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Sow Reproductive Performance in Thailand

Effects of climate, breed, parity, lactation length, weight loss during lactation and weaning-to-service interval

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SWEDISH UNIVERSITY OF AGRICULTURAL SCIENCES

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Abstract

The aims of this thesis were to study causes of variation in reproductive performance in sows under tropical conditions. The influences of climate, breed, parity, lactation length, weight loss during lactation and weaning-to-service interval were studied. In total, data from 7 purebred herds and 14 crossbred herds were included. Data were recorded in PigCHAMP® (version 2.0, Univ. of Minnesota) software. Both Landrace and Yorkshire sows were present in all purebred herds. Sows that were exposed to high ambient temperature during lactation, around mating and during early pregnancy had the lowest reproductive performance. Farrowing rate and number of total born piglets decreased significantly with increasing temperature and heat index (combining temperature and humidity) during the first four weeks after mating. Farrowing rate decreased by 1.8% and number of total born piglets decreased by 0.07 piglets for each 1°C increase within the range 26° to 38°C. An increase in maximum temperature by 1°C led to an increase in weaning-to-service interval (WSI) by 0.17 days Landrace sows had, in general, better reproductive performance than Yorkshire sows. However Yorkshire sows had a shorter WSI, a higher percentage mated within 7 days after weaning and a higher ovulation rate compared with Landrace sows. The seasonal pattern did not differ between Landrace and Yorkshire sows. Crossbred primiparous sows had a shorter WSI and a higher percent mated within 5 days after weaning compared with purebred sows. Reproductive performance changed with parity number. Parity 2 sows lost more weight during lactation than sows of other parities. There was no significant difference in ovulation rate among first to fourth parity sows. Lactation length within the range of 17-35 days had no significant effect on WSI, ovulation rate, subsequent farrowing rate or subsequent litter size. Relative weight loss during lactation had a significant effect on WSI in parity 1 and 2 sows, but not in older sows. Sows with high weight loss had significantly longer WSI than sows with medium or low weight loss. Relative weight loss during lactation had no effect on ovulation rate. Sows with WSI 7-10 days had significantly lower farrowing rate in subsequent reproductive cycles than sows with WSI ≤ 6 days. Subsequent litter size was significantly lower (0.5 piglets) for sows with WSI 6-7 days compared with sows with WSI ≤ 5 days. After the first parity, sows with WSI ≤ 5 days had the highest, sows with WSI 6 to 30 days had moderate, while sows with WSI > 30 days had the lowest lifetime piglet production. Sows with WSI > 30 days had 1.7 times higher risk of culling compared with sows with WSI 0-4 days.

Key words: sow, reproductive performance, tropical climate, season, lactation length, ovulation rate, weaning-to-service interval, stayability, lifetime production.

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ด้วยสำนึกในบุญคุณของผู้มีพระคุณทุกท่าน

To my parents and my family

Abstract

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Key words: sow, reproductive performance, tropical climate, season, lactation length, ovulation rate, weaning-to-service interval, stayability, lifetime production.

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Contents

Appendix

The present thesis is based on the following papers, which will be referred to in the text by their Roman numerals:

I. Tantasuparuk, W., Lundeheim, N., Dalin, A.-M., Kunavongkrit, A. and Einarsson, S. 2000. Reproductive performance of purebred Landrace and Yorkshire sows in Thailand with special reference to seasonal influence and parity number. Theriogenology (in press).

II. Tantasuparuk, W., Lundeheim, N., Dalin, A.-M., Kunavongkrit, A. and Einarsson, S. 2000. Effects of lactation length and weaning-to-service interval on subsequent farrowing rate and litter size in Landrace and Yorkshire sows in Thailand. Theriogenology (accepted for publication).

III. Tantasuparuk, W., Dalin, A.-M., Lundeheim, N., Kunavongkrit, A. and Einarsson, S. 2000. Body weight loss during lactation and its influence on weaning-to-service interval and ovulation rate in Landrace and Yorkshire sows in Thailand. (submitted for publication).

IV. Tantasuparuk, W., Lundeheim, N., Dalin, A.-M., Kunavongkrit, A. and Einarsson, S. 2000. Weaning-to-service interval in primiparous sows and its relationship with longevity and piglet production until parity eight. (submitted for publication).

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Abbreviations

Abbreviations used in the text, presented in alphabetical order:

ABW	Average piglet birth weight
FR	Farrowing rate
L	Landrace breed
LL	Lactation length
LWW	Litter weight at weaning
NLB	Number of live born piglets per litter
NPW	Number of pigs weaned per litter
NSB	Number of stillborn piglets per litter
NTB	Number of total born piglets per litter
RWL	Relative weight loss of sows during lactation
WSI	Weaning-to-service interval
WSI7	Percentage of sows mated within 7 days after weaning
Y	Yorkshire breed

Introduction

Reproductive efficiency of sows in tropical areas, such as Thailand (Kunavongkrit et al., 1989), is lower than in subtropical or temperate areas. One of the prominent problems is the comparatively lower litter size at birth. The sources of genetic material in Thailand mostly originate from temperate areas, i.e. countries in West Europe and North America, where the climate is quite different from that in Thailand, which has higher temperature and higher humidity and nearly constant day length. Except for housing design, most management procedures are almost the same as in the countries from which the swine breeds originate. Therefore, the climatic factors might contribute to the lower reproductive efficiency.

