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Causes of variation in litter size in Swedish piglet production

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Orsaker till variation i kullstorlek inom svensk smågrisproduktion

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Abstract

Litter size is influenced by a number of different factors including parity number and age at first mating as well as genetic potential and environmental factors such as management and feeding. The aim of this study was to evaluate the effect of age at first farrowing, lactation period and weaning to service interval on subsequent litter size, as well as to obtain descriptive statistics on the variation in litter size over the last few years. Records from 2012 to 2017 including observations from two commercial Swedish piglet producing herds were collected from the pig herd monitoring program WinPig. Sows included in the study were Landrace x Yorkshire crossbreeds. Information available for the study were, herd, sow identity number, date of the birth of the sow, date of insemination, date of farrowing, date of weaning, number of piglets born alive and number of stillborn piglets. Sows were for the analyses divided into four groups based on age at first farrowing; 330-359 days, 360-369 days, 370-379 days and 380-409 days. Four groups were also created based on length of weaning to service interval; 0-5 days, 6-20 days, 21-41 days and 42-80 days. The results show that litter size increased during the studied time period, with an increase in number of piglets born alive and no significant changes in number of stillborn piglets. Litter size also increased with increasing parity number, reaching the highest total number of born piglets in parity 5 and 4 for Herd A and B respectively. This increase in number of piglets born alive can be due to genetic improvement, however, breed was not included in the present study and can thereby not be evaluated. Litter size in first parity was lowest for sows with age 330-359 days at first farrowing. From second parity and onwards litter size differed less between the groups, which implies no long lasting effect of age at first farrowing on litter size. Therefore, it could be beneficial to inseminate gilts at an earlier age if they have reached the right body weight, as the differences in litter size are not continuous after first parity. The lactation period had an impact on subsequent litter size. Total number of born piglets and piglets born alive significantly ($P<0.001$) increased with increased lactation period, which means that the null hypothesis could be rejected. The number of stillborn piglets also increased with increased lactation period, although this increase was not significant. However, a longer lactation period would increase the pressure on sows, as piglets are heavier and more demanding later on in the lactation period. Weaning to service interval also significantly influenced subsequent litter size, which means that the null hypothesis could be rejected. Sows that were inseminated early (0-5 days) had a higher subsequent litter size compared with later inseminated sows (6-20 days). The highest subsequent litter size was found amongst sows that were bred at second estrus (21-41 days). Sows that are bred at second estrus have more time to establish a good body condition after weaning, although the number of non-productive days will increase. All factors analyzed in the present study influence litter size and each producer has to consider their own conditions in order to make the right decisions.

Sammanfattning

Kullstorlek påverkas av ett antal olika faktorer, inklusive kullnummer och ålder vid första inseminering såväl som genetisk potential och utfodring och skötsel. Syftet med denna studie var att utvärdera inverkan av ålder vid första grisning, längden på laktationen och intervallet från avvänjning till lyckad seminering, på nästkommande kullstorlek, samt att ta fram deskriptiv statistik på variationen i kullstorlek de senaste åren. Studien baseras på registreringar gjorda i WinPig, åren 2012 till 2017 på två konventionella svenska grisgårdar med smågrisproduktion. Suggor som inkluderades i studien var korsningar mellan Lantras x Yorkshire. Information som inkluderades i studien var besättning, suggans identitetsnummer, suggans födelsedatum, semineringsdatum, grisningsdatum, avvänjningsdatum, antal levandefödda smågrisar och antal dödfödda smågrisar. Suggorna delades i analyserna in i fyra grupper baserat på ålder vid första grisning; 330-359 dagar, 360-369 dagar, 370-379 dagar och 380-409 dagar. Fyra grupper skapades också från längden på intervallet mellan avvänjning och lyckad inseminering; 0-5 dagar, 6-20 dagar, 21-41 dagar och 42-80 dagar. Resultatet visar att kullstorleken har ökat under den studerade tidsperioden, med en ökning av antal levandefödda smågrisar och ingen signifikant förändring av antal dödfödda smågrisar. Kullstorleken ökade också med ökande kullnummer och nådde högsta totala antalet födda smågrisar i kull nummer 5 respektive 4 för Besättning A och B. Denna ökning i antalet levandefödda smågrisar kan bero på genetiska framsteg, men ras var inte inkluderat i denna studie och kan därför inte utvärderas. Kullstorlek bland förstagrisarna var lägst för de som tillhörde gruppen med 330-359 dagars ålder vid första grisning. För kullnummer två och högre varierade kullstorleken mindre mellan de olika grupperna, vilket tyder på att det inte fanns någon långvarig effekt av ingrisningsålder på kullstorlek. Därför kan det vara fördelaktigt att inseminera gyltor vid en lägre ålder om de har uppnått rätt kroppsvikt, eftersom skillnaden i kullstorlek i första kullen inte är ihållande. Längden på laktationen hade en inverkan på nästkommande kullstorlek. Det totala antalet födda smågrisar och antalet levandefödda smågrisar ökade signifikant ($P<0.001$) med ökad laktationslängd, vilket betyder att noll hypotesen kunde förkastas. Antalet dödfödda smågrisar ökade också med ökad laktationslängd, även om denna ökning inte var signifikant. Däremot så leder en längre laktationsperiod till ökad belastning på suggan, eftersom smågrisarna är tyngre och mer krävande längre fram i laktationen. Intervallet mellan avvänjning och inseminering gav också en signifikant ökning av nästkommande kullstorlek, vilket betyder att noll hypotesen kunde förkastas. Suggor som seminerades tidigt (0-5 dagar) hade större nästkommande kullar jämfört med suggor som seminerades sent (6-20 dagar). De största nästkommande kullarna återfanns bland suggor som seminerades vid andra brunst (21-41 dagar). Suggor som insemineras vid andra brunst har mer tid att uppnå rätt hull efter avvänjning, även om antalet icke produktiva dagar kommer att öka. Alla faktorer som undersöktes i denna studie påverkar kullstorlek och varje producent måste ta hänsyn till sina egna förutsättningar för att kunna fatta de rätta besluten.

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Introduction

For a long time period the goal in commercial piglet production has been to increase litter size in order to reach higher production results (Andersson *et al.*, 2016). Litter size is an important factor influencing the economic outcome, as a higher number of born piglets gives an opportunity to a higher number of pigs sent to slaughter (Johnson *et al.*, 1999; Kridli *et al.*, 2016). An increasing litter size has however lead to some negative effects (Rutherford *et al.*, 2013). The uterine capacity of the sow is limited due to limited uterine space and uterine blood supply (Rutherford *et al.*, 2013). Therefore, an increase in litter size will lead to a higher competition between fetuses to receive an adequate amount of vital nutrients resulting in larger number of stillborn piglets, lower birth weight and more variation in birth weight within-litter (Rutherford *et al.*, 2013). Other negative effects of increased litter size are longer duration of farrowing (Motsi *et al.*, 2006) and higher piglet mortality until weaning (Ocepek *et al.*, 2017). Despite this increase in litter size, poor litter size stands for approximately 20% of all sow removals and is the main reason for removal of sows in parities 4-6 (Lucia *et al.*, 2000). Removal rate is an important factor, as sow productivity contributes to the overall productivity and therefore sows should preferably be kept in production until the initial replacement cost has been covered (Schukken *et al.*, 1994; Calderón Díaz *et al.*, 2015). Selection of replacement gilts is of importance in order to reach a high sow profitability (Schukken *et al.*, 1994; Roongsitthichai *et al.*, 2012). This requires good management routines in order to recognize which gilts have the highest probability for high future performance (Patterson *et al.*, 2010).

A number of different factors influence litter size such as breed and parity number (Tummaruk *et al.*, 2000a) as well as genetics and management routines (Hoving *et al.*, 2011). A strong genetic correlation between litter size in first and second parity has been reported but a low phenotypic correlation (Hanenberg *et al.*, 2001), which is a sign of strong environmental effects on litter size (Hoving *et al.*, 2010). According to Engblom *et al.* (2016) the number of piglets born alive in early parities is an early sign of sow longevity. Sows with large first and second litters have a high genetic potential for large litters, something that could be either a sign of good reproductive physiology or a high ability to withstand environmental challenges (Hoving *et al.*, 2011). The importance of high producing sows in commercial piglet production as well as the many factors influencing litter size are underlying reasons to the interest in studying the phenotypic variation in litter size in Swedish commercial piglet production. The aim of this study was to investigate the impact of age at first farrowing, lactation period and length of weaning to service interval on subsequent litter size as well as to obtain updated descriptive statistics on variation in litter size. The hypothesis for this study was that there was an association between the studied factors lactation length as well as weaning to service interval and subsequent litter size. Another objective was to create helpful information for advisors and farmers to take into consideration in their work.

Literature review

A number of factors will influence litter size, including parity number, mating type, interaction between parity number and mating type, sow breed (Tummaruk *et al.*, 2000a) as well as genetic potential and environmental factors such as management and climate (Hoving *et al.*, 2011). The total number of piglets born normally increases from 1st to 2nd to 3rd parity (Koketsu & Dial, 1997; Tummaruk *et al.*, 2000a; Hoving *et al.*, 2011). Koketsu & Dial (1997) found a peak in litter size at parity 3 after which litter size tended to decrease. However, Tummaruk *et al.* (2000a) found that Landrace sows normally reached their largest litter size in parity 4 whereas Yorkshire sows reached their largest litter size in parity 5. In Swedish herds, Engblom *et al.* (2007) reported the mean parity number at sow removal to be 4.4, with a range of 3.4-5.7. Gilts that had a litter size of 9-16 piglets in their first parity were reported to have more subsequent parities than gilts with smaller or larger first litters (Andersson *et al.*, 2016). Multiple studies point out the importance of management factors during gilt rearing effecting sow productivity (Hoving *et al.*, 2010; Patterson *et al.*, 2010; Saito *et al.*, 2011; Roongsitthichai *et al.*, 2012). Strategies for farm management should therefore be included when planning gilt rearing (Hoving *et al.*, 2010).

