier et al., 2003). The ovulation rate is normally quite high and is normally not the limiting factor for litter size, but the role of decreasing ovulation rates cannot be ruled out, specifically if the decline in number of ovulations is associated with a reduced quality of *cl* for WEI between 7 and 10 days (Zak et al., 1997a; Almeida et al., 2000). In sows with a short WEI, ovulation rate is probably closely related to the numbers of selectable follicles present at weaning. The fertilization rate is affected by the WEI, as an increase in WEI has found to be associated with a decrease in ED and consequently a shorter interval between onset of estrus and ovulation (Soede and Kemp, 1997). If the insemination strategy is not adjusted to the longer WEI, the number of sows in which the first AI takes place after ovulation will be increased and hence the risk of a low fertilization rate (Kemp and Soede, 1996). No clear information is available for the relationship between the WEI and the subsequent embryo survival, but some studies found indeed an association between an increased WEI and a decreased embryo survival (Prunier et al., 2003). Litter size will be highest if the wean-to-insemination interval averages for six days or less and if 95 % of the sows is bred by day seven after weaning. Finally, all factors influencing the WEI, have thus indirectly an effect on the litter size.

1.4.2.9 AI procedures

Artificial insemination procedures are important for the reproductive performance of sows (see 1.3.3.2). The timing of insemination and the semen quality have also a major influence on the litter size. Successful breeding requires an adequate number of viable and fertile spermatozoa in the utero-tubal-junction prior to and at the moment of ovulation (Dziuk and Polge, 1965; Soede et al., 1995a), otherwise a sharp reduction in litter size will be the result (Hunter, 1983). A positive relationship between the number of sperm cells inseminated and the number entering the oviduct has been found (Baker et al., 1968). An insemination dose for conventional AI should contain at least 2 billion spermatozoa in 80-100 ml dilution solution (Soede et al., 1995a; Maes, 2009). Semen quality should be assessed by evaluating the motility and morphology. Criteria for semen quality have been reviewed by Vyt (2007).

Breeding boars cannot be overused, otherwise it will have its consequences on the semen quality and quantity. A young boar, eight to twelve months old, can be used for three times every two weeks. Mature boars can be collected twice per week. High ambient temperature (> 30°C) will reduce boar fertility, reduce the quality of the semen and consequently litter size (Aherne and Kirkwood, 2001).

The technical competence of breeding technicians and reproductive performance within a herd are often positively associated: as the skill level increases, so do farrowing rates and litter sizes (Flowers, 1996a; b; Almond et al., 2006). A difference of 1036 piglets was observed between the best and worst technicians, based on 220 sows bred over 13 weeks. If this trend would continue during the entire year, a difference of approximately 4000 piglets produced would arise (Almond et al., 2006).

1.4.2.10 Partus induction and farrowing supervision

Farrowing induction facilitates an improved supervision at parturition and subsequently should reduce the percentage of stillbirths and neonatal piglet mortality. The widely accepted and available method of inducing parturition is by injecting PGF2α up to two days before the herd mean farrowing date. However, a considerable range in interval between treatment with PGF2α and parturition needs to be expected, as fewer than 65 to 40% of the induced sows are likely to farrow during normal working hours (Kirkwood et al., 1995; Decaluwé et al., 2012). Several studies reported indeed a substantial reduction of stillbirth rate with increasing rate of supervision of farrowings (Holyoake et al., 1995; White et al., 1996; Le Cozler et al., 2002; Vanderhaeghe et al., 2010b). But it needs to be kept in mind that partus induction before day 113 of pregnancy can result in a higher stillbirth rate (First et al., 1982; Zaleski and Hacker, 1993; Cutler et al., 2006). And since rapid fetal growth occurs in the last part of gestation, artificial shortening of the gestation, *i.e.* before day 112, could also have a detrimental effect on the birth weight (Welp and Holtz, 1985).

Various additional treatments have been applied in attempts to reduce the variation in the time to onset of parturition, for example injecting oxytocin, estradiol and carazolol 24h after PGF2α treatment (Kirkwood, 1999). They have a uterotonic effect and improper treatment with oxytocin could result in an increase of intrauterine hypoxia of the piglets, due to the decreased uterine blood supply, resulting in fetal distress and death (Alonso-Spilsbury et al., 2004; Mota-Rojas et al., 2002; 2005; 2006).

1.4.2.11 Lactation length

The length of the previous lactation period has a significant effect on the total number of born piglets, for the same reasons as described in the previous chapters (1.2.4.5; 1.3.3.4; Prunier et al., 2003). Per day the lactation length decreased from 18 to 12 days, a slight decrease in litter size of 0.06 piglets was seen in the study of Aherne and Kirkwood (2001). Each additional day suckling between 14 to 28 days post farrowing, led to an extra 0.1 piglet born in the subsequent litter in the study of Clark and Leman (1987). Litter size does not seem to increase further with lactation lengths of more than 28 days.

1.4.2.12 Feeding strategies during lactation, after weaning and during gestation

Feed restriction during lactation has detrimental effects on the postweaning performance of sows (see previous chapters 1.2.4.3, 1.3.3.3; Koketsu et al., 1996b). According to Thaker and Bilkei (2005) lactational weight loss should not be greater than five percent (approximately 9kg) for first parity sows and ten percent (approximately 22kg) for older parities if high litter sizes are to be achieved.

Increasing the feed intake after weaning may not only be profitable for the WEI (see 1.2.4.3), but also to maximize litter size and for the average birth weight of the piglets (Kongsted, 2005; Opschoor et al., 2011). Gilts should be fed a good quality diet *ad lib* for at least ten days prior to breeding, in order to maximize ovulation rate and litter size (Kongsted, 2005). Supplementation of dextrose and lactose during lactation (2 x 25 g/kg) and in the WEI (2 x 150 g/d) resulted in an increase of litter weight with 84 g in the subsequent litter (Van den Brand et al., 2006; 2009). The suggested mechanism behind all this is that together with an increase in insulin and IGF-1, the secretion of FSH and LH also increases, resulting in better follicle growth and lesser follicle variation (Van den Brand et al., 2009).

In general, restricted feeding levels are advised during gestation, in order to have less energy available for fat deposition, especially in later parities (Close and Cole, 2000). However, Hoving et al. (2011) demonstrated that high feeding levels (30% more than standard gestation diet, with 15MJ/kg ME) in the first month of gestation have positive effects on the litter size: 15 piglets compared to 13 in the control group, in first and second parity sows, without affecting the average birth weight of piglets (1.45 kg). Sows fed 130 g additional feed per day during gestation would farrow more total and liveborn piglets compared to sows fed according to national research council recommendations (Mahan, 1998). A higher feed intake improves the embryonic and fetal development, but also the placental efficiency.

High nutritional requirements are imposed on the gestation feed to support the metabolic needs of both the sows and its fetuses. An incorrect maternal nutrition may be associated with fetal growth retardation, and have consequently negative effects on the piglet birth weigths and the within-litter uniformity (Campos et al., 2012). Very low levels of energy intake (< 14 MJ/kg ME per day) during gestation have no effect on litter size or number of stillborn piglets, but the piglets will generally have lower birth weights and have a higher death risk during lactation (Pluske et al., 1995; Campos et al., 2012). More energy intake during gestation could indeed result in higher birth and litter weights (Buitrago et al., 1974; Pluske et al., 1995; Noblet et al., 1997). Van den Brand (2013) demonstrated that higher feed intake after day 100 of gestation will no longer have any advantage in piglet birth weights.

Dietary protein intakes during gestation also play a critical role in the maternal and fetal growth and development (Campos et al., 2012). Rehfeldt et al. (2011) investigated the effects of protein level in gestation feed in gilts. The piglets born from gilts fed with 12% crude protein had significant higher birth weights (1.4 kg) compared to those born from gilts fed with 7 or 30% crude protein (1.2 kg). Also embryonic survival was numerically the highest in the 12% group (77 compared to 67 and 64% for respectively the 12, 7 and 30% group; Rehfeldt et al., 2011).

On the days near parturition a minimum amount of a diet containing more than seven to eight percent crude fibre daily is recommended (Tabeling et al., 2003). Impending parturition increases the dry matter of the faeces and together with a reduction of defaecation frequency, it leads to constipation. The higher the dry matter content of the faeces during the last three days of gestation, the longer the farrowing of the sows will take and the higher the rate of stillborn piglets will be (Bilkei and Bölcskei, 1993; Oliviero et al., 2009), due to the creation of a physical obstacle during birth by pressing on the birth canal.

The requirements and ideal ratios of amino acids, such as lysine, threonine, valine and leucine depend on the stage of gestation (Kim et al., 2009). No further information is given here, as this is beyond the scope of this thesis. Arginine and other functional amino acids regulate the embryonic and fetal muscle growth and development, because of the participation in angiogenesis, placental vascularization and embryogenesis (Wu et al., 2006; 2010). Supplementation with these amino acids could increase litter size (Ramaekers et al., 2006) and birth weight (Musser et al., 1999; Cooper et al., 2001; Ramanau et al., 2004; Yang et al., 2009; Opschoor et al., 2011). Feeding fish oil throughout pregnancy at a level of 1.75% improves the birth weight. This is probably through supplying omega-3-fatty acids to the piglets *in utero*, resulting in an improved organ development (Rooke et al., 2001; Mateo et al., 2009). However, it is most likely that these supplementations will only be useful when the normal supply is marginal, or in extreme situations where fetal development is pressurized, for example due to overcrowding.

1.4.2.13 Housing in gestation and at farrowing

Avoiding stress within the first 28 days of gestation not only decreases the percentage of RB (see previous chapter 1.3.3.5), but also increases the litter size (Aherne and Kirkwood, 2001; Aherne, 2002).

Group housing during gestation, with group sizes of more than 20 animals, tends to reduce litter sizes, especially in gilts (Aherne and Kirkwood, 2001), but would increase the litter birth weight compared to sows housed in individual stalls (17.7 kg versus 16.7 kg; Bates et al., 2003).

Pen design (Fraser et al., 1997) and ambient temperature (Odehnalova et al., 2008) in the farrowing unit are the most important environmental factors causing stillborn piglets. Stress disrupts the homeostasis, with consequently more problems during farrowing. Lawrence et al. (1992) demonstrated a prolonged parturition in sows that were exposed to acute stress, by moving them to farrowing crates after the birth of the first piglet. Ambient temperatures of 23°C or more during 102 to 110 days of pregnancy increases the stillbirth rate and decreases birth weight (Omtvedt et al., 1971; Vanderhaeghe et al., 2010b).

1.4.2.14 Seasonal effects

Season may also influence the pre-natal development of the pigs, influencing the final birth weight of the piglet (Lush et al., 1933). Xue et al. (1994) reported a reduction in litter size and litter weight when conception occurred in summer and also Quesnel et al. (2008) found heavier piglets when sows were conceived in spring compared to other seasons.

1.4.2.15 Reproductive diseases and toxins

Although various diseases may affect litter size and number of stillborn piglets, they will not be discussed here. As most relevant infectious causes are endemic in Europe, noninfectious causes of stillbirths are believed to be more important.

Consumption of grains containing the estrogenic mycotoxin, zearalenone, may result in small litter size and increased stillbirth rates (Maes, 2009).

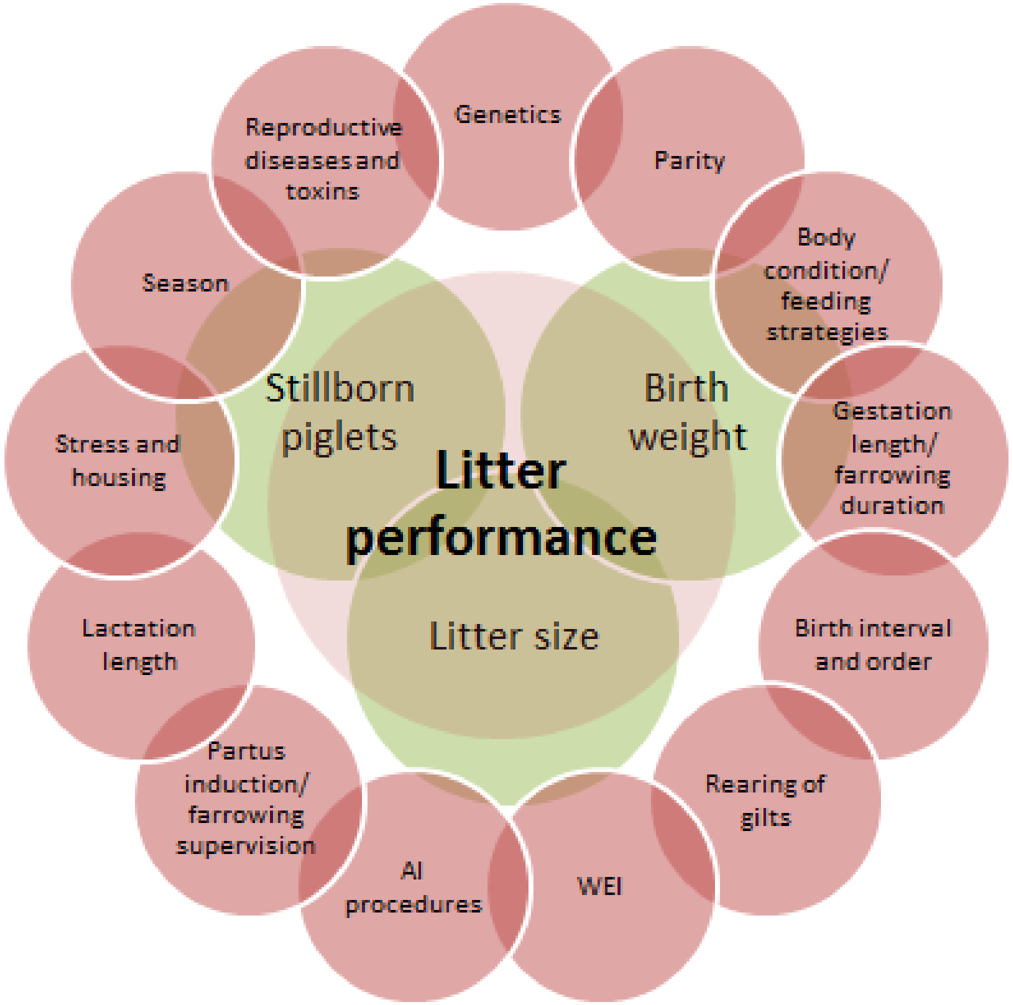

Figure 9. Schematic representation of chapter 1.4: factors influencing the litter performance.

1.5 Sow removal and slaughterhouse examination of culled sows

1.5.1 Definition of sow removal

Sow removal in a herd includes culling of sows and mortality of sows. There are two kinds of culling. The first one is the removal of old sows, which is considered normal and is called planned removal. This also includes culling of sows with low productivity. The other kind of removal is called unplanned removal and includes culling of sows due to reasons such as reproductive failure and lameness and sow removal due to mortality. The unplanned removal occurs in most cases in low parity numbers (Engblom, 2008).

1.5.2 Reasons for culling sows

Culling sows is an inevitable practice in commercial pig production, as it ensures acceptable production levels within the sow herd. Annual culling or removal rates of sows in production vary considerably between herds, ranging from 15 to 85% (D'Allaire et al., 1987; D'Allaire et al., 1992; Boyle et al., 1998; Engblom et al., 2007). D'Allaire and Drolet (2006) proposed 40% as recommended culling rate, with 35% being true culling and three to five percent natural mortality. However, target values should be adjusted for each farm, because the removal rate is influenced by many factors (see further 1.5.3; D'Allaire et al., 1992). Most of the removals are unplanned (Engblom, 2008), but to keep the number of NPD as low as possible, most pig producers cull their sows in a short period after weaning (Brandt et al., 1999; Tarrés et al., 2006a; Engblom et al., 2008). One could wonder if these cullings are indeed economically justified, and whether sows are culled for the proper reasons. No information is available on which interval is acceptable for culling sows after *e.g.* failure to show estrus symptoms or returns to estrus after AI (Kauffold et al., 2004).

The reasons for culling in commercial sow herds have been investigated all over the world. Table 1 gives an overview of the different reasons found in different studies. The most frequent reasons are associated with reproductive problems, locomotor problems and lower levels of productivity (D'Allaire and Drolet, 2006; Engblom, 2008; Mote et al., 2008; Segura-Correa et al., 2011; Masaka et al., 2014). D'Allaire and Drolet (2006) stated that 13 to 49% of all sows are culled because of impaired fertility, such as anestrus in sows post-weaning, regular and irregular returns, no pregnancy, abortion and peripartum difficulties, whereas Dalin et al. (1997) found that 67% of the sows were culled because of repeat breeding. The contribution of each of the reasons may vary from country to country, between regions within a country and from herd to herd, due to environmental, management and producer decisions

(Segura-Correa et al., 2011). Moreover, sows are very often culled for several reasons and not for a single one. For instance, an old sow with low productivity and lameness may be culled for low mothering ability, for lameness, or for its age. However, producers typically report one reason for culling, without reporting other underlying conditions, underestimating one parameter and overestimating another (Prunier et al., 2003). Additionally, these reasons do not incorporate evidence of internal lesions or diagnostic analyses, but are based on external signs or indications (Knauer et al., 2007). It is therefore interesting to examine a representative number of sows in the slaughterhouse in order to confirm whether the reasons for culling are justified.

The average parity at removal is lower than five and ranges from 3.1 to 4.6 (D’Allaire et al., 1992; Boyle et al., 1998), and 34% of the females are culled before or at first farrowing (Lucia et al., 2000b; Engblom et al., 2007). The highest proportion of young sows are removed due to unplanned removal (Dijkhuizen et al. 1989; Boyle et al., 1998) whereas the proportion of planned removal increases with higher parity numbers (Dijkhuizen et. al, 1989; Boyle et al., 1998).

1.5.2.1 Old age

Old age is a frequent reason to cull sows and is included in the planned removals. The term old age is a very subjective category. Some pig producers may accept six parities as a maximum for their productive sows, while others only decide to cull sows for old age at a parity of ten or more (D’Allaire et al., 1987). For example, in the study of Engblom (2008) and Masaka et al. (2014), only sows of parity seven or more were culled because of old age, while in the study of Segura-Correa et al. (2011) almost 90% of the sows culled because of old age were in parity six and Mote et al. (2008) reported old age as the primary reason to cull sows of parity five.

It is likely that an overlap between old age and lower productivity (see further: 1.5.2.5) occurs, since old sows experience a decrease in production. Several reasons are given in the previous chapters (1.2.4.2, 1.3.3.1 and 1.4.2.3) to maintain a balanced parity distribution of the sows in a herd and to avoid having too many young or too many old sows. To be of any economical value, a sow should produce at least three litters before culling (Lucia et al., 2000b). In general, reproduction results decline starting from parity five to six. Therefore, herd parity structure should be stable, with an average herd parity of 3 to 3.5, requiring a regular flow of gilts into the herd (< 17% of gilt farrowings), a high number of females (± <

45%) in the most productive three to six parity range and strict culling on age after seven to eight parities (Aherne and Kirkwood, 2001; Lawlor and Lynch, 2007). An example of a good and bad parity distribution is given in table 2.

It is necessary for pig producers to cull high-parity sows and these are generally preplanned (Engblom, 2008).

Table 2. An example of a good and bad parity distribution in a herd (adapted from Muirhead and Alexander, 1997)

Parity	0*	1	2	3	4	5	6	7	>7
Good (%)	17	15	14	13	12	11	10	5	3
Bad (%)	14	12	12	11	10	10	9	9	13

*****parity 0 = pregnant gilts until first farrowing

1.5.2.2 Reproductive failure

Reproductive failure is the major cause of removal of sows in several studies (D’Allaire et al., 1987; Dijkhuizen et al., 1989; Stein et al., 1990; Engblom et al., 2007; Segura-Correa et al., 2011; Masaka et al., 2014). Reproductive failure is a broad subject and different subcategories may exist, for example in the study of Engblom et al. (2007) this category included no pregnancy, no estrus, vaginal discharge, RB, abortion, metritis, prolonged WEI, mummification, dystocia, vaginal and rectal prolapse. In contrast, in the study of Sasaki and Koketsu (2011), reproductive failure only included no estrus, failure to farrow, no pregnancy and abortion. This demonstrates that different studies use different subdivisions, therefore comparison between studies is difficult.

Within the category of reproductive failure, anestrus and return to estrus are the most frequent reasons for removal of sows (Koketsu et al., 1997; Engblom et al., 2007, Tummaruk et al., 2009; Vargas et al., 2009a; Segura-Correa et al., 2011; Masaka et al., 2014) and these problems are most prevalent in early parities (Pomeroy, 1960, D’Allaire et al., 1987; Koketsu et al., 1997; Lucia et al., 2000b; Engblom et al., 2007; Masaka et al., 2014).

According to Almond et al. (2006), the main causes of reproductive failure are hormonal disbalance, poor service, disease, locomotor problems and management. When producers report reproductive problems as the cause of removal, it is believed that they refer to economic rather than to physiologic reproductive failure (Pomeroy, 1960).

1.5.2.3 Vaginal discharge

Vaginal discharge can either be normal or abnormal and only the latter can lead to early culling of sows. This phenomenon does not always have to be a separate category and can be included in the previous one, *i.e.* reproductive failure (Engblom et al., 2007), or the next one, *i.e.* peripartum problems (Segura-Correa et al., 2011).

Vaginal discharge may originate from either the vulva, the vagina, the endometrium, or the bladder (Muirhead, 1986). Purulent discharge between two and three weeks post insemination is an indication of metritis or endometritis (Almond et al., 2006). Sows inseminated late during estrus, *i.e.* after ovulation, are more susceptible to discharge problems (De Winter et al., 1992). Endometritis also occurs following parturition as a result of dystocia, traumatic injury, abortion, unhygienic manipulations, etc (see further 1.5.4.3.2).

If vaginal discharge as a reason for sow removal is considered as a separate category, the prevalence within this category varies from 21 to more than 50% (Boyle et al., 1998; Tummaruk et al., 2009).

1.5.2.4 Peripartum and udder problems

Peripartum problems can include dystocia, stillbirths, mummies, (endo)metritis, vaginal, uterus or rectal prolapse, mastitis, agalactia and other udder problems (D’Allaire et al., 1987) and also uterine, vaginal and vulval bleedings (Almond et al., 2006). In the study of Masaka et al. (2014) the specific reasons contributing the most to culling due to peripartum reasons were stillbirths and mummies, whereas in the older study of D’Allaire et al. (1987), 57% of the culled sows suffered from agalactia. In other studies, udder problems are a different culling category, including mastitis, agalactia, low milk production and poor maternal characteristics. Therefore, this category co-occurs with the category of the reproductive failure, low productivity and peripartum problems.

Culling frequencies for peripartum problems range between 2 and 36% (Engblom, 2008). One to fifteen percent of the sows is culled because of udder problems (D’Allaire and Drolet, 2006).

Parities at greatest risk of culling due to peripartum problems are first parity sows and sows between parity 5 and 8 (D’Allaire et al., 1987; Engblom, 2008; Segura-Correa et al., 2011).

1.5.2.5 Low productivity

The category low or poor productivity includes small litter sizes, *i.e.* less than five piglets born alive (Masaka et al., 2014), too little piglets weaned, low birth and/or weaning weights, high preweaning mortality (D'Allaire et al., 1987) and thus poor nursing performance of the sows (Mote et al., 2008). Also dysgalactia can be included in this category (Segura-Correa et al., 2011).

Culling sows due to inadequate performance, *i.e.* low productivity has a frequency ranging from 7 to 37% of all removals (Svendsen et al., 1975; D'Allaire et al., 1987; Mote et al., 2008; Segura-Correa et al., 2011) and is the highest in first and second parity females (Svendsen et al., 1975; Segura-Correa et al., 2011).

1.5.2.6 Trauma, locomotor problems and disease

Problems of the locomotor system include leg weakness, paralysis, injuries, abcesses, 'downer sow syndrome' and musculoskeletal diseases (D'Allaire et al., 1987). Any anatomical or functional problem involving any tissue of the foot, leg, or back could lead to culling sows because of locomotor problems. These problems are influenced by various factors, such as breed (Dagorn and Aumaitre, 1979), hygiene conditions, type and quality of flooring and type of caging (D'Allaire and Drolet, 2006; Segura-Correa et al., 2011).

Culling frequencies due to lameness exhibit a rather wide range from 8 to 27% (Friendship et al., 1986; D'Allaire et al., 1987; Engblom et al., 2007; Segura-Correa et al., 2011). A possible explanation for this wide range is that some authors include sows that are euthanized due to locomotor problems, while others prefer to exclude them from the total number culled due to this reason (Masaka et al., 2014).

Lower parities are more likely to be removed for locomotor problems than older parity sows (Friendship et al., 1986; Engblom et al., 2007; Mote et al., 2008, Segura-Correa et al., 2011). Traumatical injuries are mainly seen in young sows (Engblom et al., 2007), which can be explained by the fighting for social hierarchy in group housing systems, where older sows mount the younger sows, causing leg weakness and injuries (D'Allaire et al., 1992). Gjein and Larssen (1995) indeed demonstrated a slight higher percentage of sows culled due to locomotor problems in herds with loose housed pregnant sows compared to confined housing.

Besides musculoskeletal diseases, a large range of diseases can lead to removal of the sows, for example cardiovascular, urogenital, skin, respiratory and intestinal pathologies.

1.5.2.7 Miscellaneous problems

An important reason to cull sows is the sows' behavior, which is included in the category of miscellaneous problems. Tail biting is one of the behavioral problems in group housing systems, leading to secondary infections. Only one percent of the sows in the study of Engblom et al. (2007) was culled because of aggression and two percent in the study of Friendship et al. (1986). As secondary infections due to tail biting often lead to lameness and paralysis, it is possible that sows with behavioural problems are culled in the previous category of locomotor problems.

1.5.2.8 Death

Acute death of sows at the herd or euthanized sows, mainly because of animal welfare reasons, are classified under the category 'death'. The percentage of removals attributable to this category varies between 4 and 20%. Death is mostly ranked between the second and fifth most common reason in studies where death is included as a separate cause of removal (Svendsen et al., 1975; Dagorn and Aumaitre, 1979; Friendship et al., 1986; Engblom et al., 2007; Segura-Correa et al., 2011; Masaka et al., 2014). Sows are most at risk during the peripartum period, in one study almost half of the deaths occurred during this short period of the reproductive cycle (Chagnon et al., 1991). The main causes of natural death are torsions and accidents of abdominal organs, cardiac failure and cystitis-pyelonephritis (Chagnon et al., 1991; D'Allaire et al., 1992). In his study about culling patterns, D'allaire et al. (1987) found no reason in 29% of the dead sows. Twenty-seven percent of the females died because of locomotor problems, specifically gilts. Peripartum problems were the cause of death in 23%, in which seven percent died because of uterus prolapse.

Herds with low natural sow mortality rates have generally higher replacement rates, as these farmers decide more quickly to cull diseased sows. Annual mortality rate (of the percentage of sows in production) have been reported to range from 3.4% to 6.9% (Stein et al., 1990; D'Allaire et al., 1992; Lucia et al., 2000b).

Table 1. Overview of different culling reasons of sows, in different studies, in different countries (in % of female pigs examined in the specific study).

		High age	Reproductive failure	Anestrus	No pregnancy	Repeat breeding	Abortion	Vaginal discharge	Peripartum problems	Udder problems	Low productivity	Locomotor problems	Disease	Trauma	Miscellaneous problems	Death
Dagorn and Aumaitre, 1979	**France**	27	31	5			3		4		8	9			6	7
Friendship et al., 1986	**Canada**	18		9	13	3	2		2	9	14	12	7		6	5
D'Allaire et al., 1987	**USA**	14	32						7		17	9	2		7	12
Dalin et al., 1997	**Sweden**			10	11	67	4	4							4	
Boyle et al., 1998	**Ireland**	31	30								11	10	6	2	3	7
Heinonen et al., 1998	**Finland**	13		10	21				2	2	14	14		1	19	4
Lucia et al., 2000a	**USA**	9	12	9	13				3		21	13			13	7
Engblom et al., 2007	**Sweden**	19	27							18	9	9	3	7	4	4
Tummaruk et al., 2009	**Thailand**			44	10	16		20							10	
Segura-Correa et al., 2011	**Mexico**	24		9	4	5	3	2	4		13	15	13		7	1
Masaka et al., 2014	**Zimbabwe**	2		21	3	27	15	4	2		2	5			3	16

1.5.3 Factors influencing sow removal and longevity of sows

Sow longevity and sow removal are two issues that are intertwined. Functional longevity focusses on unplanned removal, unrelated to production, *i.e.* culling an animal at a time and for a reason that was not chosen by the pig producer (Enblom, 2008).

A first influencing factor on sow longevity is the rearing of gilts. Replacement gilts need to be fed differently from the finisher pigs, starting between 60 to 80kg, in order to build body reserves and allowing them to have long productive herd lives (Stalder, 2002). It is important to slow down protein deposition and build fat, mineral and other nutritional reserves, that can be utilized by the gilts when lactation dietary intake is not sufficient enough. High feeding intensity during rearing, *i.e. semi ad lib,* increased the removal rate due to leg weakness in Danish gilts in the study of Jørgensen & Sørensen (1998), whereas in the study of Le Cozler et al. (1999) with Swedish Yorkshire gilts, a restricted feeding pattern (only 80% of an *ad lib* level) increased culling at parity three (71%) compared with gilts fed *ad lib* (60%). Besides the quantity of feed, also the feed composition, *e.g.* the proportion protein versus energy has been reported to influence the longevity of sows (Stalder, 2002).

Not only the rearing of gilts but also the age and back fat thickness of gilts at first mating or farrowing are associated with their longevity. Considering back fat thickness, reports are contradictory. Under ideal management conditions, *i.e.* sufficient lactational feed intake, back fat plays less a role in sow longevity, thus some studies did not find an association (Rozeboom et al., 1996; Yazdi et al., 2000). However, perfect conditions do not exist and a minimum level of back fat is needed in replacement gilts. Tarrés et al. (2006b) demonstrated optimal backfat levels of 16 to 19 mm at first farrowing in Duroc females in relation to longevity, and Stalder et al. (2005) documented that gilts with more back fat had a higher longevity. High age, *i.e.* older than 10 months, at first mating has been shown to be associated with lower longevity and lifetime production (Schukken et al., 1994; Le Cozler et al., 1998; Koketsu et al., 1999; Yazdi et al., 2000; Engblom et al., 2008).

From a genetic point of view, gilts with the best value in the current index for exterior traits, *i.e.* number of teats and leg conformation, have a lower risk of culling. It is, therefore, possible to improve sow longevity via phenotypic selection based on exterior traits. For example, gilts with 13 or less good teats or with extreme feet and leg scores should be culled (Tarrés et al., 2006a). Considering leg conformation, buck-kneed front legs, swaying hindquarters and standing under position on the hind legs need to be avoided, as they all have an unfavorable association with sow longevity (Jorgensen, 2000).

Another factor influencing the removal pattern of a herd is the housing of the pregnant sows. Gjein and Larssen (1995) demonstrated higher annual removal rates and earlier culling in sows housed in loose-housed systems compared to sows housed in individual stalls or tethered during gestation, independent of floor type. Contradictory, Morris et al. (1998) found more advantages, *i.e.* higher parity at culling and higher lifetime production, in housing sows in small groups on a partially slatted floor, compared to sows in conventional gestation crates with a solid floor. A partially or totally slatted floor in the gestation unit with total confinement has however also been shown to lead to higher annual removal rates (D’Allaire et al., 1989).

The proportion of sows with reproductive failure varies with the season, thus a seasonal influence is also seen in the removal rate. Sows weaned in late summer have higher risk of removal (Dagorn and Aumaitre, 1979; Koketsu et al., 1997). Natural sow mortality during the summer months is also substantially higher, compared to other seasons of the year (Koketsu, 2000).

The observation of sows and the interpretation of their behavior is an important factor in reducing the removal rate and mortality rate in herds. Inexperienced stockmanship, who had little training nor background with livestock can contribute to high mortality in sow herds (Loula, 2000). Also herd size has been shown to be associated with sow mortality rate: an expansion with 500 sows, increased the mortality risk with 0.5% (Koketsu, 2000).

Finally, it is obvious that both the sows’ parity number and the production level influence the risk of removal. An overview has been given by Stalder (2002) and Engblom (2008) in which is stated that increasing parity, decreasing litter size, long weaning-to-service intervals and shorter/longer lactation lengths increase the risk of early culling.

1.5.4 Macroscopical examination of the reproductive tract of culled sows in the slaughterhouse

The figures in this chapter show examples of macroscopical views of different parts of the reproductive tract of culled sows in the slaughterhouse. Figure 10 presents a normal view of the complete reproductive tract.

Figure 10. Macroscopical view of the normal reproductive tract (1: vagina, 2: cervix, 3: uterine body, 4: uterine horn, 5: oviduct, 6: ovary (a: left, b: right)),

1.5.4.1 Ovaries

Visually normal ovaries are found in 52 to 85% of the culled sows (Fig. 11; Dalin et al., 1997; Heinonen et al., 1998; Karveliene et al., 2007; Knauer et al., 2007). Disturbances in ovarian functionality can mostly be attributed to problems in the maturation of the follicles and their ovulation.

Figure 11. Visually normal ovaries, characterized by the presence of small follicles and different *corpora rubra, lutea and albicantia.*

1.5.4.1.1 Inactive ovaries

Ovaries are considered inactive if only follicles less than three millimetres in diameter and no *corpora hemorrhagica* nor *lutea* are present (Fig. 12). The prevalence of acyclic or inactive ovaries in culled sows varies from 9 to 27% (Dalin et al., 1997; Heinonen et al., 1998;

Karveliene et al., 2007; Knauer et al., 2007; Kwiecien et al., 2010; Ward et al., 2010). Inactive ovaries can occur in young as well as in older sows. Inactivity is most likely caused by a blockade in the hypothalamus, resulting in a low release of GnRH. Not showing estrus is only one symptom of inactive ovaries, but several gradations exist. In the study of Karveliene et al. (2007) only 20% of the sows culled because of anestrus showed inactive ovaries.

Figure 12. Inactive ovary, characterized by the presence of only follicles less than three millimetres in diameter and no *corpora hemorrhagica* nor *lutea*.

1.5.4.1.2 Ovarian cysts

Ovarian cysts or COF are defined or as fluid-filled structures, exceeding a diameter of 11 to 12 mm (Waberski et al., 1999; Heinonen et al., 1998), or as unovulated or luteinized follicles of more than 12 mm (Castagna et al., 2004). A differentiation can be made between single and multiple cysts and also between follicular or luteal cysts, but the difference between the latter two is not always clear. Follicular cysts have a rather thin wall, while luteal cysts have a thick wall and are sometimes called “blood cysts” (Kauffold and Althouse, 2007). Ovaries with single cysts are mostly still functional, therefore it might be inappropriate to classify single cysts as abnormal. Multiple cysts can be accompanied by *cl*, those ovaries are called oligocystic, and consequences on the reproductive performance such as higher frequencies of returns to estrus, lower farrowing rates and lower litter sizes have been reported (Waberski et al., 1999; Castagna et al., 2004). Polycystic ovaries have hardly any *cl* and thus these sows may become infertile (Fig. 13; Heinonen et al., 1998; Kauffold et al., 2004; Kauffold and Althouse, 2007).

Slaughterhouse examination reveals COF in 2 to 24% of the culled sows (Ryan and Raeside, 1991; Dalin et al., 1997; Heinonen et al., 1998; Karveliene et al., 2007; Knauer et al., 2007; Tummaruk et al., 2009; Kwiecien et al., 2010; Ward et al., 2010). Ovarian cysts do not normally form in gilts, but yet 12% of the gilts examined in the study of Dalin et al. (1997) showed COF.

The presence of COF may cause lower conception rates, infertility, irregular and prolonged estrus cycles (Castagna et al., 2004). Sows with COF are mainly showing anestrus.

Figure 13. Multiple Cystic Ovarian Follicles (COF), with absence of *corpora lutea*, pointing towards infertility.

1.5.4.1.3 Para-ovarian cysts

Para-ovarian cysts are located in the *bursa ovarica* or near the ovaries in the *mesovarium* (Fig. 14). They would be remnants of mesonephric of paramesonephric duct systems and would have little effect on fertility. It may even be inappropriate to classify para-ovarian cysts as pathological structures (Heinonen et al., 1998).

The prevalence of cysts in the vicinity of the ovaries varies between 14 and 30% (Einarsson and Gustafsson, 1970; Tsumura et al., 1982; Heinonen et al., 1998). The average diameter is 1.30 ± 0.05 cm.

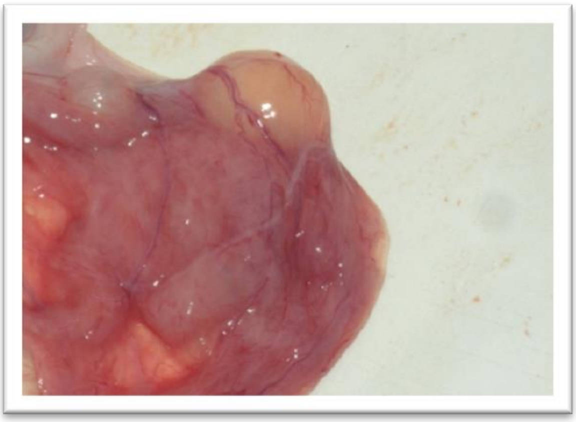

Figure 14. Para-ovarian cysts in the *mesovarium* and *bursa ovarica*.

1.5.4.2 Oviducts

When the oviduct is clogged, an enlargement of the oviduct is observed (Heinonen et al., 1998). Obstructions can be congenital or obtained due to inflammatory reactions. An accumulation of fluid in the oviducts is called *hydrosalpinx*. Oviductal anomalies are rather rare, Tummaruk et al. (2009) observed oviductal congestion in 9% of the culled gilts, *pyosalpinx*, *hydrosalpinx*, segmental aplasia, and a unilateral obstruction because of a blood clot each in one percent of the culled gilts. *Hydrosalpinx* was the only pathological observation in the oviducts in the study of Kwiecien et al. (2010) in 3.5% of the examined sows.

Para-oviductal cysts can be distinguished from para-ovarian cysts, as they are found in the *mesosalpinx*, near the oviduct (Fig. 15). If the cysts are small and do not interfere with the patency of the oviduct, their influence on reproduction is negligible (Heinonen et al., 1998).

Figure 15. Para-oviductal cyst in the *mesosalpinx*.

1.5.4.3 Uterus

1.5.4.3.1 Pregnancy

The observation of pregnancy in culled sows at slaughter varies from 6 to 14% (Knauer et al., 2007; Kwiecien et al., 2010; Ward et al., 2010). In the study of Knauer et al. (2007), 87% of them were normal pregnancies and mummified or decomposed fetuses were found in 8 and 5% of the pregnant sows, respectively.

1.5.4.3.2 Endometritis

Endometritis in the sow is associated with infections entering the uterus by either the haematogenous route or via the vagina. Ascending infections via the vagina are far most important (De Winter et al., 1995). Infections of the uterus occur either at natural service, AI or at parturition, because the cervix is patent at these times. Several factors, such as the AI-procedures and the hygiene during AI and parturition, influence the occurrence of endometritis. Towards the ending of standing heat, *i.e.* during the luteal phase, when P4 levels are high and E2 is low, the uterus is more susceptible to infections (Meredith, 1986; Dalin et al., 2004), thus inseminating after ovulation can result in endometritis. Abortion and dystocia can also cause endometritis. Some predisposing factors for endometritis are the hormonal status of the sow, *i.e.* the stage of the estrous cycle, the host defense mechanisms, the number of pathogens entering the uterus and their virulence and finally, the housing of the sow in the farrowing and the insemination unit as an influence on the prevalence of urogenital infections (Meredith, 1986; De Winter et al., 1995; Dalin et al., 2004).

The incidence of endometritis in a commercial pig herd ranges between 5 and 50% (De Winter et al., 1992; Tummaruk et al., 2009; Kwiecien et al., 2010), but endometritis *per se* is not a reason to cull sows. Slaughterhouse examination and more specifically histological examination is necessary to diagnose endometritis in subclinical cases. Histological examination revealed endometritis in 14 to 27% of the examined uteri (Dalin et al., 1997; Tummaruk et al., 2009). The incidence of endometritis is higher in sows with inactive ovaries compared to normal ovaries (Dalin et al., 1997). Eighty percent of the sows with severe endometritis has still remnants of abortions or previous litters (Fig. 16; Dalin et al., 1997).

Figure 16. Remnants of mummified fetuses present in the uterus.

1.5.4.3.3 Hydro-/mucometra and endometrial cysts

Hyperplasia of the endometrium can cause an accumulation of fluid, more specifically mucins, in the lumen of the uterus. This is called *hydro- or mucometra*. It is rarely found during slaughterhouse examination (Heinonen et al., 1998).

Cysts in the endometrium are only described by Kwiecien et al. (2010), who found it in 7% of the examined uteri of culled sows.

1.5.4.4 Cervix, vagina, vestibulum and vulva

The caudal parts of the urogenital tract, *i.e.* the cervix, vagina, vestibulum and vulva, are not frequently included in the macroscopical examination of the reproductive tract in culled sows. Infections of these parts do not usually persist and cause less reproductive problems. Therefore they are rarely a reason of early removal of sows. The main findings in the study of Tummaruk et al. (2009) in gilts were cervicitis, vaginitis or vestibulitis (9%) and hemorrhages (6%).

1.5.4.5 Congenital anomalies

Abnormalities of the reproductive organs in sows can cause impaired fertility. Different studies define different abnormalities as congenital anomalies. The study of Einarrson and Gustafsson (1970) for example reported 22% malformations, including cysts in the *mesosalpinx*. Not counting these cysts, only 8% of the gilts showed anomalies with in 4% a partial duplication of the vagina and in the remaining 4% general developmental defects of the oviduct. In the study of Heinonen et al. (1998) only 1% of the examined gilts and sows showed anomalies, including uterus unicornis, unilateral segmental aplasia, double cervix and hermaphroditism (Fig. 17). Tummaruk et al. (2009) found in 17% of the examined gilts abnormalities, mainly segmental aplasia. Aplasia, hypoplasia or doubling would have genetic compounds and can eventually lead to infertility or dystocia (Almond et al., 2006).

Figure 17. Hermaphroditism observed in a culled gilt.

1.5.4.6 Tumors

Tumor lesions are rare in pigs, as pigs are culled at a relatively young age. Studies in the eighties reported ovarian hemangiomas (4%) and uterine tumors (9%), *i.e.* leiomyomas, fibromas, cyst-adenomas and fibro-leiomyomas, in sows between five and eight years old (Hsu, 1983; Akkermans and van Beusekom, 1984). Sows with ovarian hemangiomas showed clinical symptoms related to reproductive disorders, *e.g.* small litter size, agalactia, no pregnancy, fetal death, silent estrus, anestrus, abortion, and stillbirth (Hsu, 1983). The sows having uterine tumors were culled because of problems with infertility (Akkermans and van Beusekom, 1984). Heinonen et al. (1998) observed in less than one percent of the animals ovarian tumor-like lesions, with a diameter of two to eight centimeters. In half of the animals with tumors, the ovaries were normal, the others showed inactive ovaries. No uterine tumors were detected.

1.6 References

Aherne F. (2002). Improving breeding herd efficiency: an industry perspective. Proceedings 29th Annual Symposium of the Pig Health Society, Dublin, Ireland, p.30-44.

Aherne F., Kirkwood R. (2001). Factors affecting litter size. Alberta Pork Research. http://www.thepigsite.com/articles/304/factors-affecting-litter-size (last acces: 03/03/2014).

Aherne F., Williams I. (1992). Nutrition for optimizing breeding herd performance. Veterinary Clinical North America Food Animal Practicioners 8(3), 589-608.

Akdag F., Arslan S., Dernir H. (2009). The effect of parity and litter size on birth weight and the effect of birth weight variations on weaning weight and pre-weaning survival in piglet. Journal of Animal and Veterinary Advances 8(11), 2133-2138.

Akkermans J.P., van Beusekom W.J. (1984). Tumors and tumor-like lesions in the genitalia of sows. Veterinary Quarterly 6, 90-96.

Almeida F.R.C.L., Kirkwood R.N., Aherne F.X., Foxcroft G.R. (2000). Consequences of different patterns of feed intake during the oestrus cycle in gilts on subsequent fertility. Journal of Animal Science 78, 1556-1563.