Influence of climate on reproductive performance

The influence of season is regarded as an important environmental component causing variation in sow fertility. Studies have shown adverse effects of high ambient temperature and/or change in photoperiod on reproductive efficiency of gilts and sows (Wettemann & Bazer, 1985; Paterson & Pett, 1987; Love et al., 1993; Prunier et al., 1994). Common negative seasonal effects are longer weaning-to-service interval (Hurtgen & Leman, 1981; Britt et al., 1983), lower conception rate and/or higher embryonic death, resulting in a higher remating rate and a lower farrowing rate (Hurtgen & Leman, 1980; Hancock, 1988; Prunier et al., 1997). In a few studies, a reduced litter size has also been reported, while in others no such seasonal effect has been found (Love et al., 1993). To better understand seasonal variation, climatic data should be directly related to the variation in reproductive performance.

Influence of breed and parity on reproductive performance

The majority of sows in Thailand are of Landrace and Yorkshire breeds, and their crosses. Since both these breeds are kept under similar conditions, breed differences are the result of the genetic influences on reproductive performance, and how these breeds cope with the climate. Differences in reproductive performance between breeds have been reported in many genetic studies (e.g. Kennedy & Moxley, 1978; Yen et al., 1987). The best condition for comparing populations of different sow breeds is that they are kept in the same herd and under the same management conditions.

Reproductive efficiency, e.g. litter size and return to oestrus after weaning, is generally lower for primiparous sows compared with multiparous sows, while old sows (parity > 7) have higher piglet loss (reviewed by Hughes & Varley, 1980). The highest reproductive efficiency can be found in parity 3 – 5 sows (Clark & Leman, 1986). Influence of parity on reproductive performance and how the sows in different parities response to the tropical climate is of interest.

Influence of lactation length on subsequent reproductive performance

After farrowing, sows need to spend some time nursing their piglets for regulation of their reproductive endocrine system (Rojanasthien et al., 1988). According to older studies (e.g. Palmer et al., 1965), uterine involution is completed histologically after three weeks of lactation. However, no similar studies based on the modern sow genotype and modern management system are available. The optimal lactation length (LL) for an individual herd is influenced by its particular management and environmental characteristics. LL influences the weaning-to-service interval (WSI) and the subsequent litter size (Svajgr et al., 1974; Cole et al., 1975; Dewey et al., 1994). LL shorter than two weeks prolonged WSI (Cole et al., 1975; Mabry et al., 1996) whereas LL longer than 4 weeks decreased WSI (Tubbs, 1990). Some publications suggest the optimum LL, regarding sow reproduction measured as numbers of pigs produced per sow per year, to be 3 to 4 weeks (reviewed by Tubbs, 1990). To our knowledge, no study of the effect of LL on subsequent reproductive performance has been performed in herds that have the same scheduled lactation period under tropical conditions.

Influence of weight loss during lactation on subsequent reproductive performance

Metabolic status during lactation influences the postweaning performance. High catabolism during lactation often results in a high body weight loss (Hultén et al., 1993) and in a prolonged WSI (King et al., 1982; Reese et al., 1982; Kirkwood et al., 1987). Sterning et al. (1990) observed a variation in body weight loss during lactation among primiparous sows fed a standard diet above the maintenance requirement that was adjusted for the number of piglets nursed. In experimental studies, it has been shown that the catabolic status and/or amount of body weight loss during lactation influence the WSI (Sterning et al., 1990; Zak et al., 1997; Zak et al., 1998), ovulation rate (Hughes & Pearce, 1989; Zak et al., 1997) and litter size (King & Williams, 1984; Kirkwood et al., 1987; Yang et al., 1989). However, in a subsequent study by Zak et al. (1998) no influence of different patterns of catabolism during lactation was found on ovulation rate. Ovulation rate is one of the factors that define the upper limit of litter size (Hughes & Varley, 1980). To our knowledge, no study on body weight loss during lactation and its influence on weaning-to-service interval and ovulation rate in purebred Landrace and Yorkshire sows has been performed under tropical conditions.

Influence of weaning-to-service interval on subsequent reproductive performance

WSI is an important biological parameter. The length of WSI has been reported to influence the subsequent farrowing rate and subsequent litter size (Love, 1979; Wilson & Dewey, 1993). WSI can also indirectly be used as a measurement of lactation management, particularly feed intake, indicating the fertility of postweaning sows (Tubbs & Dyer, 1996). To our knowledge, no study of the effect of WSI on subsequent farrowing rate and litter size has been performed on purebred Landrace and Yorkshire sows under tropical conditions.