Conditions for high sow reproduction

Litter size has shown to be influenced by the litter size in which the gilt itself was born, but also by characteristics such as ovulation rate, embryonic survival and uterine capacity (Tummaruk *et al.*, 2001a). Therefore, gilts born in large litters may have inherited genes with these characteristics from their mothers and therefore produce large litters themselves (Tummaruk *et al.*, 2001a). These characteristics have been shown to have moderate to high heritability (Tummaruk *et al.*, 2001a). There is also a strong genetic correlation between litter size in first and second parity (Holm *et al.*, 2005) but a low phenotypic correlation (Hanenberg *et al.*, 2001). According to Hoving *et al.* (2010) this indicates strong environmental effects on litter size. The same statement has been made about favorable genes inherited from the mother, were high environmental impact might reduce the genetic advantage (Tummaruk *et al.*, 2001a).

To be able to maximize sow performance, the length of lactation in conventional production has in many countries been reduced to three or four weeks (Chen *et al.*, 2017). Normally the uterus requires three weeks after parturition for regression and recovery before the next conception (Palmer *et al.*, 1965). This is also supported by Elsaesser & Parvizi (1980) whom stated that the hypothalamus-pituitary-ovarian axis might need two to three weeks to recover after parturition before the next conception. Low levels of luteinizing hormone (LH) during the early part of lactation was found to lead to an inability for the estrogen feedback mechanism and thereby no stimulation for ovarian activity was established (Elsaessier & Parvizi, 1980). Ovulation will occur when there is a surge of LH (Soede *et al.*, 2011), which normally would be triggered by the removal of the litter at weaning (Patterson *et al.*, 2008). This was already reported by Gaustad-Aas *et al.* (2004) whose results showed that breeding during the first three weeks after farrowing resulted in reduced subsequent litter size.

Age at when gilts reach puberty affect litter size

Reaching puberty has been defined as the time when gilts show first estrus with ovulation and have continuous estrus cycles after that (Tummaruk *et al.*, 2007; Tummaruk *et al.*, 2009) or when gilts show their first standing reflex in the presence of a boar (Patterson *et al.*, 2010; Roongsitthichai *et al.*, 2012). Physical signs of puberty are redness, swelling and mucosal discharge from the vulva (Patterson *et al.*, 2010). This normally occurs at 6-7 months of age (Tummaruk *et al.*, 2007), but if the nutritional intake of a gilt is inadequate, puberty may be delayed (Prunier & Quesnel, 2000). Gilt age at puberty varies to a large extent among gilts, but it also makes it possible to improve this trait in herd populations (Tummaruk *et al.*, 2007).

Litter size of gilts varied according to when first estrus occurred and gilts attaining puberty at an early age (181-200 days) had the highest total number of born piglets (Tummaruk *et al.*, 2007). Gilts with great potential to high lifetime performance should show first estrus before 200 days of age and be inseminated before 230 days of age (Roongsitthichai *et al.*, 2012). However, according to Patterson *et al.* (2010), gilts that reached puberty at different ages, but were all bred at third estrus, did not show any major differences regarding total number of born piglets over a lifetime. According to Roongsitthichai *et al.* (2012) this might be because these gilts were more fertile. When breeding was performed at 2nd estrus, instead of 1st estrus, an increase of 0.7 piglets was achieved in the first litter (Foxcroft *et al.*, 2010). However, if breeding was performed at 3rd estrus, the increase in litter size compared with breeding at 2nd estrus was only 0.2 piglets (Foxcroft *et al.*, 2010). In contrary, the early findings by MacPherson *et al.* (1977), where breeding at 1st, 2nd and 3rd estrus were compared after three parities, no difference in the total number of born piglets was found.

The effect of body weight on gilt performance

Gilts body weight at first estrus has been shown to influence the total number of born piglets (Tummaruk *et al.*, 2007). The highest number of piglets born alive was achieved with crossbred Landrace x Yorkshire gilts weighing 110.1-120.0kg at first observed estrus (Tummaruk *et al.*, 2007). This makes management factors regarding rearing of replacement gilts highly important (Hoving *et al.*, 2010; Roongsitthichai *et al.*, 2012). If gilts have a high average daily weight gain (ADG) they might be able to reach a high body weight at an earlier age (Roongsitthichai *et al.*, 2012). This is to prefer, as a low ADG might lead to impaired follicular growth as well as decreased competence of oocytes derived from the follicles (Van Wettere *et al.*, 2011). On the other hand, the body composition of the gilt at first mating can influence the longevity and gilts that grow should have a slow protein deposition (Calderón Díaz *et al.*, 2015). Crossbred Landrace x Yorkshire gilts that gained 604g/day were able to reach estrus at an age of 5 months compared with gilts that gained 541g/day and reached first estrus at an age of approximately 8 months (Tummaruk *et al.*, 2009).

Gilts that were inseminated when having a low body weight were found to have smaller litters (Hoving *et al.*, 2010; Roongsitthichai *et al.*, 2012) and a shortened longevity compared with gilts with a higher body weight (Roongsitthichai *et al.*, 2012). The reason for this could be that young animals have to gain enough weight in order to reach a certain mature size, because a slow growth rate may lead to gilts not being physically mature at first insemination (Hoving *et al.,* 2010). Furthermore, gilts are still growing after first insemination and if enough weight gain is not achieved until first weaning the body might prioritize growth over reproduction (Hoving *et al.,* 2010). During lactation sows lose weight which makes body reserves and feed intake highly important (Hoving *et al.,* 2010). According to Hoving *et al.* (2010), primiparous sows were more exposed to body reserve depletion than multiparous sows and heavier gilts had a better chance to cope with negative energy balance during lactation. In the postweaning period primiparous sows still used nutrients for lean tissue growth instead of depositing fat (Clowes *et al.*, 1994). If primiparous sows were in a negative energy balance it might have led to non-pregnancy or reduced litter size in parity two (Hoving *et al.,* 2010).

Choosing the right time period for first insemination

When first mating is performed, important criteria to be considered are gilts age, body weight and estrus expression (Roongsitthichai *et al.*, 2012). Age at first mating is controlled by the reach of puberty which can be achieved at an earlier age by using boar contact (Patterson *et al.,* 2010; Saito *et al.*, 2011) and ensuring the gilts a suitable growth rate (Saito *et al.*, 2011). Saito *et al.* (2011) studied influence of age at first mating on reproductive performance. The average age at first mating was 246 days and it clearly showed that high performing herds, having the largest number of weaned piglets per sow and year, had a higher proportion of early mated gilts compared with low performing herds. According to Saito *et al.* (2011) this was an indication of better gilt management and thus enabling gilts to earlier development. Schukken *et al.* (1994) suggested the most optimal economical age at first mating to be 200-220 days, compared with Babot *et al.* (2003) that found a higher longevity among gilts mated at an age of 221-240 days.

Gilts that were younger than 229 days at first mating were reported to have a higher longevity and lower culling risk (Saito *et al.*, 2011). Gilts that were mated at an older age were expected to have a shorter herd life (Schukken *et al.*, 1994) but on the contrary a higher number of piglets born alive in first parity (Schukken *et al.*, 1994; Le Cozler *et al.*, 1998; Iida *et al.*, 2015). However, according to Babot *et al.* (2003), gilts that were younger than 210 days at first mating were younger at culling and had a lower longevity. The influence of age at first mating on number of piglets born alive was higher in low parity than in mid or late parity (Tummaruk *et al.,* 2001a; Saito *et al.,* 2011). This is in disagreement with Roongsitthichai *et al.* (2012) that found no association between age at first mating and number of piglets born alive. However, they found a positive correlation between sow body weight and number of piglets born alive (Roongsitthichai *et al.,* 2012). Furthermore, Tummaruk *et al.* (2001a) found an increase of repeated breeding in gilts that were bred at an early age. Studies have not shown any effect of age at first mating on litter size in parity 3 or higher (Schukken *et al.*, 1994), which cohere with Babot *et al.* (2003) that reported age at first mating to be less important for sow performance from parity 2.

The effects of lactation length on litter size

Early weaning (10-12 days) has been shown to lead to a longer weaning to service interval (Kirkwood *et al.*, 1984; Koutsotheodoros *et al.*, 1998). This could be a result of insufficient time for the hypothalamus-pituitary-ovarian axis to recover after farrowing (Elsaesser & Parvizi, 1980; Kirkwood *et al.*, 1984). During lactation suckling piglets will stimulate the release of endogenous opioids which will inhibit the release of LH and gonadotropin releasing hormone (GnRH) and thereby keep the sow in an anestrus state (Kemp & Soede, 2012). LH levels in early weaned sows were lower than for sows weaned at 35 days, probably due to low storage of LH in the pituitary as well as GnRH in the hypothalamus (Kirkwood *et al.*, 1984). The higher levels of LH in later weaned sows could contribute to the shorter weaning to service interval (Kirkwood *et al.*, 1984).