Almeida F.R.C.L., Teerds K., Soede N.M. (2014a). Birth weight implications for ovarian development in gilts. Proceedings of the 23rd IPVS Congress, Cancun, Mexico, 135.

Almeida F.R.C.L., Laurenssen B.F., Soede N.M. (2014b). Birth weight effects on reproductive tract development and puberty onset in gilts. Proceedings of the 23rd IPVS Congress, Cancun, Mexico, 137.

Almond G., Flowers W., Batista L., D’Allaire S. (2006). Diseases of the reproductive system. In: Straw B.E., Zimmerman J.J., D’Allaire S.D., Taylor D.J. (Eds.), Diseases of Swine, ninth ed. Blackwell Publishing Ltd., 113-147.

Alonso-Spilsbury M., Mota R., Trujillo O., Martínez-Burnes J., Arch T., López-Mayagoitia A., Ramírez-Necoechea R., Olmos H., (2004). Use of oxytocin in penned sows and its effect on fetal intra-partum asphyxia. Animal Reproduction Science 84, 157–167.

Anderson L.L. (1987). Pigs. In: Reproduction in farm Animals (5th ed) ESE Hafez, ed. Philadelphia: Lea and Febiger, p.324-344.

Arango J., Misztal I., Tsuruta S., Culbertson M., Heering W. (2005). Threshold-linear estimation of genetic parameters for farrowng mortality, litter size and test performance of large white sows. Journal of Animal Science 83, 499-506.

Arango J., Misztal I., Tsuruta S., Culbertson M., Holl J.W., Heering W. (2006). Genetic study of individual preweaning mortality and birth weight in Large White piglets using threshold-linear models. Livestock Science 101, 208-218.

Archibong A.E., Maurer R.R., England D.C., Stormshak F. (1992). Influence of sexual maturity of donor on in vivo survival of transferred embryos. Biology of Reproduction 47, 1026-1030.

Arey D.S., Edwards S.A. (1998). Factors influencing aggression between sows after mixing and the consequences for welfare and production. Livestock Production Science 56, 61-70.

Ashworth C.J. (1991). Effect of pre-mating nutritional status and post-mating progesterone supplementation on embryonic survival and conceptus growth in gilts. Animal Reproduction Science 26, 311-321.

Ashworth C. (2006). Reproduction. In: Kyriazakis I., Wittemore C.T. (eds), Wittemores' Science and Practice of Pig Production, 3rd edition, Blackwell publishing, 125-126.

Ashworth C.J., Antipatis C., Beattle L. (1999). Effects of pre- and post-mating nutritional status on hepatic function, progesterone concentration, uterine protein secretion and embryo survival in Meishan pigs. Reproduction and Fertility Development 11, 67-73.

Baker R.D., Dziuk P.J., Norton H.W. (1968). Effect of volume of semen, number of sperm and drugs on sperm transport in artificially inseminated gilts. Journal of Animal Science 27, 88-92.

Baldwin D.M., Stabenfeldt G.H. (1975). Endocrine changes in the pig during late pregnancy, parturition and lactation. Biology of Reproduction 12, 508-515.

Bates R.O., Day B.N., Britt J.H., Clark L.K., Brauer M.A. (1991). Reproductive performance of sows treated with a combination of pregnant mare's serum gonadotropin and human chorionic gonadotropin at weaning in the summer. Journal of Animal Science 69, 894-898.

Bates R.O., Edwards D.B., Korthals R.L. (2003). Sow performance when housed either in groups with electronic sow feeders or stalls. Livestock Production Science 79, 29-35.

Bazer F.W., First N.L. (1983). Pregnancy and parturition. Journal of Animal Science (suppl 2) 57, 425-460.

Beaulieu A.D., Aalhus J.L., Williams N.H., Patience J.F. (2010). Impact of piglet birth weight, birth order, and litter size on subsequent growth performance, carcass quality, muscle composition and eating quality of pork. Journal of Animal Science 88, 2767-78.

Beek J., de Jong E., Van Soom A., de Kruif A., Maes D. (2011). Ovarian cysts in sows: a multifactorial disorder with consequences on the reproductive performance. Vlaams Diergeneeskundig Tijdschrift 80, 215-222.

Behan, J.R., Watson, P.F. (2005). The effect of managed boar contact in the post-weaning period on the subsequent fertility and fecundity of sows. Animal Reproduction Science, 88, 319–324.

Belstra B.A., Flowers W.L., See M.T. (2004). Factors affecting temporal relationships between estrus and ovulation in commercial sow farms. Animal Reproduction Science, 84, 377-394.

Benaglia P., Krejci R., Lopez A., Casappa P. (2012). Effect of synchronization of estrus in sows after weaning using Fertipig in comparison with another gonadotropin product. Proceedings of the 22nd IPVS Congress, Jeju, Korea, p.92.

Bennet G.L., Leymaster K.A. (1989). Integration of ovulation rate, potential embryonic viability and uterine capacity into a model of litter size in swine. Journal of Animal Science 67, 1230-1241.

Bertoldo M., Grupen C.G., Thomson P.C., Evans G., Holyoake P.K. (2009). Identification of sow-specific risk factors for late pregnancy loss during the seasonal infertility period in pigs. Theriogenology 72, 393-400.

Bevers M.M., Willemse A.H., Kruip T.A.M. (1981). Prolactin levels and LH response to synthetic LH-RH in lactating sows. Animal Reproduction Science 4-2, 155-163.

Bichard M., Bovey M., Seidel L., David P., Tomkins C. (1983). New developments in scientific pig breeding. Pig Improvement Company, Fyfield Wick, Abingdon, Oxfordshire, UK.

Bilkei G. (1992). The effect of different zootechnical practice methods on the duration of labor in swine with reference to the body condition of the sow. Tierarztliche Praxzis 20(2), 153-158.

Bilkei G., Bölcskei A. (1993). The effects of feeding regimes in last month of gestation on the body condition and reproductive performance of sows of different body condition and parity. Tierärztliche Umschau 48, 629-635.

Blasco A., Bidanel J.P., Haley C. (1995). Genetics and neonatal survival. In: Varley M.A. (ed). The neonatal pig, development and survival. GAB international, Wallingford, Oxon, UK, 17-38.

Boma M.H., Bilkei G. (2008). Field experiences with early pregnancy diagnosis by progesterone-based ELISA in sows. Journal of Veterinary Research 75, 55-58.

Borges V.F., Bernardi M.L., Bortolozzo F.P., Wentz I. (2005). Risk factors for stillbirth and foetal mummification in four Brazilian swine herds. Preventive Veterinary Medicine 70, 165-176.

Bortolozzo F.P. Uemoto D.A., Bennemann P.E., Pozzobon M.C., Castagna C.D., Peixoto C.H., Barioni J.W., Wentz I. (2005). Influence of time of insemination relative to ovulation and frequency of insemination on gilt fertility. Theriogenology 64, 1956-62.

Boyle L., Leonard F. C., Lynch B., Brophy P. (1998). Sow culling patterns and sow welfare. Irish veterinary Journal incorporating Irish veterinary Times, 51, 354-357.

Bracken C.J., Lamberson W.R., Safranski T.J., Lucy M.C. (2003). Factors affecting follicular populations on day 3 postweaning and interval to ovulation in a commercial sow herd. Theriogenology 60, 11-20.

Brandt H., von Brevern N., Glodek P. (1999). Factors affecting survival rate of crossbred sows in weaner production. Livestock Production Science 57, 127-135.

Breen S.M., Rodriguez-Zas S.L., Knox L.V. (2006). Effect of altering dose of PG600 on reproductive performance response in prepubertal gilts and weaned sows. Animal Reproduction Science 95, 316-323.

Britt J.H., Armstrong J.D., Cox N.M., Esbenshade K.L. (1985). Control of follicular development during and after lactation in sows. Journal of Reproduction and Fertility (suppl) 33, 37-54.

Britt J.H. (1996). Biology and management of the early weaned sow. Proceedings of The American Association of Swine Practicioners, 417-426.

Buitrago J.A., Maner J.H., Gallo J.T., Pond W.G. (1974). Effect of dietary energy in gestation on reproductive performance of gilts. Journal of Animal Science 39, 47-52.

Campos P.H.R.F., Silva B.A.N., Donzele J.L., Oliviera R.F.M., Knol E.F. (2012). Effects of sow nutrition during gestation on within-litter birth weight variation: a review. Animal 6(5), 797-806.

Canario L., Cantoni E., Le Bihan E., Caritez JC., Billon Y., Bidanel JP., Fouley J., (2006). Between-breed variability of stillbirth and its relationship with sow and piglet characteristics. Journal Animal Science 84, 3185-3196.

Cassar G. (2009). Hormonal control of pig reproduction. London Swine Conference – Tools of the Trade, 137-139.

Castagna C., Peixoto C., Bortolozzo F., Wentz I., Neto G.., Ruschel F. (2004). Ovarian cysts and their consequences on the reproductive performance of swine herds. Animal Reproduction Science 81, 115-123.

Cech S., Dolezel R. (2007). Treatment of ovarian cysts in sows – a field trial. Veterinarni Medicina 52, 413-418.

Cechova M. (2006). Analysis of some factors influencing the birth weight of piglets. Slovak Journal of Animal Science 39(3), 139-144.

Chagnon M., D’Allaire S., Drolet R. (1991). A prospective study of sow mortality in breeding herds. Canadian Journal of Veterinary Research 55, 180-184.

Christenson R.K. (1993). Ovulation rate and embryonic survival in Chinese Meishan and white crossbreds pigs. Journal of Animal Science 71, 3060-3066.

Clark L.K., Leman A.D. (1987). Factors that influence litter size in swine: parity 3 through 7 females. Journal of The American Veterinary Medicine Asociation 191, 49-58.

Close W.H., Cole D.J.A. (2000). Introduction. In: Close W.H., Cole D.J.A. (eds.) Nutrition in sows and boars. Nottingham University Press, United Kingdom, 1-8.

Clowes E.J., Aherne F.X., Foxcroft G.R. (1994). Effect of delayed breeding on the endocrinology and fecundity of sows . Journal of Animal Science 72, 283-291.

Clowes E., Aherne F., Foxcroft G., Baracos V. (2003). Selective protein loss in lactating sows is associated with reduced litter growth and ovarian function. Journal of Animal Science 81, 753-764.

Cooper D.R., Patience J.F., Zijlstra R.T., Rademacher M. (2001). Effect of energy and lysine intake in sow performance. Journal of Animal Science, 79, 2367-2377.

Curtis S.E. (1974). Responses of the piglet to perinatal stressors. Journal of Animal Science 38, 1031-1036.

Cutler R., Fahy V., Cronin G., Spicer E. (2006). Preweaning mortality. In: Straw B.E., Zimmerman J.J., D'Allaire S.D., Taylor D.J. (Eds.), Diseases of Swine, ninth ed. Blackwell Publishing Ltd., p.993-1010.

Dagorn J., Aumaitre A. (1979). Sow culling: Reasons for and effect on productivity. Livestock Production Science, 6, 167-177.

Dalin A.M., Gidlund K., Eliasson-Selling L. (1997). Post-mortem examination of genital organs from sows with reproductive disturbances in a sow-pool. Acta Veterinarica Scandinavica 38(3), 253-262.

Dalin A.M., Kaeoket K., Persson E. (2004). Immune cell infiltration of normal and impaired sow endometrium. Animal Reproduction Science 82-83, 401-413.

D'Allaire S. and Drolet R. (2006). Longevity in Breeding Animals. In: Straw B.E., Zimmerman J.J., D`Allaire S., Taylor D.J., eds., Diseases of Swine (9th edition), Ames Iowa State University Press, 1011-1025.

D'Allaire S., Stein T.E., Leman A.D. (1987). Culling patterns in selected Minnesota Swine Breeding Herds. Canadian Journal of Veterinary Research, 51, 506-512.

D’Allaire S., Morris R.S., Martin F.B., Robinson R.A., Leman A.D. (1989). Management and environmental factors associated with annual sow culling rate: a path-analysis. Preventive Veterinary Medicine 7, 255-265.

D’Allaire S., Leman A.D., Drolet R. (1992). Optimizing longevity in sows and boars. Veterinary Clinics of North America: food animal practice 8(3), 545-557.

Damgaard L.H., Rydhmer L., Lovendahl P., Grandison K. (2003). Genetic parameters for within-litter variation in piglet birth weight and change in within-litter variation during suckling. Journal of Animal Science 81, 604-610.

Decaluwé R., Janssens G.P.J., Declerck I., de Kruif A., Maes D. (2012). Induction of parturition in the sow. Vlaams Diergeneeskundig Tijdschrift 81, 158-165.

De Winter P., Verdonck M., de Kruif A., de Vriese L., Haesebrouck F. (1992). Endometritis and vaginal discharge in the sow. Animal Reproduction Science 29, 51-58.

De Winter P., Verdonck M., de Kruif A., Devriese L., Haesebrouck F. (1995). Bacterial endometritis and vaginal discharge in the sow: prevalence of different bacterial species and experimental reproduction of the syndrome. Animal Reproduction Science 37, 325-35.

Dial G., Marsh W., Polson D., Vaillancourt J., (1992). Reproductive failure: Differential Diagnosis. In: Leman A.L., Straw B.E., Mengeling W.L., d’ Aillaire S., Taylor D.J. (1992). Diseases of Swine, seventh edition. Iowa State University Press, Ames, 88-137.

Dijkhuizen A.A., Krabbenborg R.M.M., Huirne R.B.M. (1989). Sow replacement: a comparison of farmers’ actual decisions and model recommendations. Livestock Production Science, 23, 1-2, 207.

Distl O. (2007). Mechanism of regulation of litter size in pigs on the genome level. Reproduction of Domestic Animal 42 (Suppl.2), 10-16.

Dyck G.W., Palmer W.M., Simaraks S. (1980). Progesterone and luteinizing hormone concentration in serum of pregnant gilts on different levels of feed consumption. Canadian Journal of Animal Science 60, 877-884.

Dyck G.W., Swierstra E.E. (1983). Growth of the reproductive tract of the gilt from birth to puberty. Canadian Journal of Animal Science 63, 81-86.

Dyck G.W. (1998). The effect of housing facilities and boar exposure after weaning on the incidence of postlactational anestrus in primiparous sows. Canadian Journal of Animal Science 68, 983-985.

Dziuk P.J., Polge C. (1965). Fertility of gilts following induced ovulation. Veterinary Record 77, 236-242.

Ebbert W., Bostedt H. (1993). Cystic degeneration in porcine ovaries – first communication: morphology of cystic ovaries, interpretation of results. Reproduction in Domestic Animals 28, 441-450.

Ebbert W., Elsaesser F., Bostedt H. (1993). Cystic degeneration in porcine ovaries – second communication: concentrations of progesterone, estradiol-17B, and testosterone in cystic fluid and plasma: interpretation of results. Reproduction in Domestic Animals 28, 451-463.

Einarsson S., Gustafsson B. (1970). Developmental abnormalities of female sexual organs in swine. Acta Veterinaria Scandinavica 11, 427-442.

Einarsson S., Madej A., Tsuma V. (1996). The influence on stress on early pregnancy in the pig. Animal Reproduction Science 42, 165-172.

Elbers A.R.W., Geudeke T.J., van Rossem H., Hunneman W.A. (1995). An observational study into herd-level risk indicators of return to estrus more than five days after insemination in sow herds. Veterinary Quarterly, 17(3), 110-112.

Elbers A.R., Vernooy J.C., Van den Broek J., Verheijden J.H. (1996). Risk of recurrence of repeat breeding in sows with a repeat breeding in the first parity. Journal of Animal Science 74, 2327-2330.

Elsaesser F., Foxcroft G.E. (1978). Maturational changes in the characteristics of estrogen-induced surges of luteinizing hormone in immature domestic pig. Journal of Endocrinology 78, 455-456.

Engblom L. (2008). Culling and mortality among Swedish crossbred sows. Doctoral thesis, Swedish Univeristy of Agriculture Sciences.

Engblom L., Lundeheim N., Dalin A.-M., Andersson K. (2007). Sow removal in Swedish commercial herds. Livestock Science, 106, 76-86.

Engblom L., Lundeheim N., Strandberg E., Schnieder M.P., Dalin A.-M., Andersson K. (2008). Factors affecting length of productive life in Swedish commercial sows. Journal of Animal Science 86, 432-441.

Engl S. (2006). Untersuchungen zur Eignung einer neuen GnRH-Variante zur Brunstinduktion bei pluripare Sauen. Inaugural-Dissertation zur Erlangung des Grades eines Doctor medicinae veterinariae, Leipzig.

Engl. S., Bischoff R., Zaremba W. (2010a). Use of a new GnRH to control reproduction in gilts. Proceedings of the 21st IPVS Congress, Vancouver, Canada, 1084.

Engl S., Zepperitz H., Rath R., Zaremba W. (2010b). Practical experience with Peforelin in a large sow herd: data from primiparous sows. Proceedings of the 21st IPVS Congress, Vancouver, Canada, 1085.

Engl S., Zepperitz H., Rath R., Zaremba W. (2010c). Practical experience with Peforelin in a large sow herd: data from pluriparous sows. Proceedings of the 21st IPVS Congress, Vancouver, Canada, 1086.

Esbenshade K.E., Paterson A.M., Cantley T.C., Day B.N. (1982). Changes in plasma hormone concentration associated with onset of puberty in the gilt. Journal of Animal Science 54, 320-324.

Everaert N., Vanderhaeghe C., Mateusen B., Dewulf J., Van Soom A., de Kruif A., Maes D. (2007). Effects of altrenogest treatment in primiparous sows. Vlaams Diergeneeskundig Tijdschrift 76, 293-299.

Everts H., Blok M.C., Kemp B., van der Peet-Schwering C.M.C., Smits C.H.M. (1994). Requirements of pregnant sows. CVB documentation report 9. CVB Lelystad, The Netherlands.

Everts H., Blok M.C., Kemp B., van der Peet-Schwering C.M.C., Smits C.H.M. (1995). Requirements of lactating sows. CVB documentation report 13. CVB Lelystad, The Netherlands.

Ferguson E.M., Ashworth C.J., Edwards S.A., Hawkins N. Hepburn N., Hunter M.G. (2003). Effect of different nutritional regimens before ovulation on plasma concentrations of metabolic and reproductive hormones and occytes maturation in gilts. Reproduction 126, 61-71.

First N.L., Lohse J.K., Nara B.S. (1982). The endocrine control of parturition. In: Cole D.J.A. and Foxcroft G.R. (eds). Control of Pig Reproduction. Butterworths, London, England, 311-342.

Flowers W.L. (1996a). Succesfull AI programs. In Proceedings Swine Reproduction Symposium American Society Theriogenology, p.15-25.

Flowers W.L. (1996b). An update on Swine AI. In Proceedings 16th Technical Conference AI reproduction National Associated Animal Breeders, p.88-94.

Flowers W.L., Esbenshade K.L. (1993). Optimizing management of natural and artificial matings in swine. Journal of Reproduction and Fertility (suppl) 48, 217-228.

Flowers W.L., Knox R.V. (2008). Pregnancy diagnosis in swine. http://www.pork.org/filelibrary/Factsheets/PIGFactsheets/NEWfactSheets/08-04-03g.pdf (last acces: 11/10/2014)

Ford S.P. (1997). Embronic and fetal development in different genotypes in pigs. Journal of Reproduction and Fertility 52, 165-176.

Ford S.P., Vonnahme K.A., Wilson M.E. (2002). Uterine capacity in the pig reflects a combination of uterine environment and conceptus genotypic effects. Journal of animal Science 80, 66-73.

Forgerit Y., Martinat-Botté F., Bariteau F., Corbé H., Macar C., Poirier P, Nolibois P., Terqui M. (1995). Utilisation d’un progestagène (Regumate) au moment de tarisement de la primipare. Journée Procine en Recherche en France 27, 45-50.

Fraser D., Phillips P., Thompson B. (1997). Farrowing behaviour and stillbirth in two environments: an evaluation of the restraint-stillbirth hypothesis. Applied Animal Behaviour Science 55, 51-66.

Friend D.W., Cunningham H.M. (1966). Piglet birth weights and the order of farrowing. Canadian Journal of Competence Medicinal Veterinary Science 30, 179-182.

Friendship R.M., Wilson M.R., Almond G.W., McMillan I., Hacker R.R., Pieper R., Swaminathan S.S. (1986). Sow wastage: reasons for and effect on productivity. Canadian Journal of Veterinary Research 50, 205-208.

Gaustad-Aas A.H., Hofmo P.O., Karlberg K. (2004). The importance of farrowing to service interval in sows served during lactation or after shorter lactation than 28 days. Animal Reproduction Science 81, 287-293.

Gerritsen R.G., Langendijk P., Soede N.M., Kemp B. (2005). Effects of artificial boar stimuli on the expression of estrus in sows. Applied Animal Behaviour Science 92, 37-43.

Gerritsen R.G. (2008). Lactational estrus in sows: follicle growth, hormone profiles and early pregnancy in sows subjected to intermittent suckling. Thesis Wageningen University, The Netherlands.

Gherpelli M., Tarocco C. (1996). A study on the incidence and clinical evolution of the ovarian cysts in the sow. Proceedings of the 14th IPVS, Bologna, Italy, 587.

Gjein H., Larssen R.B. (1995). Housing of pregnant sows in loose and confined systems – a field study 1. Vulva and body lesions, culling reasons and production results. Acta veterinarica Scandinavica 36, 185-200.

Hanenberg E.H.A.T., Knol E.F., Merks J.W.M. (2001). Estimates of genetic parameters for reproduction traits at different parities in Dutch Landrace pigs. Livestock Production Science 69, 179-186.

Hazeleger W. (2013). Prenatale ontwikkeling en prenatale sterfte. Cursus Vruchtbaarheid en Voortplanting van het Varken, Wageningen University, The Netherlands.

Heinonen M., Leppävuori A., Pyörälä S. (1998). Evaluation of reproductive failure of female pigs based on slaughterhouse material and herd record survey. Animal Reproduction Science 52, 235-244.

Hemsworth P.E., Barnett J.L. (1990). Behavioral responses affecting gilt and sow reproduction. Journal of Reproduction and Fertility (suppl) 40, 343-354.

Hemsworth P.H., Salden N.T.C., Hoogerbrugge A. (1982). The influence of post-weaning social environment on weaning to mating interval of the sow. Animal Reproduction 35, 41-48.

Hendrix W.F., Kelley K.W., Gaskins C.T., Bendel R.B. (1978). Changes in respiratory rate and rectal temperature of swine near parturition. Journal of Animal Science 47, 188-191.

Hermesch S., Luxford B.G., Graser H.U. (2001). Genetic parameters for piglet moratlity, within-litter variation of birth weight, litter size and litter birth weight. In: Proceedings Assoc. Adv. Anim. Beed. Genetics, Queenstown, NZ, 14, 211-214.

Herpin P., Le Dividich J., Hulin J.C., Fillaut M., De Marco F., Bertin R. (1996). Effects if the level of asphyxia during delivery on viability at birth and early postnatal vitality of newborn pigs. Journal of Animal Science 74, 2067-2075.

Herpin P., Hulin J.C., Le Dividich J., Fillaut M. (2001). Effect of oxygen inhalation at birth on the reduction of early postnatal mortality in pigs. Journal of Animal Science 79, 5-10.

Högberg A., Rydhmer L. (2000). A genetic study of piglet growth and survival. Acta Agriculturae Scandinavica. Section. A, Animal Science 50, 300-303.

Holm B., Bakken M., Vangen O., Rekeya R. (2004). Genetic analysis of litter size, parturition length and birth assistance requirements in primiparous sows using a joint linear-threshold animal model. Journal of Animal Science 82, 2528-2533.

Holyoake P.K., Dial G.D., Trigg T., King V.L. (1995). Reducing pig mortality through supervision during the perinatal period. Journal of Animal Science 73, 3543-3551.

Hoving L.L., Soede N.M., van der Peet-Schwering C.M.C., Graat E.A.M., Feitsma H., Kemp B. (2011). An increased feed intake during early pregnancy improves sow body weight recovery and increases litter size in young sows. Journal of Animal Science 89, 3542-3550.

Hultén F., Wallenbeck A., Rydhmer L. (2006). Ovarian activity and oestrous signs among group-housed, lactating sows: influence of behaviour, environment and production. Reproduction in Domestic Animals 41(5), 448-454.

Hunter R.H.F. (1983). Physiological components of fertility in domestic pig. Proceedings 11th Annual Winter Symposium of the Pig Health Society: Efficient Production of quality Pigmeat. Dublin, Ireland, 15-26.

Hsu F.S. (1983). Ovarian hemangioma in swine. Veterinary Pathology 20, 401-409.

Iida R., Koketsu Y. (2013). Interactions between climatic ad production factors on returns of female pigs to service during summer in Japanese commercial breeding herds. Theriogenology 80, 487-493.

Jindal R., Cosgrove J.R., Foxcroft G.R. (1997). Progesterone mediates nutritionally induced effects on embryonic survival. Journal of Animal Science 75, 1063-1070.

Johnston N.E., Eastaugh M.W., Thornton E.J. (1992). The short term use of Regumate in first litter sows. Proceedings of the 12th IPVS Congress, The Hague, The Netherlands, 457.

Jorgensen B. (2000). Longevity of breeding sows in relation to leg weakness symptoms at six months of age. Acta Veterinaria Scandinavica 41, 105-121.

Jørgensen B., Sørensen M.T. (1998). Different rearing intensities of gilts: II Effects on subsequent leg weakness and longevity. Livestock Production Science 54, 167-171.

Karlbom I., Einarsson S., Edqvist L. (1982). Attainment of puberty in female pigs: clinical appearance and patterns of progesterone, oestradiol-17b and LH. Animal Reproduction Science 4, 301-312.

Karveliene B., Zilinskas H., Riskevicience V. (2007). Postmortem examination of sows genital organs culled for reproductive disturbances and immunohistochemical studies on ERα and PR A receptors in the anoestral sows uterus. Reproduction of Domestic Animals 42, 275-281.

Kauffold J., Richter A., Sobiraj A. (1997). Results and experiences of a two-year investigation in the use of sonographic pregnancy control in sows at different stages of gestation. Tierärztliche praxis, Ausgabe G, Grosstiere/Nutztiere 25(5), 429-437.

Kauffold J., Rautenberg T., Gutjahr S., Richter A., Sobiraj A. (2004). Ultrasonographic characterization of the ovaries in non-pregnant first served sows and gilts. Theriogenology 61, 1407-1417.

Kauffold J., Althouse G.C. (2007). An update on the use of B-mode ultrasonography in female pig reproduction. Theriogenology 67, 901-911.

Kauffold J., Beckjuncker J., Kanora A., Zaremba W. (2007). Synchronization of estrus and ovulation in sows not conceiving in a scheduled fixed-time insemination program. Animal Reproduction Science 98, 84-93.

Kauffold J., Sigmarsson H. (2014). Results on fixed-time insemination in a sow herd with an afternoon-weaning schedule in Germany. Proceedings of the 23rd IPVS Congress, Cancun, Mexico, 203.

Kemp B., Soede N.M., Helmond F.A., Bosch M.W. (1995a). Effects of energy source in the diet on reproductive hormones and insulin during lactation and subsequent estrus in multiparous sows. Journal of Animal Science 73, 3022-3029.

Kemp B., Soede N.M., Helmond F.A. (1995b). Relations between body condition loss, insulin and LH levels during lactation in multiparous sows. Abstracts of the 46th Annual Meeting of the EAAP, Prague, Eds. Van Arendonk, pp 333. Wageningen Press, The Netherlands.

Kemp B., Soede N. (1996). Weaning to estrus interval in relation to timing of ovulation and fertilization results in sows. Journal of Animal Science 74, 944-949.

Kemp B. (1998). Lactational effects on the endocrinology of reproduction. In: Verstegen M.W.A., Moughan P.J., Schrama J.W. The lactating Sow. Wageningen Press, The Netherlands, 241-258.

Kemp B., Steverink D., Soede N. (1998). Estrus and timing of ovulation in pigs: consequences for insemination strategies. Proceedings of the 6th ICPR, The Banff Centre, Banff, Alberta Canada, 13-22.

Kemp B., Soede N.M., Langendijk P. (2005). Effects of boar contact and housing conditions on estrus expression in sows. Theriogenology 63, 643-656.

Kemp B., Soede N.M. (2011). Reproductive problems in primiparous sows. Cursus Vruchtbaarheid en Voortplanting van het Varken, Wageningen University, The Netherlands.

Kemp B., Soede N.M., Vesseur P.C. (2011). Oorzaken en consequenties van variatie in het interval spenen en bronst. Cursus Vruchtbaarheid en Voortplanting van het Varken, Wageningen University, The Netherlands.

Kemp B., Wientjes J.G.M., Soede N.M. (2013a). The post partum sow: phyiology of the sow during lactation. Course on Fertility and Reproduction of the pig, Wageningen University, The Netherlands.

Kemp B., Wientjes J.G.M., Soede N.M. (2013b). The post partum sow: nutritional and management strategies to optimize reproduction of sows during and after lactation. Course on Fertility and Reproduction of the pig, Wageningen University, The Netherlands.

Kerr J.C., Cameron N.D. (1995). Reproductive performance of pigs selected for components of efficient lean growth. Animal Science 60, 281-290.

Kim S.W., Hurley W.L., Wu G., Ji F. (2009). Ideal amino acid balance for sows during gestation and lactation. Journal of Animal Science 87(14), 123-132.

King R.H., Martin G.B. (1989). Relationships between protein intake during lactation, LH levels and estrus activity in first litter sows. Animal Reproduction Science 19, 283-292.

Kiracofe G.H. (1980). Uterine involution: its role in regulating postpartum intervals. Journal of Animal Science (suppl 51), 16-28.

Kirkwood R.N. (1999). Pharmacological intervention in swine reproduction. Swine Health and Production 7, 29-35.

Kirkwood R.N., Thacker P.A., Aherne F.X., Goonewardene L.A. (1995). The effect of dose and route of administration of prostaglandin F2α on the parturient response of sows. Swine Health and Production 4, 123-126.

Kirkwood R.N., Giebelhaus R.J. (1998). Day of injection does not affect the response of weaned sows to PG600®. Swine Health and Production. 6(4), 171-173.

Kirkwood R.N. (2002). Non-productive days: their significance and control. http://www.porkgateway.org/FileLibrary/PIGLibrary/Factsheets/a6582v1-0.pdf (last acces: 12/05/2014)

Kirkwood R., Zanella A. (2005). Influence of gestation housing on swo welfare and productivity. National Pork Board Final Report.

Knauer M., Stalder K.J., Karriker L., Baas T.J., Johnson C., Serenius T., Layman L., McKean J.D. (2007). A descriptive survey of lesions from cull sows harvested at two Midwestern U.S. facilities. Preventive Veterinary Medicine 82, 198-212.

Knol E.F., Leenhouwers J.L., Van der Lende T. (2002). Genetic aspects of piglet survival. Livestock Production Science 78, 47-55.

Knox R.V., Althouse G.C. (1999). Visualizing the reproductive tract of the female pig using real time ultrasonography. Swine Health Production 5, 207-215.

Knox R.V., Rodriguez Zas S.L. (2001). Factors influencing estrus and ovulation in weaned sows as determined by transrectal ultrasound. Journal of Animal Science 79, 2957-2963.

Knox R.V., Breen S.M., Willenburg K.L., Roth S., Miller G.M., Ruggiero K.M., Rodriguez-Zas S.L. (2004). Effect of housing system and boar exposure on estrus expression in weaned sows. Journal of Animal Science 82, 3088-3093.

Knox R.V., Willenburg K.L., Rodriguez-Zas S.L., Greger D.L., Hafs H.D., Swanson M.E. (2011). Synchronization of ovulation and fertility in weaned sows treated with intravaginal triptorelin is influenced by timing of administration and follicle size. Theriogenology 75, 308-319.

Koketsu Y. (2000). Retrospective analysis of trends and production factors associated with sow mortality on swine breeding farms in USA. Preventive Veterinary Medicine 46, 249-256.

Koketsu Y., Dial G.D., Pettigrew J.E., March W.E., King V.L. (1996a). Characterisation of feed intake patterns during lactation in commercial herds. Journal of Animal Science 74, 1202-1210.

Koketsu Y., Dial G.D., Pettigrew J.E., March W.E., King V.L. (1996b). Feed intake patterns during lactation and subsequent reproductive performance. Journal of Animal Science 74, 2875-2884.

Koketsu Y., Dial G. (1997). Factors influencing the postweaning reproductive performance of sows on commercial farms. Theriogenology 47, 1445-1461.

Koketsu Y., Dial G., King V. (1997). Returns to service after mating and removal of sows for reproductive reasons from commercial swine farms. Theriogenology 47, 1347-1363.

Koketsu Y., Takahashi H., Akachi K. (1999). Longevity, lifetime pig production and producitivity, and age at first conception in a cohort of gilts observed over six years on commercial farms. Journal of Veterinary Medical Science 61, 1001-1005.

Kongsted A.G. (2005). A review of the effect of energy intake on pregnancy rate and litter size discussed in relation to group-housed non-lactating sows. Livestock Production Science 97, 13-26.

Kongsted A.G., Hermansen J.E. (2009). Induction of lactational estrus in organic piglet production. Theriogenology 72, 1188-1194.

Koutsotheodoros F., Hughes P.E., Parr R.A., Dunshea F.R., Fry R.A., Tilton J.E. (1998). The effect of post-weaning progestagen treatment (regumate) of early weaning primiparous sows on subsequent reproductive performance. Animal Reproduction Science 52, 71-79.

Krejci R., Carmona M., Lopez A., Sierra E.R. (2012). Induction and synchronization of estrus in problematic sows after weaning using Fertipig in comparison with another gonadotropin product. Proceedings of the 22nd IPVS Congress, Jeju, Korea, p 93.

Kuller W.I., Soede N.M., van Beers-Schreurs H.M., Langendijk P., Taverne M.A., Verheijden J.H., Kemp B. (2004). Intermittent suckling: effects on piglet and sow performance before and after weaning. Journal of Animal Science 82, 405-413.

Kwiecien E.J., Gutierrez C., Mora P., Cadenas E. (2010). A systematic approach to assess reproductive failure at slaughter. Proceedings of the 21st IPVS congress, Vancouver, Canada, 1097.

Langendijk P., Soede N.M., Kemp B. (2000a). Effects of boar contact and housing conditions on estrus expression in weaned sows. Journal of Animal Science 78, 871-878.

Langendijk P., Van den Brand H., Soede N.M., Kemp B. (2000b). Effect of boar contact on follicular development and on estrus expression after weaning in primiparous sows. Theriogenology 54, 1295-1303.

Lawlor P.G., Lynch P.B. (2007). A review of factors influencing litter size in Irish sows. Irish Veterinary Journal 60(6), 359-366.

Lawrence A.B., Petherick J.C., McLean K.A., Gilbert C.L., Chapman C., Russell J.A. (1992). Naloxone prevents interruption of parturition and increases plasma oxytocin following environmental disturbance in parturient sows. Physiology and Behaviour 52, 917-923.

Le Cozler Y., Dagorn J., Lindberg J.E., Aumaitre A., Dourmad J.Y. (1998). Effect of age at first farrowing and herd management on long-term productivity of sows. Livestock Production Science 53, 135-142.

Le Cozler Y., Cederberg E.R., Rydhmer L., Lundeheim N., Dourmar J.Y., Neil M. (1999). Effect of feeding level during rearing and mating strategy on performance of Swedish Yorkshire sows. 2. Reproductive performance, food intake, backfat changes and culling rate during the first two parities. Animal Science 68, 365-377.

Le Cozler Y., Guyomarc'h C., Pichodo X., Quinio P., Pellios H. (2002). Factors associated with stillborn and mummified piglets in high-prolific sows. Animal Research 51, 261-268.

Leenhouwers J. van der Lende T., Knol, E. (1999). Analysis of stillbirth in different lines of pig. Livestock Production Science 57, 243-253.

Leenhouwers J.J., Knol E.F., de Groot P.N., Vos H., van der Lende T. (2002). Fetal development in the pig in relation to genetic merit for piglet survival. Journal of Animal Science 80, 1759-1770.

Leite C.D.S., Lui J.F., Albuquerque L.G., Alves D.N.M. (2011). Environmental and genetic factors affecting the weaning-to-estrus interval in sows. Genetics and Molecular Research 10(4), 2692-2701.

Lucia T., Corrêa M.N., Deschamps J.C., Peruzzo I.A., Matheus J.E., Aleixo J.A. (1999). Influence of equine chorionic gonadotropin on weaning-to-estrus interval and estrus duration in early-weaned, prmiparous, female swine. Journal of Animal Science 77, 3163-3167.

Lucia T., Dial G.D., Marsh W.E. (2000a). Lifetime reproductive performance in female pigs having distinct reasons for removal. Livestock Production Science 63, 213-22.

Lucia T., Dial G.D., Marsh W.E. (2000b). Lifetime reproductive and financial performance of female swine. Journal of The American Veterinary Medical Association 216, 1802-1809.

Lucia T., Corrêa M., Deschamps J., Bianchi I., Donin M., Machado A., Meincke W., Matheus J. (2002). Risk factors for stillbirths in two swine farms in the south of Brazil. Preventive Veterinary Medicines 53, 285–292.

Lush J.L., Hetzer H.O., Culbertson C.C. (1933). Factors affecting birth weight of swine. Genetics 19, 329-343.

Loula T. (2000). Increasing sow longevity: the role of people and management. Proceedings of the Allan D. Leman Swine Conference 27, 139-142.

Love R.J., Wilson M.R. (1990). Fertility of sows mated on different days of the week. Australian Veterinary Journal 67, 1-3.

Love R.J., Evans G., Klupiec C. (1993). Seasonal effects on fertility in gilts and sows. Journal of Reproduction and Fertility 48, 191-206.

Maes D. (2009). Non-infectious reproductive problems in the sow: an overview. Proceedings of the 1st ESPHM, Copenhagen, Denmark, 14-21.

Maes D., Janssens G., Delputte P., Lammertyn A., de Kruif A. (2004). Back fat measurements in sows from three commercial pig herds: relationship with reproductive efficiency and correlation with visual body condition scores. Livestock Production Science 91, 57-67.

Maes D., Dewulf J., Vanderhaeghe C., Claerebout K, de Kruif A. (2006). Accuracy of transabdominal ultrasound pregnancy diagnosis in sows using a linear or sector probe. Reproduction of Domestic Animals 41, 438-443.

Mahan D.C. (1998). Relationship of gestation protein and feed intake level over a five-parity period using high producing sw genotype. Journal of Animals Science 76, 533-541.

Mao J., Zak L.J., Cosgrove J.R., Shostak S., Foxcroft G.R. (1999). Reproductive, metabolic and endocrine responses to feed restriction and GnRH treatment in primiparous, lactating sows. Journal of Animal Science 77, 725-735.

Marengo S.R., Bazer F.W., Thatcher W.W., Wilcox C.J., Wetteman R.P. (1986). Prostaglandin F2α as the luteolysin in swine: VI. Hormonal regulation of the movement of exogenous PGF2α from the uterine lumen into the vasculature. Biology of Reproduction 34, 284-292.

Martinat-Botté F., Renaud G., Madec F., Costiou P. Terqui M. (2000). Gestation. In: Martinat-Botté F., Renaud G., Madec F., Costiou P., Terqui M. (Eds.). Ultrasonography and reproduction in swine. Principles and practical applications. INRA, Paris, 50-70.

Martinat-Botté F., Venturi E., Guillouet P., Driancourt M.A., Terqui M. (2010). Induction and synchronization of ovulations of nulliparous and multiparous sows with an injection of gonadotropin-releasing hormone agonist (Receptal). Theriogenology 73, 332-342.

Masaka L., Sungirai M., Nyamukanza C., Bhondai C. (2014). Sow removal in a commercial pig herd in Zimbabwe. Tropical Animal Health Production DOI 10.1007/s11250-014-0554-0

Mateo R.D., Caroll J.A., Hyun Y., Smith S., Kim S.W. (2009). Effect of a dietary supplementationof n-3 fatty acids and elevated concentrations of dietary protein on the performance of sows. Journal of Animal Science 87, 948-959.

Meredith M.J. (1986). Bacterial endometritis. In: Saunders W.B., eds., Current therapy in theriogenology (2nd edition), Philadelphia, 953-956.

Milligan B.N., Fraser D., Kramer D.L. (2001). The effect of littermate weight on survival, weight gain, and suckling behavior of low-birth-weight piglets in crossfostered litters. Journal of Swine Health and Production, 9(4), 161-166.

Milligan B.N., Fraser D., Kramer D.L. (2002). Within litter birth weight variation in the domestic pig and its relation to pre-weaning survival, weight gain, and variation in weaning weights. Livestock Production Science 76, 181-191.

Molokwu E.C.I., Wagner W.C. (1973). Endocrine physiology of the puerperal sow. Journal of Animal Science 36, 1158-1163.

Morbeck D.E., Esbenshade K.L., Flowers W.L., Britt J.H. (1992). Kinetics of follicle growth in the prepubertal gilt. Biology of Reproduction 47, 485-491.

Morris J.R., Hurnik J.F., Friendship R.M., Evans N.M. (1998). The effect of the Hurnik-Morris (HM) system on sow reproduction, attrition and longevity. Journal of Animal Science 76, 2759-2762.

Morrow W., Leman A., Williamson N., Morrison R., Robinson R. (1992). An epidemiological investigation of reduced second-litter size in swine. Preventive Veterinary Medicine 12, 15-26.

Mota-Rojas D., Martinez-Burnes J., Trujillo-Ortega M.E., Alonso-Splisbury M., Ramirez-Necoechea R., Lopez A. (2002). Effect of oxytocin treatment in sows on umbilical cord morphology, meconium staining, and neonatal mortlity of piglets. American Journal of Veterinary Research 63, 1571-1574.

Mota-Rojas D., Nava-Ocampo A, Trujillo M.E., Velazquez-Armenta E., Ramirez-Necoechea R., Martinez-Burnes J., Alonso-Spilsbury M (2005). Dose minimization study of oxytocin in early labor in swine: uterine activity and fetal outcome. Reproduction Toxicology 20, 255-259.

Mota-Rojas D., Martinez-Burnes J., Alonso-Splisbury M., Lopez A., Ramirez-Necoechea R., Trujillo-Ortega M.E., Medina-Hernandez F.J., de la Cruz N.L., Albores-Torres V., Loredo-Osti J. (2006). Meconium staining of the skin and meconium aspiration in porcine intrapartum stillbirths. Livestock Science 102, 155-162.

Mote B.E., Stalder K.J., Rothschild M.F. (2008). Reproduction, culling, and mortality levels on current commercial sow farms. Animal Industry Report.

Motsi P., Sakuhuni C., Halimani T.E., Bhebhe E., Ndiweni P.N.B., Chimonyo M. (2006). Influence of parity, birth order, litter size and birth weight on duration of farrowing and birth intervals in commercial exotic sows in Zimbabwe. Animal Science 82, 569-574.

Muirhead M.R. (1986). Epidemiology and control of vaginal discharges in the sow after service. The Veterinary Record 119, 233-235.

Muirhead M., Alexander T. (1997). Managing pig health and the treatment of disease. A reference for the farm. 1st Edition, 5M Enterprises Limited.

Musser R.E., Goddband R.D., Tokach MD.D., Owen K.Q., Nelssen J.L., Blum S.A., Dritz S.S., Civis C.A. (1999). Effects of L-carnitine fed during gestation and lactation on sow and litter performance. Journal of Animal Science 77, 3289-3295.

Nissen A., Soede N., Hyttel P., Schmidt M., D'Hoore D. (1997). The influence of time of insemination relative to time of ovulation on farrowing frequency and litter size in sows, as investigated by ultrasonography. Theriogenology 47, 1571-1582.

Noblet J., Dourmad J.Y., Etienne M., le Dividich J. (1997). Energy metabolism in pregnant sows and newborn piglets. Journal of Animal Science 75, 2708-2714.

Odehnalova S., Vinkler A., Novak P., Drabek J. (2008). The dynamics of changes in selected parameters in relation to different air temperature in the farrowing house for sows. Czech Journal of Animal Science 53, 195-203.