Stayability and lifetime production

Longevity of sows is an important economic trait in pig production (de Vries, 1989). Herds with higher sow longevity, i.e. where sows are culled at an older age, have higher mean annual productivity than herds where sows are culled at a younger age (Dagorn & Aumaitre, 1979; Kroes & van Male, 1979). Anyway, planned culling due to old age is a limitation of realised longevity. This planned culling is commonly recommended to take place after approximately 3-4 years of breeding life or after parity 7-8 in order to benefit from genetic gain and to obtain the ideal parity profile in the herd.

WSI naturally has a skew distribution with a long right tail. Primiparous sows usually have a longer WSI than multiparous sows (Einarsson & Settergren, 1974; Benjaminsen & Karlberg, 1981). Gilts that reach puberty late have a longer WSI after weaning the first litter than gilts with normal age at puberty (Sterning et al., 1998). The length of WSI influences subsequent reproductive performance (Clark & Leman, 1987; Vesseur et al., 1994), and can be used to indicate the fertility in subsequent reproductive cycles (Tubbs & Dyer, 1996). Thus, this interval in primiparous sows might be a good predictor of stayability and lifetime production.

Aims of the study

The aims of the present study, being conducted on sows under tropical conditions, were to analyse the influences of:

- climate, breed and parity on reproductive performance,
- lactation length, weight loss during lactation and weaning-to-service interval on subsequent reproductive performance,
- weaning-to-service interval in primiparous sows on the stayability and lifetime production of these sows.

Materials and Methods

Database and animals

In total, data from 7 purebred herds and 14 crossbred herds located in north, northeast, east and central parts of Thailand were included. Herd sizes ranged from 200 to 1500 sows. Papers I and II were based on data from three of the purebred herds, located in the central part of Thailand. The sizes of the herds were 220, 260 and 420 sows, with 5881 litter records during 1993 to 1996. Paper IV was based on data from all 21 herds with records on 1293 Landrace (L), 1072 Yorkshire (Y) and 9334 crossbred sows from July 1992 to June 1997. In Paper III, the experiment was performed using 276 sows from the first and third purebred herds in Papers I and II. Both Landrace and Yorkshire sows were present in all purebred herds. Data were recorded in PigCHAMP® (version 2.0, Univ. of Minnesota) software. All the herds were visited by the author at least every six months and the computerized data were then checked for integrity and, if possible, corrected when necessary.

General management

Dry sows were kept in individual stalls, whereas lactating sows were kept in individual farrowing pens. Replacement gilts were penned in groups of 10. Before expected oestrus, they were moved into the mating area to get boar contact, where they were kept in individual stalls. Sows were housed in open buildings (no walls). Cooling systems, including water dripping or water sprinkling and fans, were turned on when the sows appeared to feel uncomfortable due to hot weather.

Feed and feeding

Sow feed was based primarily on broken rice, corn, soybean meal, fishmeal, and rice bran. During gestation, sows received 300-320 g crude protein and 26-30 MJ DE per day. During lactation, sows received 788-880 g crude protein and 66-74 MJ DE per day (4.6-5.8 kg feed/day). After weaning and until mating, sows received 450-590 g crude protein and 36-42 MJ DE per day.

Breeding period

Oestrous detection was performed twice a day, in the morning and in the evening, by experienced staff in the presence of boars. Sows with detected onset of standing heat in the morning were mated in the evening. Sows with detected onset of standing heat in the evening were mated in the morning. Assisted and supervised natural mating was practised at least twice in each sow with 8-12 hours interval, and matings were immediately recorded both on sow cards and on mating reports.

Gestation period

During the 2nd to 4th week after mating, a backpressure test was performed for control of repeat breeding. Pregnancy diagnosis was performed in the 5th week by detecting foetal fluid using A-mode ultrasound. Sows diagnosed not pregnant were moved back to the boar areas.

Farrowing and lactation period

The floor of the farrowing pens was fully slatted, and a thin layer of rice straw was provided as bedding for the piglets one day before expected farrowing. This bedding was replaced daily for a few days after birth. A small box was provided as a shelter for the piglets to move into when they felt cold. A heating lamp was used during the cool season. Farrowings were supervised and farrowing events were recorded twice a day. Live born piglets were weighed and the total litter weight was recorded. Cross fostering, moving piglets from large to small litters within 3 days after farrowing, was frequently practised. Creep feed was provided for the piglets starting at day 10 after farrowing. Lactation period averaged 4 weeks and had a limit of 5 weeks. Weaning was practised twice a week, and the whole litter was weighed and litter weight was recorded. Litters with best growth were weaned in the first part of the week, while the others were weaned in the second part of the week. Weaned sows that did not show oestrus within 7 days were stimulated by relocation to other individual stalls, or by grouping 3-4 sows together, and were also introduced into the boar pen for ten minutes twice a day. The sows with good health and good body condition, which had not shown oestrus at the end of the second week after weaning were treated with hormones using a combination of PMSG and HCG (PG600®, Intervet, Netherlands). Sows not coming into oestrus at the expected time after treatment were culled, except for sows with high breeding value, that got additional chances.

Laparoscopic examination

Laparoscopy (Wildt et al., 1973; Kunavongkrit & Lohachit, 1988) was used to determine the ovulation rate (Paper III). The laparoscopic examination was adapted for field conditions and performed under general anaesthesia of the sows. Sows were examined once between days 8 to 14 after insemination. The numbers of corpora lutea in both ovaries were counted, and were assumed to equal the ovulation rate.