The early weaned sows has been found to have smaller subsequent litters, which was not determined significant by Kirkwood *et al.* (1984), but on the contrary found significant by Koketsu & Dial (1997). Longer lactation length leading to larger subsequent litter size was also suggested by Tummaruk *et al.* (2000b). When lactation length was increased from 4 to 7 weeks, the subsequent litter size increased with 0.6 piglets (Tummaruk *et al.*, 2000b). This showed the important effect of lactation length on reproductive performance (Tummaruk *et al.*, 2000b). Furthermore, results from Gaustad-Aas *et al.* (2004) showed that a lactation length shorter than three weeks would decrease subsequent litter size as well as lengthen the weaning to service interval. This could be influenced by uterine recovery, hormonal imbalance and compromised follicular development, which would support the early findings by Palmer *et al.* (1965) and Elsaesser & Parvizi (1980).

An alternative to reducing lactation length could be intermitted suckling (Chen *et al.*, 2017). This method was designed to separate sow and piglets for a number of hours per day, which promoted piglets to solid feed intake and a gradual weaning process (Kemp & Soede, 2012). This allowed piglets to stay with the sow for a longer time period and at the same time allowed the sow to return to estrus and be mated (Chen *et al.*, 2017). It also made it possible to keep a longer lactation length and still increase the total number of litters produced per sow and year (Kemp & Soede, 2012; Chen *et al.*, 2017). Furthermore, intermitted suckling could ease the sows burden in late lactation and thereby enable for her to keep her body weight (Kemp & Soede, 2012). This would enable the sow to recycle as well as enhance follicular development during lactation and thereby possibly affect subsequent litter size (Kemp & Soede, 2012). However, Soede *et al.* (2012) found no difference in subsequent litter size between sows that had been bred during intermitted suckling or after weaning.

Effects of prolonging the weaning to service interval

Kemp & Soede (2012) suggested that a prolonged weaning to service interval could improve the reproductive performance in young sows. A method established for prolonging and synchronizing the interval was to use a progesterone analogue (altrenogest) (Kemp & Soede, 2012). Several studies confirm the use of altrenogest to have had positive effects on ovulation rate (Martinat-Botté *et al.*, 1995; Koutsotheodoros *et al.*, 1998; Patterson *et al.*, 2008), embryo development (Koutsotheodoros *et al.*, 1998), fetal development (Patterson *et al.*, 2008) as well as litter size (Martinat-Botté *et al.*, 1995). By using altrenogest it was possible to positively enhance follicular growth, which could be a good alternative especially for primiparous sows that have lost much weight during lactation (Kemp & Soede, 2012).

Prolonged weaning to service interval would also be achieved by skipping one heat after weaning (Kemp & Soede, 2012). In commercial herds it is common for sows to have a "second parity dip", which means that the high requirements of the first lactation have had a negative impact on the second parity litter size (Patterson *et al.*, 2008). Unlike primiparous sows, multiparous sows cope better with high weight loss during lactation and they are able to recycle despite high weight loss (Thaker & Bilkey, 2005). Normally, multiparous sows also recover more quickly from a negative energy balance (Clowes *et al.*, 1994). It has been suggested to breed at second estrus instead of first estrus after weaning, to avoid a "second parity dip" and to improve the reproductive performance (Clowes *et al.*, 1994). In their study, Clowes *et al.* (1994) could determine that parity 1 and 2 sows bred at second estrus instead of first estrus had a higher number of piglets born alive in the subsequent parity, which also was suggested by Morrow *et al.* (1990). Clowes *et al.* (1994) measured plasma progesterone concentrations after ovulation and found them to be higher at second estrus, compared to first estrus, in young sows (Clowes *et al.*, 1994). Such differences were not found in sows of higher parity when comparing between first and second estrus (Clowes *et al.*, 1994). It was suggested that this increase in progesterone might have led to a higher embryonic survival (Clowes *et al.*, 1994). If breeding at second estrus was established, the non-productive days would increase and it could be problematic to detect the second heat in an accurate way, due to management challenges (Clowes *et al.*, 1994; Kemp & Soede, 2012). Therefore the increase in litter size has to be beneficial enough so that there will be an economical advantage (Clowes *et al.*, 1994).

Similar findings were made by Tummaruk *et al.* (2001b) that studied the effect of repeated breeding on reproductive performance. Yorkshire gilts increased their first litter with 0.3 piglets when being rebred (Tummaruk *et al.*, 2001b). Landrace sows in second parity also increased their subsequent litter size as a result of repeated breeding after the first parity (Tummaruk *et al.*, 2001b). Over all, repeated breeding resulted in litters with 0.5 more piglets, for both breeds, compared to litters resulting from non-repeat breeding (Tummaruk *et al.*, 2001b). Hoving *et al.* (2011) on the other hand, found no connection between repeat breeding in second parity and litter size in subsequent parities. The reason for an increase in litter size could be that sows have had a longer resting period postweaning and a higher chance to improve their body condition before the upcoming farrowing (Tummaruk *et al.*, 2001b). However, Englom *et al.* (2008) determined a 50% higher removal risk for sows with a longer interval from weaning to next farrowing, something that could be affected by the batchwise production, as it is hard to fit the sows into other groups when returning to heat.

Seasonal variation in litter size

In southern Europe the Mediterranean temperate climate lead to a somewhat slower growth rate among gilts, because of heat stress during the summer (Iida *et al.*, 2015). This resulted in fewer piglets born alive when gilts were bred between July and September (Iida *et al.*, 2015). Iida & Koketsu (2014) found a decrease with 0.05 piglets with each degree Celsius rise prior to mating in tropical climate. Pre-service stress was shown to have more effect on fertility than post-service stress (Iida & Koketsu, 2014). Therefore, all gilts that are bred during the summer period should have reached a well-matured stage (Iida *et al.*, 2015) and use of cooling management post-service could help increase the total number of born piglets in the subsequent parity (Iida & Koketsu, 2014). However, Tummaruk *et al.* (2000a) found minor seasonal influence on litter size in Sweden, and this minor influence could be due to differences in climate compared with southern Europe; oceanic temperate climate and humid continental climate.

Sow removal and profitability

Every year, approximately 50% of all Swedish sows are removed and replaced with gilts (Engblom *et al.*, 2007). According to Calderón Díaz *et al.* (2015) the desirable number for sow removal should be around 40%. However, the target value for removal should be adapted to the individual farm, as the factors affecting removal rate is highly farm-specific (Calderón Díaz *et al.*, 2015). The most common reason for culling, accounting for approximately 30% of culled sows, is reproductive disorders (Lucia *et al.*, 2000; Engblom *et al.*, 2007: Engblom *et al.*, 2008). Another factor is litter size, were sows with less than 9 piglets have a 24-60% greater culling risk than sows with a litter size of 12-13 piglets (Engblom *et al.*, 2008). Removal due to poor litter size stands for approximately 20% of all removals among sows and is the most common culling reason for sows in parity four to six (Lucia *et al.*, 2000). The number of piglets born alive in each parity has been reported to be an early sign of sow longevity (Engblom *et al.*, 2016). From an economical point of view, sows should be kept in production until the initial investment cost for replacement has been met (Calderón Díaz *et al.*, 2015). The optimal number of parities for reaching highest profitability varies from 4 to 8 depending on the study performed (Calderón Díaz *et al.*, 2015). As sow productivity contributes to the overall productivity of the farm, the selection of gilts is highly important (Schukken *et al.*, 1994; Roongsitthichai *et al.*, 2012). Furthermore, it is of major importance to evolve management routines to recognize which gilts have the greatest potential to a high lifetime performance (Patterson *et al.*, 2010). In order to properly evaluate a gilts profitability, the gilt should have been productive for at least four years (Schukken *et al.*, 1994).

Materials and methods

Collection of data

Data originating from two Swedish commercial piglet herds with conventional production systems. Data were captured from the Swedish pig recording program, WinPig, operated by Gård & Djurhälsan. For each herd, three reports were generated from WinPig; farrowing, weaning and mating (Table 1). These records were via EXCEL imported into the SAS software, and constituted the base for creating the datasets, on which the analyses were based. The initial data consisting of all three reports contained in total 76,439 registrations from Herd A and 30,248 registrations from Herd B. The following information was included in the data; sow identity number, date of birth of the sow, date of insemination, date of farrowing, date of weaning, number of piglets born alive and number of stillborn piglets.

Table 1. Total number (*N*) of registrations made within each area of information that was collected from the two herds

	Herd A	Herd B
Registrations	*N*	*N*
Farrowing	19,754	8,993
Weaning	20,075	9,017
Mating	36,610	12,238
Total	76,439	30,248

Table 2 illustrates the total number of unique sows with their first parity registered during the studied time period (2012 until half of 2017). Classifications (1, 1-2, 1-3, …, 1-8) were made based on the total number of registered farrowings for each unique sow. For example, sows that only had a first parity belong to group 1 and sows that had five parities belong to group 1-5. The table only contains sows that had their first parity within the study period.

Table 2. Total number (*N*) of unique sows, divided into groups based on the total number of registered farrowings for each unique sow. Only sows with a first parity registered in these specific herds during the studied time period (2012 until half of 2017) were included.

	Herd A		Herd B	
Group	*N*	Percent	*N*	Percent
1	889	16.9	719	25.4
1-2	738	14.1	511	18.1
1-3	772	14.7	462	16.3
1-4	775	14.8	435	15.4
1-5	712	13.6	323	11.4
1-6	738	14.1	92	3.3
1-7	81	1.5	42	1.5
1-8	12	0.2	17	0.6
Total	4,717	89.9	2,601	91.9

Data editing

Datasets created from registrations were restricted to only include sows with an identification number and recordings made during the time period 2012 until half of 2017. Parity numbers were created with the information on farrowing date. Both herds consisted of Yorkshire x Landrace crossbred sows. Litter data was in the analyses restricted to parities 1-7. Data on parities 8 and higher were excluded from the statistical analyses. Records from farrowing, weaning and mating were merged together, based on sow identity number, in order to create datasets for analyzes. For each part of the study, three analyses were made in order to include the three variables: total number of piglets born, number of piglets born alive and number of stillborn piglets.