Oliviero C., Kokkonen T., Heinonen M., Sankari S., Peltoniemi O. (2009). Feeding sows with high fibre diet around farrowing and early lactation: Impact on intestinal activity, energy balance related parameters and litter performance. Research in Veterinary Science 86, 314-319.

Omtvedt I.T., Nelson R.E., Edwards R.L., Stephens D.F., Ruman E.J. (1971). Influence of heat stress during early, mid and late pregnancy of gilts. Journal of Animal Science 32, 312-317.

Opschoor C.T., Bloemhof S., Knauer M., Knol E.F. (2011). Management influences on birth weight, phase 2. http://www.thepigsite.com/articles/3342/management-influences-on-birth-weight-phase-2 (last acces: 03/03/2014).

Palmer W.M., Teague H.S., Venzke W.G. (1965). Macroscopic observations on the reproductive tract of the sow during lactation and early post weaning. Journal of Animal Science 24, 541-545.

Paterson A.M., Barker I., Lindasay D.R. (1978). Summer infertility in pigs. Its incidence and characteristics in an Australian commercial piggery. Australian Journal of Experimental Agricultural and Animal Husbandry 18, 698-701.

Pearce G.P., Pearce A.N. (1992). Contact with a sow in estrus or mature boar stimulates the onset of estrus in weaned sows. Veterinary Record 130, 5-9.

Pedersen L.J., Rojkittikhun T., Einarsson S., Edqvist L.E. (1993). Post-weaning grouped sows: effects of aggression on hormonal patterns and estrus behavior. Applied Animal Behavior Science 38, 25-39.

Peltoniemi O., Love R., Heinonen M., Tuovinen V., Saloniemi H. (1999). Seasonal and management effects on fertility of the sow: a descriptive study. Animal Reproduction Science 55, 47-61.

Pere M.C., Etienne M. (2000). Uterine blood flow in sows: effects of pregnancy stage and litter size. Reproduction Nutrition Development 40, 369-382.

Pharazyn A. (1992). Nutritional effects on embryo survival in the gilt. PhD thesis, Department of Animal Science, Edmonton, Alberta, Canada.

Pluske J.R., Williams I.H., AherneF.X. (1995). Nutrition of the neonatal pig. In: Varley M.A. (eds.). The neonatal pig: development and survival. Cab international Wallingford, UK, 187-235.

Poleze E., Bernardi M.L., Amaral Filha W.S., Wentz I., Bortolozzo F.P. (2006). Consequences of variation in weaning-to-estrus interval on reproductive performance of swine females. Livestock Science 103, 124-130.

Pomeroy R.W. (1960). Infertility and neonatal mortality in the sow. I. Lifetime performance and reasons for disposal of sows. Journal of Agriculture Science 54, 1-17.

Prime G.R., Varley M.A., Symonds H.W. (1988). The effect of food intake during lactation and early pregnancy on plasma progesterone concentrations and prolificacy in multiparous sows. Animal Production 46, 499.

Prunier A., Soede N.M., Quesnel H., Kemp B. (2003). Productivity and longevity of weaned sows. In: Pluske J.R., Le Dividich J., Verstegen M.W. (eds). Weaning the pig, First edition, Wageningen Academic Publishers, The Netherlands, 385-423.

Quesnel H, Prunier A. (1995). Endocrine bases of lactational anestrus in the sow. Reproduction, nutrition and development 35, 395-414.

Quesnel H., Pasquier A., Mountier A.M., Prunier A. (1998). Influence of feed restriction during lactation on gonadotropic hormones and ovarian development in primiparous sows. Journal of Animal Science 76, 856-863.

Quesnel H., Prunier A. (1998). Effect of insulin administration before weaning on reproductive performance in feed restricted primiparous sows. Animal Reproduction Science 51, 119-129.

Quesnel H., Brossard L., Valancogne A., Quiniou N. (2008). Influence of some sow characteristics on within-litter variation of piglet birth weight. Animal 2, 1842-1849.

Quesnel H., Venturi E., Royer E., Elleboudt F., Boulot S., Serriere S., Martinat-Botté F. (2009). Dietary intake during early pregnancy does not influence embryonic survival and variability in gilts. Proceedings 8th ICPR congress, The Banff Centre, Banff, Alberta Canada, May 31st-June 4th, 176.

Quiniou N., Dagorn J., Gaudre D. (2002). Variation of piglets birth weight and consequences on subsequent performance. Livestock Production Science 78, 63-70.

Ramaekers P., Kemp B., Van der Lende T. (2006). Progenos in sows increases number of piglets born. Journal of Animal Science 84, 394.

Ramanau A., Kluge H., Spilke J, Eder K. (2004). Supplementation of sows with L-carnitine during pregnancy and actation improves growth of the piglets during suckling period through increased milk production. Journal of Nutrition 135, 86-92.

Randall G.C.B., Penny R.H.C. (1967). Stillbirths in pigs: the possible role of anoxia. Veterinary Record 81, 359.

Rehfeldt C., Lang I.S., Gors U., Hennig C., Kalbe B., Stabenow K.P., Brussow R., Pfuhl O., Bellmann G., Nurnberg W., Otten C., Metges C. (2011). Limited and excess dietary protein during gestation affects growth and compositional traits in gilts and impairs offspring fetal growth. Jorunal of Animal Science 89, 329-341.

Reynolds L.P., Redmer D.A. (2001). Angiogenesis in the placenta. Biology of Reproduction 64, 1033-1040.

Roehe R. (1999). Genetic determination of individual birth weight and its association with sow productivity traits using Bayesin analyses. Journal of Animal Science 77, 330-343.

Rooke J.A., Sinclair A.G., Edwards S.A., Cordoba R., Pkiyachi S., Penny P.C., Penny P., Finch A.M., Horgan G.W. (2001). The effect of feeding salmon oil to sows throughout pregnancy on preweaning mortality of piglets. Animal Science 73, 489-500.

Rosendo A., Druet,T., Gogué J., Canario L., Bidanel J. (2007). Correlated responses for litter traits to six generations of selection for ovulation rate or prenatal survival in French Large White pigs. Journal of Animal Science 85, 1615-1624.

Rothschild M., Bidanel J.P. (1998). Biology and genetics of reproduction. In: Rothschild M.F., Ruvinsky A. (eds). The genetics of the pig. GAB Inernational, Wallingford, Oxon, UK, p 313-343.

Rozeboom D.W., Pettigrew J.E., Moser R.L., Cornelius S.G., Kandelgy S.M. (1996). Influence of gilt age and body composition at first breeding on sow reproductive performance and longevity. Journal of Animal Science 74, 138-150.

Ryan P.L., Raeside J.L. (1991). Cystic ovarian degeneration in pigs: a review. Irish Veterinary Journal 44, 22-36.

Ryan D.P., Yaakub H., Harrington D., Lynch P.B. (1994). Follicular development during early pregnancy and the estrous cycle of the sow. Theriogenology 42, 623-632.

Rydhmer L, Lundeheim N, Canario L. (2008). Genetic correlations between gestation ength, piglet survival and early growth. Livestock Science 115, 287-293.

Sallé E., Driancourt M.A., Baldwin P., Collell M. (2014). Impact on farm management of the use of buserelin (Porceptal®) in a single fixed time insemination program in sows. Proceedings of the 23rd IPVS Congress, Cancun, Mexico, 639.

Sasaki Y. Koketsu Y. (2007). Variability and repeatability in gestation length related to litter performance in female pigs on commercial farms. Theriogenology 68, 123-127.

Sasaki Y. and Koketsu Y. (2011). Reproductive profile and lifetime efficiency of female pigs by culling reason in high-performing commercial breeding herds. Journal of Swine Health Production 19(5), 284-291.

Santos J., Wentz I., Bortolozzo F., Barioni Jr. W. (2004). Early-weaned sows: altrenogest therapy, estrus, ovulation and reproductive performance. Animal Reproduction Science 84, 407-413.

Schukken Y.H., Buurman J., Huirne R.B.M., Willemse A.H., Vernooy J.C.M., van den Broek J., Verheijden J.H.M. (1994). Evaluation of optimal age at first conception in gilts from data collected in commercial swine herds. Journal of Animal Science 72, 1387-1392

Segura-Correa J.C., Ek-Mex E., Alzina-Lopez A., Segura-Correa V.M. (2011). Frequency of removal reasons of sows in Southern Mexico. Tropical Animal Health and Production 43(8), 1583-1588.

Senger P.L. (2005). Pathways to pregnancy and parturition. 2nd edition. Cadmus Professional Communications, Science Press Division, Ephrata, USA, 102-344.

Sesti L.A.C., Britt J.H. (1993). Influence of stage of lactation, exogenous luteinizing hormone releasing hormone and suckling, positive feedback of luteinizing hormone and ovulation in sows treated with estrogen. Journal of Animal Science 71, 989-918.

Signoret J.P. (1970). Reproductive behavior of pigs. Journal of Reproduction and Fertility (suppl) 11, 105-117.

Shaw H.J., Foxcroft G.R. (1985). Relationships between LH, FSH and prolactin secretion and reproductive activity in the weaned sow. Journal of Reproduction and Fertility 75, 17-28.

Smith C., Dickerson G.E., Tess M.W., Benett G.L. (1983). Expected relative responses to selection for alternative measures of life cycle economic efficiency of pork production. Journal of Animal Science 56, 1306-1314.

Soede N.M., Noordhuizen J.P.T.M., Kemp B. (1992). The duration of ovulation in pigs, studied by transrectal ultrasonography, is not related to early embryonic diversity. Theriogenology 38, 653-666.

Soede N.M., Helmond F.A., Kemp B. (1994). Periovulatory profiles of estradiol, LH and progesterone in relation to oestrus and embryo mortality in multiparous sows using transrectal ultrasonography to detect ovulation. Journal of Reproduction and Fertility 101, 633-641.

Soede N., Wetzels C., Zondag W., de Koning M., Kemp B. (1995a). Effects of time of insemination relative to ovulation, as determined by ultrasonography, on fertilization rate and accessory sperm count in sows. Journal of Reproduction and Fertility 104, 99-106.

Soede N., Wetzels C., Zondag W., Hazeleger W., Kemp B. (1995b). Effects of second insemination after ovulation on fertilization rate and accessory sperm count in sows. Journal of Reproduction and Fertility 105, 135-140.

Soede N.M., Wetzels C.C.H., Kemp B. (1996). Oestrus (standing response for boar and man) and ovulation in sows. Reproduction in Domestic Animals 31, 293-294.

Soede N.M., Kemp B. (1997). Expression of estrus and timing of ovulation in pigs. Journal of Reproduction and Fertility (suppl) 52, 91-103.

Soede N.M., Hazeleger W., Langendijk P., Kemp B. (2013). Reproductive management in pigs : emphasis on the different roles of the boar and on optimal insemination managament. Course on Fertility and Reproduction of the pig, Wageningen University, The Netherlands.

Sorensen D., Vernersen A., Andersen S. (2000). Bayesian Analysis of Repsonse to selection: a case study using litter size in Danisch Yorkshire Pigs. Genetics 156, 283-95.

Spoolder H.A.M., Geudeke M.J., Van der Peet-Schwering C.M.C., Soede N.M. (2009). Group housing of sows in early pregnancy: a review of success and risk factors. Livestock Science 125, 1-14.

Sprecher D.J., Leman A.D., Dziuk P.D., Cropper M., Debrecker M. (1974). Causes and control of swine stillbirths. Journal of The American Veterinary Medical Assocation 165, 698-701.

Stalder K. (2002). Non-genetic factors influencing sow longevity. Factsheet, Pork Information Gateway. http://www.pork.org/filelibrary/Factsheets/PIGFactsheets/NEWfactSheets/08-04-02g.pdf (last acces: 02/06/2014)

Stalder K.J., Saxton A.M., Conaster G.E., Serenius T.V. (2005). Effect of growth and compositional traits on first parity and lifetime reproductive performance in US Landrace sows. Livestock Production Science 97, 151-159.

Stein T.E., Dijkhuizen A., D’Allaire S., Morris R.S. (1990). Sow culling and mortality in commercial swine breeding herds. Preventive Veterinary Medicine 9, 85-94.

Stevenson J.S., Pollman D.S., Davis D.L., Murphy J.P. (1983). Influence of supplemental light on sow performance during and after lactation. Journal of Animal Science 56, 1282-1286.

Steverink D., Soede N., Groenland G., van Schie F., Noordhuizen J., Kemp B. (1999). Duration of estrus in relation to reproduction results in pigs on commercial farms. Journal of Animal Science 77, 801-809.

Suwanasopee T., Koonawootrittriron S. (2011). Genetic markers on reproductive traits in pigs. Thai journal of Veterinary Medicines Supplement 41, 73-76.

Svendsen J., Nielsen N.C., Bille N., Riising H.J. (1975). Causes of culling and death in sows. Nordic Veterinary Medicines 27(12), 604-615.

Swarts H., Rubion S., de Haas V., Cox P., Driancourt M.A. (2012). A single fixed time insemination following ovulation induction by buserelin injection at 86 hrs after weaning in sows generates good fertility and prolificacy. Proceedings of the 22nd IPVS Congress, Jeju, Korea, 276.

Tabeling R., Schwier S., Kamphues J. (2003). Effects of different feeding and housing conditions on dry matter content and consistency of faeces in sows. Journal of Animal Physiology and Animal Nutrition 87, 116-121.

Tabellenboek Veevoeding 2010 , CVB reeks nr 49, augustus 2010, Productschap Diervoeder CVB, Den Haag, ISSN 1567-8679, p 44-50.

Tarrés J., Bidanel J.P., Hofer A., Ducrocq V. (2006a). Analysis of longevity and exterior traits on Large White sows in Switzerland. Journal of Animal Science 84, 2914-2924.

Tarrés J., Tibau J., Piedrafita J., Fabrega E., Reixach J. (2006b). Factors affecting longevity in maternal Duroc swine lines. Livestock Science 100, 121-131.

Tast A., Hälli O., Virolainen J., Oravainen J., Heinonen M., Peltoniemi O. (2005). Investigation of a simplified artificial lighting programme to improve the fertility of sows in commercial piggeries. Veterinary Record 156, 702-705.

ten Napel J., de Vries A.G., Buiting G.A., Luiting P., Merks J.W., Brascamp E.W. (1995a). Genetics of the interval from weaning t oestrus in first-litter sows: distribution of data, direct response of selection, and heritability. Journal of Animal Science 73, 2193-2203.

ten Napel J., Kemp B., Luiting P., de Vries A. (1995b). A biological approach to examine genetic variation in weaning to oestrus interval in first litter sows. Livestock Production Science 41, 81-93.

Tess M.W., Benett G.L., Dickerson G. (1983). Simulation of genetic changes in life cycle efficiency of pork production. II. Effects of components on efficiency. Journal of Animal Science 56, 354-368.

Thaker M.Y.C., Bilkei G. (2005). Lactation weight loss influenced-subsequent reproductive performance of sows. Animal Reproduction Science 88, 309-318.

Tokach M.D., Pettigrew J.E., Dial G.D., Wheaton J.E., Crooker B.A., Johnson L.J. (1992). Characterization of luteinizing hormone secretion in primiparous, lactating sows: relationship to blood metabolites and return-to-estrus interval. Journal of Animal Science 70, 2195-2201.

Tsumura I., Sasaki H., Minami S., Nonami K., Nakaniwa S. (1982). Cyst formation in mesosalpinx, mesovarium and fimbria in cows and sows. The Japanese Journal of Veterinary Science 44, 1-8.

Tummaruk P., Lundeheim N., Einarsson S., Dalin A.M. (2000). Reproductive performance of purebred Swedish Landrace and Swedish Yorkshire sows II: effect of mating type, weaning to first service interval and lactation length. Acta. Agriculturae Scandinavica 50, 217-224.

Tummaruk P, Lundeheim N, Einarsson S, Dalin A.M. (2001a). Effect of birth litter size, birth parity number, growth rate, backfat thickness and age at first mating of gilts on their reproductive performance as sows. Animal Reproduction Science 66, 225-237.

Tummaruk P., Lundeheim N., Einarsson S., Dalin A. (2001b). Repeat breeding and subsequent reproductive performance in Swedish Landrace and Swedish Yorkshire sows. Animal Reproduction Science 67, 267-280.

Tummaruk P., Kesdangsakonwut S., Kunavongkrit A. (2009). Relationships among specific reasons for culling, reproductive data, and gross morphology of the genital tracts in gilts culled due to reproductive failure in Thailand. Theriogenology, 71 (2), 369-375.

Vallet J.L., Freking B.A., Miles J.R., Nienaber J.A., Brown-Brandl T.M. (2006). Factors affecting litter size in pigs. http://www.nsif.com/Conferences/2006/pdf%5CFactors Affecting LitterSize.pdf (last acces: 03/03/2014).

Van den Brand H. (2013). Invloed van de voeding van zeugen op de vitaliteit van de biggen. Cursus Vruchtbaarheid en Voortplanting van het Varken, Wageningen University, The Netherlands.

Van den Brand H., Dieleman S.J., Soede N.M., Kemp B. (2000). Dietary energy source at two feeding levels during lactation in primiparous sows I: Effects on glucose, insulin and LH and on follicle development, weaning-to-estrus interval and ovulation rate. Journal of Animal Science 78, 396-404.

Van den Brand H., Langendijk P., Soede N.M., Kemp B. (2001). Effects of post-weaning dietary energy source on reproductive perfomance in primiparous sows. Journal of Animal Science 79, 420-426.

Van den Brand H., Soede N.M., Kemp B. (2006). Supplementation of dextrose to the diet during the weaning-to-estrus interval affects subsequent variation in within litter piglet birth weight. Animal Reproduction Science 91, 353-358.

Van den Brand H., Van Enckevort A., Van der Hoeven E., Kemp B. (2009). Effects of dextrose plus lactose in the sows diets on subsequent reproductive performance and within litter birth weight variation. Reproduction of Domestic Animals 44, 884-888.

Vanderhaeghe C., Dewulf J., De Vliegher S., Papadopoulos G.A., de Kruif A., Maes D. (2010a). Longitudinal field study to assess sow level risk factors associated with stillborn piglets. Animal Reproduction Science 120, 78-83.

Vanderhaeghe C., Dewulf J., Ribbens S., de Kruif A., Maes D. (2010b). A cross-sectional study to collect risk factors associated with stillbirths in pig herds. Animal Reproduction Science 118, 62-68.

Vanderhaeghe C., Dewulf J., Jourquin J., de Kruif A., Maes D. (2011). Incidence and prevention of early parturition in sows. Reproduction of Domestic Animals 46(3), 428-433.

Van der Mheen H.W., Spoolder H.A.M, Kiezebrink M.C. (2003). Stable or dynamic groups for pregnant sows. Praktijkrapport Varkens, vol 23, Animal Science Group, Wageningen Univeristy.

Van de Wiel D.F.M., Boorman P. (1993). Post weaning anestrus in primiparous sows: LH patterns and effect of gonadotropin injection and boar exposure. Veterinary Quarterly, 15-4,162-166.

Van Dijk A.J., Van Rens B.T.T.M., Vander Lende T., Taverne M.A.M. (2005). Factors affecting duration of the expulsive stage of parturition and piglet birth intervals in sows with uncomplicated, spontaneous farrowings. Theriogenology 64, 1573-1590.

Van Leeuwen J.J.J., Williams S.I., Kemp B., Soede N.M. (2009). Post weaning altrenogest treatment in primiparous sows: effect of duration and dosage on follicular development and consequences for early pregnancy, Animal reproduction Science 3-4, 258-264.

Vangroenweghe F., Suls L., Van Driessche E., Vandersmissen T., Goyvaerts E., Miry C., Castryck F. (2009). Health bonus after transition to 4- or 5-week batch management systems. Proceedings of the 1st ESPHM, Copenhagen, Denmark, 77.

Van Rens B.T.T.M., Van der Lende T. (2004). Parturition in gilts: duration of farrowing, birth intervals and placenta expulsion in relation to maternal piglets and plancetal traits. Theriogenology 62, 331-352.

Vargas A., Bernardi M., Bortolozzo F., Mellagi A.., Wentz I. (2009a). Factors associated with return to estrus in first service swine females. Preventive Veterinary Medicines 89, 75-80.

Vargas A., Bernardi M., Paranhos T., Gonçalves M., Bortolozzo F., Wentz I. (2009b). Reproduction performance of swine females re-serviced after return to estrus or abortion. Animal Reproduction Science 113 (1-4), 305-310.

Varley M.A., Cole D.J.A. (1976). Studies in sows reproduction 5: the effect of lactation length of the sow on subsequent embryonic development. Animal Production, 22, 79-85.

Varley M.A., Foxcroft G.R. (1990). Endocrinology of the lactating and weaned sow. Journal of Reproduction and Fertility (suppl) 40, 47-61.

Varley M.A., Stedman (1994). Stress and reproduction. In: Cole D.J.A, Wisema J., Varley M.A. (eds), Principles of Pig Science. Univeristy Press, Nottingham, 277-296.

Vesseur P.C., Kemp B., den Hartog L.A. (1994). The effect of weaning to oestrus interval on litter size, live born piglets and farrowing rate in sows. Journal of animals Physiology and Animal Nutrition 71, 30-38.

Vesseur P.C. (1997). Causes and consequences of variation in weaning to estrus interval in the sow. PhD thesis Agricultural University of Wageningen, The Netherlands.

Vigo D., Mollo A., Luvoni G.C., Maraschi G., Faustini M., Galimberti L, Maffeo G. (1996). Ultrasonographic monitoring of the ovarian activity in sows in different seasons. Proceedings of the 14th IPVS Congress, Bologna, Italy, 572.

Vyt P. (2007). Examination and storage of liquid porcine semen. PhD thesis, Ghent University.

Waberski D., Kunz-Schmidt A., Neto G.B., Richter L., Weitze K.F. (1999). Real-time ultrasound diagnosis of ovulation and ovarian cysts in sows and its impact on artificial insemination efficiency. Proceedings of the American Society of Animal Science (http://www.asas.org/jas/symposia/proceedings/0944.pdf).

Walton J.S. (1986). Effect of boar presence before and after weaning on estrus and ovulation in sows. Journal of Animal Science 62, 9-15.

Ward A., Nevel M., Thomson J.R. (2010). Infertility investigation in Scottish pig herds by examination of reproductive tracts. Proceedings of the 21st IPVS Congress, Vancouver, Canada, 1094.

Webel S., Johnston M., Francisco C., Kraeling R. (2014). Sow reproductive performance using Triptorelin Gel and fixed-time AI in commercial swine farms. Proceedings of the 23rd IPVS Congress, Cancun, Mexico, 136

Weitze K.F., Wagner-Rietschel H., Waberski D., Richter L., Krieter J. (1994). The onset of heat after weaning, heat duration, and ovulation as major factors in AI timing in sows. Reproduction of Domestic Animals 29, 433-443.

Welp C., Holtz W. (1985). Induction of parturition with prostaglandin analogs under field conditions. Animal Reprodution Science 8, 171-179.

White K.R., Anderson D.M., Bate L.A. (1996). Increasing piglet survival through an improved farrowing management protocol. Canadian Journal of Animal Science 76, 491-495.

Willis H., Zak L., Foxcroft G. (2003). Duration of lactation, endocrine and metabolic state and fertility of primiparous sows. Journal Animal Science 81, 2088-2102.

Wilson, M.R., Dewey, C.E. (1993). The associations between weaning-to-estrus interval and sow efficiency. Swine Health Production 1, 10–15.

Wolf J., Zakova E., GRoeneveld E. (2008). Within litter variation of birth weight in hyperprolific Czech Large White sows and its relation to litter size traits, stillborn piglets and losses until weaning. Livestock Science 115, 195-205.

Wu G., Bazer F.W., Wallace J.M., Spencer T.E. (2006). Board invited review: intrauterine growth retardation: implication for the animal sciences. Journal of Animal Science 84, 2316-2337.

Wu G., Bazer F.W., Burghardt R.C., Johnson G.A., Kim S.W., Li X.L., Satterfield M.C., Spencer T.E. (2010). Impacts of amino acid nutrition on pregnancy outcome in pigs: mechanisms and implications for swine production. Journal of Animal Science 88, 195-204.

Xue J., Dial G.., Marsh W., Davies P., Momont H. (1993). Influence of lactation length on sow productivity. Livestock Production Science 34, 253-265.

Xue J.L., Dial G.D., Marsh W.E., Davies P.R. (1994). Multiple manifestations of season on reproductive performance of commercial swine. Journal of The American Veterinary Medical Association 204, 1486-1489.

Yang H., Eastham P.R., Phillips P., Whittemore C.T. (1989). Reproduction, body weight and body condition of breeding sows with different body fatness at parturition, differing nutrition during lactation, and differing litter size. Animal Production 48, 181-201.

Yang H., Pettygrew J.E., Johnston L.J., Shurson G.C., Walker R.D. (2000). Lactational and subsequent reproductive responses of lactating sows to dietary lysine (protein) concentration. Journal of Animal Science 78, 348-357.

Yang Y.X., Heo S., Jin Z., Yun J.H., Choi J.Y., Yoon S.Y., Park M.S., Yang B.K., Chae B.J. (2009). Effects of lysine intake during late gestation and lactation on blood metabolites, hormones, milk compostion, and reproductive performance in primiparous and multiparous sows. Animal Reproduction Science 112,199-214.

Yazdi M.H., Rydhmer L., Ringmar-Cederberg E., Lundeheim N., Johansson K. (2000). Genetic study of longevity in Swedish landrace sows. Livestock Production Science 63, 255-264.

Young L.G., King G.L. (1986). Low concentration of zearalenone in diets of mature gilts. Journal of Animal Science 63, 1191-1196.

Zak L., Xu X., Hardin R., Foxcroft G. (1997a). Impact of different patterns of feed intake during lactation in primiparous sow on follicular development and oocyte maturation. Journal of Reproduction and Fertility 110, 99-106.

Zak L., Cosgrove J., Aherne F., Foxcroft G. (1997b). Pattern of feed intake and associated metabolic changes differentially affect postweaning fertility in primiparous lactating sows. Journal of Animal Science 75, 208-216.

Zaleski H.M., Hacker R.R. (1993). Variables related to the progress of parturition and probability of stillbirth in swine. The Canadian Veterinary Journal 34, 109-113.

Chapter 2

Aims

2 Aims

Good reproductive performance is a prerequisite for pig herds to be profitable. Reproduction, however, is a complex process. Various internal and external elements are involved and interrelated, such as genetics, hormonal changes, season, optimal housing and feeding and management in the different phases of the reproductive cycle.

One of the major challenges is to have fertile sows showing estrus as soon as possible after weaning. The sooner sows are showing estrus, the sooner they can be inseminated, the shorter the sow’s reproductive cycle and the fewer the number of non-productive days in a herd. Many different non-infectious factors such as length of lactation, body condition, and weaning management practices may influence the weaning-to-estrus interval. To optimize the sow’s weaning-to-estrus interval, it is important to identify specific factors, with an influence on this interval, that could be easily implemented in the farmer’s management. Hence, first of all insights need to be gained into current weaning management practices on sow herds. Apart from management practices, pharmaceuticals, *i.e.* hormones, are often used in case of seasonal infertility or problems in primiparous sows. New commercial products are developed regularly, and their effects on the different phases of the reproduction cycle, *e.g.* the induction of estrus, need to be examined. Finally, a prolonged weaning-to-estrus interval can also lead to early culling of sows, resulting in a lower average parity and an increased replacement rate in the herd, which negatively influences the profitability. To determine whether these reasons for culling are justified, examination of the reproductive organs of sows in the slaughterhouse is needed.

The general aim of this thesis was to investigate weaning management practices and reasons for culling sows in commercial pig herds to optimize sow reproductive performance.

The specific objectives were to investigate:

1. management practices at weaning and to identify factors at herd level associated with different sow reproductive performance parameters,
2. the ability of peforelin to stimulate follicular growth and estrus in gilts and sows and its effect on subsequent litter performance,
3. reasons for culling of sows and to examine the reproductive tract at slaughter by visual inspection, histopathology and bacteriological examination.

Chapter 3

Management factors associated with sow reproductive performance after weaning

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3 Management factors associated with sow reproductive performance after weaning

3.1 Abstract

To achieve optimal reproductive performance in pig herds, sows need to become pregnant as soon as possible after weaning. The aim of this study was to investigate herd and management factors associated with reproductive performance of sows after weaning. A questionnaire pertaining to sow management at weaning and herd reproductive data were collected from 76 randomly selected commercial pig herds in Belgium. Associations between the herd factors and two reproductive parameters after weaning (weaning-to-estrus interval: WEI and percentage of repeat breeders: RB) were analysed using general linear mixed models. A separated feeding strategy of breeding gilts from 60kg onwards was significantly associated with a shorter WEI (5.54 versus 7.28 days; $p = 0.040$). Factors significantly associated with a lower % of RB were: housing the newly weaned sows separated from the gestating sows (7 versus 12%; $p = 0.003$), using semen less than 4 days after collection (7-9 versus 14%; $p = 0.014$) and stimulating estrus twice a day (8 versus 11%; $p = 0.025$) . In conclusion, some management practices, such as feeding strategy of breeding gilts, housing conditions of sows, method of estrus stimulation and storage duration of semen have an influence on the outcome of reproductive parameters such as weaning-to-estrus interval and percentage of repeat breeders. These practices can be implemented rather easily by pig producers and may consequently lead to improvements of reproductive performance of sows after weaning.

Keywords: sow, reproduction, management, weaning

3.2 Introduction

To maximize herd productivity and economic performance in pig herds, it is important to have a healthy sow population with good reproductive performance. Reproductive performance can be measured using various parameters, and can be influenced by many factors. The process of weaning in commercial pig herds is very critical, as it influences not only the health and productivity of the piglets (Kuller et al., 2004; 2007), but it may also largely influence the health and fertility of the sows (Knox et al., 2001; Prunier et al., 2003; Kemp et al., 2005). At weaning, lactation is interrupted abruptly at a moment when many sows reach peak lactation. Sows are physically separated from their piglets and they are most frequently moved to another part of the farm with quite different housing, feeding and management conditions. Moreover, sows are expected to switch from lactation anestrus to a cyclic phase within a few days after weaning, and to become pregnant as soon as possible. Surprisingly, this process, although very complex, does not pose major problems for most of the commercial hybrid sows, as they usually come in estrus within 5 to 7 days following weaning (Almond et al. 2006). However, in some herds, sow reproductive performance is suboptimal and serious problems regarding fertility may arise. The weaning-to-estrus interval (WEI) and the percentage of repeat breeders (RB) are two parameters that are commonly used to assess reproductive performance of weaned sows (Almond et al. 2006). Given the different events taking place at and shortly after weaning, it is obvious that many factors related to *e.g.* management, housing and sow characteristics may influence this process. The effects of several management factors on sow productivity have been studied in different countries (Bertacchini et al. 2004; King et al. 1998; Young et al. 2010). However, some studies investigated only a limited number of herds (Bertacchini et al. 2004; Young et al. 2010) or used only database records without visiting the sow herds and thus not verifying *e.g.* the actual housing conditions (Bertacchini et al. 2004; King et al. 1998). Other studies focused on one specific sow reproductive parameter, *e.g.* farrowing rate (Young et al. 2010) or return to estrus (Vargas et al. 2009), or investigated factors at sow level and not at farm level (Koketsu and Dial 1997; Koketsu et al. 1997). Finally, some findings are based on studies, which were performed one to two decades ago (King et al. 1998; Koketsu et al. 1997), when sows were less productive. Due to genetic selection for increased litter size, analysis of the performance of sow herds indicated that the total number of piglets born per litter increased from 11.9 in 1996 to 13.8 in 2006 in France (Boulot et al., 2009). Furthermore some were conducted in continents with major differences in management: for example, in Belgium, the mean weaning age is between 3 and 4 weeks after farrowing (depending on the sow batch production system, Agrovision Herd monitoring 2010, Cerco Soft N.V., Oudenaarde, Belgium), while in the United States mean weaning age is less than 21 days (King et al. 1998; Koketsu and Dial 1997; Koketsu et al. 1997). Another example is the insemination method: in Belgium more than 90% of the sows is bred by AI (Riesenbeck, 2011), while in Canada approximately one fourth of the herds still uses the boar for natural mating (Young et al., 2010).

The aim of this study was to investigate management practices at weaning and to identify and quantify herd level factors that are associated with different sow reproductive performance parameters in randomly selected commercial pig herds. Identifying such factors is the first step to implement appropriate control measures to optimize sow reproductive performance after weaning.

3.3 Materials and Methods

3.3.1 Herd selection and study design

Pig herds were selected from the National Identification and Registration database (I&R, Sanitel-Pigs, 2005), using the random function in Excel® (Microsoft Cooperation 2007). Two selection criteria were pursued (1) being located in Flanders and (2) having a herd size of at least 80 sows. These criteria were used as 94.3% of the pig production in Belgium is situated in the northern part (Flanders) and approximately 80% from the total number of herds with sows in Flanders have more than 80 sows, regarding to the Agricultural statistics of 2011. In total, 3564 herds fulfilled the selection criteria. From this study population, a random sample of 250 pig herds was selected, using a computer-generated list (Cameron 1999).

An explanatory letter about the study was sent by conventional mail to the selected herds. In the following weeks, the farms were contacted by phone and asked whether they were willing to cooperate. To encourage the farmers to take part in the study, an incentive (supermarket coupon) was provided for all participants, it was guaranteed that all data would be analysed strictly anonymously and that a report with recommendations to improve weaning management practices would be sent within one month after the herd visit. In addition, the results were presented for the collaborating farmers during a symposium after completion of the study. The non-participants were asked for the reason of non-response. Each cooperating herd was visited individually by the first author of the present paper. A questionnaire was completed by means of a face-to-face interview with the herd owner and/or manager. After filling in the questionnaire, the pig facilities were visited to inspect the housing conditions and management practices and to measure the temperature and the light intensity in the post-weaning unit or the insemination facility. This unit was defined as the barn where the newly weaned sows were housed for estrus detection and insemination and where they stayed until maximum 4 weeks of gestation. The light intensity (amount of lux) was measured in a standardized way for the different herds: with the lights on, as was done usually for the weaned sows, and approximately one meter above the head of a representative number of sows, using a Testo-540-device (N.V. Testo, Ternat, Belgium). The average of those measurements was then calculated per herd. The total time spent on the farm ranged from one and a half to two hours. The survey started in October 2009 and ended in December 2010.

3.3.2 Questionnaire design

The questionnaire consisted of different questions, divided in five items. Most questions were multiple choice or dichotomous (*e.g.* yes/no) questions, with the option for the respondents to provide additional information. The questions pertained to general herd characteristics, *e.g.* type of herd (farrow-to-finish or only breeding without finisher pigs), number of sows and breeding/teaser boars, batch management system and breed of sows; management practices of gilts, *e.g.* purchase policy and weight/age at first artificial insemination (AI); sows at weaning, *e.g.* estrus stimulation and detection; sows at breeding, *e.g.* purchase policy of semen, AI strategy and storage of semen and factors related to gestating and lactating sows, *e.g.* method of pregnancy diagnosis and lactation length. Furthermore some questions pertaining housing conditions and feeding strategy of gilts and sows were included. The recorded reproductive parameters after weaning comprised the mean WEI and mean percentage of RB per year. For all herds, these two parameters were obtained using computer-based record systems and for the period August 2008 till August 2009. The WEI was defined as the period between the day of weaning (or 24 hours after the last altrenogest administration in gilts, for herds practicing cycle blockade of maiden gilts for estrus synchronisation) and the day of the first observed standing response. Females that returned to estrus after AI and that were inseminated again were indicated as RB, with either regular (18-24 or 38-44 days) or irregular intervals (25-37 days), including sows returning to estrus for the 2nd or 3rd time. No distinction was made between regular or irregular returns, because no reliable records could be obtained or the interpretation was difficult in some herds. The latter was especially the case in herds that practised a 3, 4 or 5-week sow batch production system and that synchronized sows that returned to estrus to fit them into a next batch. The questionnaire had been pre-tested in two commercial pig herds, regarding contents, length, interpretation of questions and responses. The full questionnaire (in Dutch) is available upon request to the first author.

3.3.3 Data and statistical analyses

The information from the questionnaires was entered into a database (Excel®, Microsoft Cooperation, 2007) and then exported to SPSS 19.0 (SPSS Inc., Chicago, Illinois; USA) for statistical analyses.

Student’s t-test was used to compare the herd size of the participating and non-participating herds. Correlations between the mean reproductive parameters (WEI and RB) were tested using Spearman’s rank correlation coefficients. The relationship between influencing herd factors (independent variables) and the mean WEI or RB as outcome variables, was investigated by means of two different general linear models. For herd factors considering on-farm selection of breeding gilts, farms with only purchase of breeding gilts were not included in the analysis. The model building started with univariable evaluations of each potential herd factor. All independent variables with p-values smaller than 0.20 in these univariable analyses were selected, and correlations between those were tested by means of Spearman’s rank correlation coefficients to assess possible multicollinearity. If correlations between the selected variables were higher than the absolute value of 0.6, the variable with the highest p-value was excluded from the model. Subsequently, two separate multivariable models were built using a manual stepwise backward model building procedure, with the selected herd factors from the univariable analyses and the two outcome variables WEI and RB. Only factors with a p-value less than or equal to 0.05 were retained in the final general linear mixed model. Two- and three-way interactions were evaluated within the model for unplanned comparisons of means. Finally, a post hoc Scheffé-test was performed. The normality of the residuals was evaluated by plotting the standardized residuals versus the predicted values and by plotting a Q-Q-plot of the residuals (SPSS Inc., Chicago, Illinois; USA). Normality tests for the reproductive performance parameters did not show deviations from normality. No significant correlation was found between WEI and % RB.

3.4 Results

3.4.1 Study population

From the 250 selected herds, twenty-five farmers could not be reached due to insufficient identification records. Thirty-nine farms were excluded as they turned inactive or had less than 80 sows (which was not allowed, according to the selection criterion). One hundred and ten herds did not want to collaborate for the following reasons: no time (45/110), no interest (44/110) and 21 pig producers had personal problems or did not give a reason for not collaborating. In total, 76 herds were willing to cooperate, corresponding with a final response rate of 41% (76/186).

Nearly 80% of the participating farms were farrow-to-finish pig herds, where all or almost all pigs were raised on the same site from birth until slaughter age (± 110kg). In the other 20% of the herds, piglets were sold at weaning or at 10-12 weeks of age (end of the nursery). The percentage of selected pig herds per province namely West-Flanders: 50%, East-Flanders: 25%, Antwerp: 16%, Limburg: 8% and Flemish Brabant 1% corresponded to the overall distribution of pig herds in the different provinces in Flanders (Agricultural statistics, 2011).

Overall farm size distribution ranged from 80 to 1600 sows (mean 289; median 200 sows). The mean herd size in the 110 non-participating herds (≥ 80 sows) was significantly lower than in the participating herds (mean: 181 and median: 172 sows,, respectively, with p = 0.03).

In 65% of the herds, the sow population consisted of crossbred sows that were all purchased from breeding companies *(e.g.* PIC, Topigs20, Hypor), 22% used crossbred sows of different landrace sows and 13% had purebred sows *(e.g.* Belgian landrace, Piétrain).

Sixty-four percent of the herds practiced on-farm selection of breeding gilts and 22% of those 64 purchased breeding gilts once or twice a year from a breeding company as well.

The majority of the herds (63%) worked with a sow batch production management system, mainly three and four weeks systems (50%). The classical one week system was practised by 37% of the participating herds.

The start of estrus stimulation in the different herds was as follows: day of weaning (14%), the day after weaning (50%), two days after weaning (14%), more than two days after weaning (18%) remaining. Estrus detection started at day four post weaning in 72% of the herds. Twenty-nine percent practised estrus detection only once a day, 64% twice and 5% more than twice a day.

In 66% of the herds, first AI took place 12h after the first observed standing response. In 21% of the herds, early-estrus sows (WEI shorter than average WEI in the herd) were also inseminated 12h after first standing response. Thirty-four percent inseminated late-estrus sows (WEI longer than average WEI in the herd) immediately after showing standing estrus. Ninety-three percent of the herds practised a second AI, either 12h (33%), 18h (33%) or 24h (33%) after first AI. On 25% of the herds, the farmer did not know whether the gilts had already shown estrus symptoms before the first AI. In the other 75% of the herds, gilts were inseminated during the 2nd estrus. Semen was stored in a storage cabinet in all herds at 17°C.

A combined vaccination against Parvovirus and *E. rhusiopathiae* was carried out in 92% of the herds in gilts and in 86% in sows, PRRSv vaccination of gilts and sows was practised in 68% and 70% of the herds, respectively. Other commonly used vaccinations included atrophic rhinitis (50% in gilts, 57% in sows), *E. Coli* (55% in gilts, 54% in sows) and Swine Influenza (28% in gilts, 26% in sows). Only 5% of the herds used antimicrobials (trimethoprim-sulfamides) preventively during the weaning period. Fifty-one percent of the herds used altrenogest (Regumate®, Elanco Animal Health, Belgium) for cycle blockade in gilts and 29% used exogenous gonadotropins (PG600®, Intervet, The Netherlands) in a standard way after weaning in their primiparous sows. Finally, 75% of the herds medicated the sows against *S. scabiei* and seven percent claimed to be *S. scabiei*-free.

The average lactation length was 24.3 (± 2.8 (standard deviation)) days, varying from 19.0 to 31.0 days.The mean WEI of the selected herds was 6.3 days (± 1.4 days), with a range of 4 to 10.9 days, with sows not coming into heat excluded. The mean % of RB was 9.2 (±5.1) and ranged from 1.6 to 21.5%.

3.4.2 Factors associated with WEI and percentage of RB

The categorical variables with $p < 0.20$ in the univariable analyses for the two different outcome variables are given in table 3. For the continuous variables, only the association between lactation length and RB had a p-value < 0.20 in the univariable analysis.

The results of the two final multivariable models to determine factors associated with WEI and % RB are presented in table 4.

Feeding the breeding gilts restrictively from 60 kg onwards until first insemination with a diet for gilts was significantly associated with a shorter WEI (5.54 days), than feeding gilts *ad lib* with fattening pig diets (7.28 days) ($p = 0.040$). The feeding of the gilts was correlated with housing breeding gilts and finishing pigs in separate pens ($r > 0.6$). The first one was further included because it had the lowest p-value.

In the multivariable model, 17% of the variability in the WEI was explained by the feeding factor ($R^2_{adj} = 0.17$).

The percentage of RB in herds where the post-weaning unit or the insemination facility was separated from the gestation facility was 7% compared to 12% in herds where recently inseminated and pregnant sows were housed in the same room ($p = 0.003$). A higher percentage of RB was associated with artificial insemination (AI) using diluted semen that was collected more than four days before (14%), than when it was collected one to two (7%, $p = 0.016$) or three to four days before (9%, $p = 0.001$). Finally, the percentage of RB was higher in herds practising estrus stimulation with the boar only once a day (11%) compared to twice a day (8%) ($p = 0.025$).

Over all the observations, 36% of the variability in % RB was explained by the factors found in the multivariable model ($R^2_{adj} = 0.36$). The effect of separated housing of recently weaned and pregnant sows accounted for 21% of the total explained variation, the duration of semen storage for 20% and the frequency of estrus stimulation for 6%.