Statistical analyses

The statistical analyses were performed using the SAS procedures and macro (SAS, 1996). Continuous outcome variables were analysed by analysis of variance with restricted maximum likelihood (REML) estimation method using Procedure MIXED (Papers I, II, IV), or with least square estimation method using Procedure GLM (Paper III). Binary outcome variables were analysed by analysis of variance with the pseudo-likelihood estimation method using the GLIMMIX macro (Papers I, II, III). Sow survival was analysed by Cox proportional hazards model using procedure PHREG (Paper IV). The random effect of sow within breed and herd was included into the statistical models (MIXED and GLIMMIX) for considering the correlation between repeated observations within sow.

Results

Influence of climate on reproductive performance

Seasonal variation

In Thailand, there are three seasons: hot season from March until June; rainy season from July until October; cool season from November until February. The average over month of daily maximum temperature ranged from 29.4°C in December to 36.1°C in April. The corresponding maximum relative humidity varied from 93.5% in May to 97.8% in October. The smallest litter sizes (both number of total born piglets per litter, NTB and number of live born piglets per litter, NLB) were found during the rainy season, while the biggest litter sizes were found during the hot season (Paper I). Mothers of the litters that were born during the rainy season conceived during the hot season. WSI was longest in sows weaned during the hot season. The lowest farrowing rate (FR) was found in sows mated during late hot season and during the rainy season (Paper I). LL was shortest during the cool season compared with other seasons (Paper II). There was no systematic seasonal variation in number of stillborn piglets or in average piglet birth weight (ABW).

Influence of temperature and humidity

Average maximum temperature and heat index (combining temperature and humidity; Steadman, 1979) of the first four weeks after mating had a significant ($P<0.001$) unfavourable effect on NTB. NTB decreased by 0.07 piglets when the maximum temperature increased 1°C within the range 26° to 38°C. Temperature and heat index during lactation significantly ($P<0.001$) influenced WSI. An increase in maximum temperature by 1°C led to an increase in WSI by 0.17 days. FR decreased significantly when temperature and heat index during the first four weeks after mating were elevated. FR decreased by 1.8% for each 1°C increase within the range 26° to 38°C (Paper I).

Breed differences

L sows had significantly higher NTB, NLB, ABW, FR, shorter farrowing interval, longer LL and higher litter weight at weaning (LWW) than Y sows (Paper I and II). However, Y sows had a higher ovulation rate (number of corpora lutea) than L sows (Paper III). Y sows had a shorter WSI and a higher percent mated within 7 days than L sows (Paper I). There was no difference in seasonal pattern between L and Y sows. Crossbred primiparous sows had a shorter WSI and a higher percentage of sows mated within 5 days after weaning compared with purebred sows (Paper IV).

Parity influence

Both NTB and NLB increased with parity number, reaching their maximum values in parity 5, and thereafter declining to parity 7+8 (Paper I). The number of stillborn piglets (NSB) was low in parity 2 and 3. ABW was lowest in the first litter and highest in the second and third litters. Farrowing interval was longest in parity 2 sows (interval from first farrowing to second farrowing), and declined significantly as parity number increased. FR was lowest in parity 1 and increased significantly between parity 1 and 3, and between parity 2 and 5. LL, WSI and weaning-to-conception interval were longest in parity 1 sows and declined as parity increased. First parity sows also had the lowest percentage of sows mated within 7 days after weaning (WSI7). There was no significant difference in ovulation rate among first to fourth parity sows (Paper III).

Influence of lactation length on subsequent reproductive performance

LL was to some extent based on the LWW. LL within the range of 17-35 days had no significant effect on WSI (Paper II), ovulation rate (Paper III), subsequent FR and subsequent litter size (Paper II).

Influence of weight loss during lactation on subsequent reproductive performance

The average relative weight loss (RWL) of the sows during lactation was 11.2% (Paper III). Parity 2 sows lost more weight than other parity sows. RWL increased by 0.7% for each extra pig weaned. LL, number of pigs weaned (NPW) and LWW had significant effects on RWL. Sows with high RWL were weaned earlier than sows with low RWL. Sows with higher NPW and/or LWW lost more weight than sows with lower NPW and/or LWW.

Sows with high weight loss during lactation had a significantly longer WSI than sows with medium or low weight loss. Weight loss had a significant effect on WSI in both parity 1 and 2 sows, but not in sows that were older. Parity 1 sows had a longer WSI for all RWL groups compared with the others, and most prolonged in the high RWL group. Within parity 2, sows with high RWL had a significantly longer WSI compared with medium or low RWL. No significant difference in WSI between RWL groups was found for parity 3 and 4 sows. RWL had no significant effect on ovulation rate.