Each sow (with 1st farrowing in the herds analyzed) was grouped according to age at first farrowing; 330-359 days, 360-369 days, 370-379 days and 380-409 days. Sows that were younger than 330 days or older than 409 days at first farrowing were excluded from these analyses. Classification of groups were based on information about groupings made in similar studies, but also made to suit the data used in the present study. Weaning to service interval was defined as; successful insemination date - weaning date, and if this interval was longer than 80 days the interval was set as missing. For the analyses, groups were created based on length of weaning to successful service interval; 0-5 days, 6-20 days, 21-41 days and 42-80 days. Classification of groups were made to separate early inseminated sows at first estrus (0-5 days), late inseminated sows at first estrus (6-20 days), sows inseminated at second estrus (21-41 days) and sows inseminated even later (42-80 days).

In total, 18,214 observations from Herd A were created from records on farrowing and used to obtain descriptive statistics for litter size over years, months and parities. The same amount of observations was used for each analysis on total number of born piglets, number of piglets born alive and number of stillborn piglets. For descriptive statistics on age at first farrowing, a total of 15,725 observations from Herd A were created from records on farrowing. The same amount of observations were used for each analysis including total number of born piglets, number of piglets born alive and number of stillborn piglets. For analyzing the impact of lactation length as well as weaning to service interval on subsequent litter size, a total of 13,698 observations from Herd A were created by merging records on farrowing, weaning and mating. The same amount of observations were used in each analysis including total number of piglets born, number of piglets born alive and number of stillborn piglets.

In total, 8,111 observations from Herd B were created from records on farrowing and used to obtain descriptive statistics for litter size over years, months and parities. The same amount of observations was used for each analysis on total number of born piglets, number of piglets born alive and number of stillborn piglets. A total of 5,991 observations from Herd B were created from records on farrowing and used to obtain descriptive statistics for the impact of age at first farrowing on subsequent litter size. The same amount of observations were used for each analysis including total number of born piglets, number of piglets born alive and number of stillborn piglets. When analyzing the impact of lactation length as well as weaning to service interval on subsequent litter size, a total of 5,344 observations were created by merging records on farrowing, weaning and mating. The same amount of observations were used in each analysis including total number of piglets born, number of piglets born alive and number of stillborn piglets.

Data structure

The total number of farrowings registered for each year in both herds is illustrated in Table 3. In Herd B the number of recorded farrowings has increased remarkably over the last few years.

Table 3. Total number (*N*) of recorded farrowings for each year in the two herds

	Herd A		Herd B	
Year	*N*	Percent	*N*	Percent
2012	2,392	13.2	679	8.4
2013	3,350	18.5	655	8.1
2014	3,531	19.5	690	8.5
2015	3,615	19.6	1,868	23.0
2016	3,570	19.6	2,878	35.5
2017	1,756	9.6	1,341	16.5
Total	18,214	100	8,111	100

Table 4 illustrates the number of farrowings registered for each month during the studied time period (2012 until half of 2017) in both herds.

Table 4. Total number (*N*) of recorded farrowings for each month in the two herds

	Herd A		Herd B	
Month	*N*	Percent	*N*	Percent
January	1,645	9.0	715	8.8
February	1,511	8.3	625	7.7
March	1,721	9.4	684	8.4
April	1,614	8.9	757	9.3
May	1,661	9.1	727	9.0
June	1,577	8.7	716	8.8
July	1,426	7.8	620	7.7
August	1,485	8.2	663	8.2
September	1,379	7.5	652	8.0
October	1,382	7.6	603	7.4
November	1,307	7.2	677	8.4
December	1,506	8.3	672	8.3
Total	18,214	100	8,111	100

The total number of registered farrowings for each parity during the studied time period (2012-2017) is illustrated for both herds in Table 5. The proportion of registered farrowings was highest among first parity sows, and the proportion decreased with increasing parity number.

Table 5. Total number (*N*) of recorded farrowings for each parity in the two herds

	Herd A		Herd B	
Parity	*N*	Percent	*N*	Percent
1	4,717	25.9	2,610	32.2
2	4,027	22.1	1,954	24.1
3	3,404	18.7	1,477	18.2
4	2,723	15.0	1,047	12.9
5	1,957	10.7	612	7.5
6	1,148	6.3	265	3.3
7	238	1.3	146	1.8
Total	18,214	100	8,111	100

Table 6 illustrates the classifications made for sows, based on their age at first farrowing, and the number of registered farrowings for each group in the two herds. In Herd A the proportion of registered farrowings was similar between groups, compared to Herd B were the highest proportion was found among the youngest sows at first farrowing.

Table 6. Total number (*N*) of recorded farrowings for each group, based on sow age at first farrowing in the two herds

	Herd A		Herd B	
Age at first farrowing (days)	*N*	Percent	*N*	Percent
330-359	4,053	25.8	2,632	43.9
360-369	4,202	26.7	1,025	17.1
370-379	3,273	20.8	945	15.8
380-409	4,197	26.7	1,389	23.2
Total	15,725	100	5,991	100

Statistical analyses

Statistical Analysis Software (SAS) version 9.4 was used to combine data that was imported from WinPig via EXCEL, edit data, obtain descriptive statistics and perform statistical analyses (SAS Institute, 2012). The present study was an observational and retrospective study, where the farrowing served as the observational unit. The analyses were performed using a quantitative method with random linear models and quantitative variables. The outcome variables (Y) analyzed separately in each model were: total number of born piglets, number of piglets born alive and number of stillborn piglets. The measurement for the variables was a ratio scale, as they had a zero point and the scale steps were equidistant. Observations included were handled as being normal distributed.

Datasets with information about farrowing were used to obtain descriptive statistics about variation in litter size over time. Descriptive statistics were obtained in order to organize and summarize the observations. In SAS, procedures FREQ and MIXED were used to obtain these results.

Model 1 was created to analyze the variation in litter size in relation to sow age at first farrowing. Analysis of variance included LSMEANS option within PROC MIXED to obtain least squares means and datasets were run three times in order to obtain results on all three variables: total number of born piglets, number of piglets born alive and number of stillborn piglets. Least squares means are mean values, corrected for the effect of other factors included in the statistical model. The measure of central tendency was the mean value and measure of dispersion was standard error. Sow id was included as a random effect in the statistical model, as sows were randomly collected from the population. The other factors included in the statistical model were: farrowing year, farrowing month, parity number, sows age at first farrowing, the association between age at first farrowing and parity number, the association between farrowing year and farrowing month, the sows lactation length, regression coefficient and the time period from weaning until successful insemination, all included as fixed effects, as they were chosen to be included in the study. The statement option PDIFF was used to create pairwise comparisons between years, months and parities as well as between sow groups based on sow age at first farrowing.

Model 2 was created in order to obtain inferential statistics by analyzing possible factors influencing subsequent litter size. This analysis was used in order to try and make conclusions from observations in the descriptive statistics. In order to achieve this, calculations were made of the probability of rejecting the null hypothesis. If a low p-value was achieved the null hypothesis could be rejected. On the other hand, if the null hypothesis was achieved, no association was found between variables. Factors evaluated were lactation length and length of weaning to service interval. Datasets including information about farrowing, weaning and mating were merged together and analyzed with procedures MIXED and GLM. Within the GLM procedure, statement option SOLUTION was used to get results on the regression coefficients. This analysis was performed in order to evaluate the interaction between lactation length as well as weaning to service interval and subsequent litter size.

The level of significance was set to $P \leq 0.05$, and therefore p-values above 0.05 would lead to acceptance of the null hypothesis.

Two models were used for the analyses performed within herd:

$$Y_{ijklmn} = \mu + S_i + A_j + M_k + P_l + F_m + AM_{jk} + PF_{lm} + e_{ijklmn} \quad (1)$$

$$Y_{ijklpq} = \mu + S_i + A_j + M_k + P_l + b1{*}L + WSI_p + e_{ijklpq} \quad (2)$$

Y = outcome variable

μ = mean value

S_i = random effect of sow id

A_j = fixed effect of farrowing year (2012-2017)

M_k = fixed effect of farrowing month (Jan, Feb, …, Dec)

P_l = fixed effect of parity number (1-7)

F_m = fixed effect of the sows age at first farrowing (four groups: 330-359, 360-369, 370-379 and 380-409 days)

AM_{jk} = fixed effect of the interaction between farrowing year and farrowing month

PF_{lm} = fixed effect of the interaction between age at first farrowing and parity number

b1 = regression coefficient

L = lactation length of previous litter

WSI_p = fixed effect of the time period from weaning until successful insemination (four groups: 0-5, 6-20, 21-41 and 42-80 days)

e= random residual effect

Results

Descriptive statistics

Variation in litter size over years

The random effect of sow id as well as the residual had no significant impact on the results. The mean litter size has increased over the last few years which is shown for both herds in Figure 1. In Herd A the total number of born piglets has increased significantly from 14.1 to 15.6 and in Herd B from 14.2 to 15.7, between years 2012-2017 ($P<0.001$). The mean number of piglets born alive has increased significantly from 12.8 to 14.5 in Herd A and from 13.2 to 14.5 in Herd B ($P<0.001$). The mean number of stillborn piglets has decreased significantly from 2014 to 2015 in Herd A ($P<0.001$). In Herd B there were no significant differences in number of stillborn piglets over the studied time period.