Table 3. Categorical variables as potential herd level factors associated with weaning-to-estrus interval and % of repeat breeders (*) or with % of repeat breeders alone in the 76 pig herds (N) (with $p < 0.20$ in the univariable analyses)

Parameter	Category	N
Gilt management practices		
Age of gilts at purchase (months)*	≤ 6 / > 6	12 / 26
Feeding own-selection breeding gilts separately from finishing pigs (from … kg)*	<40 / 40-60 / >60 / no	15 / 11 / 11 / 12
Age of gilts at first AI (days)	120-240 / 240-280 / 280-320 / >320	12 / 41 / 17 / 6
Weaning practices		
Presence of boar during estrus stimulation*	Sows in front of boar pen Boar in front of sow crates Boar behind sow crates or between sows	24 44 8
Frequency of estrus stimulation (times per day)	1x / 2x	35 / 41
Presence of boar during estrus detection	Sows in front of boar pen Boar in front of sow crates Boar in front of 3-4 sows Boar behind sow crates or between sows	27 12 30 7
Breeding practices		
Purchase of semen from commercial AI centre	No / yes	7 / 69
Max. storage time of diluted semen from collection until AI (d)	1-2 / 3-4 / >4	34 / 32 / 10
Presence of boar during AI	No / yes	17 / 59
Recently inseminated sows housed separated from pregnant sows	No / yes	32 / 44
Location of teaser boar pen	in between recently weaned sows separated from recently weaned sows	55 21
Ambient temperature in insemination facility (°C)	<18 / 18-19 / 20-21 / ≥ 22	7 / 24 / 35 / 10
Light schedule for recently weaned sows	Daylight / 24 h / 16-18 h	16 / 17 / 43
Extra light above head of recently weaned sows	No / yes	26 / 50
Light intensity for recently weaned sows (lux)	< 120 / ≥ 120	34 / 42
Feed supplements for weaned sows*	No / yes	23 / 53
Practices during gestation and lactation		
Person conducting pregnancy diagnosis	Farmer Herd veterinarian Technician feeding company Other	24 31 17 4
Group housing pregnant sows (> 30d gestation)	No / Yes	33 / 43
Maximum number of suckling piglets /farrowed sow	<12 / 12 / 13 / >13	10 / 28 / 22 / 16

Table 4. Factors significantly associated with two reproductive performance parameters (weaning-to-estrus-interval and % repeat breeders) in the final multivariable models

Factors	Subcategory	
Weaning-to-estrus interval (R^2_{adj} = 0.17)		**WEI (days)**
Feeding own-selection breeding gilts separately from finishing pigs (from … kg)	< 40	6.18^{a}
	40-60	$6.04^{a, b}$
	> 60	$5.54^{a, b}$
	Not	7.28^{b}
% of repeat breeders (R^2_{adj} = 0.36)		**RB (%)**
Separated insemination facility from gestation facility	No	12^{a}
	Yes	7^{b}
Maximum storage of diluted semen (days after collection)	1-2	7^{a}
	3-4	9^{a}
	> 4	14^{b}
Frequency of estrus stimulation (times/day)	1x	11^{a}
	2x	8^{b}

^{a,b} Significantly different at a level of $p \leq 0.05$.

3.5 Discussion

This paper identified and quantified herd level management parameters in randomly selected pig herds that were significantly associated with two important reproductive parameters of weaned sows, namely WEI and % of RB (Almond et al. 2006). If weaning does not occur in an optimal way or heat stimulation is not done properly, an extension of the WEI may be seen and this reduces the overall reproductive performance of the sows, including the % of RB (Aherne et al. 1999; Vargas et al. 2009; Quesnel et al. 1998).

Herds were selected *at random* to avoid or minimize response bias. Although a higher response rate would have been preferred (Thrusfield 2005), it was considered to be acceptable and analogous to response rates obtained in other similar studies (Vaillancourt et al. 1991; Oppenheim 1992; Vanderhaeghe et al. 2010). The distribution of the pig herds per province was a good representation of the distribution in Flanders (Agricultural statistics 2011). As there was a significant difference in herd size between responders and non-responders, it is most likely that mainly bigger herds were willing to participate. However, the wide range in herd size (80 to 1600 sows) suggested that the responding herds were representative for the population complying with the selection criteria. Thus, the information derived from these 76 herds was sufficient to draw meaningful conclusions about management herd factors associated with reproductive performance of sows. After pre-testing the questionnaire in two commercial pig herds, herd visits and examination of the housing conditions were done by the first author, therefore, all farmers were interviewed and all observations of the housing conditions were done in a very standardized way.

The observed reproductive parameters in the herds followed the defined targets for the reproductive performance of the breeding herds, according to Almond et al. (2006). For the WEI this is between four and seven days and for repeat matings ten percent. The values were also representative for other pig herds in Belgium (Agrovision Herd monitoring 2010, Cerco Soft N.V., Oudenaarde, Belgium), with a WEI of 6.2 days and 8.4% of RB and it appeared that there was quite a lot of variation between herds.

Feeding the breeding gilts from 60kg onwards until first insemination with a different rearing diet compared to the finishing pigs was the only factor significantly associated with an average shorter WEI, namely two days shorter. A rearing diet for gilts generally restricts lean growth and increases back fat (Levis 1997) compared to diets aimed for fattening pigs, and may lead to a better reproductive efficiency and longevity of the sows (Jorgensen and

Sorensen 1998; Klindt et al. 2001; Levis 1997). Thus, gilt nutrition during rearing could have some long-term effects on their reproductive performance, as the average WEI of the herd was influenced by this factor. It should be considered however, that only 64% of the herds in this study had an on-farm selection of breeding gilts.

Three factors were significantly associated with a lower percentage of RB, namely in farms where the insemination facility was separated from the gestation facility, where diluted semen for AI was stored for less than 4 days and where estrus stimulation was done twice per day instead of only once.

The higher % of RB in herds where the insemination facility was not separated from the gestation facility could be explained by the restlessness of the recently weaned sows, and the subsequently possible stress generated by them and more important the presence of the teaser boar on the early pregnant sows. In terms of maintenance of pregnancy, chronic stress during the first 4 weeks of gestation should be avoided (Turner and Tilbrook 2006; von Borell et al. 2007; Einarsson et al. 2008). If however pregnant sows and newly weaned sows are housed together, the restlessness due to the presence of a teaser boar for estrus stimulation and detection may have a negative influence on early pregnant sows.

Using fresh or 1-day-old semen for AI performed significantly better than semen that was stored for a longer time. This is likely due to the decrease in fertilizing capacity of spermatozoa as a consequence of *in vitro* aging (Waberski 1994; Kirkwood 2003).

The % of RB was better if estrus stimulation with the boar was performed twice-daily. Vargas et al. (2009) also reported that a higher return to estrus rate was observed in herds where the estrus detection was carried out only once a day. Moreover, the more time spent for estrus stimulation and detection, the better sows will show estrus symptoms (Kirkwood 2003; Kemp et al. 2005), the easier it becomes to estimate the right insemination time (Steverink et al. 1999) and to achieve a successful conception, with lower regular returning rates as a consequence.

As many management and housing conditions are applied at herd level, the present study mainly focused on herd level factors and not on sow characteristics individually within each herd. Sow characteristics (such as individual body condition and parity) can have an influence on the outcome of the reproductive parameters as well and future research should take this into consideration. In addition, the statistical associations between a factor and the reproduction parameter are not necessarily an indication of a causal relationship. The obtained R^2_{adj} in the final two models, explained a considerable amount of variation in the outcome parameters compared with other multivariable studies in pig reproduction. However, there is still a lot of unexplained variation, meaning that other factors not included in the final models may have an influence on the outcome parameters

In conclusion, this study documents that feeding strategy of breeding gilts is significantly associated with WEI, and that the housing conditions of newly weaned sows, the frequency of estrus stimulation and the storage duration of diluted semen are significantly associated with RB. These factors can be implemented rather easily by pig producers and may consequently lead to improvements of reproductive performance of sows after weaning.

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3.7 References

Agricultural statistics: FOD Economie (2011). Algemene Directie Statistiek en Economische Informatie. http://publicaties.vlaanderen.be/docfolder/21429/LARA_Sectorenboek_DIGI.pdf (last access: 30/01/2012)

Almond G.W., Flowers W.L., Batista L., D'Allaire S. (2006). Diseases of the reproductive system. In: Diseases of Swine (9th edition), Straw B.E., Zimmerman J.J., D`Allaire S., Taylor D.J., eds., Ames Iowa State University Press, pp. 113-147.

Aherne F.X., Foxcroft G.R., Pettigrew J.F. (1999). Nutrition of the sow. In Diseases of Swine (8th edition), Straw B.E., D`Allaire S., Mengeling W.I., Taylor D.J., eds., Ames Iowa State University Press, pp. 1029-1043.

Bertacchini F., Frisenna M., Melli F., Demontis G. (2004). Relationship between some management measures and fertility results. Proceedings of the 18th IPVS Congress, Hamburg, Germany - Volume 2, 461.

Cameron A. (1999). Survey toolbox: a practical manual and software package for active surveillance of livestock diseases in developing countries. Australian Centre for International Agricultural Research. Monograph No. 54, Canberra.

Einarsson S., Brandt Y., Lundeheim N., Madej A. (2008). Stress and ist influence on reproduction in pigs: a review. Acta Veterinaria Scandinavica 50, 48.

Jorgensen B., Sorensen M.T. (1998). Different rearing intensities of gilts: II. Effect on subsequent leg weakness and longevity. Livestock Production Science 54, 167-171.

Kemp B., Soede N.M., Langendijk P. (2005). Effects of boar contact and housing conditions on estrus expression in sows. Theriogenology 63, 643-656.

King V.L., Koketsu Y., Reeves D., Xue J., Dial G.D. (1998). Management factors associated with swine breeding-herd productivity in the United States. Preventive Veterinary Medicine 35, 255-264.

Kirkwood R. (2003). Techniques to fine-tune reproduction. London Swine Conference – Maintaining your competitive Edge.

Klindt J., Yen J.T., Christenson R.K. (2001). Effect of prepubertal feeding regimen on reproductive development and performance of gilts through the first pregnancy. Journal of animal Science 79, 787-795.

Knox R.V., Zas S.L. (2001). Factors influencing estrus and ovulation in weaned sows as determined by transrectal ultrasound. Journal of Animal Science 79, 2957-2963.

Koketsu Y. and Dial G.D. (1997). Factors influencing the postweaning reproductive performance of sows on comercial farms. Theriogenology 47, 1445-1461.

Koketsu Y., Dial G.D., King V.L. (1997). Influence of various factors on farrowing rate on farms using early weaning. Journal of Animal Science 75, 2580-2587.

Kuller W.I., Soede N.M., van Beers-Schreurs H.M.G., Langendijk P., Taverne M.A.M., Verheijden J.H.M., Kemp B. (2004). Intermittent suckling: effects on piglet and sow performance before and after weaning. Journal ofAnimal Science 82, 405-413.

Kuller W.I., Soede N.M., van Beers-Schreurs H.M.G., Langendijk P., Taverne M.A.M., Kemp B., Verheijden J.H.M. (2007). Effects of intermittent suckling and creep feed intake on pig performance from birth to slaughter. Journal of Animal Science 85, 1295-1301.

Levis D.G. (1997). Management of replacement gilts for efficient reproduction. University of Nebraska Cooperative Extension EC 97-274-A. Lincoln, NE.

Oppenheim A. (1992). Questionnaire design, Interviewing and attitude measurement. London and New York, Pinter Publishers, St Martin’s Press.

Prunier A., Soede N.M., Quesnel H., Kemp B. (2003). Productivity and longevity of weaned sows. In: Pluske J.R., Le Dividich J., Verstegen M.W. (Editors). Weaning the pig, First edition, Wageningen Academic Publishers, The Netherlands, p 385-423.

Quesnel H., Pasquier A., Mounier A.M., Prunier A. (1998). Influence of feed restriction during lactation on gonadotropic hormones and ovarian development in primiparous sows. Journal of Animal Science 76, 856-863.

Riesenbeck A. (2011). Review on International Trade with Boar Semen. Reproduction of Domestic Animals 46 (suppl 2), 1-3.

Steverink D.W.B., Soede N.M., Groenland G.J.R., van Schie F.W., Noordhuizen J.P.T.M., Kemp B. (1999). Duration of estrus in relation to reproduction results in pigs on commercial farms. Journal of Animal Science 77, 801-809.

Thrusfield M. (2005). Data collection and management. Veterinary Epidemiology, 3rd edition, Blackwell Publishing Ltd., 188-213.

Turner A.I., Tilbrook A.J. (2006). Stress, cortisol and reproduction in femal pigs. Society of reproduction and fertility supplement 62, 191- 203.

Vaillancourt J.P., Martineau G., Morrow M., Marsh W., Robinson A. (1991). Construction of questionnaires and their use in veterinary medicine, in: Proceedings of the Society for Veterinary Epidemiology and Preventive Medicine, Annual Meeting, London, 94-106.

Vanderhaeghe C., Dewulf J., Ribbens S., de Kruif A., Maes D. (2010). A cross-sectional study to collect risk factors associated with stillbirths in pig herds. Animal Reproduction Science 118, 62-68.

Vargas A.J., Bernardi M.L., Bortolozzo F.P., Mellagi A.P.G., Wentz I. (2009). Factors associated with return to estrus in first service swine females. Preventive Veterinary Medicine 89, 75-80.

Von Borell E., Dobson H., Prunier A. (2007). Stress, behaviour and reproductive performance in female cattle and pigs. Hormones and Behavior 52, 130-138.

Waberski D., Weitze K.F., Lietmann C., Lubbert zur Lage W., Bortolozzo F.P., Willmen T., Petzoldt R. (1994). The initial fertilizing capacity of longterm-stored liquid boar semen following pre- and postovulatory insemination. Theriogenology 41, 1367-1377.

Young B., Dewey C.E., Friendship R.M. (2010). Management factors associated with farrowing rate in commercial sow herds in Ontario. The Canadian Veterinary Journal 51, 185-189.

Chapter 4

Effect of a GnRH-analogue (Maprelin®)

Chapter 4.1

Effect of a GnRH analogue (Maprelin®) on the reproductive performance of gilts and sows

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4 Effect of a GnRH-analogue (Maprelin®)

4.1 Effect on the reproductive performance of gilts and sows

4.1.1 Abstract

The ability of peforelin (l-GnRH-III) to stimulate follicular growth, FSH release and estrus in gilts after altrenogest treatment and in sows after weaning was investigated. In three farrow-to-wean herds, with at least 600 sows and average production performance, 216 gilts, 335 primi- and 1299 pluriparous sows were randomly allocated to three treatments: peforelin (M group: Maprelin®), eCG (F group: Folligon®), and physiological saline solution (C group). Animals were treated 48h after their last altrenogest treatment (gilts) or 24h after weaning (sows). The weaning-to-estrus-interval, estrus duration, estrus rate (ER), pregnancy rate, and total birth (TB), live birth and stillbirth (SB) numbers were recorded and compared between treatments for the different parity groups (gilts, primi- and pluriparous sows). Follicle sizes were measured in representative animals from each group on the occasion of their last altrenogest treatment or at weaning, and also on the occasions of their first (FS1) and second (FS2) attempted inseminations. Blood samples were taken to determine FSH concentrations at weaning and 2 hours after injection, and progesterone (P4) concentrations 10 days after the first insemination attempt. The relative change in FSH concentrations was calculated. Significant differences were found for ER within 7 days of weaning in pluriparous sows (95, 91 and 90% for the M, F and C groups, respectively, p=0.005). Gilts in the F-group had high TB numbers and pluriparous sows in the M group had high SB numbers (TB gilts=13.6, 15.4 and 14.9 (p=0.02) and SB pluriparous sows=1.8, 1.4 and 1.7 (p=0.05) for the M, F and C groups, respectively). The M group had the highest FS1 (for gilts) and FS2 (for pluriparous sows) values: FS1=5.4, 4.9 and 4.9mm (p=0.02) and FS2=6.8, 5.3 and 6.3mm (p=0.03) for the M, F and C groups, respectively. There were no significant differences between the different treatments within each parity group with respect to any of the other variables. Overall, peforelin treatment had small but positive effects on the estrus rate and follicle growth in certain parity groups but did not seem to affect litter sizes or FSH and P4 levels in sows on the occasions of the corresponding examinations.

Keywords: *sows, gonadotropins, peforelin, estrus*

4.1.2 Introduction

Maintaining optimal reproductive performance is essential for meeting economic targets in commercial pig production. Management strategies, including accurate feeding at different stages of breeding, batch farrowing, optimal housing and a sufficiently long photoperiod in the insemination facility are not always sufficient to meet farmers' performance requirements. Pharmaceuticals, *i.e.* hormones, can be used to manipulate the estrus cycle in swine, for example to synchronize estrus and ovulation within a herd, which can increase reproductive performance (Brüssow et al., 2010). In females that have undergone an estrus synchronization program, it is possible to inseminate multiple batches of sows within a short time frame - one or two days - which results in a relatively synchronized onset of farrowing within these batches. These procedures are increasingly important, especially in herds where batch production systems for sows are used or will be used.

Treatment with exogenous gonadotropins in sows after weaning or in gilts after altrenogest treatment has been used to stimulate follicular development, and to induce ovulation in prepuberal, cycling, lactating and anestrus sows (Brüssow et al., 2001). It has also been shown to improve the synchronization of estrus onset within batches (Brüssow et al., 2010; Martinat-Botté et al., 2010; Benaglia et al., 2012). In addition, gonadotropins have been used to decrease the weaning-to-estrus interval (WEI), which proved to be particularly helpful in sows that were at a high risk of reduced fertility during the post-weaning period, such as 1st parity sows (Patterson et al., 2010) or animals experiencing seasonal infertility problems (Krejci et al., 2012).

The release of luteinizing hormone (LH) and, to a lesser extent, follicle-stimulating hormone (FSH) from the pituitary gland is governed by the hypothalamic gonadotropin-releasing hormone (GnRH) (Brüssow et al., 2001; 2010; McCann et al., 1993; 2001). GnRH is therefore a key regulator of the growth, maturation, and ultimately, the ovulation of follicles. While LH secretion is dependent on GnRH, that of FSH is not. Instead, FSH levels are regulated by other peptides, such as gonadal activins, inhibins and follistatins (McCann et al., 2001; Padmanabhan and McNeilly, 2001; Kauffold et al., 2005). Twenty years ago, Sower et al. (1993) demonstrated for the first time that there is another selective FSH-releasing factor produced by the hypothalamus in fish - specifically, the lamprey, *Petromyzon marinus* (lamprey GnRH-III). This variant of GnRH was put forward as a potential FSH-releasing factor. Numerous subsequent *in vivo* and *in vitro* studies were conducted in different species, yielding inconsistent results. Based on *in vitro* and *in vivo* studies with rats, cows and barrows, treatment with l-GnRH-III induces increases in the levels of FSH but not of LH (Kauffold et al., 2005; Yu et al., 1997; 2000; Dees et al., 2001). However, studies on mid-luteal intact cows (Amstalden et al., 2004) and barrows (Barretero-Hernandez et al., 2010) showed that l-GnRH-III only stimulates the release of LH and does not affect FSH. Still other studies indicated that treatment with 1-GnRH-III did not cause any increase in the levels of either FSH or LH in rodent brain tissues (Montaner et al., 2001) or in gilts (Brüssow et al., 2010), but stimulated the secretion of both gonadotropins in rat pituitary cells (Kovacs et al., 2002) and ovariectomized cows (Amstalden et al., 2004). To date, no studies have been conducted to explore the influence of l-GnRH-III on the secretion of the different reproductive hormones in gilts and sows at the same time.

Recently, a German company, Veyx, launched the product Maprelin®, whose active substance is l-GnRH-III (peforelin). This agent is marketed for the induction of the estrous cycle in sows after weaning and in sexually mature gilts, in animals that have undergone progestogen therapy to inhibit the estrous cycle. Different studies conducted in Germany have suggested that treatment with peforelin (Maprelin®, l-GnRH-III, Veyx-Pharma, Schwarzenborn, Germany) has positive effects on estrus induction in gilts and sows (Engl et al., 2010a; b) and reduces the interval between the animals' most recent altrenogest treatment and the onset of estrus in gilts (Engl, 2006; Engl et al., 2010c). It may also decrease the negative effects of seasonal infertility (Engl et al., 2010a).

The purpose of the study reported herein was to investigate the ability of peforelin to stimulate follicular growth and estrus in gilts after altrenogest treatment and in post-weaning sows, and to study its effects on litter size in Belgian farrow-to-wean herds with average production performance. In addition, FSH and progesterone (P4) levels in the studied animals were analyzed to investigate the effects of l-GnRH-III on FSH release and the ability of the *corpora lutea* to produce P4. The performance of the peforelin treated animals was compared to that of a pregnant mare serum gonadotropin (ECG) treated group and an untreated control group.

4.1.3 Materials and methods

The study was conducted between January 2010 and May 2011, and was approved by the Ethical Committee of the Faculty of Veterinary Medicine of Ghent University (approval: EC2010/035).

4.1.3.1 Herd selection, study animals and management practices

Three farrow-to-wean herds in the province of West Flanders with at least 600 sows (600 to 1,700) and an average reproductive performance for the Belgian swine industry were included in the study. Briefly, the number of weaned piglets/sow/year ranged from 23 to 27, and on average, 85 to 95% of the sows showed estrus within seven days of weaning. More detailed information on the farms is presented in table 5.

In total, 1,945 gilts and sows (average: 650 per herd) were investigated during one reproductive cycle, starting at the point of weaning for sows or from their most recent altrenogest treatment for gilts, to their subsequent weaning (table 5). Animals with clinical disease and/or reproductive disorders, such as puerperal disease or pathological vaginal discharge were not included. Gilts had been treated with altrenogest (Regumate®, MSD Animal Health, Brussels, Belgium) for 18 days (20 mg per gilt per day, administered orally) after having shown at least one estrus. To ensure accurate dosing, gilts were housed in individual stalls during altrenogest treatment. Sows were weaned on days 20 to 21 of lactation. One day after the final altrenogest treatment (gilts) or at weaning (sows), the animals were moved to a breeding facility, with individual housing and a light schedule of 16 hours per day giving 250 lux, measured at the sows' heads.

Estrus stimulation started on the first day post weaning (pw) in sows or 48 hours after the last altrenogest treatment in gilts (the last altrenogest treatment was given one day before weaning, thus for the sake of convenience and consistency, 48 hours after the last altrenogest treatment is henceforth referred to as the first day post-weaning or 'pw'), using at least two teaser boars. All animals were fed *ad lib* with a gestation feed from day one pw until insemination. A supplement of 150 mg dextrose per day per animal was provided as a top dressing. To further optimize estrus stimulation and detection, supplemental boar noises were played to the animals in herd A via a voice recorder, and herd C used a Contact-O-Max (Ro-Main Europe, France), which is a remote controlled mobile unit with a boar inside.

Estrus detection was performed twice a day (am and pm) from day four pw onwards. The same artificial insemination (AI) schedule was used in all three herds. Briefly, sows showing standing estrus before man on day 4 pw in the morning were inseminated 24 hours later, and those showing estrus in the evening were inseminated 12 hours later. Sows showing standing estrus on day 5 were inseminated 8 hours later, while those showing estrus on day 6 pw were inseminated immediately. Sows that still showed estrus 12 hours after their first round of AI were inseminated a second time, and a third time in the rare cases where standing estrus persisted for 24 hours. Single sire semen from boars of proven fertility was purchased from a commercial AI centre.

Pregnancy testing was performed by the herd veterinarian using ultrasound at 23 to 28 days of gestation and again two weeks later. Gilts and sows that were found to be pregnant at day 23 to 28 were moved to the gestation unit. In herds A and B, pregnant females were housed in groups, with the exception of gilts and sows that had previously experienced reproductive problems (*e.g.* repeat breeding) in herd A. In herd C, only gilts were housed in groups, and weaned sows were housed in individual stalls. In all three herds, animals were fed a gestation diet *ad lib* in the group housing-gestation unit.

All of the participating herds used similar vaccination schedules for their sows. Sows were vaccinated for Parvovirus and *E. rhusiopathiae* (2 weeks post partum), *E. coli* (2 weeks pre partum in herd A), atrophic rhinitis (2 weeks pre partum in herd A and C), Porcine Respiratory and Reproductive Syndrome virus (4 times a year in herd B and C) and finally Swine Influenza Virus (3 times a year in herd C).

Table 5. Characteristics of the three pig herds included in the study

	Herd A	**Herd B**	**Herd C**
Number of sows per herd	1200	1700	600
Number of sows included in study	627	685	633
Breed of sows	Danbred x York	PIC	Topigs20
Batch-production-system for sows (weeks)	1	2	4
Lactation period (weeks)	3	3	3
Piglets weaned/sow/year	25.9	26.1	26.3
Average weaning-to-insemination-interval (days)	7.0	7.1	7.8
Age of gilts at first insemination (days)	280	290	250

4.1.3.2 Experimental design

The study population was grouped into three age categories: gilts and primiparous and pluriparous sows. Within each age category, animals were randomly allocated to one of three treatment groups prior to treatment: peforelin (the M group), in which gilts and pluriparous sows were treated with 150µg peforelin, corresponding to 2 ml of Maprelin® based on the manufacturers' documentation, and primiparous sows were treated with 37.5µg peforelin, corresponding to 0.5 ml of Maprelin®; equine Chorion Gonadotropin (eCG; the F group) as a positive control, in which animals were treated with 1,000 IU eCG, corresponding to 1 ml of Folligon®, MSD Animal Health, Brussels, Belgium; and physiological saline solution as a negative control (the C group), in which animals were treated with 1 ml of phys. saline solution.

All treatments were applied via intramuscular injection into the neck 24(±1)h pw (sows) or 48(±1)h after their last altrenogest treatment (gilts). The entire study, including estrus detection, AI, and the recording of the different parameters was conducted using a blinded design.

4.1.3.3 Major parameters

4.1.3.3.1 Estrus and pregnancy

The measured variables were the estrus rate (ER: the proportion of gilts and sows showing estrus), weaning-to-estrus interval (WEI: the interval between the day of the last altrenogest treatment for gilts or the day of weaning for sows and the onset of estrus), estrus duration (ED: the interval between the detection of the first and last observed standing estrus) as well as pregnancy rate (PR: the proportion of pregnant animals from the animals inseminated).

4.1.3.3.2 Litter size

The number of total born piglets (TB), live born (LB), stillborn (SB) and mummified (Mu) piglets was recorded for each litter.

4.1.3.4 Minor parameters

For the minor parameters, 10 animals per age group and per treatment group in each herd (*i.e.* 90 animals per herd) were selected at random and individually identified at weaning, *i.e.* 24 hours prior to treatment for sows, or on the last day of altrenogest treatment for gilts.

4.1.3.4.1 Follicle size

Ovary scanning was conducted according to the procedures described earlier (van Leeuwen et al., 2011). The ovaries of the sows were monitored using trans-abdominal ultrasound scans performed with a sectorial probe (5 MHz, MS Multiscan digital, MS Schippers, The Netherlands) to estimate the average follicle size. Ultrasound scans were performed twice daily, at intervals of approximately eight hours, at the time of weaning or the last altrenogest treatment (FS0) and during the first (FS1) and second (FS2) insemination attempts. The latter two scans were conducted to estimate whether ovulation had already occurred, *i.e.* to detect the presence of follicles with diameters in excess of 2 mm following larger follicles, as well as to identify potential abnormalities such as ovarian cysts, *i.e.* cyst-like formations with diameters of > 15 mm. Where possible, four (at minimum, two) clearly defined follicles were measured in the right ovary, after which the mean follicle size was calculated to assess the follicular diameter. Ultrasound testing was always performed by the same experienced person (first author).

4.1.3.4.2 FSH and progesterone concentrations

Three blood samples for hormone analyses were drawn by venopuncture from the *vena jugularis*. Samples were collected immediately prior to treatment in order to determine a base line concentration of FSH; two (±0.5) hours after treatment, in order to determine the effect of l-GnRH-III on the release of FSH; and finally on the tenth day after the first AI attempt, to determine the capability of the *corpora lutea (cl)* to produce progesterone (P4). Samples were transported to the Faculty of Veterinary Medicine (Ghent University, Merelbeke, Belgium) and centrifuged for 10 minutes at 2.504 x *g* at 4°C within 12 hours of collection. The serum was then collected and stored at -20°C until analysis.

For analysis, the serum was shipped in bulk to the laboratory of the Faculty of Veterinary Medicine in Leipzig (Germany). FSH concentrations were determined in the first two blood samples, by radioimmunoassay (RIA) following the procedure described by Kauffold et al. (2008). The limit of detection was 0.4 ng/ml, and the intra- and inter-assay coefficients of variation (CV) were 6.4% and 10.6%, respectively. Progesterone analysis was performed using the third samples (*i.e.* those collected ten days after the first AI attempt), as described by Brüssow et al. (2010). The intra- and inter-assay CVs for this procedure were 7.5 and 8.1% respectively, and its lower limit of detection was 0.5 ng/ml.

The mean FSH levels before treatment for females within the treatment and parity groups were used as baseline concentrations, and the relative change in concentration between the post- and pre-treatment periods was used as the treatment response.

4.1.3.5 Statistical analysis

The number of animals in each age category (gilts, primiparous and pluriparous) was sufficient to detect differences of at least 5.0% in the estrus rates between the groups with 95% confidence, 80% power and a standard deviation of 3.1 (WinEpiscope 2.0; Thrusfield et al., 2001). Data analysis was conducted in a blinded manner. All statistical calculations were performed using version 20.0 of the SPSS software package (SPSS Inc., Chicago, Illinois, USA).

The normality of the data sets was tested using the Kolmogorov-Smirnov-test and the Shapiro-Wilk-test. The results for the different treatment groups were expressed as arithmetic means and the corresponding standard deviations (SD). For all parameters, separate analyses were performed for animals with a WEI less than or equal to seven days after weaning (≤7d) and those with a WEI of more than 7 days (>7d). Comparisons between the three treatment groups were made for all animals and separately for the three different parity groups. For all parameters, the effect of parity and herd was significant. Therefore, three different analyses were performed per parity group and herd was included in the statistical model. Multiple comparisons for the parameters TB, LB, SB, M and FS were performed using analysis of variance. Pairwise comparisons between groups were conducted using the *post hoc* Bonferroni test. For parameters with non-normal distributions (WEI, ED, FSH and P4), non-parametric tests were used. Cross-tabulations and the Chi squared test were used to detect differences between the treatment groups with respect to the ER and PR parameters. The significance threshold applied was $p \leq 0.05$.

4.1.4 Results

Results for a total of 1,918 animals were included in the statistical analysis. Twenty-seven sows (1.4%) had incomplete records and were excluded from the analysis.

4.1.4.1 Major parameters

4.1.4.1.1 Estrus and pregnancy

The ER≤7d and the WEI≤7d for the three different treatment and parity groups are shown in table 6.

For pluriparous sows, the ER≤7d was significantly ($p = 0.005$) higher in the M group (95%) than the F (91%) or the C group (90%).

The WEI≤7d tended to be shorter in the F group (4.5d) than the C or M groups (4.7d) in primiparous sows ($p = 0.07$). The WEI>7d in gilts was greater than 21 days in the M and C groups ($p = 0.05$) and also in the M and F groups for pluriparous sows ($p= 0.07$). For primiparous sows, the WEI>7d value was greater than 21 days in all three treatment groups. There were no significant differences between any of the treatments for each parity group with respect to their ED≤7d values (mean = 36.3±16.0h, 39.6±14.1h and 43.0±14.9h for gilts, primiparous and pluriparous sows, respectively) nor with respect to their PR≤7d values (mean = 82%, 79%, 84% for gilts, primiparous and pluriparous sows, respectively).

4.1.4.1.2 Litter size

Table 7 shows the TB, LB and SB numbers for the different parity and treatment groups.

The TB number was significantly higher in the F group (15.4 piglets) than the M group (13.6 piglets) in gilts ($p = 0.02$). In primiparous sows, the TB number for the F group tended to be greater than in the C group (15.4 vs. 14.1 respectively, $p = 0.09$).

The SB number was higher in the M group (1.8 piglets) than in the F group (1.4 piglets) in pluriparous sows ($p = 0.05$).

The number of Mu per litter was similar for all treatment groups and for all parity groups (0.2 ± 0.5 mummies, $p > 0.05$).

4.1.4.2 Minor parameters

4.1.4.2.1 Follicle size

The percentage of sows that had no follicles with diameters above 2mm at weaning and still had only small follicles on their first and second AI attempts (*i.e.* that experienced no post-weaning follicular growth or had already ovulated) was 0%, 8% and 23%, respectively, over all animals and all treatments. There were no significant differences between the treatment groups with respect to these variables. Polycystic ovaries were found in three sows at first AI, one from the F group and two from the C group. These sows were excluded from subsequent analyses.

The FS0, FS1 and FS2 results are presented in table 8. The mean FS1 value was significantly larger in the M group (5.4 mm) than the F (4.9 mm) or C groups (4.9 mm) for gilts ($p = 0.02$). The mean FS2 value was significantly larger in the M group (6.8 mm) than the F group (5.3 mm) in pluriparous sows ($p = 0.03$).

4.1.4.2.2 FSH and progesterone concentrations

There was no significant difference between the treatment groups with respect to the relative change in mean FSH levels over the studied period (-0.04±0.43 µg/l, 0.19±1.09 µg/l and 0.04±0.66 µg/l for gilts and primiparous and pluriparous sows respectively). There was no increase in FSH levels following treatment in either of the treatment groups.

The mean P4 levels of all sows (pregnant and non-pregnant) in the F group (15.24 ng/ml) tended to be lower than those in the M (20.50 ng/ml) and C (17.86 ng/ml) groups for primiparous sows ($p = 0.07$). No significant differences were observed in either gilts or pluriparous sows (mean 18.78±5.89 ng/ml and 17.81±7.72 ng/ml for gilts and pluriparous sows respectively). Significant differences were found between pregnant sows and non-pregnant sows (18.65±6.53 and 14.87±8.84 ng/ml, respectively, with $p = 0.03$). When only the pregnant sows were compared for the different parity groups, no significant differences were found (19.84±6.38; 18.84±7.81 and 17.97±5.92 ng/ml, for gilts, primiparous and pluriparous sows, respectively).

Table 6. Estrus rates (ER) and weaning-to-estrus intervals (WEI), for the different treatment (M=Maprelin®, F=Folligon®, C=control) and parity groups, in estrus within 7 days of weaning (≤7d; SD = standard deviation)

	group	**n**	**ER≤7d(%)**	**WEI≤7d±SD(d)**
Gilts	**M**	83	73	5.3 ± 1.0
	F	73	71	5.7 ± 1.0
	C	77	74	5.6 ± 1.0
Primiparous	**M**	129	88	4.7^{c} ± 0.8
	F	109	90	4.5^{d} ± 0.9
	C	108	90	4.7^{c} ± 0.8
Pluriparous	**M**	446	95^{a}	4.5 ± 0.8
	F	432	91^{b}	4.5 ± 0.8
	C	461	90^{b}	4.5 ± 0.8

[a, b] Within a specific parity group, differences between treatment groups were statistically significant (p ≤ 0.05)
[c, d] Within a specific parity group, differences between treatment groups showed a tendency (p = 0.07)

Table 7. The number of total born (TB), live born (LB) and stillborn (SB) piglets for the different treatment (M=Maprelin®, F=Folligon®, C=control) and parity groups (SD = standard deviation)

	group	**N**	**TB ± SD**	**LB ± SD**	**SB ± SD**
Gilts	**M**	49	13.6 ± 3.5^{b}	12.8 ± 3.2	0.7 ± 1.1
	F	42	15.4 ± 2.4^{a}	14.2 ± 2.5	1.0 ± 1.3
	C	48	14.9 ± 2.9^{a,b}	13.9 ± 3.6	0.9 ± 1.9
Primiparous	**M**	90	14.7 ± 3.6^{c,d}	13.5 ± 3.7	1.1 ± 2.0
	F	76	15.4 ± 3.6^{d}	14.1 ± 3.6	1.3 ± 2.1
	C	74	14.1 ± 3.3^{c}	12.9 ± 3.7	1.0 ± 1.5
Pluriparous	**M**	347	15.4 ± 3.5	13.5 ± 3.3	1.8 ± 2.0^{b}
	F	332	14.8 ± 3.9	13.2 ± 3.5	1.4 ± 1.9^{a}
	C	341	15.0 ± 3.9	13.2 ± 3.6	1.7 ± 2.2^{a,b}

[a, b] Within a specific parity group, differences between treatment groups were statistically significant (p ≤ 0.05)
[c, d] Within a specific parity group, differences between treatment groups showed a tendency (p = 0.09)

Table 8. Follicle size (mean ± standard deviation (SD); in mm) at weaning (FS0), at first (FS1) and second insemination (FS2) for the different treatment (M=Maprelin®, F=Folligon®, C=control) and parity groups

	group	**n**	**FS0 ± SD**	**FS1 ± SD**	**FS2 ± SD**
Gilts	**M**	40	2.6 ± 0.8	5.4^{b} ± 1.0	5.7 ± 1.8
	F	20	2.5 ± 0.8	4.9^{a} ± 0.6	5.0 ± 1.7
	C	32	2.5 ± 1.1	4.9^{a} ± 1.2	5.9 ± 1.7
Primiparous	**M**	35	2.9 ± 0.8	5.5 ± 1.1	6.2 ± 2.0
	F	23	2.8 ± 1.4	5.7 ± 1.8	6.2 ± 1.9
	C	30	3.1 ± 1.0	5.6 ± 1.3	5.8 ± 2.5
Pluriparous	**M**	27	3.0 ± 1.1	5.5 ± 1.3	6.8^{a} ± 2.3
	F	34	3.1 ± 1.1	5.6 ± 1.6	5.3^{b} ± 2.5
	C	34	3.4 ± 1.1	5.4 ± 1.3	6.3^{a,b} ± 2.3

[a, b] Within a specific parity group, differences between treatment groups were statistically significant (p ≤ 0.05).

4.1.5 Discussion

This study was conducted to determine the effects of peforelin, *i.e.* synthetic l-GnRH-III, on the reproductive capabilities of gilts after altrenogest treatment and post-weaning sows in commercial Belgian pig herds. All herds had an average to suboptimal reproductive performance based on recent benchmarking data for Belgian and Dutch farms (PR = 88%, WEI = 5.6 and weaned piglets/sows/year = 28.5, Agrovision Herd monitoring 2011, Cerco Soft N.V., Oudenaarde, Belgium). In general, the differences between the treatment groups were relatively small for all of the studied variables. Statistically significant differences were only observed for the estrus rate in pluriparous sows, the follicle size at AI for gilts and pluriparous sows and the total numbers of born and stillborn piglets in gilts and pluriparous sows respectively.

Significantly more pluriparous sows in the peforelin treatment group showed estrus within seven days of weaning than was the case for the negative control group or the eCG treatment group. This is important from an economical and practical perspective because it reduces the number of non-productive days. Assuming a cost of €3.5 per sow per non-productive day (Tully, 2013) and an average treatment cost of €3.2 per treated sow for peforelin, the elimination of even one non-productive day would be economically beneficial (€0.3 profit per sow per day). Since peforelin treatment increased the number of sows in estrus within 7 days of weaning by 5% in herds with 650 sows on average, it would save the farmer almost ten euros per day (32.5 sows * €0.3). Peforelin treatment can also easily be incorporated into sow batch management systems. Sows that do not enter estrus within a set time frame in a batch production system are good candidates for culling, but are frequently given another chance in order to limit the replacement rate. However, if the proportion of sows that do not enter estrus can be decreased sufficiently, as was the case for pluriparous sows treated with peforelin, these problematic sows can safely be culled and replaced. It is not clear why this effect was only seen in pluriparous sows. Engl et al. (2010a; b; c) observed an increase in ER for all parity groups treated with peforelin (relative to eCG treatment). It is worth mentioning that according to the participating producers, the gilts treated with peforelin had the best performance in terms of ER (personal communication). However, the measured ER data do not support this observation. The physical body condition of the sows is very important for the reproductive cycle (De Rensis et al., 2005), and major back fat losses during lactation may negatively influence the outcome of their estrous performance. However, it is unlikely that differences in metabolic stage alone can explain the aforementioned discrepancies in the ER data, since there were no differences in back fat loss between the studied groups (data not shown).

There were no differences between the treatment groups with respect to ED and WEI, with one exception: primiparous sows treated with eCG tended to have shorter WEI values. This is consistent with the results of Engl (2006) and Engl et al. (2010b), and may occur because eCG exhibits both LH- and FSH-like activities (Farmer and Papkoff, 1979); LH stimulates the growth of follicles from 4 mm to preovulatory size (Driancourt et al., 1995), which in turn shortens the follicular phase and thus the WEI (Cassar, 2009).

The PR of the sows examined in this work was approximately 80%, and was lower than the PR obtained before the study (± 85%). This may indicate that the selected herds did not have optimal reproductive performance, since the typical PR target values are 90% or more (Almond et al., 2006). The reason for the lower PR in this case is not clear. However, in 23% of the studied sows, no follicles were seen at the 2nd AI, indicating that they had already ovulated. Therefore, it is possible that the timing of the insemination was not optimal in (some of) these sows (Steverink et al., 1999) and that the relatively low PR values in the study were due to the use of an inappropriate insemination scheme.

The lack of significant differences with respect to TB between the control and treatment groups could indicate the safety of the products, since they did not induce superovulation. This would be consistent with the results of Manjarin et al. (2010) and Patterson et al. (2010). More piglets were born to gilts and primiparous sows treated with PMSG than to untreated animals or animals injected with peforelin. According to Brüssow and Wähner (2008), PMSG is the only agent that can stimulate sufficient ovulatory follicles to produce large viable litters. However, do Lago et al. (2005) and Martinat-Botté et al. (2010) found that PMSG treatment increased the ovulation rate but also had a negative influence on embryonic viability, probably because it increased follicular heterogeneity in the pre-ovulatory pool and caused the asynchronous development of embryos (Zak et al., 1997; Knox, 2005).

Previous studies (Kauffold et al., 2005; Yu et al., 1997; 2000; Dees et al., 2001) have shown that l-GnRH-III treatment increases FSH levels. Increased levels of FSH during the follicular phase increase follicular size (Picton et al., 1999; Hunter et al., 2004) and the size of the *corpora lutea (cl)* (Knox, 2005; Hazeleger et al., 2005), which lead to elevated progesterone levels (Wientjes et al., 2012).

The largest follicles at insemination were observed in gilts and pluriparous sows treated with peforelin. This is in keeping with the results of Engl (2006), who suggested that peforelin promotes the release of FSH (Kauffold et al., 2005; Yu et al., 1997; 2000; Dees et al., 2001). Surprisingly, FSH levels did not increase significantly following treatment in any group examined in this work, including the peforelin group. It is possible that the animals' FSH levels increased rapidly after treatment but then returned to the baseline level within two hours of injection. This would be consistent with the report of Kauffold et al. (2005), who observed that FSH levels peaked at 205% of their initial value one hour after peforelin treatment in barrows. Dees et al. (2001) found that the peak response occurred within 15 minutes of treatment and that basal FSH levels were restored 1.5 hours after stimulation with l-GnRH-III in cows. The results obtained in this work are consistent with those reported by Brüssow et al. (2010) and Barretero-Hernandez et al. (2010), who used l-GnRH-III in either gilts or barrows and found no evidence of FSH-releasing activity. It is therefore not clear why peforelin-treated animals had larger follicles than those seen in other treatment groups at first AI, nor can the results of this study explain the differences between the results of previous studies with respect to the FSH releasing activity of l-GnRH-III. It may be that l-GnRH-III acts locally at the ovarian level, as has been shown for GnRH in rats (Hsueh and Schaeffer, 1985).

Wientjes et al. (2012) demonstrated that there is a positive relationship between follicle size and the size and weight of the *cl*, indicating that larger follicles develop into larger *cl*, which then produce more progesterone. Although treatment with peforelin increased follicle diameter in this work, this did not significantly increase progesterone levels. Suboptimal LH surge levels could potentially cause inadequate luteinization of the ovulated follicles and therefore reduce plasma progesterone levels and increasing embryo mortality (Einarsson and Rojkittikhun, 1993). Since LH was not measured in this work, no conclusion can be drawn on this matter. However, the progesterone levels in pregnant sows were significantly higher than in their non-pregnant counterparts, indicating that the timing of blood sampling was correct and that the lack of differences between groups with respect to their progesterone levels was not due to inappropriate sampling.

The trial was conducted in three different herds, with similar reproductive histories. The management procedures applied to the three herds were all relatively similar in terms of weaning, insemination, housing, and feeding regimes. In addition, seasonal effects can be ruled out because the study was conducted over a period of seventeen months. Nevertheless, a significant herd effect was observed for all of the studied parameters; this may have been related to the breed of the sows. The study was conducted in a double-blinded fashion because estrus detection was performed by the farmers, who were blinded to the applied treatments, and the statistical analysis was performed by an independent statistician.

4.1.6 Conclusion

The results presented herein demonstrate that treatment with peforelin caused a significant increase in the number of pluriparous sows in estrus within seven days of weaning. Peforelin also seems to have a positive effect on follicle growth in gilts and pluriparous sows. If the number of sows that have not entered estrus within seven days can be minimized, for example by treatment with peforelin, culling decisions become easier to make and losses due to non-productive days are minimized, which can save farmers up to ten euros per day. However, the administration of hormonal products cannot be used as a substitute for adequate management.