Influence of weaning-to-service interval on subsequent reproductive performance

Subsequent FR was significantly lower when WSI was 7 to 10 days than when WSI was 1 to 6 days (Paper II). An increase in WSI from 9-10 days to 11-21 days resulted in a significant increase in FR. Subsequent litter size decreased significantly by 0.5 piglets when WSI increased from 1-5 days to 6-7 days. Litter size increased again significantly when WSI increased from 9-10 days to 11-21 days. Subsequent litter sizes were lowest in the WSI group 9-10 and highest in the WSI group 11-21.

Stayability and lifetime production

WSI of primiparous sows had a significant effect on their stayability measured as farrowing or not farrowing 2nd to 8th litters (Paper IV). Primiparous sows with WSI > 30 days had significantly lower stayability than sows with WSI 9 days or shorter. Breed, LL and LWW had no significant influence on stayability of purebred sows, while LWW had positive significant influence on stayability of crossbred sows.

WSI of primiparous sows had a significant effect on the sums of NTB, NLB, NPW and LWW over seven parities (2 to 8). Primiparous sows with WSI ≤ 5 days had the highest, sows with WSI 6 to 30 days had moderate, while sows with WSI longer than 30 days had the lowest piglet production.

The risk of culling for purebred sows with WSI 19-30 days and with WSI > 30 days was higher than for sows with WSI 0-4 days. Crossbred sows with WSI 6 days or longer had significantly higher risk of culling than sows with WSI 0-4 days. The risk ratio was 1.7 times higher for sows with WSI > 30 days compared with sows with WSI 0-4 days.

General discussion

Influence of climate on reproductive performance

The present study demonstrated a seasonal pattern of reproductive performance in sows under tropical climatic conditions (Paper I). The overall reproductive performance observed in this study was relatively low compared with studies based on European pig production. However, the overall level of the reproductive performance is in agreement with two previous studies based on data from Thailand (Kunavongkrit et al., 1989; Yu et al., 1994).

The reproductive response of sows to high ambient temperature depends on which stage of the reproductive cycle that they are in. Before oestrus until early pregnancy, high ambient temperature has been reported to alter reproduction either directly on the ovarian function or via the hypothalamic pituitary axis, by affecting oestrus, ovulation, gametes, implantation of embryos and/or embryo survival (Wettemann & Bazer, 1985; Paterson & Pett, 1987; Kunavongkrit & Tantasuparuk, 1995; Kunavongkrit et al., 1995). This could explain both the lower litter size and the lower FR for sows mated during the hot season. The negative effect of high ambient temperature on spermatogenesis is evident in the ejaculate from 2 up to 6 weeks after exposure (Cameron & Blackshaw, 1980; Malmgren, 1989), and might also contribute to the low litter size and low FR observed.

During lactation, high ambient temperature reduces the appetite of sows (Prunier et al., 1997). A prolonged WSI is also associated with a reduced appetite (Koketsu et al., 1996b; Prunier et al., 1997), as well as with limitations of feed allowance during lactation (Martinat-Botte et al., 1984; Messias de Bragança et al., 1998). In the present study, a prolonged WSI was found not only for sows nursing during the hot season, but also during the early rainy season, when the heat index was still high due to high humidity.

In temperate or subtropical areas where the temperature seldom or only for a few weeks exceeds 30°C, some studies have shown a lower litter size during some periods of the year (Martinat-Botte et al., 1984; Yen et al., 1987; Xue et al., 1994), while other studies do not show any variation in litter size due to season (Love, 1978; Peltoniemi et al., 1999; Tummaruk et al., 2000a). One may conclude that the temperature might have had less influence on litter size in the latter cases. A direct comparison concerning the effect of temperature between different field studies is, however, not possible because of the lack of climatic information. One explanation of these different results might be a variation in the length of the hot period.

The present study clearly showed a reduction in litter size (both NTB and NLB) in sows that farrowed during the rainy season. Those sows had farrowed previous litters and later weaned and conceived during the hot season. The combined effects in sows having a prolonged WSI and being mated during the hot season, together with a suspected poor sperm quality of the boars exposed to high temperature, might together explain the significant reduction in litter size.

Most of the parameters analysed had the same seasonal pattern for all parities. There was no significant interaction for WSI between parity and season in the present study, which is in agreement with Vesseur et al. (1994), but is in disagreement with some other studies (Clark et al., 1986; Tummaruk et al., 2000a). The significant interactions between parity and season were found only for FR and farrowing interval. Young sows were found to be more sensitive to climatic changes than older sows, which might indicate an adaptation to climatic changes with age.

According to the type of sow housing used in Thailand, the temperature is expected to be nearly the same both inside and outside the building. Therefore, the outdoor temperature, retrieved from official meteorological stations, was used instead of the more specific indoor temperature (not available). This field study showed a significant influence of the climate, the maximum temperature and the heat index, on litter size, farrowing rate and weaning-to-service interval, while humidity alone had no significant effect. To our knowledge, this has not been studied before under field conditions. To conclude, the differences in average reproductive performance between tropical areas and temperate areas might to a certain degree be explained by climatic differences.

The results from the present study indicate that the use of a cooling system, such as water dripping, water sprinkling and fans, is not effective enough for eliminating the adverse effects of high ambient temperature.