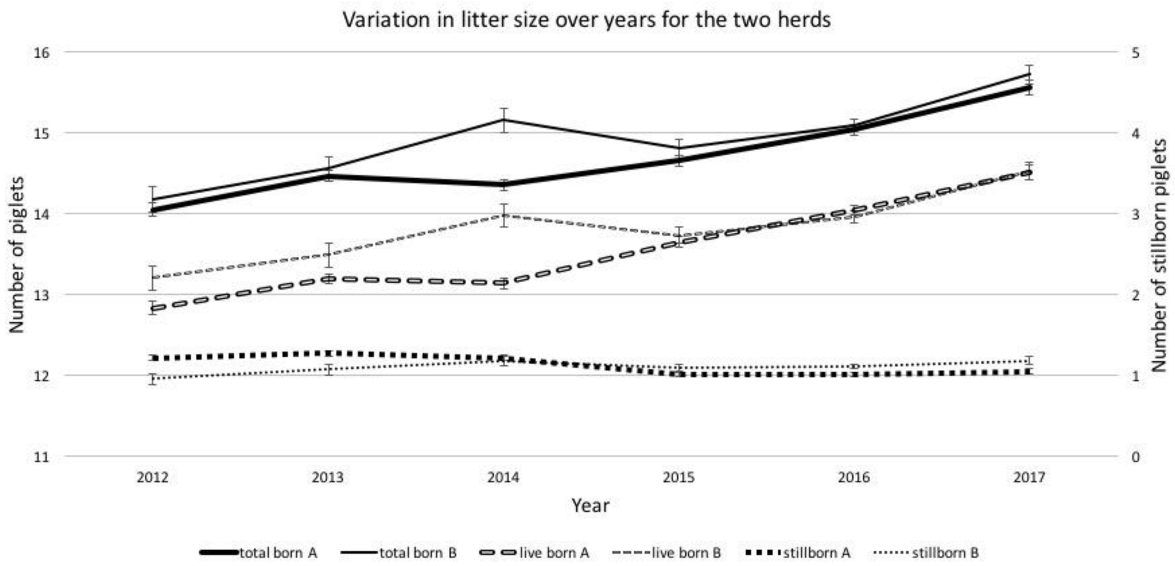

Figure 1. Adjusted mean litter size from year 2012 until half of 2017 for the two herds. The total number of born piglets and piglets born alive on the left side and the number of stillborn piglets on the right side. N = 18,214 (Herd A) and 8,111 (Herd B).

Variation in litter size over months

The random effect of sow id as well as the residual had no significant impact on the results. The mean litter size has varied between months in both herds, which is shown in Figure 2. In Herd A the total number of born piglets in November and December was significantly ($P<0.001$) different from total number of born piglets in July and August. The number of stillborn piglets in July was also significantly ($P<0.001$) different from number of stillborn piglets in November and December. In Herd B there were no significant differences in litter size over months of the year.

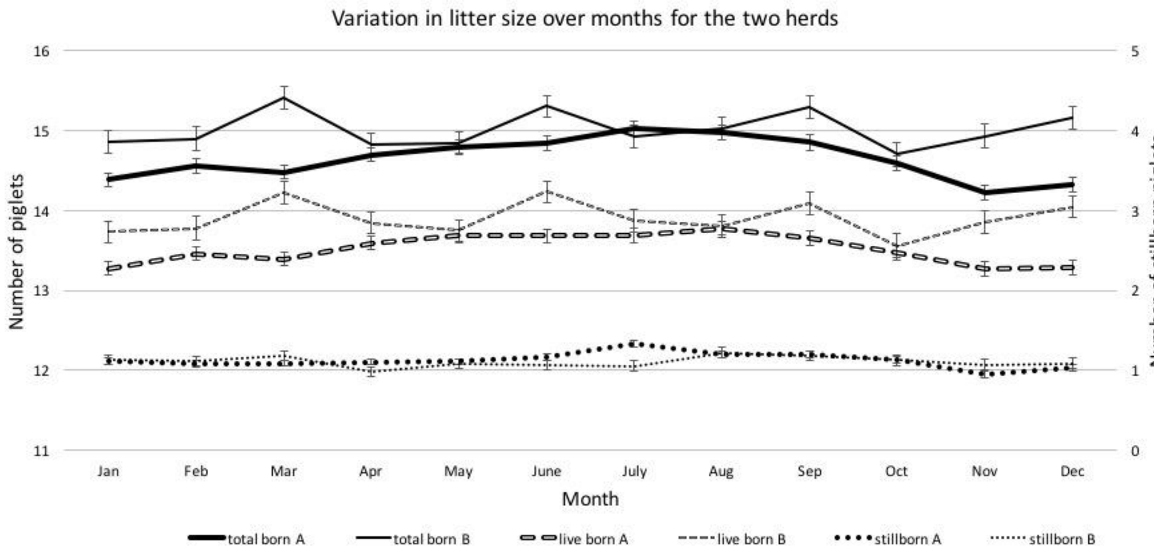

Figure 2. Adjusted mean litter size from January to December for the two herds. The total number of born piglets and piglets born alive on the left side and the number of stillborn piglets on the right side. N = 18,214 (Herd A) and 8,111 (Herd B).

Variation in litter size over parities

The random effect of sow id as well as the residual had no significant impact on the results. Litter size differ between parities in the present study, which is shown for both herds in Figure 3. Total number of born piglets and piglets born alive increased significantly ($P<0.001$) until third parity in both herds. The number of stillborn piglets increased significantly ($P<0.001$) from second to fifth parity, in both herds.

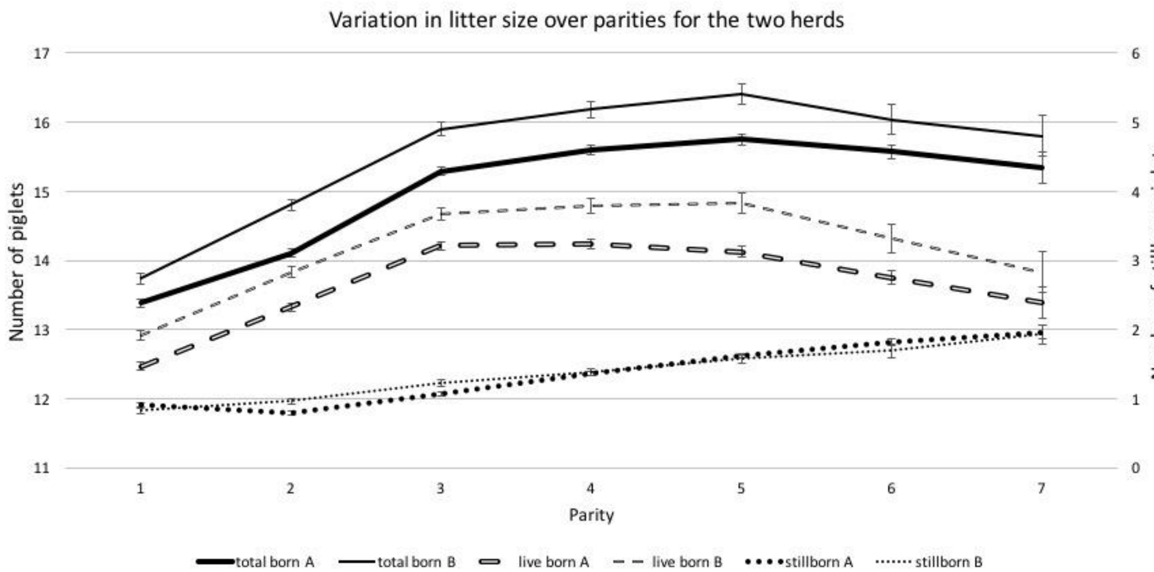

Figure 3. Adjusted mean litter size in parity 1-7 for the two herds. The total number of born piglets and piglets born alive on the left side and the number of stillborn piglets on the right side. N = 18,214 (Herd A) and 8,111 (Herd B).

Variation in litter size in relation to age at first farrowing

The random effect of sow id as well as the residual had no significant impact on the results. Table 7 illustrates the four groups of sows based on their age at first farrowing and the mean number of piglets born alive for each group. The average number of piglets born alive, over all parities, in relation to sow age at first farrowing differed less in Herd A compared to Herd B.

Table 7. The average number of piglets born alive for all parities of all sows, divided into groups based on the sows age at first farrowing. N = 15,725 (Herd A) and 5,991 (Herd B)

Age at first farrowing (days)	Number of piglets born alive	
	Herd A	Herd B
330-359	13.7	14.0
360-369	13.6	14.3
370-379	13.6	14.7
380-409	13.4	14.4

For Herd A, the total number of born piglets in first parity was significantly (P<0.001) lower for the yongest sows (330-359 days) at first farrowing, compared to all other groups (Fig.4). The total number of born piglets in first parity differed between the other groups as well, although these differences were not significant. Throughout parities 2-5 the total number of born piglets increased similar between the four groups with different age at first farrowing.