Further studies on the FSH-releasing activity of l-GnRH-III are warranted because the available data on this topic are highly inconsistent; in almost half of the previous studies, there was no increase in FSH levels following 1-GnRH-III treatment.

4.1.7 Acknowledgements

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4.1.8 References

Almond G.W., Flowers W.L., Batista L., D'Allaire S. (2006). Diseases of the reproductive system. In: Straw B.E., Zimmerman J.J., D`Allaire S., Taylor D.J. (eds.) Diseases of Swine (9th edition), Ames Iowa State University Press, p.113-147.

Amstalden M., Zieba D.A., Garcia M.R., Stanko R.L., Welsh T.H., Hansel W.H., Williams G.L. (2004). Evidence that lamprey GnRH-III does not release FSH selectively in cattle. Reproduction 127, 35-43.

Barretero-Hernandez R., Vizcarra J.A., Bowen A., Galyean M. (2010). Lamprey GnRH-III releases luteinizing hormone, but not follicle stimulating hormone in pigs. Reproduction of Domestic Animals 45, 983-987.

Benaglia P., Krejci R., Lopez A., Casappa P. (2012). Effect of the synchronisation of estrus in sows using Fertipig® in comparison with another gonadotropin product. Proceedings 22nd IPVS, Jeju, Korea, 92.

Brüssow K.P., Wähner M. (2008). Biotechnological regulation of reproduction in female swine. Züchtungskunde 80, 370-377.

Brüssow K.P., Schneider F., Nürnberg G. (2001). Alteration of gonadotrophin and steroid hormone release and of ovarian function by a GnRH antagonist in gilts. Animal Reproduction Science 66, 117-128.

Brüssow K.P., Schneider F., Tuchscherer A., Kanitz W. (2010). Influence of synthetic lamprey GnRH-III on gonadotropin release and steroid hormone levels in gilts. Theriogenology 74(9), 1570-1578.

Cassar G. (2009). Hormonal control of pig reproduction. London Swine Conference, Tools of the Trada, 137-139.

Dees W.L., Dearth R.K., Hooper R.N., Brinsko S.P., Romano J.E., Rahe H., Yu W.H., McCann S.M. (2001). Lamprey gonadotropin-releasing hormone-III selectively releases follicle-stimulating hormone in the bovine. Domestical Animal Endocrinology 20, 279-288.

De Rensis F., Gherpelli M., Superchi P., Kirkwood R.N. (2005). Relationships between backfat depth and plasma leptin during lactation and sow reproductive performance after weaning. Animal Reproduction Science 90, 95-100.

do Lago V., Vianna W.L., Gama R.D., de Campos Rosseto A., Pinese M.E., de Sant'Anna Moretti A. (2005). Second oestrus synchronization and precocious embryo viability after puberty induction in gilts by the use of Gonadotrophin treatment. Reproduction of Domestic Animal 40, 141-144.

Driancourt M.A., Locatelli A., Prunier A. (1995). Effects of gonadotrophin deprivation on follicular growth in gilts. Reproduction Nutrition and Development 35, 663-673.

Einarsson S., Rojkittikhun T. (1993). Effects of nutrition on pregnant and lactating sows. Journal of Reproduction and Fertility (Suppl) 48, 229-239.

Engl S. (2006). Untersuchungen zur Eignung einer neuen GnRH-Variante zur Brunstinduktion bei pluripare Sauen. Inaugural-Dissertation zur Erlangung des Grades eines Doctor medicinae veterinariae, Leipzig.

Engl S., Zepperitz H., Rath R., Zaremba W. (2010a). Practical experience with Peforelin in a large sow herd: data from primiparous sows. Proceedings 21st IPVS, Vancouver, Canada, 1085.

Engl S., Zepperitz H., Rath R., Zaremba W. (2010b). Practical experience with Peforelin in a large sow herd: data from pluriparous sows. Proceedings 21st IPVS, Vancouver, Canada, 1086.

Engl S., Bischoff R., Zaremba W. (2010c). Use of a new GnRH to control reproduction in gilts. Proceedings 21st IPVS, Vancouver, Canada, 1084.

Farmer S.W., Papkoff H. (1979). Immunochemical studies with Pregnant Mare Serum Gonadotropin. Biology of Reproduction 21, 425-431.

Hazeleger W., Soede N.M., Kemp B. (2005). The effect of feeding strategy during the pre-follicular phase on subsequent follicular development in the pig. Domestical Animal Endocrinology 29, 362-370.

Hunter M.G., Robinson R.S., Mann G.E., Webb R. (2004). Endocrine ad paracrine control of follicular development and ovulation rate in farm species. Animal Reproduction Science 82-83, 461-477.

Hsueh A.J., Schaeffer J.M. (1985). Gonadotropin-releasing hormone as a paracrine hormone and neurotransmitter in extra-pituitary sites. Journal of Steroid Biochemistry 23(5B), 757-764.

Kauffold J., Schneider F., Zaremba W., Brüssow K.P. (2005). Lamprey GnRH-III stimulates FSH secretion in barrows. Reproduction of Domestic Animals 40, 475-479.

Kauffold J., Gottschalk J., Schneider F., Beynon N., Wähner M. (2008). Effects of feeding level during lactation on FSG and LH secretion patterns and follicular development in primiparous sows. Reproduction of Domestic Animal 43, 234-238.

Knox R.V. (2005). Recruitment and selection of ovarian follicles for determination of ovulation rate in the pig. Domestical Animal Endocrinology 29, 385-397.

Kovacs M., Seprodi J., Koppan M., Horvath J.E., Vincze B., Teplan B., Flerko B. (2002). Lamprey gonadotropin hormone-releasing hormone-III has no selective follicle-stimulating hormone-releasing effect in rats. Journal of Neuroendocrinology 14, 647-655.

Krejci R., Carmona M., Lopez A., Sierra E.R. (2012). Induction and synchronisation of estrus in problematic sows after weaning using Fertipig® in comparison with another gonadotropin product. Proceedings 22nd IPVS, Jeju, Korea, 93.

Maes D.G.D., Janssens G.P.J., Delputte P., Lammertyn A., de Kruif A. (2004). Back fat measurements in sows from three commercial pig herds: relationship with reproductive efficiency and correlation with visual body condition scores. Livestock Production Science 91, 57-67.

Martinat-Botté F., Venturi E., Guillouet P., Driancourt M.A., Terqui M. (2010). Induction and synchronization of ovulations of nulliparous and multiparous sows with an injection of gonadotropin-releasing hormone agonist (Receptal). Theriogenology 73, 332-342.

Manjarin R., Garcia J.C., Dominguez J.C., Castro M.J., Alegre B., Munoz J.D., Kirkwood R.N. (2010). Effect of gonadotropin treatment on estus, ovulation and litter size in weaned and anestrus sows. Journal of Animal Science 7, 2356-2360.

McCann S.M., Marubayashi U., Sun H.-Q., Yu W.H. (1993). Control of follicle-stimulating hormone and luteinizing hormone release by hypothalamic peptides. Annals of the New York Academy Science 687, 55-59.

McCann S.M., Karanth S., Mastronardi C.A., Dees W.L., Childs G., Miller B., Sower S., Yu W.H. (2001). Control of Gonadotropin secretion by Follicle-Stimulating Hormone-Releasing Factor, Luteinizing Hormone-Releasing Hormone and Leptin. Archives of Medical Research 32, 476-485.

Montaner A.D., Mongiat L., Lux-Lantos V.A., Park M.K., Fischer W.H., Craig A.G., Rivier J.E., Lescheid D., Lovejoy D., Libertun C, Sherwood N.M., Somoza G.M. (2001). Structure and biological activity of gonadotropin-releasing hormone isoforms isolated from rat and hamster brains. Neuroendocrinology 74, 202-212.

Padmanabhan V., McNeilly A.S. (2001). Is there an FSH-releasing factor? Reproduction 121, 21-30.

Patterson J.L., Cameron A.C., Smith T.A., Kummer A.B., Schott R.L., Greiner L.L., Connor J.F., Foxcroft G.R. (2010). The effect of gonadotrophin treatment at weaning on primiparous sow performance. Journal of Swine Health and Production 18(4), 196-199.

Picton H.M., Miller A.T., Hunter M.G. (1999). Effect of FSH infusion on follicle development in GnRH agonist-treated gilts. Journal of Reproduction and Fertility 117(2), 246-257.

Prunier A., Quesnel H. (2000). Influence of the nutritional status on ovarian development in female pigs. Animal Reproduction Science 60-61, 185-197.

Sower S.A., Chiang Y., Lovas S., Conlon J.M. (1993). Primary structure and biological activity of a third gonadotropin-releasing hormone from lamprey brain. Endocrinology 60, 1125-1131.

Steverink D.W.B., Soede N.M., Groenland G.J.R., van Schie F.W., Noordhuizen J.P.T.M., Kemp B. (1999). Duration of estrus in relation to reproduction results in pigs on commercial farms. Journal of Animal Science 77, 801-809.

Thrusfield M., Ortega C., de Blas I., Noordhuizen J.P., Frankena K. (2001). WIN EPISCOPE 2.0: improved epidemiological software for veterinary medicine. Veterinary Record 148(18), 567-572.

Tully B. (2013). With uncomfortably high production costs and slim to negative margins, it is imperative to pay attention to non productive days (npd) in the sow farm. http://benchmark.farms.com/2013_Sow_Non_Productive_Days.html (25/06/2013)

van Leeuwen J.J.J., Williams S.I., Martens M.R.T.M., Jourquin J., Driancourt M.A., Kemp B., Soede N.M. (2011). The effect of different postweaning altrenogest treatments of primiparous sows on follicular development, pregnancy rates, and litter sizes. Journal of Animal Science 89, 397-403.

Wientjes J.G.M., Soede N.M., Van den Brand H., Kemp B. (2012). Nutritionally induced relationships between insulin levels during the weaning-to-ovulation interval and reproductive characteristics in multiparous sows: II. Luteal development, progesterone and conceptus development and uniformity. Reproduction of Domestic Animal 47, 62-68.

Yu W.H., Karanth S., Walczewska A., Sower S.A., McCann S.M. (1997). A hypothalamic follicle-stimulating hormone-releasing decapeptide in the rat. Proceedings National Academy Science USA 94, 9449-9503.

Yu W.H., Karanth S., Sower S.A., Parlow A.F., McCann S.M. (2000). The similarity of FSH-releasing factor to lamprey gonadotropin-releasing hormone III (l-GnRH-III). Proceedings Society for Experimental Biology and Medicine 224, 87-92.

Zak L.J., Xu X., Hardin R.T., Foxcroft G.R. (1997). Impact of different patterns of feed intake during lactation in the primiparous sow on follicular development and oocyte maturation. Journal of Reproduction and Fertility 110, 99-106.

Chapter 4.2

Effect of a GnRH analogue (Maprelin®) on the litter performance of gilts and sows

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Paper in preparation

4.2 Effect on the litter performance of gilts and sows

4.2.1 Abstract

The effect of peforelin (l-GnRH-III) on the litter performance was investigated. In three farrow-to-wean herds, 270 animals stratified in three parity groups: gilts, primi- and pluriparous sows, were randomly allocated to three treatments: peforelin (M group: Maprelin®), eCG (F group: Folligon®), and physiological saline solution (C group). Animals were treated 48h after their last altrenogest treatment (gilts) or 24h after weaning (sows). The gestation length, number of total, live born, stillborn and weaned piglets and mortality rate during lactation were recorded. The birth and weaning weight were assessed and the coefficient of variation in weights per litter was calculated. All parameters were compared between treatments for the different parity groups. Litter size and number of stillborns was greater in the F group in gilts (13.1, 15.2, 14.2 ($p = 0.03$) and 0.7, 1.6 and 0.6 piglets ($p = 0.05$) for the M, F and C group, respectively). The stillbirth numbers in the pluriparous sows were 2.2, 0.9 and 1.4 for the M, F and C groups, respectively ($p < 0.01$). Piglets in the F group had the lowest birth weight in gilts, primiparous sows and over all parities (1.36, 1.26, 1.32kg ($p < 0.03$), 1.47, 1.40, 1.45kg ($p = 0.02$) and 1.42, 1.35 and 1.40kg ($p < 0.01$) for the M, F and C groups, respectively) and the highest coefficient of variation of birth weight of total born in gilts and over all parities (0.19, 0.22, 0.21 ($p = 0.02$) and 0.22, 0.25 and 0.23 ($p \leq 0.05$) for the M, F and C groups, respectively). The weaning weight of the M group was the highest in gilts and the lowest in pluriparous sows: 5.30, 5.07, 5.08kg ($p < 0.03$) and 5.43, 5.80 and 5.71kg ($p < 0.02$) for the M, F and C group, respectively. The coefficient of variation of weaning weight was the lowest in the M group in primiparous sows (0.18, 0.19 and 0.20 for the M, F and C group, respectively ($p = 0.05$)). There were no significant differences between the different treatments within each parity group with respect to any of the other variables.

In conclusion, peforelin treatment showed no difference compared to no treatment according to litter performance. It seems to have positive effects on the weaning weight in gilts, but this was the other way round in pluriparous sows. Furthermore, peforelin could increase the uniformity of the piglets at weaning in young sows, but this effect was not seen in older sows.

Keywords: *sows, gonadotropins, peforelin, birth weight*

4.2.2 Introduction

Maintaining optimal reproductive and litter performance is essential for meeting economic targets in commercial pig production. Treatment with exogenous gonadotropins in sows after weaning or in gilts after altrenogest treatment has been used to stimulate follicular development (Brüssow et al., 2010; Martinat-Botté et al., 2010; Benaglia et al., 2012). Follicular stimulation could lead to a better quality of the oocytes and to better embryo viability (Knox, 2005; Ferguson et al., 2006; 2007), subsequently leading to a higher number of piglets born (Ferguson et al., 2004) and eventually higher birth weights (Wientjes et al., 2012).

The release of luteinizing hormone (LH) and, to a lesser extent, follicle-stimulating hormone (FSH) from the pituitary gland is governed by the hypothalamic gonadotropin-releasing hormone (GnRH) (Brüssow et al., 2001; 2010; MacCann et al., 1993; 2001). GnRH is therefore a key regulator of the growth, maturation, and ultimately, the ovulation of follicles. While LH secretion is only dependent on GnRH, FSH is also regulated by other peptides, such as gonadal activins, inhibins and follistatins (McCann et al., 2001; Padmanabhan and McNeilly, 2001; Kauffold et al., 2005). Twenty years ago, Sower et al. (1993) demonstrated for the first time that there is another selective FSH-releasing factor produced by the hypothalamus in fish, more specifically in the lamprey, *Petromyzon marinus* (lamprey GnRH-III). It has been five years, since a German company, Veyx, launched the product Maprelin®, whose active substance is l-GnRH-III (peforelin). This product is marketed for the induction of estrous in sows after weaning and in sexually mature gilts upon progestagen therapy to inhibit the estrous cycle. Different studies conducted in Germany and Belgium have confirmed that treatment with peforelin (Maprelin®, l-GnRH-III, Veyx-Pharma, Schwarzenborn, Germany) has positive effects on estrus induction in gilts and sows (Engl et al., 2010a; b; de Jong et al., 2013).

Peforelin could positively influence the oocyte quality, ovulation rate, embryonic survival and litter weight, by increasing FSH. This was suggested by Jourquin and Goossens (2011) and Vangroenweghe et al. (2013) in litters from peforelin treated sows. The mortality rate of litters born to peforelin treated sows was significantly lower (14 versus 17%) and the birth weight was significantly higher (average of 1.24 versus 1.20 kg) than in litters from untreated control sows. However, no comparison was made with another gonadotropin-like product and no data were available on the homogeneity of the litters, nor the weaning weight of the piglets.

The purpose of the study reported herein was to investigate the effect of peforelin on subsequent litter performance in gilts after altrenogest treatment and in post-weaning sows in Belgian sow herds. The performance of the peforelin treated animals was compared to that of a pregnant mare serum gonadotropin (ECG) treated group and an untreated control group.

4.2.3 Materials and methods

The study was conducted between January 2010 and May 2011, and was approved by the Ethical Committee of the Faculty of Veterinary Medicine of Ghent University (approval: EC2010/035).

4.2.3.1 Study animals and management practices

In three sow herds, 270 breeding animals were randomly selected from the study population described in de Jong et al. (2013). The animals were stratified in three age categories, *i.e.* gilts, primiparous and pluriparous sows.

Pregnancy testing was performed by the herd veterinarian using ultrasound at 23 to 28 days after insemination and again two weeks later. Gilts and sows that were found to be pregnant at day 23 to 28 were moved to the gestation unit. In herds A and B, pregnant females were housed in groups, with the exception of gilts and sows in herd A that had previously experienced reproductive problems (*e.g.* repeat breeding). In herd C, only gilts were housed in groups, and weaned sows were housed in individual stalls as was still in accordance with EU legislation in 2010. In all three herds, animals were fed *ad lib* a gestation diet after confirmed pregnancy. Sows were moved to the farrowing unit approximately one week before the expected farrowing date. Induction of parturition was practised by means of intramuscular injection of prostaglandins on day 115 of gestation, combined with oxytocin 24 hours later. To obtain equal litter sizes (12-13 piglets/litter), cross fostering of piglets was allowed within 24 hours after farrowing, but only between sows of the same treatment group and after first weighing (<12h after birth). Therefore, piglets were individually identified at first weighing using ear tags with different colors according to the treatment. Piglets in all three herds were weaned after twenty to twenty-two days of lactation.

4.2.3.2 Experimental design

Within each herd and each age category, animals were randomly allocated to one of three treatment groups prior to treatment (Table 9): 1) peforelin (the M group), in which gilts and pluriparous sows were treated with 150µg peforelin, corresponding to 2 ml of Maprelin® based on the manufacturers' instruction, and primiparous sows with 37.5µg peforelin, corresponding to 0.5 ml of Maprelin®; 2) equine Chorion Gonadotropin (eCG; the F group) as a positive control, in which animals were treated with 1,000 IU eCG, corresponding to 1 ml of Folligon® (MSD Animal Health, Brussels, Belgium) and 3) physiological saline solution as a negative control (the C group), in which animals were treated with 1 ml of physiological saline solution. All treatments were applied via intramuscular injection into the neck 24 (±1) h post weaning (sows) or 48 (±1) h after the last altrenogest treatment (gilts). The entire study, including AI and the recording of the different parameters was conducted using a blinded design.

4.2.3.3 Data recording and calculated measures

Gestation length was calculated, with day 0 being the day of first insemination and from each litter the number of total born, live born, stillborn, mummified and weaned piglets.

All piglets (live and stillborn) were individually identified and weighed within 12 hours after birth, but before cross fostering, and the live born again the day before weaning. The coefficient of variation was calculated to assess the weight variations within a litter. Mortality rate was used to describe pre-weaning mortality.

Back fat levels of gilts and sows were measured one month after AI following treatment, the day of farrowing and of weaning. The measurements were performed at the P2 position (Maes et al., 2004) by the first author using ultrasonography (linear probe, Tringa, Pie Medical Esaote, BENELUX). Differences between back fat at weaning and at farrowing were calculated in order to determine the losses in back fat during lactation.

4.2.3.4 Statistical analysis

Results for a total of 212 animals were included in the statistical analysis: 70 gilts, 69 primi- and 73 pluriparous sows. Of the initial 270 animals, twenty gilts and forty-eight sows were not pregnant or had incomplete records and were excluded from the analysis. Statistical analysis was performed using version 20.0 of the SPSS software package (SPSS Inc., Chicago, Illinois, USA). Normal distribution of the data was tested using the Kolmogorov-Smirnov-test and the Shapiro-Wilk-test. The results for the different treatment groups were expressed as arithmetic means and the corresponding standard deviations (SD). Results were compared between groups and between group and age categories. Multiple comparisons for all parameters were performed using univariate analysis: with GL, TB, LB, SB, Mu, PW, BW, WW, CV and MR as dependent variables, treatment and parity as fixed effects and herd as random effect. Pairwise comparisons between groups were conducted using the *post hoc* LSD test. A significance level of $p \leq 0.05$ was employed.

4.2.4 Results

There were no differences between any of the treatments with respect to the mean gestation length: 115.4 ± 1.8, 115.1 ± 1.8 and 115.1 ± 1.9 days for the M, F and C group respectively ($p > 0.05$). The number of inductions of parturition was similar for all treatment groups (7.1, 6.9 and 6.9 % for the M, F and C group respectively, $p > 0.05$).

Table 9 shows the numbers of total born, live born, stillborn and weaned piglets according to parity and treatment. Litter size was greater in the F group in gilts, compared to the M group ($p = 0.03$). The number of stillborn piglets was higher in the F group in gilts, compared to the C group ($p = 0.05$) and in the M group in pluriparous sows, compared to the F group ($p < 0.01$). The number of mummified piglets per litter over all parities was similar for all treatment groups: 0.2 ± 0.6, 0.2 ± 0.5 and 0.1 ± 0.4 mummies for the M, F and C group respectively ($p > 0.05$).

In total, 3,014 piglets (2,688 live born) were individually weighed at birth (Table 10). The average birth weight both with and without stillborn numbers, was higher in the M and the C group, compared to the F group in gilts ($p \leq 0.03$ and live born only: $p \leq 0.02$). In the primiparous sows, the live born piglets in the M group weighed more than in the F group ($p = 0.02$). This higher birth weight in the M and C group compared to the F group was also seen over all parity groups both for total born piglets ($p < 0.01$) and for live born piglets alone ($p < 0.01$). The coefficient of variation of birth weight of total born piglets was lower in the M group compared to the F group in gilts ($p = 0.02$) and was the highest in the F group over all parities ($p = 0.01$ for the M group and 0.05 for the C group) (Table 10).

The weaning weight in the M group was higher compared to the F ($p = 0.03$) and C group ($p = 0.02$) in gilts and lower in pluriparous sows compared to the F ($p < 0.01$) and C group ($p = 0.02$, Table 10). The coefficient of variation of weaning weight was lower in the M group compared to the C group in primiparous sows ($p = 0.05$).

The interaction between herd and product was significant for both birth and weaning weight ($p \leq 0.05$).

No significant differences between any of the treatments for each parity group were found with respect to mortality rate during lactation (Table 11) nor at any time for the back fat measurements, nor for the calculated back fat losses during lactation.

Table 9. Number of total born (TB), live born (LB) and stillborn (SB) piglets and piglets weaned (PW) according to treatment (M=Maprelin®, F=Folligon®, C=control) and parity of 212 litters of 3 herds.

	Group	**N**	**Litter numbers (mean ± SD)**			
			TB	**LB**	**SB**	**PW**
Gilts	**M**	28	13.1^{a} ± 3.4	12.3 ± 2.9	0.7^{a,b} ± 0.9	11.9 ± 1.3
	F	17	15.2^{b} ± 2.8	13.5 ± 3.1	1.6^{a} ± 2.7	11.8 ± 1.6
	C	25	14.2^{a,b} ± 3.5	13.6 ± 3.4	0.6^{b} ± 1.0	11.6 ± 1.8
Primiparous	**M**	30	14.8 ± 3.9	13.6 ± 3.4	1.0 ± 1.8	11.8 ± 1.5
	F	15	15.7 ± 3.2	14.4 ± 2.9	1.3 ± 1.5	11.8 ± 1.5
	C	24	14.0 ± 3.0	13.3 ± 3.1	0.5 ± 0.9	11.6 ± 1.6
Pluriparous	**M**	20	15.1 ± 3.7	12.4 ± 3.8	2.2^{a} ± 0.5	11.2 ± 1.9
	F	27	14.9 ± 4.4	13.7 ± 3.8	0.9^{b} ± 1.0	11.9 ± 1.7
	C	26	14.4 ± 4.4	12.9 ± 4.2	1.4^{a,b} ± 2.3	11.0 ± 2.0
All parities	**M**	78	14.3 ± 3.7	12.8 ± 3.3	1.3 ± 1.8	11.7 ± 1.6
	F	59	15.2 ± 3.7	13.8 ± 3.4	1.2 ± 1.8	11.8 ± 1.6
	C	75	14.2 ± 3.6	13.2 ± 3.6	0.9 ± 1.6	11.4 ± 1.8

[a, b] Within a specific parity group, differences between treatment groups were statistically significant (p ≤ 0.05)

Table 10. Mean birth weight ± standard deviation (BW ± SD, in kg) and coefficient of variation (CV) based on the sum of live born and stillborn piglets (LB+SB) and based on LB piglets only, mean weaning weight (WW ± SD, in kg) and CV, and mortality rate (MR) according to treatment (M=Maprelin®, F=Folligon®, C=control) and parity of 3014 piglets (2688 LB) in 212 litters in 3 herds.

	group	**n**	**Weight**						**MR (%)**
			BW_LB+SB		**BW_LB**		**WW**		
			Mean ± SD	**CV**	**Mean ± SD**	**CV**	**Mean ± SD**	**CV**	
Gilts	**M**	28	1.33^{a} ± 0.37	0.19^{a}	1.36^{a} ± 0.34	0.22	5.30^{a} ± 1.06	0.17	9
	F	17	1.23^{b} ± 0.31	0.22^{b}	1.26^{b} ± 0.30	0.22	5.07^{b} ± 1.18	0.18	13
	C	25	1.29^{a} ± 0.34	0.21^{a,b}	1.32^{a} ± 0.32	0.21	5.08^{b} ± 1.27	0.19	12
Primiparous	**M**	30	1.42 ± 0.41	0.25	1.47^{a} ± 0.39	0.22	5.64 ± 1.19	0.18^{a}	12
	F	15	1.37 ± 0.36	0.27	1.40^{b} ± 0.35	0.25	5.56 ± 1.14	0.19^{a,b}	13
	C	24	1.42 ± 0.40	0.25	1.45^{a,b} ± 0.37	0.23	5.72 ± 1.36	0.20^{b}	12
Pluriparous	**M**	20	1.36 ± 0.43	0.25	1.41 ± 0.40	0.26	5.43^{a} ± 1.24	0.21	15
	F	27	1.34 ± 0.39	0.26	1.38 ± 0.36	0.23	5.80^{b} ± 1.34	0.21	16
	C	26	1.38 ± 0.48	0.25	1.43 ± 0.46	0.23	5.71^{b} ± 1.56	0.20	12
All parities	**M**	78	1.37^{a} ± 0.40	0.22^{a}	1.42^{a} ± 0.38	0.23	5.47 ± 1.17	0.18	12
	F	59	1.31^{b} ± 0.36	0.25^{b}	1.35^{b} ± 0.35	0.23	5.52 ± 1.28	0.20	14
	C	75	1.36^{a} ± 0.41	0.23^{a}	1.40^{a} ± 0.39	0.22	5.49 ± 1.43	0.20	12

[a, b] Within a specific parity group, differences between treatment groups were statistically significant (p ≤ 0.05)

4.2.5 Discussion

This study investigated the effects of peforelin, *i.e.* synthetic l-GnRH-III, on the litter performance of gilts after altrenogest treatment and post-weaning sows in commercial Belgian pig herds, compared to treatment with eCG and no treatment.

No significant differences were observed between the negative control group and the group treated with peforelin considering litter size, mortality rate and piglets weaned. In the univariate analysis, there was no statistically significant difference between the treatment groups in all parity groups for the birth and weaning weights. Although the trial was conducted in three commercial herds, with similar reproductive performance (de Jong et al., 2013) and the management procedures used in the three herds were all relatively similar in terms of farrowing, weaning, insemination, housing, and feeding regimes, the interaction between herd and treatment was highly significant. This indicates that the different treatments had different outcomes in the different herds. More research is needed whether the difference in breeds or other factors could be the cause of this significant interaction. However, comparing the products interdependent, some significant differences yet became clear. The birth weights of the piglets in the eCG group were lower in all parity groups. Statistically significant differences between no treatment and peforelin treatment were observed for the weaning weights in gilts and pluriparous sows and the coefficient of variation of weaning weight in primiparous sows.

Litter size was significantly higher in gilts treated with eCG, compared to no treatment or peforelin treatment. The effect of treatment with supplemental LH-like activity products (such as eCG) was shown to be age dependent (Manjarin et al., 2010). Therefore it is possible that the endogenous LH support of older sows is adequate enough to support follicular development, whereas that of gilts is maybe not. Treatment with eCG in gilts and younger sows could thus have more influence on the outcome of total born piglets, compared to the litter size in older sows. The lack of significant differences with respect to litter size between the control and treatment groups in sows is consistent with the results of Manjarin et al. (2010) and Patterson et al. (2010). The number of liveborn piglets was similar for all treatment groups, demonstrating the difference in litter size in gilts is caused by a difference in stillborn piglets. Indeed, significantly more stillborn piglets were found in the eCG-treated group in gilts compared to the other groups. do Lago et al. (2005) and Martinat-Botté et al. (2010) found that eCG treatment increased the ovulation rate but also had a negative influence on embryonic viability. Probably because it increased follicular heterogeneity in the pre-ovulatory pool and caused the asynchronous development of embryos (Zak et al., 1997; Knox et al., 2005). The latter could lead to more stillborn piglets, lower birth weights of the live born piglets and more variability between those weights within the litter, which was the case for the eCG treated group in gilts in this study. Moreover, the lower birth weights in this treatment group over all parity groups was possibly caused by the differences in total and live born piglets, as piglets born in a large litter mostly have lower birth weights, compared to piglets in small litters (Kerr and Cameron, 1995; Roehe, 1999; Sorensen et al., 2000; Beaulieu et al., 2010).

Several environmental factors, *e.g.* ventilation, nutrition, farrowing supervision have an influence on the stillbirth rate (Vanderhaeghe et al., 2013). The overall management practices around farrowing were similar for all treatment groups within each of the three herds, therefore the higher SB number in the M group of the pluriparous sows was probably not caused by environmental factors. A lower BW was found to increase the probability of stillbirth (Canario et al., 2006) and, vice versa, a higher BW (>1.35kg) could lead to more birth difficulties, also leading to asphyxia and likely to more stillborn piglets (Olmos-Hernàndez et al., 2008). Although the birth weight of the stillborn piglets was significantly higher in the M group of the pluriparous sows, compared to the F group (data not shown), it did not exceed 1.35kg, thus a higher number of stillborns due to difficulties during farrowing is doubtful. Sow factors, such as body condition and farrowing duration have also been shown to influence the number of stillborn piglets (Vanderhaeghe et al., 2013). The back fat of the pluriparous sows at farrowing was similar for the M and C group and was approximately 20mm (data not shown), which would not have detrimental effects on the number of stillborns (Maes et al., 2004). The farrowing duration was not measured in this trial, therefore no conclusion can be drawn on this matter.

The lack in differences in number of weaned piglets between the treatment groups could most likely be attributed to the fact that the participating farmers insisted to practice cross-fostering to obtain similar litter sizes and specifically to obtain equal numbers of piglets weaned.

Previous studies (Kauffold et al., 2005; Yu et al., 1997; 2000; Dees et al., 2001) have shown that l-GnRH-III treatment could increase FSH levels. Increased levels of FSH during the follicular phase increase follicular size (Picton et al., 1999; Knox, 2005). It was hypothesized that treatment with peforelin results in a more uniform pre-ovulatory pool, containing more competent and larger follicles to ovulate (Engl, 2006). A more uniform pre-ovulatory follicle pool at the ovary may result in a more uniform oocyte quality (Zak et al., 1997) and more uniformly developed embryos (Pope et al., 1990; Xie et al., 1990), which could finally result in more uniform birth weights (Wientjes et al., 2012; Jourquin and Goossens, 2011; Vangroenweghe et al., 2013). It has been shown that animals treated with peforelin, similar as in the present study, had larger preovulatory follicles than control and eCG treated animals (Engl, 2006; de Jong et al., 2013). The coefficient of variation of birth weights is a measure of the homogeneity of the piglets' weight at birth. The coefficient of variation of both live and stillborn piglets was numerically the lowest in the peforelin treated groups. Significant differences were only found between the eCG treated gilts and the peforelin treated gilts. The eCG treated gilts had the largest variation and no differences were observed between control and peforelin treated gilts. A low within-litter-variation in birth weight is beneficial, as this is positively associated with survival and performance of the piglets (Damgaard et al., 2003; Milligan et al., 2002), leading to a higher weight at weaning (Opschoor et al., 2012). The weaning weight in the M group in gilts was indeed the highest in this study, compared to no treatment or eCG treatment, but in pluriparous sows this was the other way around. And again, the herd effect was significant. The weaning weights in primiparous sows was similar for all treatment groups, but in the M group the coefficient of variation was significantly the lowest, indicating the homogeneity of the weaned piglets in the M group of primiparous sows was the best. But this effect was not statistically significant in the other parity groups.

In conclusion, peforelin treatment showed no difference compared to no treatment based on litter performance. It seems to have positive effects on the weaning weight in gilts, but this was the other way round in pluriparous sows. Furthermore, peforelin could increase the uniformity of the piglets at weaning in young sows, but this effect was not seen in older sows.

4.2.6 Acknowledgements

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4.2.7 References

Beaulieu A.D., Aalhus J.L., Williams N.H., Patience J.F. (2010). Impact of piglet birth weight, birth order, and litter size on subsequent growth performance, carcass quality, muscle composition, and eating quality of pork. Journal of Animal Science 88(8), 2767-78.

Benaglia P., Krejci R., Lopez A., Casappa P. (2012). Effect of the synchronisation of estrus in sows using Fertipig® in comparison with another gonadotropin product. Proceedings 22nd IPVS, Jeju, Korea, 92.

Brüssow K.P., Schneider F., Nürnberg G. (2001). Alteration of gonadotrophin and steroid hormone release and of ovarian function by a GnRH antagonist in gilts. Animal Reproduction Science 66, 117-128.

Brüssow K.P., Schneider F., Tuchscherer A., Kanitz W. (2010). Influence of synthetic lamprey GnRH-III on gonadotropin release and steroid hormone levels in gilts. Theriogenology 74(9), 1570-1578.

Canario L., Cantoni E., Le Bihan E., Caritez J.C., Billon Y., Bidanel J.D., Foulley J.L. (2006). Between-breed variability of stillbirth and its relationship with sow and piglet characteristics. Journal of Animal Science 84(12), 3185-3196.

Damgaard L.H., Rydhmer L., Lovendahl P., Grandinson K. (2003). Genetic parameters for within-litter variation in piglet birth weight and change in within-litter variation during suckling. Journal of Animal Science 81, 604-610.

Dees W.L., Dearth R.K., Hooper R.N., Brinsko S.P., Romano J.E., Rahe H., Yu W.H., McCann S.M. (2001). Lamprey gonadotropin-releasing hormone-III selectively releases follicle-stimulating hormone in the bovine. Domestical Animal Endocrinology 20, 279-288.

de Jong E., Kauffold J., Engl S., Jourquin J., Maes D. (2013). Effect of a GnRH analogue (Maprelin®) on the reproductive performance of gilts and sows. Theriogenology 80, 870-877.

do Lago V., Vianna W.L., GamaR.D., de Campos Rosseto A., Pinese M.E., de Sant’Anna Moretti A. (2005). Second oestrus synchronization and precocious embryo viability after puberty induction in gilts by the use of Gonadotrophin treatment. Reproduction of Domestic Animals 40, 141-144.

Engl S. (2006). Untersuchungen zur Eignung einer neuen GnRH-Variante zur Brunstinduktion bei pluripare Sauen. Inaugural-Dissertation zur Erlangung des Grades eines Doctor medicinae veterinariae, Leipzig.

Engl S., Zepperitz H., Rath R., Zaremba W. (2010a). Practical experience with Peforelin in a large sow herd: data from primiparous sows. Proceedings 21st IPVS, Vancouver, Canada, 1085.

Engl S., Zepperitz H., Rath R., Zaremba W. (2010b). Practical experience with Peforelin in a large sow herd: data from pluriparous sows. Proceedings 21st IPVS, Vancouver, Canada, 1086.

Ferguson E.M., Ashworth C.J., Hunter M.G., Penny P., Slevin J., Edwards S.A. (2004). The effect of feeding a high fibre diet from mid lactation until breeding on subsequent litter size of sows. In: Thompson JE, Gill BP, Varley MA. The appliance of pig science. Nottingham University Press, Nottingham, UK, p.175-179.

Ferguson E.M., Slevin J., Edwards S.A., Hunter M.G., Ashworth C.J. (2006). Effect of alterations in the quantity and composition of the pre-mating diet on embryo survival and foetal growth in the pig. Animal Reproduction Science 96, 89-103.

Ferguson E.M., Slevin J., Hunter M.G., Edwards S.A., Ashworth C.J. (2007). Beneficial effects of a high fibre diet on oocyte maturity and embryo survival in gilts. Reproduction 133, 433-439.

Jourquin J., Goossens L. (2011). Impact of oestrus induction with Peforelin on subsequent litter performance. Proceedings 15th ESDAR, Belek, Antalya, Turkey, 129.

Kauffold J., Schneider F., Zaremba W., Brüssow K.P. (2005). Lamprey GnRH-III stimulates FSH secretion in barrows. Reproduction of Domestic Animals 40, 475-479.

Kerr J.C., Cameron N.D. (1995). Reproductive performance of pigs selected for components of efficient lean growth. Animal Science 60(2), 281-290.

Knox R.V. (2005). Recruitment and selection of ovarian follicles for determination of ovulation rate in the pig. Domestical Animal Endocrinology 29, 385-397.

Maes D., Janssens G., Delputte P., Lammertyn A., de Kruif A. (2004). Back fat measurements in sows from three commercial pig herds: relationship with reproductive efficiency and correlation with visual body condition scores. Livestock Production Science 91, 57-67.

Manjarin R., Garcia J.C., Dominguez J.C., Castro M.J., Alegre B., Munoz J.D., Kirkwood R.N. (2010). Effect of gonadotropin treatment on estus, ovulation and litter size in weaned and anestrus sows. Journal of Animal Science 7, 2356-2360.

Martinat-Botté F., Venturi E., Guillouet P., Driancourt M.A., Terqui M. (2010). Induction and synchronization of ovulations of nulliparous and multiparous sows with an injection of gonadotropin-releasing hormone agonist (Receptal). Theriogenology 73, 332-342.

McCann S.M., Marubayashi U., Sun H.-Q., Yu W.H. (1993). Control of follicle-stimulating hormone and luteinizing hormone release by hypothalamic peptides. Annals of the New York Academy Science 687, 55-59.

McCann S.M., Karanth S., Mastronardi C.A., Dees W.L., Childs G., Miller B., Sower S., Yu W.H. (2001). Control of Gonadotropin secretion by Follicle-Stimulating Hormone-Releasing Factor, Luteinizing Hormone-Releasing Hormone and Leptin. Archives of Medical Research 32, 476-485.

Milligan B.N., Dewey C.E., de Grau A.F. (2002). Neonatal-piglet weight variation and its relation to pre-weaning mortality and weight gain on commercial farms. Preventive Veterinary Medicine 56(2), 119-127.

Olmos-Hernàndez A., Alononso-Spilsbury M., Nava-Ocampo A., Truijillo Ortega M.E., Orozco-Gregorio H., Ramírez-Necoechea R., Mota-Rojas D. (2008). Heavier newborn piglets are more prone to intra-partum asphyxia and show longer first udder contact vs. average weight pigs. Proceedings 20th IPVS, Durban, South-Africa, 223.

Opschoor C.T., Bloemhof S., Knol E.F., Willems E. (2012). The economic benefit of heavier piglets: relations between birthweight and piglet survival and finisher performance. Proceedings 22nd IPVS, Jeju, Korea, 156.

Padmanabhan V., McNeilly A.S. (2001). Is there an FSH-releasing factor? Reproduction 121, 21-30.

Patterson J.L., Cameron A.C., Smith T.A., Kummer A.B., Schott R.L., Greiner L.L., Connor J.F., Foxcroft G.R. (2010). The effect of gonadotrophin treatment at weaning on primiparous sow performance. Journal of Swine Health and Production 18(4), 196-199.

Picton H.M., Miller A.T., Hunter M.G. (1999). Effect of FSH infusion on follicle development in GnRH agonist-treated gilts. Journal of Reproduction and Fertility 117(2), 246-257.

Pope W.F., Xie S., Broermann D.M., Nephew K.P. (1990). Causes and consequences of early embryonic diversity in pigs. Journal of Reproduction and Fertility Suppl 40, 251-260.

Roehe R. (1999). Genetic determination of individual birth weight and its association with sow productivity traits using Bayesian analyses. Journal of Animal Science 77(2), 330-343.

Sorensen D., Vernersen A., Andersen S. (2000). Bayesian analysis of response to selection: a case study using litter size in Danish Yorkshire pigs. Genetics 156(1), 283-295.

Sower S.A., Chiang Y., Lovas S., Conlon J.M. (1993). Primary structure and biological activity of a third gonadotropin-releasing hormone from lamprey brain. Endocrinology 60, 1125-1131.

Vanderhaeghe C., Dewulf J., de Kruif A., Maes D. (2013). Non-infectious factors associated with stillbirth in pigs: a review. Animal Reproduction Science 139(1-4), 76-88.

Vangroenweghe F., Van Loocke H., Labarque G., Jouquin J. (2013). Effect of a GnRH analogue (peforelin) on subsequent reproductive performance and piglet birth weight on a high productive farm. Proceedings 5th ESPHM, Edinburgh, Scotland, 204.

Wientjes J.G.M., Soede N.M., Van den Brand H., Kemp B. (2012). Nutritionally induced relationships between insulin levels during the weaning-to-ovulation interval and reproductive characteristics in multiparous sows: II. Luteal development, progesterone and conceptus development and uniformity. Reproduction of Domestic Animal 47, 62-68.

Xie S., Broermann D.M., Nephew K.P., Geisert R.D., Pope W.F. (1990). Ovulation and early embryogenesis in swine. Biology of Reproduction 43, 236-240.

Yu W.H., Karanth S., Walczewska A., Sower S.A., McCann S.M. (1997). A hypothalamic follicle-stimulating hormone-releasing decapeptide in the rat. Proceedings National Academy Science USA 94, 9449-9503.

Yu W.H., Karanth S., Sower S.A., Parlow A.F., McCann S.M. (2000). The similarity of FSH-releasing factor to lamprey gonadotropin-releasing hormone III (l-GnRH-III). Proceedings Society for Experimental Biology and Medicine 224, 87-92.

Zak L.J., Xu X., Hardin R.T., Foxcroft G.R. (1997). Impact of different patterns of feed intake during lactation in the primiparous sow on follicular development and oocyte maturation. Journal of Reproduction and Fertility 110, 99-110.

Chapter 5

Slaughterhouse examination of culled sows in commercial pig herds

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5 Slaughterhouse examination of culled sows in commercial pig herds

5.1 Abstract

A proper culling policy in sow herds is a prerequisite to maintain a stable parity profile of the breeding animals and to maintain consistent production. This study investigated reasons for culling of 502 sows from 7 commercial pig herds and examined the reproductive tract of these sows by macroscopical, bacteriological and histopathological examination. Associations between all three examinations were statistically analysed. More than 50% of the sows was culled because of reproduction failure, while old age was the second most common reason (23%). Approximately 75% of the examined uteri were visually normal. Purulent exudate was detected in 18% of the animals. No abnormalities were found in 54% of the ovaries, whereas 28% showed inactivity. Sixty-two percent of the uteri were bacteriologically positive, with *E. coli* (18%) being the most frequently isolated. Histologically, 52% of the uteri showed mild to severe inflammation. From the uteri with endometritis based on visual inspection and histology, 26% and 30% was bacteriologically negative, respectively. The presence of bacteria showed a slight agreement with macroscopical ($\kappa=0.14$, $p=0.04$) and histopathological endometritis ($\kappa=0.18$, $p=0.04$). No agreement was found between macroscopical and histopathological lesions ($\kappa = -0.06$, $p > 0.05$). Major differences were found between herds for all parameters. In conclusion, sows are mostly culled because of insufficient reproductive performance, and many of the culled sows show endometritis lesions. Histopathology appears to be more sensitive than visual inspection.