Breed differences

All three herds involved in the study focusing on breed differences had stable populations of both L and Y sows in almost the same proportions during the period studied. Therefore, the differences between breeds in reproductive performance could be directly compared under the same environment and the same management without confounding effects. Breed differences in reproductive performance have been reported from many countries with various breeds (e.g. Gaugler et al., 1984; Yen et al., 1987). In this study, most reproductive parameters of L sows were significantly better than of Y sows. Litter size was higher for L sows than for Y sows, which for NLB is in agreement with Tummaruk et al. (2000a) based on Swedish data. Ovulation rate, embryo survival and uterine length did not differ between Landrace and Large White purebred gilts in a study investigating these parameters (Irgang et al., 1993). On the other hand, the ovulation rate (checked by laparoscopy) in Y sows was significantly higher than in L sows in the present study (Paper III), which is in agreement with Legault & Gruand (1981, cited by Legault, 1985). Indirectly, by comparing the herd records from the same year, L sows had a higher average number of total born piglets than Y sows. This indicates a higher loss of potential foetus during the fertilisation period and/or early embryonic period in Y sows than in L sows. There was no significant difference in NSB between the two breeds, which is in agreement with Leenhouwers et al. (1999). L sows had significantly longer WSI and lower WSI7 than Y sows, but weaning-to-conception interval did not differ between the two breeds. Tummaruk et al. (2000a) also found a longer WSI in Swedish L sows than in Swedish Y sows.

Parity influence

Litter size showed an increase with parity number, reaching a plateau at parity 3-5, and then declining (Paper I). This is largely in accordance with earlier studies (Clark & Leman, 1986; Yen et al., 1987; Dewey et al., 1995). The herds in the present study had no policy to cull parity 1 sows due to low litter size. This might, to a certain degree, explain why there was no significant difference in litter size between parity 1 and parity 2 sows for any of the breeds. The general effect of parity on litter size might be related to ovulation rate. A study by Perry in 1954 (reviewed by Hughes & Varley, 1980) showed an increase in ovulation rate over the first four parities, reaching a plateau at about the sixth parity and no drops later. In contrast, the results from the present study (Paper III) revealed that the ovulation rate did not increase as parity increased from 2 to 4. This indicates that the increase in litter size with parity number is not caused by an increase in ovulation rate, but rather by an increase in embryonic survival with the age of the sow and/or by an increase in uterine dimension. However, there was a large variation in ovulation rate among sows in the same parity (SD. = 2.9 in parity 1), suggesting that a large number of sows are needed for studies of this parameter to be able to get enough statistical power. In young sows, the uterine capacity might be a limiting factor for litter size (Gama & Johnson, 1993). The reduction of litter size in higher parity sows in the present study might be due to an increase in embryo mortality with age (reviewed by Hughes & Varley, 1980). NSB in L sows in the present study was lower in parity 2 than in parity 1 sows, but there was no difference between parity 1 and parity 3 to 6 sows. This pattern is comparable with results from an earlier study (Leenhouwers et al., 1999).

The longer WSI in primiparous sows compared with pluriparous sows in the present study is in agreement with other studies (Einarsson & Settergren, 1974; Clark et al., 1986; Vesseur et al., 1994). Inadequate or low voluntary feed intake during lactation is found to prolong WSI (reviewed by Whittemore, 1996), especially in primiparous sows that on average consume less feed (Koketsu et al., 1996a) and utilize more nutrients for body growth than multiparous sows (Pluske et al., 1998). Even parity 2 sows had a longer WSI than higher parity sows in the present study. In Paper III, it was demonstrated that body weight loss during lactation affected WSI not only in parity 1 but also in parity 2 sows.

Influence of lactation length on subsequent reproductive performance

In Paper II the seasonal variations in LL and LWW were analysed. In spite of a seasonal variation in LL, which was aimed to reduce a variation in LWW, the LWW still showed a seasonal variation. LL was, on average, shorter during the cool season than during the hot season, while LWW did not differ between these two seasons. This indicates that the herds followed the general routines (litters were weaned earlier during the cool season because the scheduled LWW was reached faster), which means that the LL to some extent was based on the LWW. However, in the present study LWW was significantly lower during the rainy season than during the other seasons. The reason might be the smaller litter size for farrowings during the rainy season, compared with the other seasons (Paper I).

No significant influences of LL on WSI, subsequent FR and litter size were found in this study, in contrast to a number of earlier studies in temperate areas (Svajgr et al., 1974; Cole et al., 1975; Aumaitre et al. 1976; Xue et al., 1993; Dewey et al., 1994; Mabry et al., 1996; Xue et al., 1997; Tummaruk et al., 2000b). One reason for this might be the low variation in LL. Thus, the major part of the observations (94.3%) had an LL of 23 to 32 days. Another reason might be the lower reproductive efficiency under tropical climate conditions (Paper I) compared with subtropical and temperate areas.