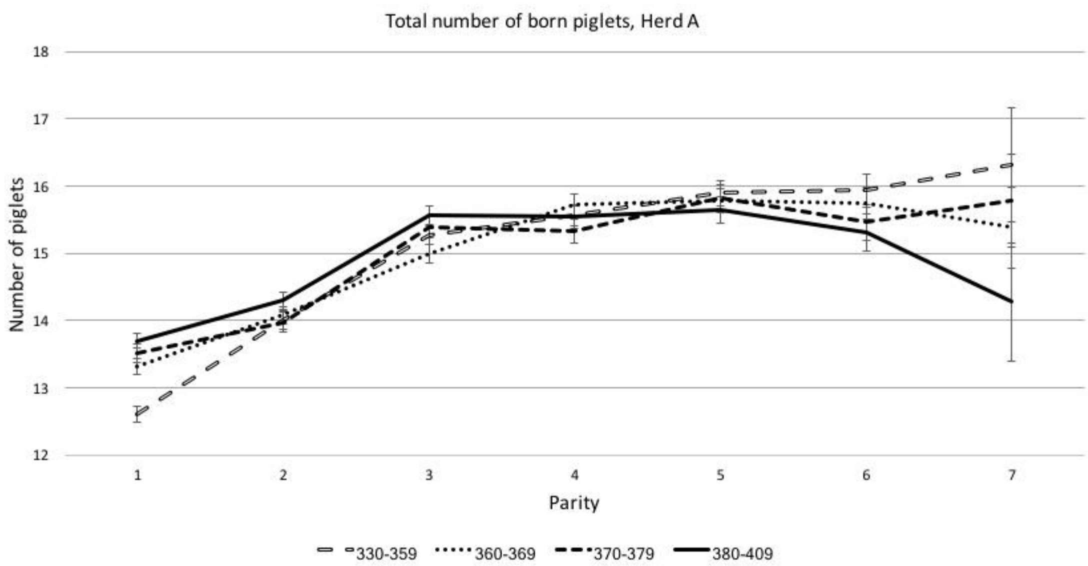

Figure 4. Adjusted mean total number of born piglets throughout parity 1-7 in relation to age at first farrowing in Herd A. N = 15,725.

For Herd B, the total number of born piglets in first parity was significantly (P<0.001) lower for the youngest sows (330-359 days) at first farrowing, compared with sows at age 370-379 days and 380-409 days at first farrowing (Fig. 5). For sows at age 360-369 days, the total number of born piglets in first parity was significantly (P<0.001) different from sows with age

370-379 days. Throughout parities 2-5 the total number of born piglets increased in a similar way between the groups of sows.

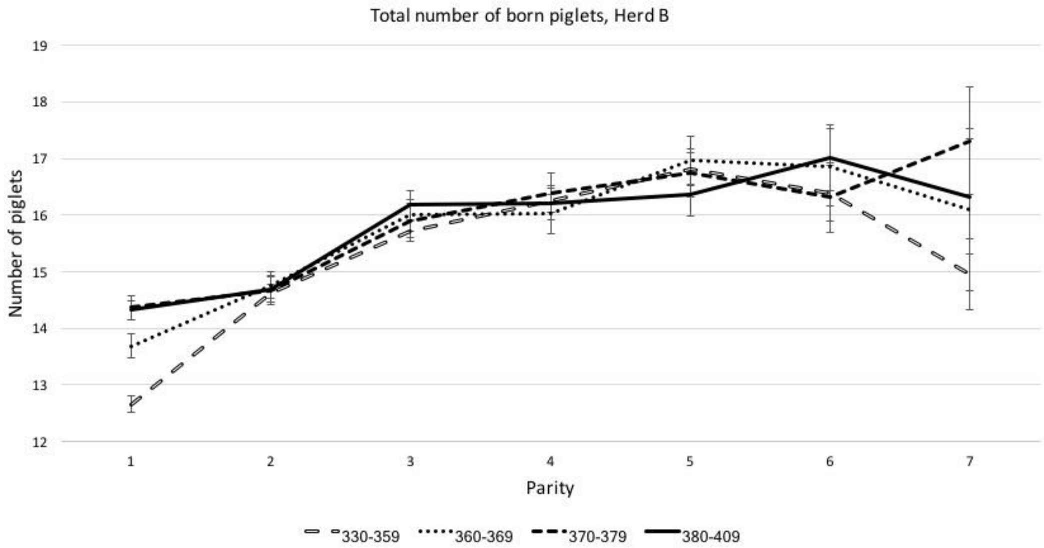

Figure 5. Adjusted mean total number of born piglets throughout parity 1-7 in relation to age at first farrowing in Herd B. N = 5,991.

The number of piglets born alive in Herd A was significantly (P<0.001) lower for the youngest sows (330-359 days) compared with all other groups (Fig. 6). The differences between the other groups were not significant. After first farrowing the number of piglets born alive increased with parity throughout all groups of sows. In later parities the number of piglets born alive decreased.

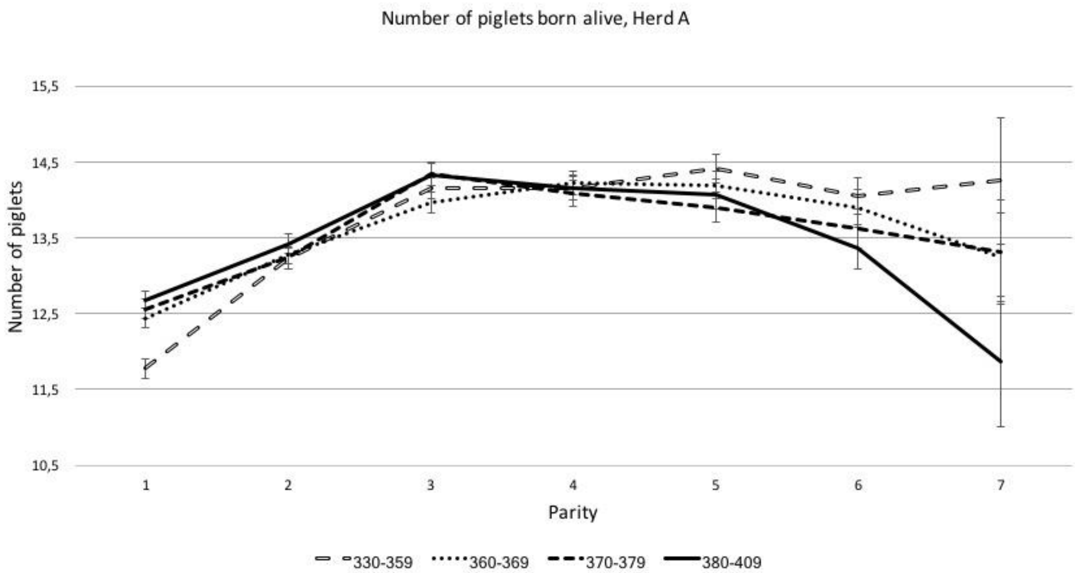

Figure 6. Adjusted mean number of piglets born alive throughout parity 1-7 in relation to age at first farrowing in Herd A. N = 15,725.

The number of piglets born alive in first parity in Herd B was lowest for the youngest sows (330-359 days) (Fig. 7). This number was significantly (P<0.001) different from sow groups with age 370-379 days and 380-409 days at first farrowing. The number of piglets born alive in first parity for sows with age 360-369 days was also significantly (P<0.001) different from sows at age 370-379 days at first farrowing. Throughout parities 2-4 the number of piglets born alive increased.

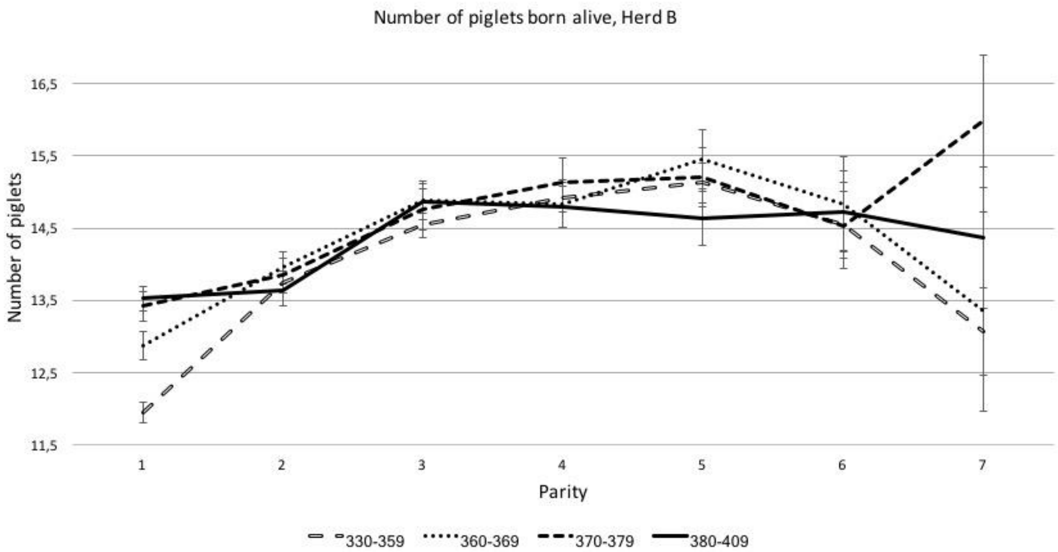

Figure 7. Adjusted mean number of piglets born alive throughout parity 1-7 in relation to age at first farrowing in Herd B. N = 5,991.

The mean number of stillborn piglets in Herd A was quite similar between all groups in first parity, ranging from 0.8 to 1.0 piglets (Fig. 8). The differences between the groups were not significant. The number of stillborn piglets decreased in parity 2 for all groups, regardless age at first farrowing. Throughout parities 3-7 the number of stillborn piglets increased with increasing parity.