Keywords: *sows, culling, reproduction, post-mortem examination, endometritis*

5.2 Introduction

A proper culling policy in sow herds is a prerequisite to maintain a stable parity profile of the breeding animals. This is necessary to maintain consistent production and to avoid huge swings in the number of replacement gilts. Culling rates of sows vary considerably between herds, ranging from 15 to 85% (D’Allaire et al., 1987) or from 26 to 70% (Boyle et al., 1998). D’Allaire and Drolet (2006) proposed 40% as recommended culling rate, with 35% being true culling and 3-5% deaths. The decision to cull sows is not that straightforward, and inappropriate culling can cause major financial losses to the pig producer. Krabbenborg et al. (1989) reported that sows not showing estrus are often culled too early post-weaning whereas sows failing to conceive too late. The price for culling sows has also become a significant factor in determining culling decision over the past years. As a result, old sows may be retained too long in the herd and young sows may be removed too early from the herd, with decreasing productivity as a consequence (D’Allaire et al., 1987; Ciaran, 1999).

Reproduction failure is one of the major causes for culling sows. D’Allaire and Drolet (2006) stated that 13 to 49% of all sows are culled because of impaired fertility, such as anestrus in sows post-weaning, regular and irregular returns, no pregnancy, abortion and peripartal difficulties. Other important reasons for culling include old age, locomotion problems, disease, and poor performance. Culling reasons may vary over time, among countries, herds and parities. Some findings in literature are based on old studies, performed decades ago (Dagorn et al., 1979; Dalin et al., 1997; Boyle et al., 1998), when sows were far less productive than nowadays. Other studies in different countries investigated reasons for culling in sows and/or assessed post-mortem lesions. However, reasons for culling are influenced by many factors such as sow genotype, housing conditions, and management policies (Svendsen et al., 1975), thus studies in the United States, Canada or Asia (Friendship et al., 1985; D’Allaire et al., 1987; Tummaruk et al., 2009; Kwiecien et al., 2010; Sasaki and Koketsu, 2011) are not always comparable with the European situation, because of the major differences in management, feeding, genetics, climate and housing conditions. In addition, monitoring culling rate and reasons for culling, and investigating whether reasons for culling correspond with the results of diagnostic examinations, can identify diseases or management deficiencies. Examination of culled sows in the slaughterhouse can therefore be very helpful to verify culling decisions. As insufficient reproductive performance is the main reason for culling, most emphasis is placed on the examination of the reproductive tract. A representative number of culled breeding animals can be investigated in a simple way, and the visual inspection can be complemented with further histopathological and/or bacteriological examinations. De Winter et al. (1995) reported that endometritis was diagnosed in 67% of the sows culled because of vaginal discharge and in 56% of the sows culled for other reasons. Affected sows are often infected with bacteria such as *Escherichia coli (E. coli), Staphylococcus spp.* and *Streptococcus spp.* (Meredith, 1986; De Winter et al., 1995). However, performing both histopathological and bacteriological examinations is time consuming and expensive, making it interesting to know which method is most sensitive to detect endometritis.

The present study investigated reasons for culling of sows in commercial pig herds in Belgium and examined the reproductive tract of these sows in the slaughterhouse by visual inspection, histopathology and bacteriological examination. Associations between macroscopical, histopathological and bacteriological findings indicating endometritis were assessed.

5.3 Materials and methods

5.3.1 Herd selection and study population

Seven Flemish pig herds with more than 500 sows were included in the study. They were randomly selected from the National Identification and Registration database (I&R, Sanitel-Pigs, 2005). From each herd, some reproduction parameters were recorded, using computer-based record systems for the period December 2009 till December 2010. The recorded reproduction parameters per herd included the number of piglets weaned per sow per year and the replacement rate. The replacement rate was calculated as the number of pigs mated for the first time multiplied by 100 and divided by the average sow inventory during the same time period. From each herd, two or three batches of culled gilts and sows were investigated. Gilts were female pigs which had been selected for breeding purposes but had not farrowed yet. For each individual animal, the parity and the reason for culling were recorded. If more than one reason was reported, the most decisive reason was taken into consideration. The reason ‘anestrus’ was given to sows not showing clinical signs of estrus within ten days after weaning.

The examined sows were culled during two periods, first from December of 2010 until April 2011 and next from December 2011 until February 2012.

5.3.2 Macroscopical examination

The reproductive tracts of the animals were individually identified and collected in the slaughterhouse, and subsequently transported to the faculty of veterinary medicine, Ghent University, where they were examined within two hours after collection. The ovaries, oviducts, bursae ovaricae and uteri were inspected macroscopically and palpated. The stage of the estrus cycle was determined based on the presence of small (≤ 4mm), medium (5-8mm) or large (>8mm) follicles, ovulation points (OP) and *corpora rubra* (*cr*), *lutea* (*cl*) and *albicantia* (*ca*). Follicles were defined as transparent, fluid-containing structures, OP were seen as little red points on a follicle, *cr* were characterized as ovulated follicles with blood clots, *cl* were structures of pink, tan or yellow colour and finally *ca* were defined as regressed and shrunken white *cl*. Ovaries were considered as inactive if only follicles less than 3 mm in diameter or no *corpora* were present. Cyst-like formations larger than 15 mm in diameter were recorded as ovarian cysts (COF, Dalin et al., 1997; Heinonen et al., 1998; Knauer et al., 2007). No differentiation was made between follicular or luteal cysts, as the difference is not always clear using visual assessment alone. A further distinction was made between para-ovarian, para-oviductal and oviductal cysts. Para-ovarian cysts were located in the bursa ovarica or near the ovaries in the mesovarium, para-oviductal cysts were located in the mesosalpinx and oviductal cysts on the oviduct. The patency of the oviducts was tested using a needle and syringe with physiological solution. The cervix and the uterus were incised longitudinally and inspected for presence of *e.g.* foetuses, mummies or macerated foetuses or congenital malformations. The endometrium was examined for edema and signs of inflammation. Endometritis was defined as severe edema and congestion, dark red colour of the endometrium and the presence of purulent exudate in the lumen (De Winter et al., 1995).

5.3.3 Bacteriological examination

Thirty-five percent of the uteri were randomly selected and used for further bacteriological and histopathological examination. One swab was taken for bacteriological examination from the cranial part of one of the uterine horns. First, the serosa of the uterus was burned with a preheated spoon, then, an incision with a sterile scalpel was made and finally the swab was inserted. The cranial part was sampled to minimize the risk for contamination with vaginal flora, faeces and/or scalding water during slaughter. The swabs were cultured on Columbia agar supplemented with 5% sheep blood (blood agar; Oxoid, Hampshire, United Kingdom), blood agar supplemented with colistin and nalidixic acid (CNA; Oxoid, Hampshire, United Kingdom) and MacConkey Agar n° 3 (Oxoid, Hampshire, United Kingdom). The first two media were incubated in an atmosphere enriched with 5% CO_2, the latter medium was aerobically incubated, both at 35°C for 16-20 hours. One to three colony types (if present) were purified and identified to the species level according to standard microbiological methods (Quinn et al., 1999). A Sabouraud dextrose agar was used for mold or fungal growth. The sample was considered polybacterial if more than three types of colonies had grown on blood agar.

5.3.4 Histopathological examination

Three tissue samples were taken from each of the selected uteri: one from each horn and one from the corpus. The samples were fixed in a 10% buffered formalin solution for at least 24 hours at room temperature. They were embedded in paraffin, sectioned at 5µm and stained with haematoxylin-eosin, according standard techniques. Afterwards, they were microscopically examined for edema and inflammation. To obtain standard results, all slides were examined at a magnification of 400x and possible presence of inflammatory cells in the subepithelial layer was listed as absent (-), present in small (+), medium (++) or large amounts (+++). For the histopathological interpretation, the stage of the estrus cycle was taken into account based on the macroscopical examination of the ovaries, according to the description of Dalin et al. (2004). The stage of endometritis was determined according to De Winter et al. (1995), with a large amount of neutrophils linked to acute endometritis, an increase of both neutrophils and lymphocytes to subacute endometritis and an increase of lymphocytes, plasma cells and histiocytes to chronic endometritis. All examinations were carried out by the same two persons to avoid bias and interpretation problems.

5.3.5 Statistical analyses

Statistical analyses were performed using RStudio (Version 0.98.507, RStudio Inc, 2009) and statistical significance was set at $p < 0.05$. Accordance between presence of endometritis and culling reason were tested by performing a Cochran-Mantel-Haenszel Chi-square test with the different herds as the strata (mantelhaen.test of the stats package). Homogeneity of the odds ratios of the different strata was verified by means of the Breslow-Day test without Tarone’s correction (BreslowDayTest of the DescTools package).

Extent of agreement between bacteriological and histopathological examination, between bacteriological and macroscopical examination, and between histopathological and macroscopical examination was calculated using the Cohen’s Kappa statistics for agreement

(Kappa.test of the fmsb package). No clustering on herd level was performed for these data as this is a test of agreement between different diagnostic methods.

The Confidence Interval (CI) was calculated according to following formula:
$(100\% - \alpha)$ CI = 95% CI = $P_s \pm Z_\alpha$ x $(\sqrt{((P_{s*}\ Q_s)/n)})$
with $Z_\alpha = 1.96$ and the frequencies calculated, using SPSS 20.0 (SPSS Inc., Chicago, Illinois; USA).

5.4 Results

An overview of the herd characteristics and the reproduction parameters of the sows in the seven study herds is given in table 11.

5.4.1 Parity of culled sows and reasons for culling

A total of 502 reproductive organs were examined. The parity distribution of the culled sows and the reasons for culling are presented in Figures 18 and 19, respectively.

The parity of six percent of the sows could not be established with 100% certainty. The mean parity of the culled sows was five with a 13th parity sow as oldest. Sows in parity six and seven were most frequently culled (Fig. 16). The differences between herds are demonstrated in table 12.

Approximately 50% of all slaughtered females was culled because of reproduction failure, with no pregnancy (18%; 95% CI: [15-22]), too little piglets weaned (14%; 95% CI: [11-17]) and showing no estrus (10%; 95% CI: [8-13]) as the most frequent reasons (Fig. 17). Age was the second most common reason for culling (23%; 95% CI: [19-27]). The main reasons for culling differed among herds (table 13) and parity (table 14).

5.4.2 Macroscopical examination of the reproductive tract

The results of the macroscopical examination of the ovaries, the oviducts and the uteri are presented in table 15. More than half of the examined ovaries showed no abnormalities and more than one fourth was inactive. Almost 15% showed COF. Inactivity was the main finding in the ovaries of all parities, except for parity three, where COF were found in 25% of the ovaries (table 14). Taking into account only the ovaries with COF, they were mostly found in sows of parity three (13%; 95% CI: [5-20]), six (14%; 95% CI: [6-22]) or seven (21%; 95% CI: [12-30]).

From the oviducts, only nine percent showed abnormalities, with two percent of them having oviductal cysts with obstruction of the oviduct. Four sows had severe peritonitis. The ovaries and oviducts of these sows could not be eviscerated in the slaughterhouse.

More than 75% of the examined uteri were visually normal. Purulent exudate was detected in 18% of the uteri. Almost three percent of the sows were pregnant and complete normal foeti were observed, in two percent of the uteri mummies or macerated foeti were found. Congenital anomalies were found in four uteri, with three ovo-testes and one with a double uterine horn at the right. Pregnancy was mainly detected in gilts and 2nd parity sows, whereas the presence of purulent exudate in the uterus was mostly found in sows of parity seven and eight (table 14).

The main macroscopic findings on the reproductive tract differed among the herds (table 13).

5.4.3 Comparison between reasons for culling and macroscopical examination of the reproductive tract

The main macroscopical findings according to culling reasons are shown in table 16. Four percent of the sows culled because of no pregnancy, were pregnant. The macroscopical examination of the uteri of sows culled due to leg weakness, demonstrated 10% pregnancy and 17% purulent exudate in cervix and uterus. Inactive ovaria were found in less than 50% of the ovaries from sows culled because of anestrus. Purulent exudate in the uteri was seen in 80% of the sows culled because of vaginal discharge, in 18% of the sows culled because of no pregnancy and in 18% of those culled because of too little piglets weaned. Cystic ovarian follicles were mainly found in sows culled because of not showing estrus (38%), in sows with too little piglets weaned (26%) and in sows culled because they were not pregnant (21%). Within the sows culled for reproduction failure, only no pregnancy and too little piglets weaned were significantly associated with macroscopical endometritis ($p = 0.006$).

5.4.4 Bacteriological and histopathological examination of the uteri

In 38% (95% CI: [31-46]) of the uteri, no bacteria could be isolated. *E. coli* and *enterococci* were isolated from 18% (95% CI: [12-24]) and 12% (95% CI: [7-17]) of the uteri, respectively. Many other bacteria (*e.g. Trueperella pyogenes*, *Streptoccoccus spp.*, *Staphylococcus spp.*, etc.) were found, each in less than five percent of the uteri. Twenty-six percent of the swabs resulted in pure cultures, with the presence of only one species, in 13%

of the samples two species had grown and in three percent three. In ten percent of the uteri, more than three bacterial species were found (polybacterial).

Histologically, 52% (95% CI: [46-56])of all examined uteri showed mild to severe inflammation. Different stages of endometritis were distinguished namely acute (3%; 95% CI: [1-5]), subacute (16%; 95% CI: [11-22]) and chronic (81%; 95% CI: [75-86]) endometritis. Only 7% (95% CI: [4-9]) of the samples showed excessive edema and nearly 50% (95% CI: [42-52]) had no signs of edema.

From the uteri with endometritis assessed macroscopically, 26% was bacteriologically negative and 24% was positive for *E. coli*. From the uteri showing inflammation on histopathology, one third was bacteriologically negative and one third was positive for *E. coli*.

5.4.5 Comparison between macroscopical, bacteriological and histopathological examination of the uteri

All three tests were compared pairwise. The results (kappa-value with 95% CI) are presented in table 17. The presence of bacteria showed a slight agreement with macroscopical endometritis ($\kappa = 0.14$, $p = 0.04$) and with the histopathological detection of endometritis ($\kappa = 0.18$, $p = 0.04$). No agreement was found between histopathological and macroscopical endometritis ($\kappa = -0.06$, $p > 0.05$).

Table 11. Characteristics and reproduction parameters of the seven participating pig herds for the period December 2009 till December 2010 in Flanders

Herd	**A**	**B**	**C**	**D**	**E**	**F**	**G**
Herd size (number of sows)	700	800	2700	1700	1700	550	750
Breed	90% Danbred + 10% PIC	Danbred/ Topigs	Topigs/ English Landrace	PIC	Danbred/York x Danish landrace	Topigs	PIC
Sow batch management system (weeks)	3	2	1	2	2	3	1
Housing during gestation	group	group	Group	Group	group	group	group
AI: cleaning of vulva	yes	no	No	Yes	no	no	no
AI: use of lubricant	no	no	No	No	yes	no	yes
Assistance during farrowing: use of different gloves per sow	yes	yes	Yes	Yes	yes	yes	yes
Assistance during farrowing: use of lubricant	yes	No	Yes	Yes	yes	yes	yes
Lactation period (days)	28	21	21	21	21	28	21
Weaned piglets/sow/year	28.7	29.3	29.0	25.0	31.2	32.9	22.9
Replacement rate (%)	33.1	58.4	40.4	51.0	49.8	41.0	55.0

Table 12. Parity distribution data of the 502 culled sows in the seven herds in Flanders from December 2010 until February 2012. In 6% of the sows the parity could not be established reliably.

Herd	**A**	**B**	**C**	**D**	**E**	**F**	**G**
Number of gilts/sows culled	31	70	92	97	103	26	52
Mean parity	6.1	4.5	3.4	6.5	4.3	5.5	6.3
Median parity	7.0	6.0	3.0	7.0	4.0	5.5	7.0
Minimum parity	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Maximum parity	12.0	7.0	13.0	10.0	9.0	11.0	10.0

Table 13. Main culling reason and main macroscopical observation and their confidence interval at 95% (95% CI) per herd of 502 culled sows in seven herds in Flanders from December 2010 until February 2012.

Herd	**Main culling reason (% [95% CI])**	**Main macroscopical observation of ovaries (% [95% CI])**	**Main macroscopical observation of uterus (% [95% CI])**
A	No pregnancy (55 [37-72])	Inactivity (26 [10-41])	Pregnancy (13 [1-25])
B	High age (68 [57-79])	Inactivity (51 [39-62])	Purulent exudate (9 [2-15])
C	Leg weakness (29 [20-38])	Inactivity (39 [29-48])	Purulent exudate (9 [4-15])
D	No estrus (18 [11-25])	Inactivity (17 [10-24])	Purulent exudate (22 [14-29])
E	High age (27 [19-35])	Inactivity (25 [17-33])	Purulent exudate (16 [9-22])
F	No pregnancy (31 [13-49])	Cystic Ovarian Follicles (23 [7-39])	Purulent exudate (19 [4-34])
G	Too little pigs weaned (38 [25-51])	Cystic Ovarian Follicles (28 [16-40])	Purulent exudate (15 [6-25])

Table 14. Main culling reason and macroscopical observations with 95% confidence intervals (95% CI) according to parity. In total, 471 culled sows from seven herds in Flanders were included and investigated from December 2010 until February 2012.

Parity	**Main culling reason (% [95% CI])**	**Main macroscopical observation of ovaries (% [95% CI])**	**Main macroscopical observation of uterus (% [95% CI])**
0	No pregnancy (44 [30-58])	Inactivity (12 [3-21])	Pregnancy (14 [4-24])
1	Leg weakness (35 [15-56])	Inactivity (40 [19-61])	Purulent exudate (15 [1-30])
2	No pregnancy (25 [11-39])	Inactivity (22 [9-35])	Purulent exudate/Pregnancy (9 [1-18])
3	Too little piglets weaned (28 [13-42])	Cystic Ovarian Follicles (25 [11-39])	Purulent exudate (20 [7-33])
4	No pregnancy (34 [19-49])	Inactivity (37 [17-52])	Purulent exudate (18 [6-30])
5	No pregnancy (20 [8-32])	Inactivity (32 [18-46])	Purulent exudate (14 [3-25])
6	High age (59 [49-69])	Inactivity (44 [34-54])	Purulent exudate (15 [8-22])
7	High age (31 [21-41])	Inactivity (23 [14-32])	Purulent exudate (20 [11-29])
8	High age (41 [27-55])	Inactivity (25 [12-38])	Purulent exudate (23 [11-35])
≥ 9	High age (32 [17-47])	Inactivity (30 [15-45])	Purulent exudate (21 [8-34])
TOTAL	High age (23 [19-27])	Inactivity (28 [24-32])	Purulent exudate (18 [15-21])

Table 15. Results of the macroscopical examination of the ovaries, oviducts and uteri of culled sows (n = 502) and 95% confidence interval (95% CI) from seven pig herds in Flanders from December 2010 until February 2012.

	Percentage	**95% CI**
Ovaries		
no abnormalities	54	[50-58]
cystic ovarian follicles	14	[11-17]
Inactive	28	[24-32]
para-ovarian cysts	3	[1-4]
not examined	1	[0-2]
Oviducts		
no abnormalities	90	[88-93]
(para)oviductal cysts	9	[7-12]
Not examined	1	[0-2]
Uterus		
no abnormalities	76	[72-80]
purulent exudate in corpus and horns, not in cervix	14	[11-17]
purulent exudate in corpus, horns and cervix	4	[2-5]
foeti (normal, mummified or macerated)	4.5	[3-6]
peritonitis or congenital abnormalities	1.5	[1-3]

Table 16. The main macroscopical findings according to the main culling reasons (in %) of 502 sows in seven pig herds in Flanders from December 2010 until February 2012.

Culling Reason	**Ovary**		**Uterus**	
	Cystic Ovarian Follicles	**Inactivity**	**Purulent exudate**	**Foeti**
Insufficient reproductive performance	21	18	20	4
Leg weakness and health issues	20	59	35	22
High age	7	53	13	2
No reason	3	20	17	9

Table 17. Extent of agreement (κ with confidence interval at 95%) between macroscopical, bacteriological and histopathological examination in 170 sows from seven pig herds in Flanders from December 2010 until February 2012.

Examination	**Macroscopical**	**Bacteriological**	**Histopathological**
Macroscopical		0.14 [-0.02–0.29] (p = 0.04)	-0.05 [-0.21-0.09] (p > 0.05)
Bacteriological	0.14 [-0.02–0.29] (p = 0.04)		0.18 [-0.01-0.37] (p = 0.04)
Histopathological	-0.05 [-0.21-0.09] (p > 0.05)	0.18 [-0.01-0.37] (p = 0.04)	

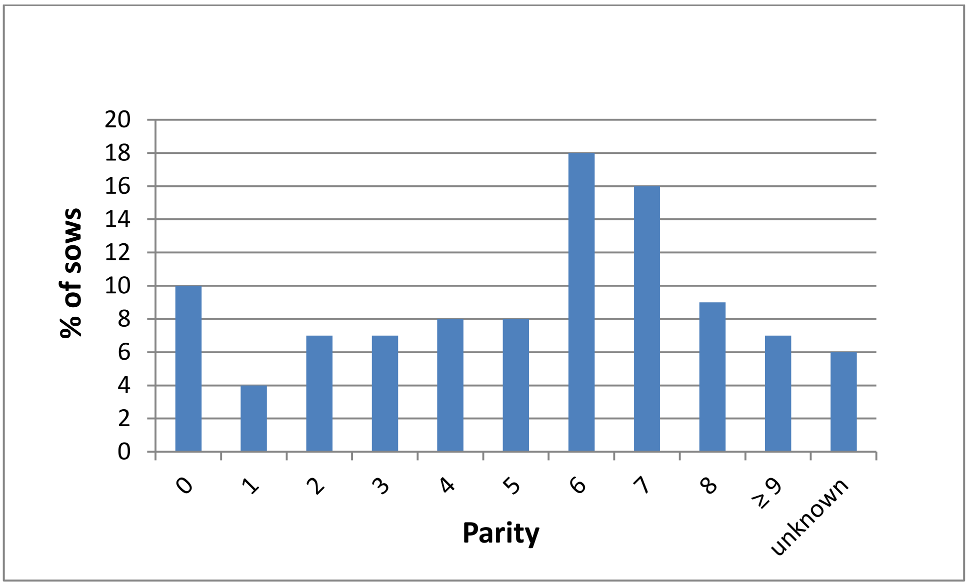

Figure 18. Parity distribution of the culled sows (n=502) from the seven pig herds in Flanders from December 2010 until February 2012.

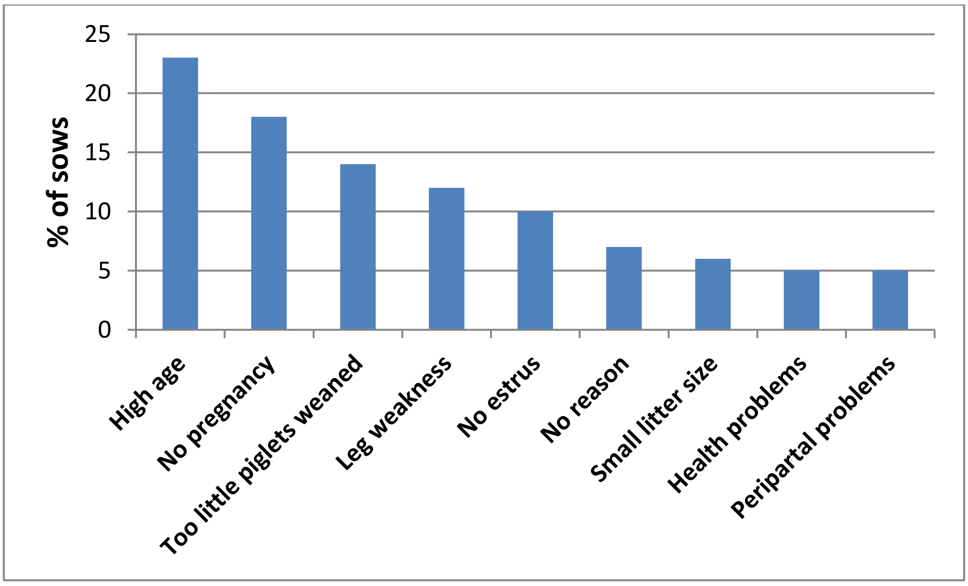

Figure 19. Reasons for culling of the sows (n=502) in the seven pig herds in Flanders from December 2010 until February 2012.

5.5 Discussion

The present study investigated reasons for culling of sows and examined the reproductive tract of 502 culled sows in seven randomly selected pig herds in Flanders. Associations between macroscopical, histopathological and bacteriological findings indicating endometritis were assessed in order to reveal the most sensitive method to diagnose endometritis.

The most common reason for culling was insufficient reproductive performance, with no pregnancy (18%), too little piglets weaned (14%) and no estrus (10%) as most frequent reasons. These percentages are in line with those of previous studies (D' Allaire et al., 1987; Dalin et al., 1997; Tummaruk et al., 2009; Ek-Mex et al., 2010; Roongsitthichai et al., 2010). The comparison of results between different studies is however not always straightforward, as not all studies used the same subdivisions of culling reasons. In fact, in all studies, including this one, the percentage of sows culled for insufficient reproductive performance is likely higher, as many old sows culled for “old age” also show decreased reproductive performance.

Cystic ovarian follicles were mainly seen in sows culled due to insufficient reproductive performance (21%). Of all culled sows, on average 15% had COF, but ranged up to 28% in one herd. The mean percentage of COF was similar to the study of Dalin et al. (1997): 14%, but higher than in other studies (6.2% in Heinonen et al., 1998; 6.3% in Knauer et al., 2007). The presence of COF may cause infertility, irregular and prolonged oestrus cycles and can lead to lower conception rates, because of no ovulation (Castagna et al., 2004). Sows with COF are mainly showing anoestrus. Most of the sows with COF in the present study had been culled for reasons of no estrus or no pregnancy.

Endometritis, although not always clinical detectable, is a major lesion found in culled sows, specifically in sows culled due to insufficient reproductive performance (20%). To confirm this diagnosis, uteri of slaughtered sows were not only grossly examined, but also histopathological examinations of samples were performed. Based on the latter, more than 50% of the uteri showed mild to severe inflammation. This is a high percentage, and higher than the percentage (14-27%) reported by Dalin et al. (1997) and Tummaruk et al. (2009). The histopathological lesions in most of the uteri were chronic (81%), which was also observed by Dalin et al. (2004), indicating that problems had occurred several weeks before slaughter. It is not totally clear why the percentage of histopathological endometritis observed in the present study is higher than in other studies. It may be due to differences in management and hygiene practices, or to housing conditions, as they can predispose to endometritis (De Winter et al., 1995; Oravainen et al., 2008). However, the procedures and housing conditions were representative for many other pig herds in Europe. All sows in the present study were in group housing systems from four weeks of gestation until the end of gestation. Hygiene measures during parturition and AI were similar for all herds. Only minor differences between herds, *e.g.* no cleaning of the vulva before AI, were noted, but they were not associated with a difference in percentage of endometritis. Faecal contamination of the vulvovestibular region can lead to an increased prevalence of ascending urogenital infections (Meredith, 1982). The higher percentage of animals with histopathological lesions than with macroscopical lesions indicate that histopathology is more sensitive to detect endometritis (Biksi et al., 2002), especially in chronically affected animals (De Winter et al., 1995).

Endometritis diagnosed at gross examination was associated with two reasons for culling: no pregnancy and too little piglets weaned. This is in agreement with literature. Spermatozoa will have more difficulties to survive in the presence of pus in the uterus (Rozeboom et al., 2000) and an infected endometrium will increase the embryonic mortality, leading to lower pregnancy rates (Scofield et al., 1974). As for the second association, sows suffering from endometritis could have more chance to develop the periparturient hypogalactic syndrome, leading to lower milk production and higher mortality rates among their offspring during lactation (Martineau et al., 2012).

The major reason for endometritis in sows is bacterial infection (De Winter et al., 1995; Almond et al., 2006). On average, more than half of the samples were bacteriologically positive, with *E. coli* (18%) being most frequently isolated. *E. coli* was also the most frequently isolated bacterium from sow uteri in previous studies (De Winter et al., 1995; Kwiecien et al., 2010; Ward et al., 2010). *Staphylococcus spp.* and *Streptococcus spp.* were the second and third most isolated species in the other studies (De Winter et al., 1995; Kwiecien et al., 2010; Ward et al., 2010), indicating that sow endometritis is mainly caused by facultative pathogenic bacteria. Surprisingly, 26% and 30% of the uteri with endometritis based on macroscopical and histopathological assessment, respectively, were bacteriologically negative. This implies that bacteriological examination of uteri at slaughter is not a sensitive tool to detect endometritis, although the presence of bacteria showed a slight agreement with macroscopical and histopathological endometritis. Biksi et al. (2002) stated that performing macroscopical and bacteriological testing together had beneficial effects in order to detect endometritis. The absence of culturable bacteria in uteri of sows with endometritis could have several reasons. First, since conventional culture techniques are used, some bacteria such as anaerobic bacteria, *Chlamydia* spp. or *Mycoplasma* spp. will not grow. To detect these, other (*eg*. molecular) techniques are required. Secondly, in chronic infectious inflammatory reactions, the etiologic agent is not always present anymore. And finally, bacteria are localized within the mucosa, which renders luminal sampling by swab perhaps less effective. The findings of this study demonstrate that conventional cultivation of endometrium samples is not a very sensitive technique for diagnosis of endometritis. In addition, the presence of bacteria is not always associated with endometritis, thus care has to be taken when interpreting the results. Indeed, infections of the reproductive tract are often present during some phases of the reproductive cycle *e.g.* at farrowing and at insemination. However, most of these infections do not persist (Bara et al., 1993).

Endometritis is also associated with locomotory problems. Seventeen percent of the uteri of the sows culled due to leg weakness contained purulent exudate. This is likely due to the higher risk for ascending infections in sows with leg problems (Meredith, 1982). These sows lie down for a longer period and have a greater faecal contamination of the vulvovestibular region. This can also explain the presence of the facultative pathogenic bacteria.

Pregnancy was detected in three percent of the uteri in this study. This is less than the study of Ward et al. (2010) and Kwiecien et al. (2010), where 13% of the sows culled for infertility reasons turned out to be pregnant. Some pregnant sows, however, were culled for another reason. In sows culled for leg weakness reasons for example, ten percent was pregnant in this study.

The percentage of sows culled because of “old age” (*i.e.* mostly sows with at least six parities) in the present study (23%) was similar to previous studies (14-31%, D’Allaire et al., 1987; Boyle et al., 1998; Ek-Mex et al., 2010). However, the mean parity of the culled sows was five. This finding is higher than the parity reported in previous studies, namely 3.6 (Svendsen et al., 1975), 3.8 (D’Allaire et al., 1987), 4.0 (Sasaki and Koketsu, 2011), 4.2 (Ciaran, 1999) and 4.6 (Boyle et al., 1998). According to Huirne et al. (1991), the optimal replacement policy results in an average herd life of 5.5 parities, and the maximum economic life of average producing sows is nine parities. In the present study, there was a large variation in parity at culling (min 0, max 13) and also between the herds (mean parity between 3.4 and 6.5). Nevertheless, the replacement rates of sows in the participating herds is representative for other pig herds in Belgium with a similar sow inventory: 33 to 58%, with an average rate of

41% for commercial pig herds in Belgium (Agrovision Herd monitoring, 2011-2012, Cerco Soft N.V., Oudenaarde, Belgium).

Inactive ovaria were found in more than one fourth of the animals, with large herd variations (8-51%), specifically in sows culled due to old age (53%). However, the presence of inactive ovaria can be considered physiologically in lactating sows and until one day after weaning (Einarsson et al., 1982). If sows that were culled within one day after weaning were excluded (data not shown), 16% of the remaining sows had inactive ovaria. In the group of sows culled due to old age, still 32% had inactive ovaria, when excluding sows culled within the day after weaning. This percentage was also found by Dalin et al. (1997). This is still a considerable percentage, as inactive ovaria are associated with anestrus and lead to an increase in the number of nonproductive sow days. This observation also supports the overlap between the categories ‘old age’ and ‘inadequate reproductive performance’.

Finally, the present study also showed that the reasons of culling could not always be substantiated by the findings of the slaughterhouse examination. An example is the percentage of inactive ovaries observed in the sows culled in the category of anestrus, where more than half of them had perfectly normal cycling ovaries. Considering the culling reasons of the sows and their correlation with the observed lesions, significant differences between the herds were found. In some herds, sows were culled for “no pregnancy”, whereas up to 20% of these sows appeared to be pregnant. This emphasizes the need for a more stringent pregnancy diagnosis on such herds. However, it should also be mentioned that up to 10% of sows culled for leg weakness was pregnant. Also in previous studies, reasons for culling did not correspond very well with the findings at slaughter (Einarsson et al.; 1974; Karveliene et al., 2007;). In the study of Einarsson et al. (1974), 54 gilts were culled for anestrus whereas 23 of them had active *cl* and two were pregnant.

5.6 Conclusion

The present study documented that sows are mostly culled because of insufficient reproductive performance, and that many of the culled sows show endometritis lesions, in which *E. coli* was frequently found. Histopathological examination appeared to be more sensitive to detect endometritis than macroscopical examination. The results also indicated that the culling decisions are not always confirmed by the observations at slaughter, implying that examination of culled sows in the slaughterhouse may help to optimize culling decisions and the sow reproductive performance on pig herds.

5.7 Acknowledgements

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5.8 References

Almond G.W., Flowers W.L., Batista L., D’Allaire S. (2006). Diseases of the reproductive system. In: Straw B., Zimmerman J.J., D’Allaire S., Taylor D.J. (eds). Diseases of Swine (9th edition), Blackwell Publishing, Ames, Iowa, 113-147.

Bara M.R., McGowan M.R., O’Boyle D., Cameron R.D. (1993). A study of the microbial flora of the anterior vagina of normal sows during different stages of the reproductive cycle. Australian Veterinary Journal 70(7), 256-259.

Biksi I., Takács N., Vetési F., Fodor L., Szenci O., Fenyõ E. (2002). Associations between endometritis and urocystitis in culled sows. Acta Veterinara Hungarica 50(4), 413-423.

Boyle L., Leonard F., Lynch B., Brophy P. (1998). Sow culling patterns and sow welfare. Irish Veterinary Journal incorporating Irish Veterinary Times 51, 354-357.

Castagna C.D., Peixoto C.H., Bortolozzo F.P., Wentz I., Neto G.B., Ruschel F. (2004). Ovarian cysts and their consequences on the reproductive performance of swine herds. Animal Reproduction Science 81, 115-123.

Ciaran C. (1999). Sow culling and parity profile. http://www.teagasc.ie/publications/pig1999/paper04.asp (last access: 19 January 2013)

Dagorn J., Aumaitre A. (1979). Sow culling: reasons for and effect on productivity. Livestock Production Science 6, 167-177.

Dalin A.M., Gidlund K., Eliasson-Selling L. (1997). Post-mortem examination of genital organs from sows with reproductive disturbances in a sow-pool. Acta Veterinarica Scandinavica 38(3), 253-262.

Dalin A.M., Kaeoket K., Persson E. (2004). Immunce cell infiltration of normal and impaired sow endometrium. Animal Reproduction Science 82-83, 401-413.

D’Allaire S., Stein T.E., Leman A.D. (1987). Culling patterns in selected Minnesota Swine Breeding Herds. Canadian Journal of Veterinary Research 51, 506-512.

D’Allaire S. and Drolet R. (2006). Longevity in Breeding Animals. In: Straw B.E., Zimmerman J.J., D`Allaire S., Taylor D.J., eds., Diseases of Swine (9th edition), Ames Iowa State University Press, 1011-1025.

De Winter P.J.J., Verdonck M., de Kruif A., Devriese L.A., Haesebrouck F. (1995). Bacterial endometritis and vaginal discharge in the sow: prevalence of different bacterial species and experimental reproduction of the syndrome. Animal Reproduction Science 37, 325-335.

Einarsson S., Linde C., Settergren I. (1974). Studies of the genital organs of gilts culled for anestrus. Theriogenology 2, 109-113.

Einarsson S., Lundeheim N., Martinsson K., Persson N., Persson I. (1982). Post mortem examination of the genital organs of culling sows from a large herd with relation to fertility data. Proceedings of the 7th IPVS Congress, Mexico city, Mexico, 211.

Ek-Mex J.E., Segura-Correa J., Alzina-López A., Rodríguez J. (2010). Productive life and reasons for removal of sows in four pig farms on Yucatan. Proceedings of the 21st IPVS Congress, Vancouver, Canada, 796.

Friendship R.M., Wilson M.R., Almond G.W., McMillan I., Hacker R.R., Pieper R., Swaminathan S.S. (1986). Sow wastage: reasons for and effect on productivity. Canadian Journal of Veterinary Research 50, 205-208.

Heinonen M., Leppävuori A., Pyörälä S. (1998). Evaluation of reproductive failure of female pigs based on slaughterhouse material and herd record survey. Animal Reproduction Science 52, 235-244.

Huirne R., Dijkhuizen A., Renkema J., 1991. Economic optimization of sow replacement decisions on the personal computer by method of stochastic dynamic programming. Livestock Production Science 28, 331-47.

Karveliene B., Zilinskas H., Riskevicience V. (2007). Postmortem examination of sows genital organs culled for reproductive disturbances and immunohistochemical studies on ERα and PR A receptors in the anoestral sows uterus. Reproduction of Domestic Animals 42,275-281.

Knauer M., Stalder K.J., Karriker L., Baas T.J., Johnson C., Serenius T., Layman L., McKean J.D. (2007). A descriptive survey of lesions from cull sows harvested at two Midwestern U.S. facilities. Preventive Veterinary Medicine 82, 198-212.

Krabbenborg R.M., Dijkhuizen A.A., Huirne R.B. (1989). An economic comparison of replacement decisions for sows in the field and in model conditions. Tijdschrift voor Diergeneeskunde, 114 (19), 987-996.

Kwiecien E.J., Gutierrez C., Mora P., Cadenas E. (2010). A systematic approach to assess reproductive failure at slaughter. Proceedings of the 21st IPVS Congress, Vancouver, Canada, 791.

Martineau G.P., Farmer C., Peltoniemi O. (2012). Mammary glands. In: Zimmerman J.J., Karriker L.A., Ramirez A., Swartz K.J., Stevenson G.W. (eds). Diseases of Swine (10th edition), Wiley-Blackwell, p.273-293.

Meredith M.J. (1982). Vulval discharges – are they a problem? Pig Farming supplement October 1982, 75-81.

Meredith M.J. (1986). Bacterial endometritis. In: Saunders W.B., eds., Current therapy in theriogenology (2nd edition), Philadelphia, 953-956.

Oravainen J. (2008). Field studies on infectious reproductive diseases and lameness in sows. Doctoral Thesis, University of Helsinki.

Quinn P.J., Carter M.E., Markey B., Carter G.R. (1999). Enterobacteriaceae. In: Quinn P.J., Carter M.E., Markey B., Carter G.R., Clinical Veterinary Microbiology, Mosby, London, 209-236.

Rozeboom K.J., Troedsson M.H., Hodson H.H., Shurson G.C., Crabo B.G. (2000). The importance of seminal plasma on the fertility of subsequent artificial inseminations in swine. Journal of Animal Science, 78, 443-448.

Roongsitthichai A., Olanratmanee E., Koonjaenak S., Techakumphu M., Tummaruk P. (2010). The removal of gilts and primiparous sows from swine breeding herds in Thailand. Proceedings of the 21st IPVS Congress, Vancouver, Canada, 795.

Sasaki Y. and Koketsu Y. (2011). Reproductive profile and lifetime efficiency of female pigs by culling reason in high-performing commercial breeding herds. Journal of Swine Health Production 19(5), 284-291.

Scofield A.M., Clegg F.G., Lamming G.E. (1974). Embryonic mortality and uterine infection in the pig. Journal of the Society for Reproduction and Fertility 36, 353-361.

Svendsen J., Nielsen N.C., Bille N., Riising H.J., (1975). Causes of culling and death in sows. Nordic Veterinary Medicines 27(12), 604-615.

Tummaruk P., Kesdangsakonwut S., Kunavongkrit A. (2009). Relationships among specific reasons for culling, reproductive data, and Gross morphology of the genital tracts in gilts culled due to reproductive failure in Thailand. Theriogenology 71, 369-375.

Ward A., Nevel M., Thomson J.R. (2010). Infertility investigation in Scottish pig herds by examination of reproductive tracts. Proceedings of the 21st IPVS Congress, Vancouver, Canada, 788.

Chapter 6

General discussion

6 General Discussion

6.1 Introduction

The general aim of this thesis (**chapter 2**) was to investigate weaning management practices and reasons for culling sows in commercial pig herds to optimize sow reproductive performance. Good reproductive performance is a prerequisite for pig herds to be profitable. The financial result of swine breeding herds is strongly related to reproduction efficiency (Biksi et al., 2002). Economical losses are mostly associated with indirect costs, such as unplanned culling of sows not showing estrus. Reproductive failure causes a higher replacement rate and a high number of non-productive days (NPD; Tast et al., 2005).

Weaning is an important step in the reproductive cycle. The timing of weaning in commercial farms generally occurs when milk production is still high. In contrast with weaning under natural conditions, it is an abrupt process for the sow and the piglets. Weaned sows are expected to show estrus and to ovulate four to seven days after weaning. However, many different factors may influence onset of estrus after weaning, and by extension, reproductive performance of sows. **Chapter 1** provides an overview of factors influencing a prolonged weaning-to-estrus interval (WEI). Many of those factors influence also repeat breeding and litter performance. The WEI on its turn is also influencing the percentage of repeat breeders (RB; Kemp and Soede, 1996; Soede and Kemp, 1997) and litter performance (Tummaruk et al., 2000). The literature review in chapter 1 provides a useful guide for pig veterinarians to screen herds suffering from reproductive problems.

This general discussion focuses on strategies to reduce the number of NPD, by means of decreasing the percentage of unnecessary cullings, through (1) weaning management factors related with WEI and the percentage of RB (**Chapter 3**) (2) hormonal treatments that can be used to induce estrus and their influences on the subsequent reproductive performance (**Chapter 4**) and (3) the use of slaughterhouse examination as a means to improve the culling policy of pig herds (**Chapter 5**). The knowledge obtained in this thesis is schematically presented in figure 20.

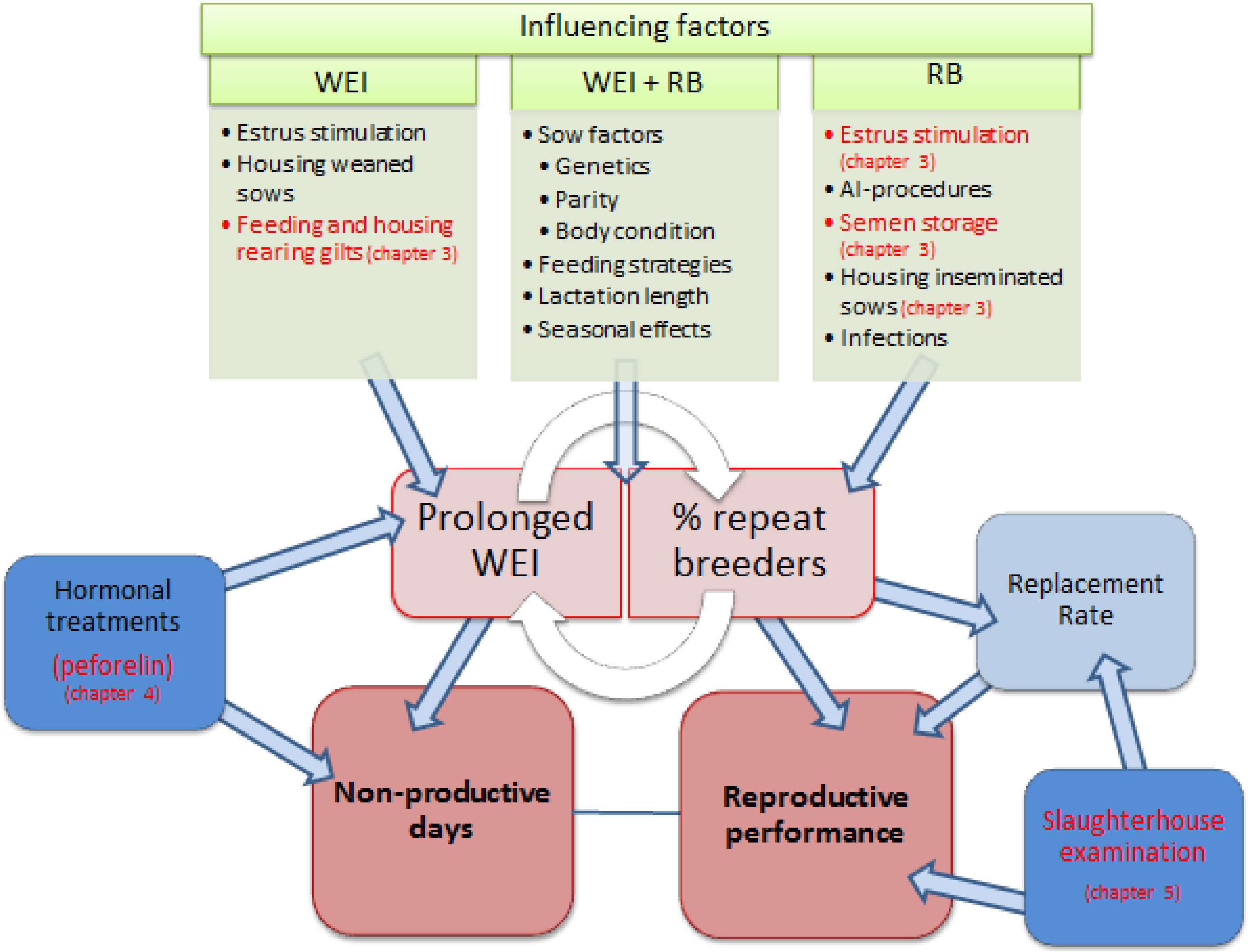

Figure 20. Schematic representation of the influencing factors of Weaning-to-Estrus interval (WEI) and percentage of regular Repeat Breeders (RB), with accent on the results obtained in this thesis.