Influence of weight loss during lactation on subsequent reproductive performance

A variation in RWL during lactation was demonstrated among sows on the same feeding regime and nursing approximately the same number of piglets (Paper III). This result is in agreement with Sterning et al. (1990), who performed a similar study on primiparous sows in temperate areas. RWL has otherwise been reported to be influenced by the number of piglets nursed (Knudson et al., 1987; Yang et al., 1989). In the present study, litter size, e.g. the number of live born piglets, the litter birth weight, the number of pigs weaned and the litter weaned weight were tested and found to significantly influence RWL. Cross fostering, which adjusted the number of piglets nursed at the beginning of lactation, might have influenced the result. Nonetheless, the significant factors, particularly the number of pigs weaned, without doubt influenced the level of sow body reserve utilisation during lactation.

Over-condition of the sows at farrowing (or over-fed during gestation) reduces the feed intake during lactation (Yang et al., 1989; Carroll et al., 1996), and affects feed intake patterns during lactation (Koketsu et al., 1996a). The true mechanism behind reduced appetite needs further investigation. No recording of the appetite/true feed intake was performed in the present study, but the feeding regime practised during gestation should avoid over-condition of the sows before farrowing. It is therefore unlikely that the deviation in RWL in the present study was caused by low appetite due to over-condition of the sows before farrowing. On the other hand, the climatic conditions, such as high ambient temperature, might have influenced the sows' appetite during lactation; an individual tolerance of the sows to high temperature will cause a deviation in RWL. The feed intake of the sows in the present study cannot be directly compared with studies in temperate areas, because the energy requirement for maintaining body temperature against cold weather is much lower for sows in tropical areas. It has been shown that the variation in RWL among sows that were fed a standard diet reflected differences in individual body reserve utilisation during lactation (Rojkittikhun et al., 1992; Rojkittikhun et al., 1993; Hultén et al., 2000).

An undesirable influence of RWL on WSI was found for 1st and 2nd parity sows (Paper III). No such effect appeared in 3rd and 4th parity sows, which is in agreement with other studies (e.g. Hultén et al., 1993; Hultén et al., 2000). Hultén et al. (2000) found no difference in WSI between multiparous sows with mild or severe catabolism during the last 3 weeks of lactation. Young sows, compared with multiparous sows, still require nutrients for growth (Cole, 1982). This might, in part, explain the different influence of RWL on WSI among parities.

The present study confirmed observations from previous studies showing no influence of body weight loss during lactation on ovulation rate (Kirkwood et al., 1987; Baidoo et al., 1992; Carroll et al., 1996). In contrast, Zak et al. (1997) observed decreased ovulation rate in primiparous sows given restricted feeding throughout, or during the last week of, lactation. However, when repeating their study with primiparous sows nursing larger numbers of piglets, Zak et al. (1998) found no relationship between body weight loss and ovulation rate. Recently Hultén et al. (2000), studying multiparous sows fed the same amount of feed and nursing approximately the same number of piglets, found no detrimental effect of catabolism on ovulation rate. The deviating results might be due to differences between the studies in feed composition, feeding treatment, number of piglets nursed and lactation length.

Influence of weaning-to-service interval on subsequent reproductive performance

Both subsequent FR and litter sizes were influenced by WSI (Paper II), which is in agreement with other studies (e.g. Clark & Leman, 1987; Vesseur et al., 1994; Koketsu et al., 1997; Steverink et al., 1999; Tummaruk et al., 2000b). Summarising the results from those studies, subsequent reproductive performance for sows showing oestrus between 6 to 10 days after weaning was lower than for sows showing oestrus earlier or later after weaning. The reason for this has not yet been fully elucidated. A shorter duration of oestrus has been found among sows showing oestrus between 6 to 10 days after weaning (Rojkittikhun et al., 1992; Kemp & Soede, 1996), which might cause suboptimal timing of insemination relative to ovulation (Kemp & Soede, 1996). Suboptimal timing of insemination (more than 28 h prior to or more than 4 h after ovulation) results in a significantly lower farrowing rate and tends to result in smaller litter size (Nissen et al., 1997). In the present study, practising two natural matings per oestrus, such a negative effect might occur for sows showing oestrus between 6 to 10 days after weaning and accepting the first mating but refusing the second mating. Another factor that should be considered is the ovulation rate, since Deckert et al. (1997) have shown that ovulation rate decreased in parity 2 sows with weaning-to-breeding intervals of 6 - 8 days.

The highest subsequent NTB in the present study was found in sows with WSI 11-21 days, which coincides with previous studies (Vesseur et al., 1994; Koketsu et al., 1997). The reason for this increase in NTB might be that these sows have had a longer period to recover from a catabolic stage around weaning. In addition, the use of hormonal treatment for induction of oestrus in most of the sows in this group might also have contributed to the result.

Stayability and lifetime production

Longevity of sows is an important economic trait in pig production (de Vries, 1989; Dijkhuizen et al., 1989). The present study showed that primiparous sows with short WSI had higher lifetime piglet production and longer productive life than sows with long WSI (Paper IV). However, the results from the purebred herds did not show as clear significances as the results from the crossbred herds. Contributing factors to these differences might be the lower number of purebred sows analysed than crossbred sows, and/or a lower percentage of purebred sows showing early oestrus (0-4 days) after weaning, compared with crossbred sows.