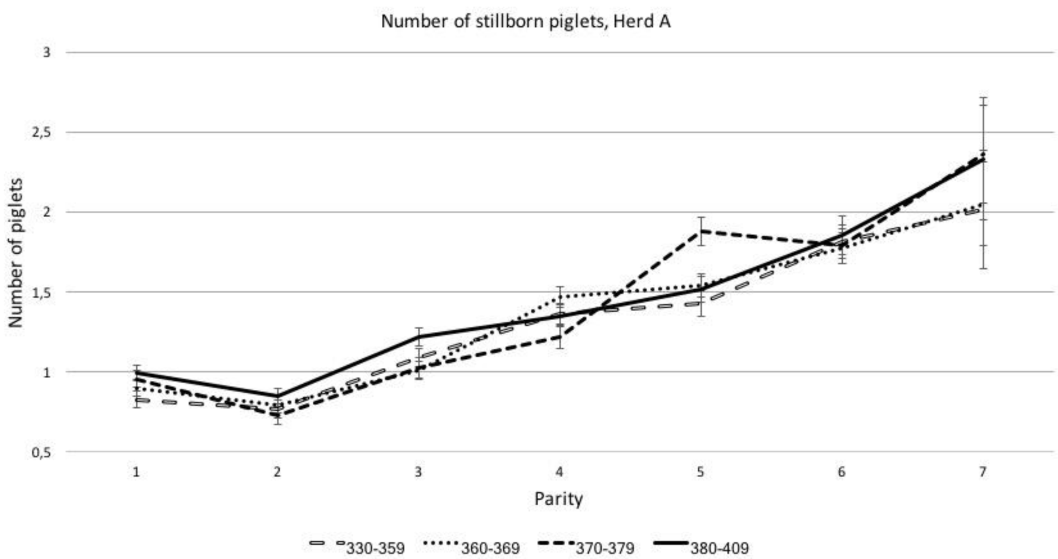

Figure 8. Adjusted mean number of stillborn piglets throughout parity 1-7 in relation to age at first farrowing in Herd A. N = 15,725.

The mean number of stillborn piglets in Herd B were quite similar for all groups of sows in first parity, ranging from 0.7 to 0.8 piglets (Fig. 9). The only significant (P<0.001) difference in number of stillborn piglets was found between the youngest sows (330-359 days) and sows with age 370-379 days at first farrowing.

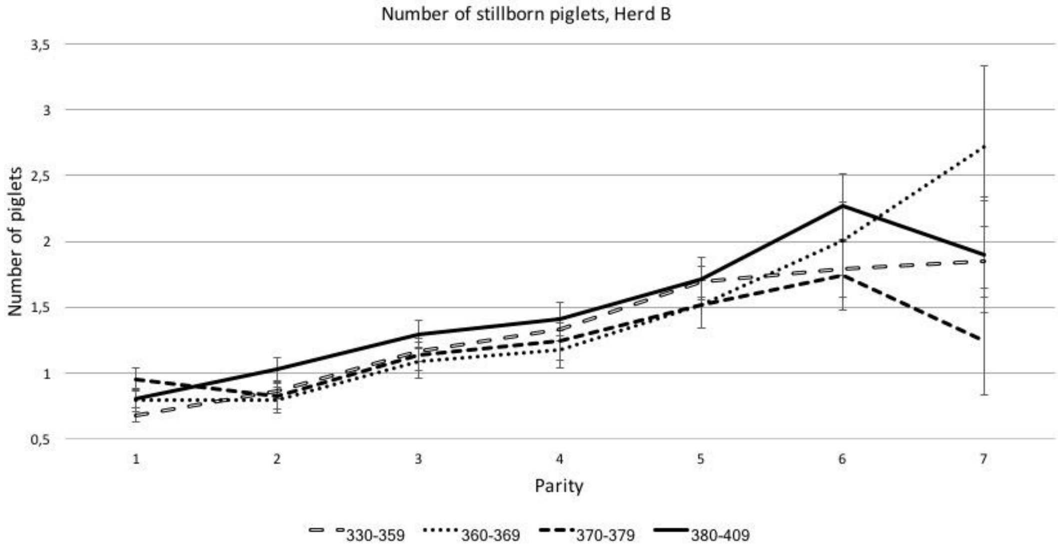

Figure 9. Adjusted mean number of stillborn piglets throughout parity 1-7 in relation to age at first farrowing in Herd B. N = 5,991.

Impact of lactation period on subsequent litter size

The random effect of sow id as well as the residual had no significant impact on the results. For Herd A the total mean number of born piglets in subsequent litter increased with increasing lactation period. When increasing the lactation period, each extra day gave 0.056 ($P<0.001$) piglets more in the subsequent litter. The mean number of piglets born alive also increased with increasing lactation period. Each extra day of the lactation period increased the number of piglets born alive in subsequent litter with 0.051 piglets ($P<0.001$). Furthermore, each extra day of lactation increased the number of stillborn piglets in subsequent litter with 0.004 piglets, although this number was not significant ($P=0.163$).

In Herd B the total mean number of born piglets in subsequent litter increased with increasing lactation period. For each extra day of lactation the subsequent total number of born piglets increased with 0.058 piglets ($P<0.001$). For piglets born alive, the subsequent litter increased with 0.054 piglets with each extra day of lactation ($P<0.001$). With each extra day of lactation the subsequent number of stillborn piglets increased with 0.004 piglets, however this number was not significant ($P=0.478$).

Impact of length of weaning to service interval on subsequent litter size

The random effect of sow id as well as the residual had no significant impact on the results. Table 8 illustrates the length of the weaning to service interval and the mean subsequent litter size for each group in Herd A. The highest subsequent total number of born piglets was found amongst sows with a weaning to service interval of 21-41 days and 42-80 days. The subsequent number of piglets born alive was highest for sows with a weaning to service interval of 42-80 days. The number of stillborn piglets in subsequent litter was highest for sows with a weaning to service interval of 21-41 days.

Table 8. Sows were divided into groups based on the length of their weaning to service interval. Table also shows the mean numbers of subsequent litter size, in relation to the weaning to service interval.

WSI (days)	*N*	TNB ± SE	BA ± SE	SB ± SE
0-5	10,306	15.5 ± 0.09[a]	14.1 ± 0.09[a]	1.5 ± 0.04[a]
6-20	2,135	15.1 ± 0.12[b]	13.6 ± 0.12[b]	1.5 ± 0.05[a]
21-41	1,049	16.6 ± 0.14[c]	14.9 ± 0.13[c]	1.7 ± 0.06[c]
42-80	208	16.6 ± 0.26[c]	15.1 ± 0.25[c]	1.5 ± 0.11[ac]

N=number of sows, TNB=total number of born piglets, BA=piglets born alive, SB=stillborn piglets, SE=standard error, a, b, c: different superscripts within a column represent significant differences (P<0.05)

With each extra day between weaning and insemination, the subsequent total number of born piglets increased with 0.038 piglets (P<0.001), number of piglets born alive increased with 0.031 (P<0.001) and number of stillborn piglets increased with 0.007 piglets (P<0.001).

Table 9 illustrates the length of the weaning to service interval and the mean subsequent litter size for each group in Herd B. The highest subsequent total number of born piglets and piglets born alive occurred for sows with a weaning to service interval of 21-41 days. The subsequent number of stillborn piglets, however, was highest for sows with the shortest weaning to service interval (0-5 days) as well as for sows with an interval of 21-41 days.

Table 9. Sows were divided into groups based on the length of their weaning to service interval. Table also shows the mean numbers of subsequent litter size, in relation to the weaning to service interval.

WSI (days)	*N*	TNB ± SE	BA ± SE	SB ± SE
0-5	3,038	15.9 ± 0.16[a]	14.3 ± 0.15[a]	1.6 ± 0.07[a]
6-20	1,714	15.3 ± 0.17[b]	13.9 ± 0.17[b]	1.4 ± 0.08[b]
21-41	474	16.6 ± 0.22[c]	15.0 ± 0.22[c]	1.6 ± 0.10[a]
42-80	79	16.4 ± 0.43[ac]	14.9 ± 0.41[ac]	1.5 ± 0.20[ab]

N=number of sows, TNB=total number of born piglets, BA=piglets born alive, SB=stillborn piglets, SE=standard error, a, b, c: different superscripts within a column represent significant differences (P<0.05)

With each extra day between weaning and insemination the subsequent total number of born piglets increased with 0.021 (P=0.0005) piglets and number of piglets born alive increased with 0.022 (P=0.0002) piglets. The subsequent number of stillborn piglets decreased with 0.0003 piglets for each extra day, however this number was not found significant (P=0.903).

Discussion

The aim of this study was to evaluate the mean litter size and analyze factors that may impact litter size. Litter size is influenced by many different factors, such as parity number and breed as well as genetics and management factors, (Tummaruk *et al.*, 2000a; Hoving *et al.*, 2010) and has a high economic value as most piglet producers want to produce a large number of pigs (Kridli *et al.*, 2016). Both genetics and environment have a high impact on litter size (Hoving *et al.*, 2011), which could explain the high variation in litter size over time (Fig. 1), both within herds and between herds in the present study. The results show a clear increase in mean litter size in the last few years which could have been affected by genetic improvements. As breed was not included as a factor in this study the genetic effect is hard to evaluate. The mean litter size in the present study also varied over months and the results for Herd A (Fig. 2) showed a peak during the summer and low numbers during winter, which may be due to seasonal effects. These results corresponded with findings by Iida *et al.* (2015), were sows inseminated during the summer were reported to produce smaller litters. However, according to Tummaruk *et al.* (2000a) these seasonal effects have not been reported in Swedish climate. For Herd B (Fig. 2) mean litter size differed between months but this difference was recurring and showed no signs of seasonal effects. The number of observations collected from Herd B were lower compared with Herd A, which could be one explanation to the high variety in litter size between months, as each observation has a higher impact on the results.