6.2 Weaning management practices

Several management factors influence the WEI and the percentage of RB. In **chapter 3**, factors associated with the WEI and RB were identified and quantified at herd level. One factor was significantly associated with a shorter WEI, three factors were significantly associated with less RB (Fig. 20).

Housing the breeding gilts seperately from the finishing pigs and feeding the breeding gilts from 60 kg onwards until first insemination with a rearing diet different from the diet for finishing pigs was the only factor significantly associated with a shorter WEI, namely 2 days shorter. A rearing diet for gilts generally restricts lean growth and increases back fat (Levis, 1997) compared with diets aimed for fattening pigs. A rearing diet for gilts also aims to optimize reproductive efficiency and longevity of the sows, *inter alia* through providing greater levels of Ca and P compared to grow-finish concentrations (Levis, 1997; Jørgensen and Sørensen, 1998; Klindt et al., 2001, Whitney and Masker, 2010). As has been described in chapter 1, management of the gilts is a very important starting point to avoid reproduction problems. Primiparous sows need extra nutrients for growth during lactation. They have a lower feed intake capacity than older sows and they lack substantial reserves of fat and protein (ten Napel et al., 1995), especially if they are fed with diets for fattening pigs. Primiparous sows generally loose more bodyweight during lactation, what makes them more susceptible to impaired reproductive performance and decreased longevity (Stalder, 2002). The most common reason to cull primiparous sows is often leg weakness (D'Allaire et al., 1987; Engblom et al., 2007; Masaka et al., 2014), as was also observed in the study of chapter 5, with 35%. Rearing diets in gilts target a back fat thickness of 17-20 mm and a weight of at least 120 kg at second estrus and subsequent insemination (Aherne and Williams, 1992).

Three factors were significantly associated with a lower percentage of RB, namely the separation of the insemination facility from the gestation facility, storing diluted semen for artificial insemination (AI) for less than four days and performing estrus stimulation twice a day instead of once. Firstly, the higher percentage of RB in herds where the insemination facility was not separated from the gestation facility could be explained by the restlessness of the recently weaned sows, and the stress they may generate. Chronic stress during the first weeks of gestation, which is the period of implantation of embryos in the uterus (days 12-14) and the period where maternal recognition and thus many associated hormonal changes take place, should be avoided (Bokma, 1990; Turner and Tilbrook, 2006; Von Borell et al., 2007; Einarsson et al., 2008; Spoolder et al., 2009). If pregnant sows and newly weaned sows are housed next to each other in the same compartment, the restlessness due to the estrous sows and the presence of a teaser boar for estrus stimulation and detection may negatively influence sows in early pregnancy. Secondly, using fresh or one-day-old semen for AI was significantly better than semen that was stored for more than four days. This is likely due to the decrease in fertilizing capacity of spermatozoa as a consequence of *in vitro* ageing (Waberski et al., 1994; Kirkwood, 2003). It is therefore recommended to evaluate the semen quality not only immediately after ejaculation and dilution, but preferably also before insemination, and not to use semen collected more than four days ago. Thirdly, the percentage of RB was lower if estrus stimulation with the boar was performed twice daily. Vargas et al. (2009) also reported that more RB were observed in herds where the estrus detection was carried out only once a day. Other studies showed that the more time spent for estrus stimulation and detection, the better sows will show estrus symptoms (Kirkwood, 2003; Kemp et al., 2005; Bortolozzo et al., 2005). This will eventually lead to less problems due to missed estrus, and consequently decrease the unnecessary cullings due to so-called anestrus (chapter 5). Moreover, better estrus detection allows to better estimate the right insemination time (Steverink et al., 1999) and to achieve a successful conception, with lower regular return to estrus rates as a consequence and also less sows culled because of no pregnancy. In addition, a correct timing of insemination decreases the occurence of endometritis, as less sows will be inseminated after the end of estrus (Meredith, 1986; De Winter, 1995).

In the study of **chapter 3**, many unexplained variation remained in the final models, meaning that other not statistically significant factors may influence the outcome parameters as well (WEI, RB). Some of these factors such as lactation length, procedures of estrus stimulation, detection and insemination, housing conditions of weaned sows (*e.g.* ambient temperature and light) have been described in chapter 1. Seasonal influences did likely not influence the results, as all four seasons were included in the study. However, infections and sow-related factors, such as body condition, parity and breed were not investigated and may have contributed to the variation.

In conclusion, **chapter 3** investigated management strategies at herd level by means of a questionnaire in 76 commercial pig herds in Flanders. This approach, together with the identification of associated factors for WEI and percentage of RB, had not yet been described in literature to the authors' knowledge. The findings in this chapter documented that feeding strategy of breeding gilts was significantly associated with WEI and that the housing conditions of newly weaned sows, the frequency of estrus stimulation and the storage duration of diluted semen were significantly associated with RB. These factors were as such not yet described in literature as having an influence on the WEI and percentage of RB (Fig. 20). Some factors can be easily implemented by the farmer and should always be adviced in herds with reproductive problems, *e.g.* stimulating estrus twice a day instead of once and the examination of diluted semen before insemination. Other factors require more pronounced changes and/or financial investments *e.g.* housing conditions of gilts and pregnant sows. These factors certainly should be kept in mind when building new stables.

6.3 Hormonal treatments

To maximize the reproductive performance of sows, *i.e.* the number of litters per sow per year, the WEI of sows needs to be as short as possible. Management strategies for an optimal sow reproductive performance, as discussed in chapter 1 are not always sufficient. Pharmaceuticals (*i.e.* hormones) can be used to manipulate the estrus cycle in swine, and more specifically to synchronize estrus and ovulation in a group of sows. This can increase reproductive performance (Brüssow et al., 2010). The major challenge in commercial pig herds is to have fertile sows showing estrus as soon as possible after weaning, and to keep the variability in onset of estrus between sows as low as possible. A prolonged WEI and/or anestrus still occur frequently in pig herds. They are common reasons to cull sows (Koketsu et al., 1997; chapter 5), resulting in an increase of the replacement rate which is detrimental for the profitability of the herd. If problems of prolonged WEI occur in a herd and the number of NPD increases dramatically, one has to identify and adjust the underlying causes. When management factors described in chapter 1 and 3 are already implemented, but the problems are difficult to handle, a solution can be found in the administration of hormonal products (Fig. 20).

As described in chapter 1**,** PMSG/eCG, hCG or peforelin can be used to induce estrus in gilts and in weaned sows. Upon administration, estrus occurs approximately three to seven days after treatment. In the study of **chapter 4.1,** it was found that significantly more pluriparous sows in the peforelin treatment group showed estrus within seven days of weaning than was the case for the negative control group or the eCG treated group. This difference was however not demonstrated in gilts, nor in primiparous sows. As not showing estrus within a set time frame in a batch production system is a frequent reason to cull sows (chapter 5), peforelin can limit the replacement rate in pluriparous sows, by decreasing the proportion of sows not entering estrus within seven days post-weaning. This reduces also the number of NPD in a herd (Fig. 20).

During summer and fall, anestrus after weaning is more common, because of the suppression of GnRH release levels (chapter 1; Love et al., 1993; Peltoniemi et al., 1999). It is also more likely to occur in primiparous sows than in pluriparous sows (Britt, 1986). Treatment with gonadotropins (eCG, hCG) or peforelin at weaning can reduce the incidence of anestrus (Bates et al., 1991; Engl et al., 2010a; Benaglia et al., 2012; Krejci et al., 2012) either by increasing the levels of endogenous gonadotropins or by stimulating the insufficient secretion of the endogenous GnRH and thus subsequently also the gonadotropins. Primiparous sows treated with eCG tended to have shorter WEI (**chapter 4.1**). This was consistent with the results of Engl (2006) and Engl et al. (2010b), and may occur because eCG exhibits both LH- and FSH-like activities (De Rensis et al., 2005). Luteinizing hormone stimulates the growth of follicles from 4 mm to preovulatory size (Farmer and Papkoff, 1979), which in turn shortens the follicular phase and thus the WEI (Driancourt et al., 1995). In the gilts and pluriparous sows, no significant differences were found in WEI after the use of eCG or peforelin. This indicates that these products mainly have effects on problematic sows, such as primiparous sows and during seasonal infertility periods.

It has been suggested that sows with a low ovulation rate can be treated with exogenous GnRH to increase the litter size (Ferguson et al., 2004; Kemp et al., 2011; Wientjes et al., 2012). In **chapter 4,** no significant increase in litter size was found after the use of peforelin, but an increase in litter size in young sows treated with eCG was observed. Luteinizing Hormone-like activity products have been shown to support follicular development better in younger animals, because of the less adequate endogenous LH levels (Manjarin et al., 2010a, b). Treatment with eCG could thus have more influence on litter size in younger sows than in older sows. The lower birth weights obtained in the eCG treated animals (**chapter 4.2**), is possibly related to these larger litters in this groups as litter size has an influence on the birth weight of piglets (Lush et al., 1933; Kerr and Cameron, 1995; Roehe, 1999; Sorensen et al., 2000; Akdag et al., 2009; Beaulieu et al., 2010).

Administration of exogenous GnRH has been shown to increase the internal FSH levels in sows, increasing the follicular size (Picton et al., 1999; Knox, 2005). This leads to larger follicles at ovulation in a uniform pre-ovulatory pool (Engl, 2006), with more uniform qualities of oocytes (Zak et al., 1997), more uniformly developed embryos (Pope et al., 1990; Xie et al., 1990) and subsequently a higher homogeneity in weights at birth (Wientjes et al., 2012). Peforelin had a positive effect on follicle growth in gilts and pluriparous sows (**chapter 4.1**), therefore it was hypothesized that the birth weight and the homogeneity of birth weights would increase as well. However, in the study of **chapter 4.2**, the birth weight of piglets born from females treated with peforelin did not significantly differ with those from the non treated females. A significant herd effect was present. Analysing the herds individually revealed three different reactions on the treatments: in one herd the peforelin group had the highest birth weights in all parity groups, except for the primiparous sows. In the second herd peforelin did not differ from the control group in all parity groups, except in the gilts. And in the third herd there was no effect at all of any of the treatments. It would thus be interesting to look further into detail why these herds differed so much. Several confounding factors can be the cause of the non reaction of sows to the treatments, *e.g.* breed, subclinical infections, etc. In chapter 5, it has been demonstrated that many sows suffer from subclinical endometritis. This could perhaps have an effect on the outcome of hormonal treatments.**Chapter 4** described the effects of the administration of peforelin in commercial Belgian pig herds with an average reproductive performance. The combination of the comparison with both a positive and negative control group, the comparison between gilts, primi- and pluriparous sows and the investigation of as well as estrus events, back fat, follicle size and blood parameters as litter performance had not yet been described as such in literature to the authors' knowledge. It was shown that administration of peforelin can increase reproductive performance in Belgian commercial pig herds with average reproductive results (Fig. 20), although the effects differ according to parity group. Peforelin increased the number of pluriparous sows in estrus within seven days post weaning, but did not have any effect on litter performance. Therefore, peforelin is recommended to be used in herds trying to improve their estrus performance, but more research is needed to investigate whether peforelin could improve litter performance, more specifically birth weights.

6.4 Slaughterhouse examination

Problems with prolonged WEI or anestrus, repeat breeding and poor litter performance increase the percentage of culled sows and subsequently the replacement rate of a herd (Fig. 20). A proper culling policy in sow herds is a prerequisite to maintain a stable parity profile of the breeding animals. This is necessary to maintain consistent production and to avoid huge swings in the number of replacement gilts. The mean parity of the culled sows in the study of **chapter 5** was five, indicating that the herds had an optimal replacement policy (Huirne et al., 1991; chapter 1). Reproductive failure is one of the major reasons for culling sows. Up to 50% of all sows are culled because of impaired fertility in the study of D'Allaire and Drolet (2006) which is in agreement with the results described in **chapter 5**. In the latter study, no pregnancy (18%), too few piglets weaned (14%) and no estrus (10%) were the most important culling reasons. Management strategies, such as an increased estrus stimulation (chapter 3) or the use of hormonal products (chapter 4) could decrease the number of cullings due to the forementioned problems. To optimize culling decisions in a herd, examination of culled sows in the slaughterhouse could be helpful (Fig. 20). It appeared that the reasons of culling could not always be substantiated by the findings of the slaughterhouse examination (**chapter 5**). For example, in the category of sows culled because of anestrus, more than half of them had perfectly normal cycling ovaries. In these herds, one could advise to improve the practices of estrus stimulation and detection (chapter 3). In the category of sows culled because of no pregnancy, 20% of the uteri were found to be pregnant. In these herds, recommendations to improve the pregnancy diagnosis are warranted.

Overall, 16% of the culled sows showed inactive ovaries (**chapter 5**). This is a considerable percentage, as inactive ovaria are associated with anestrus and lead to an increase in the number of NPD. The study in chapter 5 was carried out during the winter period, which is the darkest period of the year, resulting in higher levels of melatonin (Spoolder et al., 2009). It has been shown that sows have more problems with showing estrus due to the suppression of the GnRH release, because of increased melatonin levels. It is therefore possible that the percentage of inactive ovaries observed in the study is higher than when sows would have been examined throughout the year. Nonetheless, during winter, sows in Belgium do have problems with inactive ovaries and the use of hormonal products can then reduce the incidence of anestrus and thus decrease the number of inactive ovaries.

Examination of slaughterhouse material also reveals the presence of cystic ovarian follicles (COF), which was 15% in the study in **chapter 5**, leading to sows with prolonged WEI or sows showing anestrus (Castagna et al., 2004). An increased incidence of COF has been associated with several factors. Yet, it is believed that many other influencing factors are still unknown. A first important risk factor is stress. Stress causes endocrine disbalance and consequently it may prevent ovulation. Follicles continue to grow and form COF. Additionally, chronic stress increases cortisol concentrations, which has been associated with COF *e.g.* in gilts during their acclimatization period in a herd (Flowers et al., 1989). Lactation lengths shorter than three weeks have also been shown to be a risk factor for COF, which may consequently impair the WEI (Soede et al., 2009). But also short WEI, less than three days, are frequently associated with COF (Castagna et al., 2004). The use of hormonal products in gilts, *e.g.* administration of gonadotropins at an unknown cycle stage or an underdosed administration of progestagens (< 13 mg per day), may contribute to the formation of COF, due to insufficient suppression of the reproduction cycle (Kirkwood, 1999). Finally, zearalenone toxicity is also a risk factor (Gherpelli and Tarocco, 1996). The incidence of COF is herd dependent and no equivocal results have been found considering parity prevalence (**chapter 5**; Gherpelli and Tarocco, 1996; Castagna et al., 2004; Beek et al., 2011). Treatment of sows with COF is difficult and generally unsatisfactory, therefore culling is mostly the best option (Cech and Dolezel, 2007). Sows, suspected of having COF, can be examined by ultrasound to determine whether they have to be culled, *i.e.* when large cysts are present, or whether they could be treated with hormonal products to restore the ovarian activity (Kauffold et al., 2004). The routine use of ultrasonography of the ovaries can decrease the number of unnecessary cullings.

Endometritis was frequently detected in the study in **chapter 5**, whereas it was not always clinically observed by the farmers. Infections of the uterus may occur at insemination or at parturition. Endometritis originating post parturition is generally accompanied with systemic symptoms, whereas this is mostly not the case for post-service endometritis. Some sows can show signs of vulvar discharge, but they will likely not show fever, depression and/or anorexia. However, they will be temporarily or even permanent infertile (De Winter, 1995). Lower pregnancy rates, increases in irregular returns to estrus, embryonic death, abortions and reduced farrowing rates on a herd are signals of possible problems with subclinical endometritis (De Winter, 1995). Hence, a correct diagnosis is difficult. Chronic endometritis, which was the majority of the observed infections in the study of chapter 5, cannot definitively be diagnosed by ultrasonography (Kauffold et al., 2005; Kauffold and Althouse, 2007). In the study of **chapter 5**, subclinical endometritis was associated with lower pregnancy rates and poor nursing performance, indicating that slaughterhouse examination, including histopathology, could reveal endometritis as the cause of certain reproductive problems in a herd. Treatment of endometritis is rather doubtful. Antibiotics should only be used, when sensitivity tests are performed after bacteriological isolation. The choice of antibiotic depends on the infectious agents involved, the pharmacokinetic and -dynamic properties, *i.e.* whether the antibiotic will reach the place of infection and whether it will be effective there (De Winter, 1995). Interpretation of results of bacteriological examination needs to be done with care, as false positive and false negative results can be present. Bacteriological examination appeared not to be a sensitive tool to diagnose endometritis (chapter 5). Therefore, it should be combined with for example visual inspection (Biksi et al., 2002). When endometritis is frequently detected in a herd at slaughter, management (*e.g.* estrus stimulation and detection together with the timing of insemination) and hygiene conditions during insemination and parturition (*e.g.* pen hygiene in the insemination and farrowing unit and the use of lubricants) need to be inspected thoroughly (De Winter, 1995). The study in **chapter 5** investigated the reasons for culling sows in commercial pig herds in Flanders together with a macroscopical, bacteriological and histopathological examination of the reproductive tract of the culled females. This, together with the assessed agreements between macroscopical, bacteriological and histopathological diagnostic methods for endometritis, had not yet been described in literature to the authors'knowledge.

Examination of culled sows in the slaughterhouse may help to optimize culling decisions and finally also the sow reproductive performance on pig herds (Fig. 20). The reproductive tract of culled breeding animals can be investigated in a simple way, and the visual inspection can be complemented with further histopathological and/or bacteriological examinations. Doing this on a routine basis, the pig farmer receives more information about the exact causes of culling and can adjust his culling policy in order to improve the reproductive performance in his herd.

6.5 Conclusion

In conclusion, pig producers can limit the NPD associated with prolonged WEI and with repeat breeding. Therefore, they should develop strategies (1) to minimize the prevalence of reproduction inefficiencies, and (2) to limit the interval from the last reproductive event (*e.g.* farrowing, weaning, insemination) until removal, being the number of NPD per culled sow (Koketsu et al., 1997). These strategies could comprise first of all the optimization of certain management practices associated with the herd specific problems (**chapter 3**), the use of hormonal products (**chapter 4**) and/or the use of slaughterhouse examination to optimize the decisions on culling sows (**chapter 5,** Fig. 20). Pig producers should minimize the percentage of unnecessary cullings. To avoid leg weakness in primiparous sows, gilts should be reared separately from the finishing pigs (chapter 3); to limit culling of sows due to no pregnancy or anestrus, emphasis should be placed on estrus stimulation and detection (chapter 3). The number of sows culled because of anestrus and small litter size could be reduced by treating them with hormonal products (chapter 4). It is obvious that assessing the stage of reproductive failure and identifying the associated risk factors are not always straightforward. As there are numerous risk factors or differential diagnoses for the different types of reproductive failure, a diagnostic examination of the environment, management, nutrition, housing and infectious diseases is necessary. In addition, monitoring culling rate and culling reasons, and investigating the correspondence of culling reasons with the results of diagnostic examinations in the slaughterhouse, can identify diseases or management deficiencies.

6.6 Perspectives for future research

Based on the studies performed in this thesis, areas for future research have come forward.

- The first study focused on factors associated with WEI and percentage of RB at herd level. It would be interesting to investigate associations between factors at sow level, *e.g.* breed, body condition or parity, and other reproductive parameters, *e.g.* litter performance, as some unexplained variation in the final statistical models may be attributed to individual sow characteristics. The effects of peforelin on birth weight were quite variable between the herds. More research is needed to identify factors *e.g.* breed, that may explain this variation.
- In the peforelin study, an economical advantage was demonstrated by the decrease of NPDs. However, a detailed economic analysis needs to be done in order to quantify the benefits of the use of peforelin and the possible improvement of reproductive performance in relation to the additional costs. What is the return on investment of the use of peforelin?
- More studies need to be done in order to confirm the results obtained in the peforelin studies. The largest follicles at insemination were observed in sows treated with peforelin, but the FSH levels did not increase significantly after treatment. Therefore, further research is needed to investigate whether peforelin could increase the FSH levels in gilts or sows. More research is also needed to investigate whether l-GnRH-III would act locally at the ovarian level. Besides the influence of peforelin on FSH, the influence of peforelin on the LH level in gilts and sows is not clear. If peforelin indeed increases the follicle sizes and improves oocyte quality, it would be interesting to know whether these follicles indeed develop in larger *cl*, producing more P4.
- Cystitis and endometritis are strongly associated (Biksi et al., 2002). It would be interesting to perform the study on slaughterhouse examination of the reproductive tract again, but including the urinary tract of the animals, and to compare the results of the bacteriological and histopathological examination of the bladder with those from the uterus. In addition, to fully assess a seasonal effect, studies including all months of the year should be conducted.
- Finally, it has been shown that slaughterhouse examination can provide useful information for the pig owners. It would be interesting to develop a tool which automatically gives relevant feedback (*e.g.* condition of the uterus and ovaries) to farmers when sows are culled. This information could be provided in addition to the current information on slaughter pigs that is provided to farmers. Associations could be made between reason for

culling and macroscopical examination, but also between macroscopical examination and lifetime productivity of the sows.

6.7 General conclusions of the thesis

From the results of this thesis, the following conclusions can be drawn:

1. Reproductive failure is the most frequent reason for culling sows. The decision to cull is mainly made at or shortly before weaning. Macroscopical examinations of the reproductive tract do not always corroborate with the reasons for culling.
2. To minimize the percentage of unnecessary cullings due to reproductive failure, following aspects need to be kept in mind:
    a. The management of rearing gilts has an influence on the reproductive outcome of the gilt in her further life. Feeding a rearing diet for gilts from 60kg onwards increases the longevity of sows, decreases the percentage of cullings due to leg weakness and improves the WEI.
    b. Estrus stimulation and estrus detection are of utmost importance in the weaning management of a herd. Performing estrus stimulation twice a day instead of once decreases the percentage of sows culled because of so-called anestrus and no pregnancy and decreases the percentage of RB.
    c. Insemination procedures, specifically the timing of insemination, need to be addressed carefully. Many reproductive outcomes are related with the procedures of AI. A proper AI-scheme decreases the percentage of sows culled because of no pregnancy and storage of semen longer than four days increases the percentage of RB.
    d. The housing of recently inseminated sows must provide a quiet environment in which sows do not suffer from stressors. Separation of newly inseminated sows and weaned sows decreases the percentage of RB and consequently decreases the percentage of sows culled because of no pregnancy.
    e. Administration of hormonal products can enhance the reproductive efficiency in gilts and sows. More specifically, peforelin increases the proportion of pluriparous sows in estrus within seven days post-weaning and can decrease the percentage of sows culled because of anestrus.
3. Finally, endometritis is frequently found at slaughter in sows culled for reproductive failure. Examination of sows in the slaughterhouse can identify diseases or management deficiencies and optimize the culling policy.

6.8 References

Aherne F., Williams I. (1992). Nutrition for optimizing breeding herd performance. Veterinary Clinical North America Food Animal Practicioners 8(3), 589-608.

Akdag F., Arslan S., Dernir H. (2009). The effect of parity and litter size on birth weight and the effect of birth weight variations on weaning weight and pre-weaning survival in piglet. Journal of Animal and Veterinary Advances 8(11), 2133-2138.

Bates R.O., Day B.N., Britt J.H., Clark L.K., Brauer M.A. (1991). Reproductive performance of sows treated with a combination of pregnant mare's serum gonadotropin and human chorionic gonadotropin at weaning in the summer. Journal of Animal Science 69, 894-898.

Beaulieu A.D., Aalhus J.L., Williams N.H., Patience J.F. (2010). Impact of piglet birth weight, birth order, and litter size on subsequent growth performance, carcass quality, muscle composition and eating quality of pork. Journal of Animal Science 88, 2767-2778.

Beek J., de Jong E., Van Soom A., de Kruif A., Maes D. (2011). Ovarian cysts in sows: a multifactorial disorder with consequences on the reproductive performance. Vlaams Diergeneeskundig Tijdschrift 80, 215-222.

Benaglia P., Krejci R., Lopez A., Casappa P. (2012). Effect of synchronization of estrus in sows after weaning using Fertipig in comparison with another gonadotropin product. Proceedings of the 22nd IPVS Congress, Jeju, Korea, 92.

Biksi I., Takacs N., Vetesi F., Fodor L., Szenci O., Fenyo E. (2002). Associations between endometritis and urocystitis in culled sows. Acta Veterinaria Hungarica 50(4), 413-423.

Bokma (1990). Housing and management of dry sows in groups in practice: partly slatted systems. Electronic identification in pig production. Monograph Series, 10, Royal Agricultural Society, UK, 37-46.

Bortolozzo F.P. Uemoto D.A., Bennemann P.E., Pozzobon M.C., Castagna C.D., Peixoto C.H., Barioni J.W., Wentz I. (2005). Influence of time of insemination relative to ovulation and frequency of insemination on gilt fertility. Theriogenology 64, 1956-1962.

Britt J.H. (1986). Improving sow productivity through management during gestation, lactation and after weaning. Journal of Animal Science 63, 1288-1296.

Brüssow K.P., Schneider F., Tuchscherer A., Kanitz W. (2010). Influence of synthetic lamprey GnRH-III on gonadotropin release and steroid hormone levels in gilts. Theriogenology 74(9):1570-1578.

Castagna C., Peixoto C., Bortolozzo F., Wentz I., Neto G.., Ruschel F. (2004). Ovarian cysts and their consequences on the reproductive performance of swine herds. Animal Reproduction Science 81, 115-123.

Cech S., Dolezel R. (2007). Treatment of ovarian cysts in sows – a field trial. Veterinarni Medicina 52, 413-418.

D'Allaire S. and Drolet R. (2006). Longevity in Breeding Animals. In: Straw B.E., Zimmerman J.J., D`Allaire S., Taylor D.J., eds., Diseases of Swine (9th edition), Ames Iowa State University Press, 1011-1025.

De Rensis F., Gherpelli M., Superchi P., Kirkwood R.N. (2005). Relationships between backfat depth and plasma leptin during lactation and sow reproductive performance after weaning. Animal Reproduction Science 90, 95-100.

Driancourt M.A., Locatelli A., Prunier A. (1995). Effects of gonadotrophin deprivation on follicular growth in gilts. Reproduction Nutrition Development 35, 663-673.

Einarsson S., Brandt Y., Lundeheim N., Madej A. (2008). Stress and ist influence on reproduction in pigs: a review. Acta Veterinaria Scandinavica 50, 48.

Engl S. (2006). Untersuchungen zur Eignung einer neuen GnRH-Variante zur Brunstinduktion bei pluripare Sauen. Inaugural-Dissertation zur Erlangung des Grades eines Doctor medicinae veterinariae, Leipzig.

Engl S., Zepperitz H., Rath R., Zaremba W. (2010a). Practical experience with Peforelin in a large sow herd: data from primiparous sows. Proceedings 21st IPVS, Vancouver, Canada, 1085.

Engl S., Zepperitz H., Rath R., Zaremba W. (2010b) Practical experience with Peforelin in a large sow herd: data from pluriparous sows. Proceedings 21st IPVS, Vancouver, Canada, 1086.

Farmer S.W., Papkoff H. (1979). Immunochemical studies with Pregnant Mare Serum Gonadotropin. Biology of Reproduction 21, 425-431.

Ferguson E.M., Ashworth C.J., Hunter M.G., Penny P., Slevin J., Edwards S.A. (2004). The effect of feeding a high fibre diet from mid lactation until breeding on subsequent litter size of sows. In: Thompson JE, Gill BP, Varley MA. The appliance of pig science. Nottingham University Press, Nottingham, UK, p. 175-179.

Flowers B., Cantley T.C., Martin M.J., Day B.N. (1989). Effect of elevated ambient temperatures on puberty in gilts. Journal of Animal Science 67, 779-784.

Gherpelli M., Tarocco C. (1996). A study on the incidence and clinical evolution of the ovarian cysts in the sow. Proceedings of the 14th IPVS, Bologna, Italy, 587.

Huirne R., Dijkhuizen A., Renkema J. (1991). Economic optimization of sow replacement decisions on the personal computer by method of stochastic dynamic programming. Livestock Production Science 28, 331-347.

Jørgensen B., Sørensen M.T. (1998). Different rearing intensities of gilts: II. Effect on subsequent leg weakness and longevity. Livestock Production Science 54, 167-171.

Kemp B., Soede N. (1996). Weaning to estrus interval in relation to timing of ovulation and fertilization results in sows. Journal of Animal Science 74, 944-949.

Kemp B., Soede N.M., Langendijk P. (2005). Effects of boar contact and housing conditions on estrus expression in sows. Theriogenology 63, 643-656.

Kemp B., Soede N.M., Vesseur P.C. (2011). Oorzaken en consequenties van variatie in het interval spenen en bronst. Cursus Vruchtbaarheid en Voortplanting van het Varken, Wageningen University, The Netherlands.

Kerr J.C., Cameron N.D. (1995). Reproductive performance of pigs selected for components of efficient lean growth. Animal Science 60, 281-290.

Kirkwood R.N. (1999). Pharmacological intervention in swine reproduction. Swine Health and Production 7, 29-35.

Kirkwood R. (2003). Techniques to fine-tune reproduction. London Swine Conference – Maintaining your competitive Edge.

Klindt J., Yen J.T., Christenson R.K. (2001). Effect of prepubertal feeding regimen on reproductive development and performance of gilts through the first pregnancy. Journal of Animal Science 79, 787-795.

Knox R.V. (2005). Recruitment and selection of ovarian follicles for determination of ovulation rate in the pig. Domestic Animals Endocrinology 29, 385-397.

Koketsu Y., Dial G., King V. (1997). Returns to service after mating and removal of sows for reproductive reasons from commercial swine farms. Theriogenology 47, 1347-1363.

Krejci R., Carmona M., Lopez A., Sierra E.R. (2012). Induction and synchronization of estrus in problematic sows after weaning using Fertipig in comparison with another gonadotropin product. Proceedings of the 22nd IPVS Congress, Jeju, Korea, 93.

Levis D.G. (1997). Management of replacement gilts for efficient reproduction. University of Nebraska Cooperative Extension EC 97-274-A. Lincoln, NE.

Love R.J., Evans G., Klupiec C. (1993). Seasonal effects on fertility in gilts and sows. Journal of Reproduction and Fertility 48, 191-206.

Lush J.L., Hetzer H.O., Culbertson C.C. (1933). Factors affecting birth weight of swine. Genetics 19, 329-343.

Manjarin R., Dominguez J.C., Castro M.J., Alegre B., Driancourt M.A., Kirkwood R.N. (2010a). Effect of hCG on early luteal serum progesterone concentrations in PG600-treated gilts. Reproduction of Domestic Animals 45(3), 555-557.

Manjarin R., Garcia J.C., Dominguez J.C., Castro M.J., Alegre B., Munoz J.D., Kirkwood R.N. (2010b). Effect of gonadotropin treatment on estus, ovulation and litter size in weaned and anestrus sows. Journal Animal Science 7, 2356-2360.

Peltoniemi O., Love R., Heinonen M., Tuovinen V., Saloniemi H. (1999). Seasonal and management effects on fertility of the sow: a descriptive study. Animal Reproduction Science 55, 47-61.

Picton H.M., Miller A.T., Hunter M.G. (1999). Effect of FSH infusion on follicle development in GnRH agonist-treated gilts. Journal of Reproduction and Fertility 117(2), 246-257.

Pope W.F., Xie S., Broermann D.M., Nephew K.P. (1990). Causes and consequences of early embryonic diversity in pigs. Journal of Reproduction and Fertility Supplement 40, 251-260.

Roehe R. (1999). Genetic determination of individual birth weight and its association with sow productivity traits using Bayesin analyses. Journal of Animal Science 77, 330-343.

Soede N.M., Kemp B. (1997). Expression of estrus and timing of ovulation in pigs. Journal of Reproduction and Fertility (suppl) 52, 91-103.

Soede N.M., Hazeleger W., Geristsen R.R., Langendijk P., Kemp B. (2009). Ovarian responses to lactation management strategies. Society for Reproduction and Fertilization (suppl) 66, 177-186.

Stalder K. (2002). Non-genetic factors influencing sow longevity. Factsheet, Pork Information Gateway. http://www.pork.org/filelibrary/Factsheets/PIGFactsheets/NEWfactSheets/08-04-02g.pdf (last acces: 02/06/2014)

Sorensen D., Vernersen A., Andersen S. (2000). Bayesian Analysis of Repsonse to selection: a case study using litter size in Danisch Yorkshire Pigs. Genetics 156, 283-295.

Spoolder H.A.M., Geudeke M.J., Van der Peet-Schwering C.M.C., Soede N.M. (2009). Group housing of sows in early pregnancy: a review of success and risk factors. Livestock Science 125, 1-14.

Steverink D., Soede N., Groenland G., van Schie F., Noordhuizen J., Kemp B. (1999). Duration of estrus in relation to reproduction results in pigs on commercial farms. Journal of Animal Science 77, 801-809.

Tast A., Hälli O., Virolainen J., Oravainen J., Heinonen M., Peltoniemi O. (2005). Investigation of a simplified artificial lighting programme to improve the fertility of sows in commercial piggeries. Veterinary Record 156, 702-705.

ten Napel J., Kemp B., Luiting P., de Vries A. (1995). A biological approach to examine genetic variation in weaning to oestrus interval in first litter sows. Livestock Production Science 41, 81-93.

Tummaruk P., Lundeheim N., Einarsson S., Dalin A.M. (2000). Reproductive performance of purebred Swedish Landrace and Swedish Yorkshire sows II: effect of mating type, weaning to first service interval and lactation length. Academica Agriculturae Scandinavica 50, 217-224.

Turner A.I., Tilbrook A.J. (2006). Stress, cortisol and reproduction in femal pigs. Society of reproduction and fertility supplement 62, 191- 203.

Vargas A., Bernardi M., Bortolozzo F., Mellagi A.., Wentz I. (2009). Factors associated with return to estrus in first service swine females. Preventive Veterinary Medicines 89, 75-80.

Von Borell E., Dobson H., Prunier A. (2007). Stress, behaviour and reproductive performance in female cattle and pigs. Hormones and Behavior 52, 130-138.

Waberski D., Weitze K.F., Lietmann C., Lubbert zur Lage W., Bortolozzo F.P., Willmen T., Petzoldt R. (1994). The initial fertilizing capacity of longterm-stored liquid boar semen following pre- and postovulatory insemination. Theriogenology 41, 1367-1377.

Whitney M.H., Masker C. (2010). Replacement gilt and boar nutrient recommendations and feeding management. National Swine Nutrition Guide, 97-107.

Wientjes J.G.M., Soede N.M., Van den Brand H., Kemp B. (2012). Nutritionally induced relationships between insulin levels during the weaning-to-ovulation interval and reproductive characteristics in multiparous sows: II. Luteal development, progesterone and conceptus development and uniformity. Reproduction of Domestic Animals 47, 62-68.

Xie S., Broermann D.M., Nephew K.P., Geisert R.D., Pope W.F. (1990). Ovulation and early embryogenesis in swine. Biology of Reproduction 43, 236-240.

Zak L., Cosgrove J., Aherne F., Foxcroft G. (1997). Pattern of feed intake and associated metabolic changes differentially affect postweaning fertility in primiparous lactating sows. Journal of Animal Science 75, 208-216.

Summary

Good reproductive performance is a prerequisite for pig herds to be profitable. Reproduction, however, is a complex process. Various internal and external elements are involved and interrelated, such as hormonal changes, season, housing condition, feeding and sow management in the different phases of the reproductive cycle.

One of the major challenges is to have fertile sows showing estrus as soon as possible after weaning. The sooner sows are showing estrus, the sooner they can be inseminated, the shorter the sow's reproductive cycle and the fewer the number of non-productive days in a herd. Many different non-infectious factors such as length of lactation, body condition, and weaning management practices may influence the weaning-to-estrus interval. To optimize the sow's weaning-to-estrus interval, it is important to identify influencing factors, that could be easily implemented in the farmer's management. Hence, first of all insights need to be gained into current weaning management practices on sow herds. Apart from management practices, pharmaceuticals *i.e.* hormones, are often used in case of seasonal infertility or problems in primiparous sows. New commercial products have been developed, and their effects on different phases of the reproduction cycle, *e.g.* the induction of estrus, need to be examined. Finally, a prolonged weaning-to-estrus interval can also lead to early culling of sows, resulting in a lower average parity and an increased replacement rate in the herd, which negatively influences the profitability. To determine whether these reasons for culling are justified, examination of the reproductive organs of sows in the slaughterhouse is needed.

Chapter 1 starts with an overview of the normal reproduction cycle of the sow and focuses then on the different influencing factors of a prolonged weaning-to-estrus interval, the percentage repeat breeders and the litter performance. The chapter concludes with an overview of the reasons for culling found in literature, the influencing factors for sow removal and the macroscopical examination of the reproductive organs of gilts and sows.

The general aim of this thesis was to investigate weaning management practices and reasons for culling sows in commercial pig herds to optimize sow reproductive performance (**chapter 2**).

To obtain more knowledge about the weaning management practices in commercial pig herds and to identify factors associated with specific reproductive parameters of sows after weaning, the study described in **chapter 3** was performed. A questionnaire pertaining to sow management at weaning and herd reproductive data was used on 76 randomly selected commercial pig herds in Belgium. Associations between the herd factors and two reproductive parameters after weaning (weaning-to-estrus interval: WEI and percentage of repeat breeders: RB) were analysed using general linear mixed models. A separated feeding strategy of breeding gilts from 60 kg onwards was significantly associated with a shorter WEI (5.54 vs 7.28 days; p = 0.040). Factors significantly associated with a lower percentage of RB were housing the newly weaned sows separated from the gestating sows (7% vs 12%; p = 0.003), using semen < 4 days after collection (7–9 vs 14%; p = 0.014) and stimulating estrus twice a day (8 vs 11%; p = 0.025). It was concluded that some management practices, such as feeding strategy of breeding gilts, housing conditions of sows, method of estrus stimulation and storage duration of semen, have an influence on the outcome of reproductive parameters such as WEI and percentage of RB. These practices can be implemented rather easily by pig producers and may consequently lead to improvements of reproductive performance of sows after weaning.

Hormonal treatments may be used for problems of reproductive failure in gilts and sows, therefore the aims in **chapter 4.1** were to investigate the ability of peforelin (l-GnRH-III) to stimulate follicular growth, FSH release and estrus in gilts after altrenogest treatment and in sows after weaning. In three farrow-to-wean herds, with at least 600 sows and average production performance, 216 gilts, 335 primi- and 1299 pluriparous sows were randomly allocated to three treatments: peforelin (M group: Maprelin®), eCG (F group: Folligon®), and physiological saline solution (C group). Animals were treated 48h after the last altrenogest treatment (gilts) or 24h after weaning (sows). The WEI, estrus duration, estrus rate, pregnancy rate, and total birth, live birth and stillbirth numbers were recorded and compared between treatments for the different parity groups (gilts, primi- and pluriparous sows). Follicle sizes were measured in representative animals from each group on the occasion of their last altrenogest treatment or at weaning, and also on the occasions of their first and second attempted inseminations. Blood samples were taken to measure FSH concentrations at weaning and 2 hours after injection, and progesterone (P4) concentrations 10 days after the first insemination attempt. The relative change in FSH concentrations was calculated. Significant differences were found for estrus rate within 7 days of weaning in pluriparous sows (95, 91 and 90% for the M, F and C groups, respectively, p = 0.005). Gilts in the F-group had high total birth numbers and pluriparous sows in the M group had high stillbirth numbers (number of total born piglets gilts = 13.6, 15.4 and 14.9 (p = 0.02) and number of stillborn piglets pluriparous sows = 1.8, 1.4 and 1.7 (p = 0.05) for the M, F and C groups, respectively). The M group had the highest follicle size at first insemination (for gilts) and follicle size for the second insemination (for pluriparous sows) values: follicle size at first insemination = 5.4, 4.9 and 4.9mm ($p = 0.02$) and at second insemination = 6.8, 5.3 and 6.3mm ($p = 0.03$) for the M, F and C groups, respectively. There were no significant differences between the different treatments within each parity group with respect to any of the other variables. Overall the study demonstrated that peforelin treatment has small but positive effects on the estrus rate and follicle growth in specific parity groups but does not seem to affect litter sizes or FSH and P4 levels in sows on the occasions of the corresponding examinations.

In **chapter 4.2** the effects of peforelin on the litter performance were investigated. In the same three farrow-to-wean herds as in **chapter 4.1**, 270 animals were randomly allocated to three treatments: peforelin (M group), eCG (F group), and physiological saline solution (C group). Animals were treated 48h after their last altrenogest treatment (gilts) or 24h after weaning (sows). The gestation length, number of total, live born, stillborn and weaned piglets and mortality rate during lactation were recorded. The birth and weaning weight were assessed and the coefficient of variation in weights per litter was calculated. All parameters were compared between treatments for the different parity groups (gilts, primi- and pluriparous sows). Litter size and number of stillborns were greater in the F group in gilts (13.1, 15.2, 14.2 ($p = 0.03$) and 0.7, 1.6 and 0.6 piglets ($p = 0.05$) for the M, F and C group, respectively). The stillbirth numbers in the pluriparous sows were 2.2, 0.9 and 1.4 for the M, F and C groups, respectively ($p < 0.01$). Piglets in the F group had the lowest birth weight in gilts, primiparous sows and over all parities (1.36, 1.26, 1.32kg ($p < 0.03$), 1.47, 1.40, 1.45kg ($p = 0.02$) and 1.42, 1.35 and 1.40kg ($p < 0.01$) for the M, F and C groups, respectively) and the highest coefficient of variation of birth weight of total born in gilts and over all parities (0.19, 0.22, 0.21 ($p = 0.02$) and 0.22, 0.25 and 0.23 ($p \leq 0.05$) for the M, F and C groups, respectively). The weaning weight of the M group was the highest in gilts and the lowest in pluriparous sows: 5.30, 5.07, 5.08kg ($p < 0.03$) and 5.43, 5.80 and 5.71kg ($p < 0.02$) for the M, F and C group, respectively. The coefficient of variation of weaning weight was the lowest in the M group in primiparous sows (0.18, 0.19 and 0.20 for the M, F and C group, respectively ($p = 0.05$)). There were no significant differences between the different treatments within each parity group with respect to any of the other variables.

Chapter 4.2 demonstrated that peforelin treatment showed no difference compared to no treatment according to litter performance. It seemed to have positive effects on the weaning weight in gilts, but this was the other way round in pluriparous sows. Furthermore, peforelin could increase the uniformity of the piglets at weaning in young sows, but this effect was not seen in older sows.