The length of WSI in the present study concurs with the finding from a previous study by ten Napel et al. (1995a). The percentage of primiparous sows not showing oestrus within 30 days after weaning in the present study is in agreement with Maurer et al. (1985), reporting that the percentage of primiparous sows not showing oestrus within 30 days after weaning ranged from 5.7 to 32.8%. The variation in WSI of primiparous sows is influenced by metabolic status, genetic background, physical/social stimuli, and season (Tubbs, 1990; ten Napel et al., 1995b; Einarsson et al., 1998). Within a herd, where environment, feeding and management conditions are the same, a variation in WSI was still found, together with a large variation in body weight loss during lactation (Sterning et al., 1990). In addition, body weight loss influences the length of WSI for both parity 1 and 2 sows in this study under tropical climate (Paper III). This type of variation might be due to a variation in appetite among individual sows in herds where all sows receive ad lib feeding, or due to a variation in feed utilisation among sows in herds where all sows receive the same amount of feed. The health status of sows at weaning might also influence the WSI (Sterning et al., 1997). All these factors influence the body weight loss during lactation and thereby WSI. Moreover, for body weight loss during lactation a heritability of 0.41 (Rydhmer et al., 1992) has been presented, indicating a genetic influence on appetite and feed utilisation, which also can be linked to the variation in WSI.

The present results (Paper IV) showed a lower percentage of purebred primiparous sows being mated early after weaning, particularly within 4 days, compared with crossbred sows. Lactation length did not differ between the purebred and the crossbred sows. Thus, differences in body weight loss, metabolic state and/or appetite during lactation might have caused the difference between the purebred and crossbred sows mated within a certain day after weaning. Also heterosis by crossbreeding has been reported to result in a shortening of WSI (Legault et al., 1975).

The present study (Paper IV) showed that primiparous sows mated within 5 days after weaning had the best stayability. The reason for this has to be elucidated through further studies, but different possible mechanisms behind it have been proposed. Studies have shown that a short WSI has a favourable effect on both subsequent farrowing rate and litter size (Love, 1979; Wilson & Dewey, 1993; Vesseur et al., 1994; Paper II). Thus, primiparous sows with short WSI in the present study are expected to have higher farrowing rate and thereby a lower risk of being culled. Body condition and metabolic status are associated with the culling rate (Dourmad et al., 1994). Primiparous sows, which had a delayed puberty, also had a longer WSI (Sterning et al., 1998). This might indicate that sows with early sexual development also have better stayability. In the present study, the sows not showing oestrus within 7 days after weaning were stimulated by relocation, regrouping, mixing with the boar, etc, including hormonal therapy at day 14 after weaning. This also indicates that the sows with long WSI had lower reproductive capacity. The length of WSI, for sows in parity 2 up to 4, has a repeatability of approximately 0.15 (Tantasuparuk et al., unpublished results). Thus, primiparous sows with long WSI to some degree have a long WSI also in subsequent parities. Sows that were ill during the previous lactation had a higher risk to be ill in the next lactation (Lingaas, 1991). Sows with high weight loss during the first lactation perhaps might be affected by diseases like mastitis, endometritis, hypocalcemia, etc., predisposing for recurrence in subsequent parities.

The higher total piglet production for primiparous sows with shorter WSI found in this study is due to a better stayability in those groups, since the means of litter sizes per parity were not different among different WSI groups. Long WSI in primiparous sows normally leads to a higher risk for culling. The present study showed that primiparous sows with long WSI had lower stayability after weaning their first litter, as well as lower stayability after farrowing the subsequent 7 litters. This indicates that long WSI in first parity sows predicts subfertility in later parities. It is likely that differences in stayability among WSI groups were formed at rather early parities.

The lifetime production and longevity analysed in the present study were limited at parity 8, and the sows that were not yet culled or sows that were still alive after 8 parities were treated as censored data. To study the entire lifetime production and longevity without any censored data, complete records of at least six consecutive years are required.

To our knowledge, the relationships between first WSI and stayability, and first WSI and lifetime piglet production have never been reported before. The present study demonstrates that WSI of primiparous sows can be used as a predictor of sow longevity and total piglet production.

Conclusions

- Sows are sensitive to hot climate especially during lactation, postweaning, around mating and during early pregnancy.
- There are differences in reproductive performance between Landrace and Yorkshire sows.
- Reproductive performance changes with parity number.
- Lactation length has no effect on subsequent reproductive performance (i.e. weaning-to-service interval, farrowing rate and litter size) in herds practising a lactation period of 3 to 4 weeks.
- Sows under the same restricted feeding regime show a high variation in weight loss during lactation. Weight loss has a significant effect on weaning-to-service interval in parity 1 and 2 sows, but not in older sows. Ovulation rate was not affected by weight loss during lactation.
- Sows with a weaning-to-service interval 6-10 days have lower reproductive performance in subsequent reproductive cycles compared with sows mated within 5 days after weaning.
- Weaning-to-service interval of primiparous sows can be used as a predictor of their future longevity and lifetime piglet production. Primiparous sows that are not mated within 30 days after weaning have lower longevity and lower lifetime piglet production.

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