Findings in the present study showed an increase in mean litter size until parity 5 in both herds (Fig. 3). Such an increase was also reported earlier, were the mean litter size increased with increasing parity number until parity 3-5 after which litter size decreased (Koketsu & Dial, 1997; Tummaruk *et al.*, 2000a; Hoving *et al.*, 2011). However, the number of stillborn piglets, in the present study, also increased with increasing parity which makes it important to evaluate the change in piglets born alive and not only the total number of born piglets. In the present study the number of piglets born alive showed a clear increase until third parity with almost one piglet increase for each parity. In the fourth parity the number of piglets born alive was almost unchanged and thereafter decreased with each parity. Sows should be kept in production until the initial replacement cost has been covered and in order to reach the highest profitability sows should produce 4-8 litters, the results varies depending on the study performed (Calderón Díaz *et al.*, 2015). Despite this, the average parity for sow removal in Sweden is 4.4 (Engblom *et al.*, 2007).

Age at first mating has been reported to influence litter size and longevity as well as culling risk (Saito *et al.*, 2011). The results in the present study is in accordance with the findings by Saito *et al.* (2011), showing a difference in litter size in relation to age at first farrowing (Fig. 4 and Fig. 5). The youngest sows had the lowest number of piglets born alive in their first parity, but also the largest increase in piglets born alive in parity 2 (Fig. 6 and Fig. 7). These results corresponds with findings by Le Cozler *et al.* (1998), where sows that farrowed before 330 days of age had the highest increase in litter size from first to second parity. The influence of age at first mating on number of piglets born alive was reported to be higher in low parity than in later parities (Tummaruk *et al.*, 2001a; Saito *et al.*, 2011). The present study showed that the mean number of piglets born alive in parities 2-4 varied less with age at first farrowing. This implies that young sows have smaller litters at first farrowing, but this difference then evens out between sow groups in subsequent parities. This is also supported by results presented in table 7 were the mean number of piglets born alive throughout parities 1-7 is shown. Especially in Herd A, this number did not differ much between sow groups based on age at first farrowing. In later parities results in the present study differed between herds. In Herd A the youngest sows at first farrowing had the highest number of piglets born alive in parities 5-7 compared to Herd B were they had the lowest number of piglets born alive. The data collected from Herd B consisted of a lower number of observations, compared with Herd A. This could be a reason to the bigger differences in litter size between groups especially in later parities for Herd B, as the number of sows reaching higher parities was quite low. It would have been interesting to know how many sows that were left in each group for each parity, in order to see which sows that were the most sustainable.

Gilts body weight at first mating was reported to influence litter size (Tummaruk *et al.*, 2007; Hoving *et al.*, 2010; Roongsitthichai *et al.*, 2012). This could be a reason to why young first parity sows had smaller litters in the present study. It could be possible that the older sows had reached a more mature body weight which might have been necessary in order to produce large litters. However, litter size differed less between sow groups (based on age at first farrowing) in later parities, which implies that the difference in parity 1 is not continuous. Furthermore, gilts with low body weight at first mating were reported to have a shortened longevity (Roongsitthichai *et al.*, 2012), which implies that if young sows had a low body weight at first mating, they would have been culled before reaching higher parities. As mentioned above, it would have been interesting to know which sows that were kept for most parities and also connect this to their body weight as gilts. Thereby, it would have been possible to evaluate if gilts body weight had an impact on litter size and longevity. According to Lucia *et al.* (2000), removal due to poor litter size stands for 20% of removals among sows, which also implies that sows with small liters would have been removed in early parities. In the present study, the number of sows kept for many parities was quite low compared to the initial amount of sows having a first parity (Table 2). It is possible that litter size had an impact on the choice to keep or remove sows.

As mentioned, litter size has an economical value for piglet production, but producers also want to maximize sow performance by reducing lactation length and thereby enable sows to have more litters (Chen *et al.*, 2017). However, to keep a good profitability sows have to produce the same litter size despite a shorter lactation length. In early reports by Palmer *et al.* (1965) they stated that a sow uterus require at least three weeks after farrowing to recover before next conception. This implies that a lactation length of at least three weeks is to prefer, which is also supported by Elsaesser & Parvizi (1980) that stated a time period of two to three weeks for the hypothalamus-pituitary-ovarian axis to recover after farrowing before next conception. In the present study a longer lactation period lead to a higher subsequent litter size. For both herds the number of piglets born alive increased ($P<0.001$) with each extra day of lactation, which also the number of stillborn piglets did although these numbers were not found significant. These results corresponds with findings reported by Koketsu & Dial (1997) as well as Tummaruk *et al.* (2000b), were sows with longer lactation lengths had larger subsequent litters. This implies that the length of the lactation period is an important value for the reproductive performance (Tummaruk *et al.*, 2000b). Gaustad-Aas *et al.* (2004) reported a lactation length shorter than three weeks to decrease subsequent litter size as well as increase the weaning to service interval. These are important findings to consider when deciding on length of lactation period in commercial piglet production. However, there are other factors having an impact on the choice of length of lactation period. Although the subsequent litter size might increase with a longer lactation period, a shorter lactation period would allow the sow to have more litters during her productive life, as mentioned earlier (Chen *et al.*, 2017).

For commercial piglet producers it is important to evaluate all valuable factors to achieve the most economical option. The method of intermittent suckling was established to combine two aspects, piglets could stay with the sow for a longer lactation period, and at the same time the sow could return to estrus and be inseminated. This might also ease the sows burden as piglets are able to increase their solid feed intake (Chen *et al.*, 2017). However, the sow will need sufficient nutrients to enable development of fetuses in the uterus and thereby has to be in good body condition to combine lactation with gestation. Multiparous sows cope better with a negative energy balance during lactation and are able to recycle despite high weight loss (Thaker & Bilkey, 2005). Therefore, primiparous sows on average have a longer weaning to service interval, if they are not able to keep a good body condition during lactation (Thaker & Bilkey, 2005). In the present study, there was no record of body condition, something that would be interesting for future studies, as body condition clearly has an impact on sow reproduction. However, the present study showed differences in subsequent litter size based on length of weaning to service interval (Table 8 and 9). It would have been interesting to know if the sows body condition had an impact on these results.

Differences in litter size between sows based on their weaning to service interval that was reported in the present study corresponds with findings by Kemp & Soede (2012). Interesting to see was that early inseminated sows (0-5 days after weaning) had larger subsequent litters compared to late inseminated sows (6-20 days after weaning). Furthermore, sows inseminated at second estrus (21-41 days after weaning) had larger subsequent litters than early inseminated sows, which could be because they had longer time to establish a good body condition after weaning (Tummaruk *et al.*, 2001b). For Herd A this increase in litter size was almost one extra piglet born alive between early inseminated sows and sows inseminated at second estrus. Morrow *et al.* (1990) and Clowes *et al.* (1994) also reported an increase in litter size when inseminating on second estrus, compared with first estrus after weaning. On the other hand, the non-productive days for each sow will increase when insemination is performed at second estrus after weaning, which could be an economic disadvantage (Clowes *et al.*, 1994).

There are clearly many factors influencing litter size, which leads to a difficulty in giving straight advice to piglet producers. However, as the sow uterus is in need of at least three weeks recovery the lactation period should not be shorter than three weeks. After that, factors such as sow body condition, number of piglets and piglet weight should also be considered before choosing length of lactation period. Results in the present study showed that a longer lactation period would lead to higher subsequent litter size, but it would have been interesting to know sow body condition at weaning, number of weaned piglets, piglet weight at weaning as well as weaning to service interval. This would enable to see if sows with longer lactation periods had better production results compared with sows that had shorter lactation periods. Because if a longer lactation period would lead to a longer weaning to service interval the non-productive days would increase, which is not beneficial. When deciding on gilts age at first mating, the present results show smaller litters for younger sows, although this difference is not consistent from second parity and onwards. Therefore, other factors might have an impact on the choice of age at first mating. As batch wise production is most common, producers might want to fill up the sow groups and therefore choose to inseminate gilts at an earlier age. Gilts that reach a high body weight at an early age might also be inseminated early. Important is to see the whole picture and evaluate which choices are the most beneficial for each individual farm.

As economy is an important factor in commercial production it would be interesting with future studies on how factors influencing litter size, such as those presented in the present study, would affect the economical outcome. This would be important information as many choices made in commercial production are connected to the economy.

Conclusion

The mean litter size in the studied herds has increased over the last few years, with the highest increase in number of piglets born alive. Gilts age at first mating influences litter size by decreasing litter size in first parity, but not in later parities. Therefore, the choice of age at first mating should be considered with regard to producers own conditions. It could be beneficial to inseminate gilts at an earlier age, given that they have reached the right body condition, since litter size is not affected after first parity. Increasing length of lactation period led to larger subsequent litters and should be considered in combination with other factors, such as sow body condition, when deciding on length of lactation period. Longer lactation period will put a higher pressure on sows, as piglets are bigger and more demanding in the later stages of lactation. Weaning to service interval has an impact on subsequent litter size and by increasing the interval, litter size will increase. Sows bred at second estrus after weaning had the highest increase in subsequent litter size.

Further studies on the impact of length of lactation period on weaning to service interval would be interesting, in order to establish the combined effect of length of lactation period and weaning to service interval on subsequent litter size. Further studies including economical aspects are also of interest, as many choices in commercial production are connected to economy.

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