Reproductive failure is one of the most frequent reasons for removal of sows. In **chapter 5** the reasons for culling of 502 sows from 7 commercial pig herds were investigated and the reproductive tract of these sows were examined by macroscopical, bacteriological and histopathological examination. Associations between all three examinations were statistically analysed. More than 50% of the sows was culled because of reproduction failure, while old age was the second most common reason (23%). Approximately 75% of the examined uteri were visually normal. Purulent exudate was detected in 18% of the animals. No abnormalities were found in 54% of the ovaries, whereas 28% showed inactivity. Sixty-two percent of the uteri were bacteriologically positive, with *E. coli* (18%) being the most frequently isolated. Histologically, 52% of the uteri showed mild to severe inflammation. From the uteri with endometritis based on visual inspection and histology, 26% and 30% was bacteriologically negative, respectively. The presence of bacteria showed a slight agreement with macroscopical ($\kappa = 0.14$, $p = 0.04$) and histopathological endometritis ($\kappa = 0.18$, $p = 0.04$). No agreement was found between macroscopical and histopathological lesions ($\kappa = -0.06$, $p > 0.05$). Major differences were found between herds for all parameters. The study showed that sows are mostly culled because of insufficient reproductive performance, and that many of the culled sows show endometritis lesions. Histopathology appears to be more sensitive than visual inspection to diagnose endometritis. Bacteriological examination appears to be the least reliable diagnostic method.

Finally, in **chapter 6** the main results are recapitulated and discussed. This thesis concluded that non-productive days could be minimized with strategies comprising the optimization of management practices associated with the herd specific problems (**chapter 3**), the use of hormonal products (**chapter 4**) and/or the use of slaughterhouse examination to optimize the decisions on culling sows (**chapter 5**). Further research is necessary to assess the economic benefits of using hormonal treatments. A tool which automatically generates relevant feedback to farmers about the macroscopical lesions found in culled sows could identify diseases or management deficiencies in the herd and lead to an optimization of the culling policy.

Samenvatting

Voor een winstgevend varkensbedrijf is de vruchtbaarheid van de zeugen en alles wat daarmee te maken heeft onontbeerlijk. Veel verschillende factoren hebben hier echter een invloed op. Ten eerste zijn de interne factoren, zoals bv. de hormonale veranderingen bij de zeug, van belang. Ten tweede moet er nog rekening gehouden worden met een groot aantal externe factoren die een rol spelen in de verschillende fasen van de reproductiecyclus van een zeug, zoals het seizoen, de huisvesting, het voeder en het management. Deze elementen zorgen ervoor dat vruchtbaarheid en al de bijhorende aspecten een complex geheel vormen.

Eén van deze aspecten is het spenen-bronst interval. Zeugen zo snel mogelijk bronstig krijgen na het spenen is één van de grootste uitdagingen in de varkenshouderij. Hoe sneller zeugen berig zijn, hoe sneller ze kunnen worden geïnsemineerd, hoe korter hun reproductiecyclus is en hoe lager het aantal niet-productieve dagen zal zijn. Verschillende niet-infectieuze factoren kunnen het spenen-bronst interval beïnvloeden, zoals de zoogduur, de lichaamsconditie en het speenmanagement. Bovendien kan een verlengd spenen-bronst interval leiden tot het vroegtijdig afvoeren van zeugen. Dit resulteert dan op zijn beurt in een daling van de gemiddelde pariteit op een bedrijf en een stijging van het vervangingspercentage met negatieve repercussies op de rendabiliteit van het bedrijf.

Om het spenen-bronst interval te optimaliseren, is het belangrijk om inzicht te krijgen in het speenmanagement en specifieke beïnvloedende factoren te identificeren, die gemakkelijk aanpasbaar zijn door de varkenshouder. Eén van de maatregelen, gemakkelijk en vaak toegepast, is de toediening van hormonale middelen. Regelmatig worden nieuwe producten ontwikkeld en hun effect op de verschillende fasen van de reproductiecyclus, zoals de inductie van bronst, moet worden onderzocht. Om na te gaan of zeugen met een verlengd spenen-bronst interval een onterechte opruiming ondergaan, is onderzoek van het geslachtsapparaat na het slachten noodzakelijk.

Hoofdstuk 1 start met een overzicht van de normale reproductiecyclus van de zeug. Hierna wordt de focus gelegd op de verschillende factoren die een invloed uitoefenen op o.a. een verlengd spenen-bronst interval, het percentage herlopers en de verschillende worp parameters (worpgrootte, aantal doodgeboren biggen en geboortegewicht). Het hoofdstuk sluit af met een literatuuroverzicht dat afvoerredenen aangeeft bij reforme zeugen, de beïnvloedende factoren ervan en het macroscopisch onderzoek van het voortplantingsapparaat bij gelten en zeugen.

In deze thesis werd het speenmanagement en het opruimbeleid van reforme zeugen op commerciële varkensbedrijven in kaart gebracht met als doel een optimale zeugenvruchtbaarheid te bekomen (**hoofdstuk 2**).

Een eerste studie werd opgezet omtrent het speenmanagement en deze wordt beschreven in **hoofdstuk 3**. De doelstelling van deze studie was enerzijds meer inzicht verwerven in het speenmanagement en anderzijds verschillende factoren identificeren, die geassocieerd zijn met de reproductieparameters van gespeende zeugen. Zes-en-zeventig willekeurig geselecteerde Vlaamse varkensbedrijven beantwoordden een vragenlijst, omtrent speenmanagement bij zeugen en de bedrijfsproductiviteit. Verbanden tussen bedrijfsfactoren en twee reproductieparameters na spenen (spenen-bronst interval: SBI en percentage herlopers: H) werden geanalyseerd door middel van *general linear mixed models*.

De strategie waarbij opfokgelten vanaf 60kg gescheiden worden gevoederd van de vleesvarkens kwam significant overeen met een korter SBI (5,54 vs 7,28 dagen; p = 0,040). Drie factoren waren significant geassocieerd met een lager percentage H. Ten eerste was dit een gescheiden huisvesting van pas gespeende en drachtige zeugen (7% vs 12%; p = 0,003), ten tweede het gebruik van sperma binnen de vier dagen na afname (7 – 9% vs 14%; p = 0,014) en tot slot het tweemaal per dag uitvoeren van bronststimulatie (8 vs 11%; p = 0,025).

Uit deze studie volgt dat een aantal managementmaatregelen, zoals het gescheiden voederen van opfokgelten, de huisvesting van zeugen, de methode van bronststimulatie en de bewaringsduur van sperma, een invloed hebben op de resultaten van sommige reproductieparameters zoals het SBI en het percentage H. Deze maatregelen kunnen varkenshouders gemakkelijk in praktijk brengen, wat kan leiden tot een verbetering van de vruchtbaarheidsprestaties van de gespeende zeugen.

Behandeling met hormonale producten kan soms een oplossing bieden voor reproductiestoornissen bij zeugen. Daarom werden in **hoofdstuk 4** de effecten van peforelin (l-GnRH-III) bestudeerd. De studie in **hoofdstuk 4.1** onderzocht of peforelin de folliculaire groei en de vrijstelling van FSH stimuleert, en of dit product in staat is de bronst bij gespeende zeugen en gelten te induceren. Voor deze laatste groep gebeurde dit na toediening van altrenogest. Drie gesloten bedrijven met minstens 600 zeugen en gemiddelde reproductieresultaten namen deel aan de studie. De aanwezige zeugen (216 gelten, 335 eerste- en 1299 meerdereworps zeugen) werden willekeurig verdeeld over de drie volgende behandelingsgroepen: peforelin (M groep: Maprelin®), eCG (F groep: Folligon®), en fysiologische zoutoplossing (C group). De gelten en zeugen werden behandeld respectievelijk 48u na de laatste altrenogestopname en 24u na het spenen. Per groep werd het SBI, de bronstduur, het percentage zeugen in bronst binnen de zeven dagen, het drachtpercentage en de worpgrootte (levend en doodgeboren biggen) bijgehouden. De gegevens werden vergeleken tussen de drie behandelingsgroepen, voor de verscheidene pariteiten (gelten, eerste- en meerdereworpszeugen). Bij een representatief aantal dieren werd de follikelgrootte op verschillende tijdstippen gemeten: op het moment van de laatste altrenogestopname of bij spenen, na de eerste en de tweede inseminatie. Op verschillende ogenblikken was er eveneens bloedafname bij deze dieren. Hieruit kon de concentratie van FSH bepaald worden zowel op het moment van spenen als 2u na de injectie en de concentratie aan progesteron (P4) 10 dagen na de eerste inseminatie. De relatieve verandering in FSH concentratie tussen beide tijdstippen werd berekend.

Significante verschillen werden aangetoond voor het percentage meerdereworpszeugen in bronst binnen de 7 dagen na spenen (95%, 91% en 90% voor respectievelijk de M, F en C groep, p = 0,005). De gelten in de F groep hadden grotere worpen (13,6; 15,4 en 14,9 voor respectievelijk de M, F en C groep, p = 0,02). De meerdereworpszeugen in de M groep hadden meer doodgeboren biggen (1,8; 1,4 en 1,7 voor respectievelijk de M, F en C groep, p = 0,05). De grootste follikels werden gevonden in de M groep en dit zowel bij de gelten bij de eerste inseminatie als bij de meerdereworpszeugen bij de tweede inseminatie (1e inseminatie gelten = 5,4; 4,9 en 4,9 mm (p = 0,02) en 2e inseminatie meerdereworpszeugen = 6,8; 5,3 en 6,3 mm (p = 0,03) voor respectievelijk de M, F en C groep). De overige variabelen gaven geen significante verschillen aan tussen de behandelingsgroepen noch binnen elke pariteitsgroep.

Over het algemeen toonde deze studie aan dat behandeling met peforelin beperkte positieve effecten heeft op het aantal zeugen in bronst binnen de zeven dagen na spenen en de groei van de follikels in bepaalde pariteiten. Op de tijdstippen waarop dit onderzoek werd uitgevoerd had perforelin echter geen effect op de worpgrootte, noch op de FSH of P4 concentraties van zeugen.

De studie in **hoofstuk 4.2** onderzocht de invloed van peforelin op bepaalde worpparameters. Dit gebeurde op dezelfde drie gesloten bedrijven als in **hoofdstuk 4.1.** Tweehonderzeventing dieren, willekeuring verdeeld over de 3 behandelingsgroepen: peforelin (M groep: Maprelin®), eCG (F groep: Folligon®), en fysiologische zoutoplossing (C groep). Na een behandeling van de gelten, 48u na de laatste altrenogestopname en van de zeugen, 24u na spenen, werden volgende gegevens bijgehouden: drachtduur, worpgrootte, aantal levend en doodgeboren, aantal gespeende biggen en de biggensterfte tijdens de zoogperiode. Verder werd het geboorte- en speengewicht gemeten en de variatiecoefficient van de gewichten per nest berekend. Na een vergelijking van alle parameters tussen de behandelingsgroepen en de pariteitsgroepen (gelten, eerste- en meerdereworpszeugen) volgden deze resultaten: worpgrootte en het aantal doodgeboren biggen was groter in de F groep in gelten (13,1; 15,2; 14,2 ($p = 0,03$) en 0,7; 1,6 en 0,6 biggen ($p = 0,05$) voor respectievelijk de M, F en C groep). Het aantal doodgeboren biggen bij de meerdereworpszeugen duidden ook grote verschillen aan (2,2; 0,9 en 1,4 voor respectievelijk de M, F en C-groep, $p < 0,01$). Biggen in de F groep hadden het laagste geboortegewicht in gelten, eersteworpszeugen en over alle pariteiten (1,36; 1,26; 1,32kg ($p < 0,03$), 1,47; 1,40; 1,45kg ($p = 0,02$) en 1,42; 1,35 en 1,40kg ($p < 0,01$) voor respectievelijk de M, F en C groep) en de hoogste geboortegewicht variatiecoëfficient voor totaal geboren biggen (0,19; 0,22; 0,21 ($p = 0,02$) en 0,22; 0,25 en 0,23 ($p \leq 0,05$) voor respectievelijk de M, F en C groep). Het speengewicht was het hoogst in de M-groep bij de gelten (5,30; 5,07 en 5,08 kg voor de M, F en C groep respectievelijk, $p < 0,03$), en was het laagste bij de meerdereworpszeugen (5,43; 5,80 en 5,71 kg voor de M, F en C groep respectievelijk, $p < 0,02$). De speengewicht variatiecoëfficient was het laagste in de M groep bij eersteworpszeugen (0,18; 0,19 en 0,20 voor respectievelijk de M, F en C groep ($p = 0,05$). Voor de andere parameters was er geen specifiek onderscheid tussen de behandelingsgroepen of binnen iedere pariteitsgroep.

Tot slot toonde **hoofdstuk 4.2** aan dat behandeling met peforelin geen effect heeft op de worpparameters in vergelijking met de negatieve controle groep. Het lijkt wel positieve effecten te hebben op het speengewicht bij gelten, maar niet bij de meerdereworps zeugen. Bovendien kan peforelin de uniformiteit van biggen bij spenen verhogen in jonge zeugen, maar niet bij de meerdereworps zeugen.

Vruchtbaarheidsproblemen zijn één van de meest voorkomende redenen om zeugen vroegtijdig af te voeren naar het slachthuis. **Hoofdstuk 5** toont de resultaten van de studie waarin de redenen tot afvoer van 502 zeugen op 7 commerciële varkensbedrijven zijn bevraagd. Van al deze zeugen werd het geslachtsapparaat onderzocht en dit zowel macroscopisch, bacteriologisch als histopathologisch. De overeenkomsten tussen reden van afvoer en de verschillende diagnostische testen werden statistisch bepaald.

De belangrijkste redenen tot afvoer van zeugen waren vruchtbaarheidsstoornissen (>50%) en ouderdom (23%). Bijna 75% van de baarmoeders had een normaal macroscopisch uitzicht, 18% bevatten etter in de uterus. In 54% van de gevallen waren de ovaria normaal, terwijl 28% geen activiteit liet zien.

Tweeënzestig procent van de baarmoeders leverden een bacteriologisch positief resultaat, met *E. coli* als meest voorkomende kiem (18%). In het histopathologisch onderzoek vertoonden 52% een milde tot ernstige ontsteking. Van alle baarmoeders met endometritis, gebaseerd op aanwezigheid van etter enerzijds en histopathologisch onderzoek anderzijds, toonden er respectievelijk 26% en 30% bacteriologisch negatief aan. De aanwezigheid van bacteriën kwam matig overeen met het vinden van etter ($\kappa = 0{,}14$; $p = 0{,}04$) en histopathologisch gedetecteerde endometritis ($\kappa = 0{,}18$; $p = 0{,}04$). De macroscopische en de histopathologische letsels kwamen niet overseen ($\kappa = -0{,}06$; $p > 0{,}05$). Voor alle parameters werden duidelijke verschillen geobserveerd tussen de bedrijven.

Deze studie toont aan dat vruchtbaarheidsproblemen de voornaamste reden tot het afvoeren van zeugen is en dat er velen endometritis vertonen. Hierbij blijkt dat bacteriologisch onderzoek het minst betrouwbaar is, gevolgd door macroscopisch onderzoek. Histopathologie lijkt het gevoeligst te zijn voor de detectie van baarmoederontsteking.

Hoofdstuk 6, tenslotte, herhaalt de belangrijkste resultaten van deze thesis, bediscussieert ze en geeft enkele praktische richtlijnen voor het aanpassen van het management en het verantwoord gebruik van hormonale producten**.** Uit deze thesis kan geconcludeerd worden dat het aantal niet productieve dagen geminimaliseerd kan worden. Dit is te bereiken door middel van verschillende strategiëen. Ten eerste, en heel belangrijk: een optimalisatie van het management, geassocieerd aan bedrijfsspecifieke factoren (**hoofdstuk 3**). Ten tweede omvat dit het correct gebruik van hormonale producten (**hoofdstuk 4**). Verder onderzoek is echter nodig om een gedetailleerde economische analyse te maken van het gebruik van hormonale producten. Tot slot kan slachthuisonderzoek de kennis omtrent de redenen van afvoer van reforme zeugen optimaliseren (**hoofdstuk 5**).

Het uitwerken van een *tool* die automatisch relevante feedback geeft aan de varkenshouders over de macroscopische letsels gevonden in het voortplantingsstelsel van de reforme zeugen zou kunnen bijdragen tot de identificatie van onderliggende ziekten en/of managementsproblemen in de vruchtbaarheid van zeugen. Daarnaast zou dit eveneens kunnen leiden tot een correcter afvoerbeleid.

Curriculum Vitae

Ellen de Jong zag het levenslicht op 18 november 1984, om 7u ’s morgens in Oostende. Na het behalen van haar diploma hoger secundair onderwijs in de richting Wiskunde-Wetenschappen aan het Sint-Godelieve college in Gistel, begon ze in 2002 aan de studie Diergeneeskunde aan de Universiteit van Gent. Ellen behaalde in 2008 haar diploma van Dierenarts in de optie Varken-Pluimvee-Konijn met onderscheiding.

In datzelfde jaar (2008) trad ze in dienst als assisterend academisch personeel op de vakgroep Voortplanting, Verloskunde en Bedrijfsdiergeneeskunde aan de faculteit Diergeneeskunde van de UGent. In deze functie deed ze haar doctoraatsonderzoek naar speenmanagement bij zeugen onder leiding van prof. Dr. D. Maes. Daarnaast was ze actief in de Bedrijfsbegeleiding Varken, stond ze mee in voor de opleiding van de laatstejaarsstudenten optie Varken-Pluimvee-Konijn, voerde ze bedrijfsbezoeken en projecten uit in het kader van Veepeiler Varken en draaide ze mee in de nacht- en weekenddiensten van de Buitenpraktijk, rundvee. Gedurende haar doctoraatsopleiding volgde ze verscheidene cursussen statistiek, epidemiologie, proefdierkunde, time management, etc.

In maart 2012 startte ze als Veepeiler Varkensdierenarts bij Diergezondheidszorg Vlaanderen, met als standplaats Torhout, alwaar ze nu nog steeds werkzaam is. Ze verzorgt er grotendeels de bedrijfsbezoeken in het kader van tweedelijnsdiergeneeskunde en voert er praktijkgerichte onderzoeken uit.

Ze behaalde in september 2013 het diploma vakdierenarts Varken aan de faculteit Diergeneeskunde van de UGent .

Ellen is auteur of mede-auteur van meerdere wetenschappelijke publicaties in nationale en internationale tijdschriften en was spreker op verschillende nationale en internationale congressen. Tevens is ze reviewer in verschillende internationale tijdschriften.

Bibliography

Publications in national and international journals

de Jong E., Vanderhaeghe C., Lopèz-Rodríguez A., Simoens P., Van Soom A., de Kruif A., Maes D. (2009). Ultrasonography of the ovaries in the sow: a helpful tool to determine the time of insemination. Vlaams Diergeneeskundig Tijdschrift 79, 276-281.

de Jong E., Maes D. (2009). Vaccinatie tegen berengeur: hoe werkt het vaccin precies? Vlaams Diergeneeskundig Tijdschrift 79, 282-283.

Maes D., Steyaert M., Vanderhaeghe C., Lopèz-Rodriguez A., **de Jong E.,** del Pozo Sacristan R., Vangroenweghe F., Dewulf J. (2010). Comparison of oral versus parental iron supplementation on health and productivity of pigs. Veterinary Record 168(7), 188.

Beek J., **de Jong E.**, Van Soom A., de Kruif A., Maes D. (2011). Ovarian cysts in sows: a multifactorial disorder with consequences on the reproductive performance. Vlaams Diergeneeskundig Tijdschrift 80, 215-222.

de Jong E., Laanen M., Dewulf J., Jourquin J., de Kruif A., Maes D. (2013). Management factors associated with sow reproductive performance after weaning. Reproduction of Domestic Animals 48(3), 435-440.

de Jong E., Kauffold J., Engl S., Jourquin J., Maes D. (2013). Effect of a GnRH analogue (Maprelin) on the reproductive performance of gilts and sows. Theriogenology 80(8), 870-877.

Geldhof M.F., Van Breedam W., **de Jong E.**, Lopez Rodriguez A., Karniychuk U.U., Vanhee M., Van Doorsselaere J., Maes D., Nauwynck H.J. (2013). Antibody response and maternal immunity upon boosting PRRSV-immune sows with experimental farm-specific and commercial PRRSV vaccines. Veterinary Microbiology 167 (3-4), 260-271.

Maes D., Vandersmissen T., **de Jong E.,** Boyen F., Haesebrouck F. (2013). *Staphylococcus hyicus* infections in pigs. Vlaams Diergeneeskundig Tijdschrift 82, 259-264.

Laanen M., Persoons D., Ribbens S., **de Jong E.**, Callens B., Strubbe M., Maes D., Dewulf J. (2013). Relationship between biosecurity and production/antimicrobial treatment characteristics in pig herds. Veterinary Journal 198(2), 508-512.

Mahu M., **de Jong E.**, De Pauw N., Vande Maele L., Vandenbroucke V., Vandersmissen T., Miry C., Pasmans F., Haesebrouck F., Martel A., Boyen F. (2013). First isolation of "Brachyspira hampsonii" from pigs in Europe. Veterinary Record 174(2), 47

de Jong E., Appeltant R., Beek J., Cools A., Boyen F., Chiers K., Maes D. (2014). Slaughterhouse examination of culled sows in commercial pig herds. Livestock Science 167, 362-369.Callens B., Faes C., Maes D., Catry B., Boyen F., Francoys D., **de Jong E.,** Haesebrouck F., Dewulf J. (2014). Presence of antimicrobial resistance and antimicrobial use in sows are risk factors for antimicrobial resistance in their offspring. Microbial Drug Resistance, *in press* (DOI: 10.1089/mdr.2014.0037)

de Jong E., Kauffold J., Engl S., Jourquin J., Maes D. (2014). Effect of a GnRH analogue (Maprelin) on the litter performance of gilts and sows. *In preparation*

Oral presentations at international scientific meetings

de Jong E., Kauffold J., de Kruif A., Maes D. (2010). Effect of a GnRH Analogue (Maprelin®) to Stimulate Estrus in Gilts and Sows, 14th ICPD, Ghent, Belgium, p. 25

Laanen M., Persoons D., Ribbens S., **de Jong E.**, Callens B., Strubbe M., Maes D., Dewulf J. (2011). Investigation of the relationship between biosecurity measures and production, health- and treatment characteristics in pig herds. VEE Studiedag, St Niklaas, Belgium.

Laanen M., Persoons D., Ribbens S., **de Jong E.**, Callens B., Strubbe M., Maes D., Dewulf J. (2012). Investigation of the relationship between biosecurity measures and production, health- and treatment-characteristics in pig herds. 4th ESPHM, Bruges, Belgium, p. 109.

de Jong E., Kauffold J., Jourquin J., Engl S., de Kruif A., Maes D. (2012). Effect of a GnRH analogue (peforelin) on subsequent birth weight of piglets. 22nd IPVS, Jeju, South-Korea, p. 152.

de Jong E., Mahu M., Vandenbroucke V., Vandersmissen T., Boyen F., Miry C. (2013). Importance of microbial culture to identify (novel) highly beta-hemolytic *Brachyspira* species. 5th ESPHM, Edinburgh, Scotland, p. 54.

de Jong E., Appeltant R., Beek J., Boyen F., Chiers K., Van Soom A., Maes D. (2013). Slaughterhouse examination of culled sows in commercial pig herds. 5th ESPHM, Edinburgh, Scotland, p.71.

de Jong E., Appeltant R., Maes D. (2013). Using slaughterhouse data to improve management of reproduction in sows. Satellite Symposium ICPR, Pig Reproduction for practitioners, Olsztyn, Poland, 44-51.

Poster presentations at international scientific meetings

de Jong E., Dewulf J., Laanen M., Jourquin J., Maes D. (2010). A Descriptive Questionnaire on Weaning Management in Commercial Pig Herds in Belgium. 2nd ESPHM, Hannover, Germany, p.168.

de Jong E., Dewulf J., Van Soom A., Adriaens C., Deley W., de Kruif A., Maes D. (2010). Effect of Temperature and Packing Method on Storage of Boar Semen. 2nd ESPHM, Hannover, Germany, p.169.

Vandersmissen T., Vangroenweghe F., **de Jong E.**, Van Driessche E., Maes D. (2010). Serum micro-element reference values in sows at different stages during the reproductive cycle. 2nd ESPHM, Hannover, Germany, p.171.

Vangroenweghe F., Vandersmissen T., **de Jong E.,** Van Driessche E., Maes D. (2010). Serum macro-element reference values in sows at different stages during the reproductive cycle. 2nd ESPHM, Hannover, Germany, p.172.

Vangroenweghe F., Vandersmissen T., Van Driessche E., Maes D., **de Jong E.** (2010). Serum micro-element reference values for gestating and lactating sows. 21st IPVS, Vancouver, Canada, p.1046.

Vangroenweghe F., Vandersmissen T., **de Jong E.,** Van Driessche E., Maes D. (2010). Serum macro-element reference values for gestating and lactating sows. 21st IPVS, Vancouver, Canada, p. 1047.

Vanderhaeghe C., Dewulf J., Vangroenweghe F., Steyaert M., **de Jong E.,** Villareal I., Lopéz A., Del Pozo Sacristan R., Maes D. (2010). Effect of a peroral iron supplementation in piglets on health and production. 21st IPVS, Vancouver, Canada, p. 1057.

de Jong E., Dewulf J., Van Soom A., Adriaens C., Deley W., de Kruif A., Maes D. (2010). Effect of Temperature and Packing Method on Storage of Boar Semen. 21st IPVS, Vancouver, Canada, p. 1065.

de Jong E., Dewulf J., Laanen M., Jourquin J., Maes D. (2010). A Descriptive Questionnaire on Weaning Management in Commercial Pig Herds in Belgium. 21st IPVS, Vancouver, Canada, p. 1089.

Geldhof M., **de Jong E.**, López-Rodríguez A., Van Doorsselaere J., Maes D., Nauwynck H. (2011). Efficacy of a farm-specific inactivated PRRSv vaccine in the field. 6th Symposium of Emerging and Re-emerging diseases, Barcelona, Spain, p. 223.

de Jong E., Laanen M., Dewulf J., Jourquin J., de Kruif A., Maes D. (2012). Weaning management practices associated with sow reproductive performance in commercial pig herds. 4th ESPHM, Bruges, Belgium, p.119.

Laanen M., Persoons D., Ribbens S., **de Jong E.**, Callens B., Strubbe M., Maes D., Dewulf J. (2011). Investigation of the relationship between biosecurity measures and production, health- and treatment characteristics in pig herds. International Conference on the Responsible Use of Antibiotics in Animals, Egmond aan Zee, The Netherlands.

de Jong E., Jourquin J., Kauffold J., de Kruif A., Maes D. (2012). Effect of a GnRH analogue (Maprelin) on estrus and reproductive performance in gilts and sows. 4th ESPHM, Bruges, Belgium, p. 119.

Vandersmissen T., Brossé C., **de Jong E.,** Geldhof M. (2013). Insights in *Brachyspira hyodysenteriae* detection on nine Belgian pig herds. 5th ESPHM, Edinburgh, Scotland, p.108.

Brossé C., Hautekiet V., Van Hamme V., **de Jong E.,** Vandersmissen T. (2013). Coated Calciumbutyrate: a potential tool to control *Salmonella* in high risk pig herds. 5th ESPHM, Edinburgh, Scotland, p. 176.

de Jong E., Appeltant R., Beek J., Boyen F., Chiers K., Van Soom A., Maes D. (2013). Slaughterhouse examination of culled sows in commercial pig herds reveals few macroscopical lesions. 9th ICPR, Olsztyn, Poland, p. 175.

Brossé C., Vandersmissen T., **de Jong E.**, Verhegghe M., Rasschaert G. (2014). MRSA on Belgian mixed species farm. 6th ESPHM, Sorrento, Italy, p. 209

Vandersmissen T., **de Jong E.**, Vandenbroucke V., Miry C. (2014). Development of an abortion protocol in pigs in Flanders. 6th ESPHM, Sorrento, Italy, p. 258

Oral presentations at national scientific meetings

de Jong E. 23 april 2009. Casuïstiek vruchtbaarheidsproblemen zeugen, casuïstiekenavond IPVS Belgian Branch, Merelbeke, Belgium.

de Jong E. 22 april 2010. Casuïstiek Vruchtbaarheidsproblemen zeugen – mycotoxines, casuïstiekenavond IPVS Belgian Branch, Merelbeke, Belgium.

de Jong E. 24 mei 2012**.** Casuïstiek abortus, casus-café IPVS Belgian Branch, Merelbeke, Belgium.

de Jong E., 7 september 2012. Vruchtbaarheid, bedrijfsdiergeneeskunde en bedrijfsvoering, Post-IPVS Zuid-Korea, IPVS Belgian Branch, Merelbeke, Belgium.

de Jong E. 27 september 2012. Vervangbeleid en slachthuisbevindingen bij reforme zeugen, studienamiddag IPVS Belgian Branch, Merelbeke, Belgium.

de Jong E. 5 september 2014. Vruchtbaarheid. Post-ESPHM/IPVS, Italïe/Mexico, IPVS Belgian Branch, Merelbeke, Belgium.

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En dan brengt me dit tot mijn huidige werkomgeving. Mijn collega's bij DGZ! Misschien beginnen bij het begin, Sigrid, bedankt om mij de job te geven en erin te geloven dat ik het wel zou kunnen combineren: DGZ, doctoraat en gezin. Ik kon het, maar het heeft wel wat langer geduurd dan gepland ;). Herman, ondertussen hebt u Sigrids' taken overgenomen. U kwam in een onbekende omgeving terecht, met dansende koebeesten ☺ en een werknemer die meteen al vroeg om 4/5^e^ te gaan werken om haar doctoraat af te werken. Het was voor u wellicht wat gokken wat u er mee moest doen, maar bedankt om mij de kansen te geven en ik hoop dat ik vandaag dan toch een beetje de verwachtingen heb ingevuld ;).

Tamara, waar zal ik starten? Bij het moment van onze eerste ontmoeting, dat je mijn kot in Gent kwam binnengevallen en je me spontaan vertelde hoe je sollicitatie bij DGZ was geweest? Of op het moment dat we op het ESPHM in Hannover besloten om samen bedrijfsbezoeken te gaan uitvoeren ipv. elk in onze eigen werkomgeving? Of toen je me opbelde en vroeg of ik geen zin had om te komen solliciteren bij DGZ, want dat er een plaatsje vrijkwam? Waarmee ik maar wil zeggen: je was erbij van in het begin, eerst als kennis, daarna als vriendin, vervolgens als collega om nu hier het resultaat te zien als teamleidster ☺. En het feit dat je mij "boven" Tommetje stelde vandaag, toont aan dat je er nog steeds staat als vriendin ook ;). Bedankt om met het voorstel van het ouderschapsverlof als 4/5^e^ op de proppen te komen. Zonder dat was de kans groot geweest dat ik er onderdoor was gegaan of vooral dat ik hier vandaag niet had gestaan. Bedankt ook om er af en toe op toe te zien dat ik niet teveel hooi op mijn vork neem en om mij af en toe te vragen of ik wel zeker ben dat het gaat lukken. Het doet me dan eens nadenken en twijfelen ook ☺. Van zodra ik terugkom van duikreis, sta ik weer full time ter beschikking en dan vliegen we er met ons wonderteam (wonderteam wonderteam, je hulp in nood! We zijn niet sterk en we zijn niet groot, maar met z'n drieën beter dan de middenmoot!) volledig in. Ik zie het in alle geval zitten ☺.

Charlotte, mijn teammaatje, mijn bureaugenootje, mijn allerliefste collega! Ook jij bent nog "mijn studentje" geweest en bent nu "uitgegroeid" tot een superenthousiaste en intelligente dierenarts! Bedankt om altijd een luisterend oor te bieden als ik ergens mee zit, ik mag je altijd storen – je calculeert het zelfs in in je planning ;) - en bedankt om mee te helpen denken aan oplossingen voor de kleinste onbenulligheden tot grote kwesties ☺. Je bent een supercollega en volgend jaar ga je je verlof goed vastleggen en er niet meer aan bougeren ;). Sorry dat mijn interne temperatuur altijd een pak hoger ligt dan die van jou, waardoor je altijd je dikke pull moet bijhebben in de bureau… het zou wel eens kunnen dat ik deze winter het onderspit ga moeten delven en me gewoon heel zomers ga moeten kleden ;). Bedankt ook voor het nalezen van mijn nederlandse samenvatting en het oefenpubliek te zijn voor mijn presentatie ☺. En natuurlijk, dankzij jou en Jochen hebben wij een "beste vriend" in ons gezinnetje, dus bedankt om Wilbur zo goed te verzorgen de eerste maanden van zijn leven ☺. We spreken gauw nog eens af hé, voor een winterbarbecuetje ;).

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En sedert 6 oktober 2001 – of 17 juli 2009 (kies maar ;)) - heb ik er ook een fantastische schoonfamilie bijgekregen! Dankjewel schone nonkels en tantes, neefje en nichtjes! Onze kerstfeestjes en af en toe eens een trouwfeest ;), zijn altijd ambiance verzekerd! Ik kijk er telkens weer naar uit! Merci voor die heerlijk gezellige momenten samen! Mémé Denise en tante Nicole, ik noem jullie in één adem. Jullie konden er vandaag niet bijzijn, omdat jullie voor de kindjes wilden zorgen! Dat typeert precies waarom ik jullie vernoem in mijn dankwoord: Dankjewel om nog altijd zo te springen voor ons! Ik vind het fantastisch dat Ward en Lies hun overgrootmoeder en overgroottante van zo dichtbij mogen meemaken! En dan kom ik natuurlijk terecht bij mijn schoonzusje, Manon! Je hebt al heel wat watertjes doorzwommen en ik heb je weten opgroeien van lief klein lager schoolmeisje, over een (helse ☺) puber naar een mooie zelfstandige vrouw die eindelijk de rust en zekerheid gevonden heeft bij Bram ☺. Wat kijk ik uit naar 18 september 2015! Ook wij hebben elkaar te weinig gezien de laatste maanden, maar ik beloof dat ik snel eens jullie stekje kom bewonderen (shame on me)! Succes met de voorbereidingen van de trouw en je weet, als ik ergens mee kan helpen…!!! En dan schoonma en schoonpha, oftewel oma Sien en opa! BEDANKT! Om zo flexibel te zijn in het opvangen van de kindjes. Jullie vloeken wellicht af en toe eens (of veel?) als ik weer eens te lang blijf werken of later ben dan beloofd (Sorry daarvoor!) en ook jullie weekends worden soms eens opgeëist als we weer eens op duikweekend zijn, of naar één of ander whiskyfestival. Bedankt om zo'n goeie oma en opa te zijn voor Ward en Lies. Ik hoop dat jullie vandaag ook een beetje trots zijn op jullie schoondochter en dat jullie weten waaraan ik mijn tijd spendeer als ik weer eens pas om 19u kom opdagen…. En natuurlijk, een extra woordje voor fotografe Francine, alias, schoonmama ;). Bedankt om zo *last minute* de cover van mijn boekje in elkaar te flansen! Jouw creativiteit is iets waar ik enorm naar opkijk en het gemak waarmee jij dingen ontwerpt is bewonderenswaardig! Zullen we er dit jaar maar eens vroeg bij zijn om de kerstkaartjes te ontwerpen met kerstmannetje Ward en kerstvrouwtje Lies?

Zusje, Melanie, je hebt ongelooflijk zware tijden achter de rug. Soms had ik het gevoel er onvoldoende voor je te zijn, door mijn drukke leventje… onze "wekelijkse" fitness avondjes verwaterden en ook het sms-contact was niet altijd meer wat het moest zijn. Dan kwam de definitieve beslissing en ik weet niet of ik de zus ben geweest, zoals het zou moeten… Ik ben zo opgelucht om je zo gelukkig te zien met Mike en ik hoop dat dat "mijn aandeel" wat goedmaakt. Sedert Ward naar school gaat, zie ik je wel eens regelmatiger, maar dat zorgt natuurlijk weer voor minder diepe contacten, aangezien het telkens om een vluchtig babbeltje gaat aan de schoolpoort. Eén van mijn goede voornemens (en ondertussen voel ik me al alsof het 1 januari is EN dat ik al weet dat ik mijn zeeën tijd snel ga kwijtspelen ;)) is om vaker met jullie af te spreken. Samen een uitstapje met de kids, een etentje, een drankje, een gezellige babbel! Zusje, bedankt om zo trots op me te zijn (als ik al proficiat-wensen krijg van de andere juffen aan de schoolpoort… ;)), bedankt voor het smsje de dag voor mijn begeleidingscommissie en de vraag of ik dan al “doctor” mocht genoemd worden…☺. Zoals ik toen zei, je zult het wel te weten komen als het zover is, wel… vandaag is het zover: groot feest ;). Merci om mijn grote zus te zijn, Mel, je bent de liefste van de hele wereld! Dikke knuffel!

Broertje – ik hoop dat je nu ondertussen al “trots” bent ingecheckt op facebook bij “faculteit diergeneeskunde”? ☺ – je vroeg me vanavond nog of je ook in mijn dankwoord zou staan… want je had toch niets gedaan? Als je dit alles nu gelezen hebt, zou je wel verwonderd zijn zeker mocht ik je niet vermelden?! Broertje, jij zorgde voor de ontspanning tussen al dat doctoraatwerk door. Een uitje hier, een quizje ginder, een voetbalmatchje daar, een kerstmarktje elders, een middagje strand en sangria aan de Q Beach… en altijd stelde je mij trots aan iedereen voor als “je kleine zusje, die wel bezig was met een doctoraat hé?!”. ’t Is alweer veel te lang geleden dat we nog samen een stapje in de wereld zetten of dat we samen Chinees aten ;). Verder kan ik ook altijd op je rekenen als ik een *catchy* titel nodig heb voor een artikeltje of een naar-meer-smakende-inleiding! Merci om mijn grote broer te zijn, Jan, je bent de beste van de hele wereld! Big huggie!

Mams en paps, om jullie te bedanken is eigenlijk een apart boek nodig! Het is ongelooflijk wat jullie al die jaren voor mij gedaan hebben. Jullie onaflatende steun, jullie altijd luisterende oor, jullie hulp in het huishouden (mandén strijk heb je verzet, mams) en de tuin (tonnen gras heb je afgereden, paps), jullie zorg voor de kindjes, jullie inspringen op de meest onmogelijke momenten, jullie manieren om af en toe bij ons de stoom te laten afblazen door een barbecuetje, een cavaatje, een etentje, … ik weet niet hoe ik jullie daar ooit allemaal moet voor bedanken. Jullie – ten gevolge van trots – blinkende gezichten zijn mij meer waard dan ieder ander! Het was vaak alleen die gedachte die mij op moeilijke momenten erdoor haalde om toch door te zetten, omdat ik wist hoe “preus” jullie vandaag zouden zijn, uitgedost in jullie netste pak en kleedje ☺. Mams en paps, ik kan jullie niet genoeg bedanken, maar weet dat ik zonder jullie hulp hier vandaag nooit had gestaan. De eer van dit doctoraat is dus zeker aan jullie toe te schrijven en ik kan alleen maar hopen dat ik dezelfde ouder zal zijn als jullie voor mij zijn, want dan weet ik dat ik alles heb gegeven wat mijn kindjes verdienen! Bedankt voor alles!

Wilbur, mijn trouwe viervoeter. Hoewel een hond niet kan lezen, vind ik je toch vernoemenswaardig. Jij bent namelijk degene die er de laatste maanden misschien wel het meeste van afgezien heeft: “vrouwtje die continu achter haar computer zit – en vaak dan nog al vloekend - in plaats van samen met baasje en mij in de zetel; vrouwtje die altijd tot een gat in de nacht wakker is, in plaats van samen met baasje en mij in bed te kruipen; vrouwtje die nooit tijd heeft om met mij te gaan wandelen; vrouwtje die soms lichtgeraakt is en het niet kan verdragen als ik vrolijk goeiedag zeg….”. Lieve Wilbur, je bent een ongelooflijke knuffelhond, ik zou je niet hebben kunnen missen in die laatste paar maanden, want hoewel ik me wel ergerde aan die kopstoten om me tot in de zetel te krijgen, deed het me toch plezier om te merken dat je met me meeleefde als ik voor de zoveelste keer vloekte op dat Word-document. Vanaf nu zal het vrouwtje haar avonden en weekenden knuffelend met jou spenderen ☺.

Basje, mijn ventje. Jij hebt serieus afgezien met mij de laatste jaren en vooral de afgelopen maanden. Het is eigenlijk een wonder dat ik nog niet vastgeroest ben op deze stoel aan de eettafel, en dat de letters van mijn toetsenbord van mijn laptop nog niet afgesleten zijn… Avonden, nachten (volgens het motto: “de vroege vogel vangt de eerste worm, de nachtuil vangt een hele pot” ☺), weekends lang… kon je me maar op één plekje vinden. Jij, die standvastig bleef vasthouden aan het principe “’t is gezelliger samen in bed te kruipen, dan alleen”, bent ontelbare avonden in de zetel in slaap gevallen, omdat ik weer eens wou doorwerken. Hoe vaak moest je geen afleveringen van Dexter, Sons of Anarchy of The Leftovers tweemaal bekijken omdat ik de eerste keer niet meegekeken had, omdat ik aan het werken was achter mijn computer... Hoe vaak moest je de afgelopen maanden niet met je koptelefoon opzitten, omdat je persee wou dat ik bij je zat in de living, maar ik niet wou afgeleid worden door je film ;), … Maar dat zijn allemaal maar kleine dingen. Ik wil je bedanken voor het geduld dat je met me hebt gehad. Als ik weer eens kortaf was, doordat ik gestresseerd was, of als ik het weer eens moeilijk had, omdat ik teveel hooi op mijn vork had genomen. Ik wil je bedanken voor de troostende knuffels, de oplossingen die je aanbracht bij problemen, de revisie van mijn Engelse teksten, … Ik wil je bedanken voor het vele werk dat je aan het huisje hebt gedaan en in de tuin, dat je alleen moest doen omdat ik bezig was met mijn doctoraat. Ik wil je bedanken voor het af en toe zeggen: “Stop nu met erover te piekeren, je kan er niets aan veranderen, geniet er nu van!”. Ik wil je bedanken voor het aanwezig zijn in mijn leven en voor de papa dat je bent voor onze kindjes! Kun je je voorstellen wat het zal geven volgend weekend? Zou het echt? Een vrij weekend voor ons gezinnetje? Geen continu zeurende stemmetjes in mijn hoofd die zeggen dat ik aan mijn doctoraat moet werken? Maar echt een vrij weekend? Ik kan het nog niet zo goed geloven… Maar ik vermoed dat we er snel aan gewoon zullen worden ☺. Merci ventje, om er te zijn! Ik hou van je!

En tot slot, mijn twee grootste schatten op aarde, Wardje en Liesje, jullie zijn nog klein en jullie weten niet goed wat er zich afgespeeld heeft de eerste jaren van jullie leven. Jullie ondervonden wellicht wat last van mama’s stress (allebei drie weken te vroeg geboren ;)) en mama was soms wat lichtgeraakt (“mama, je moet niet boos zijn…” ☺) en zat de laatste tijd meer achter haar computer dan dat ze puzzelde of tekende met jou, Ward of een ganse ontdekkingstocht deed door het huis met jou, Liesje! Maar ik vermoed dat jullie dat allemaal zullen vergeten zijn, eens jullie groter zijn. Toch hoop ik dat jullie ooit met een beetje trots zullen kunnen zeggen dat jullie mama is gedoctoreerd in de diergeneeskunde ☺. Jullie zorgden er alleszins voor dat ik na een stresserende dag/nacht kon ontspannen, door jullie lachjes en vertellementen. En vanaf nu, kindjes, beloof ik om op een zonnige zondagmiddag wel degelijk een strand- of boswandeling te maken, om regelmatig te gaan zwemmen en om jullie de aandacht te geven die jullie verdienen. Want niets, echt niets ter wereld is belangrijker voor mij dan jullie!

En zo ben ik aan het einde gekomen van mijn dankwoord. Het is een lange geworden, want ik had geen tijd voor een korte ;). Zes jaar van je leven is dan ook heel wat, waarop heel wat mensen mijn pad hebben gekruist. Aan het einde van mijn relaas wil ik nog eens iedereen bedanken voor de hartverwarmende mailtjes die ik mocht ontvangen als respons op de uitnodiging van deze dag. Het was fijn om te lezen hoeveel mensen in mij geloven en hoeveel mensen om mij geven. Bedankt daarvoor!

Veel liefs,
Ellen
(27 oktober 2014; 1u32)

“I am fond of pigs.

Dogs look up to us.

Cats look down to us.

Pigs treat us as equals.”

~ Winston Churchill