Pigs for Organic Production

Studies of Sow Behaviour, Piglet-production and GxE interactions for Performance

Anna Wallenbeck
Faculty of Veterinary Medicine and Animal Science
Department of Animal Breeding and Genetics
Uppsala

Doctoral Thesis
Swedish University of Agricultural Sciences
Uppsala 2009

Acta Universitatis agriculturae Sueciae
2009:37

Cover illustration by Karin Wallenbeck

ISSN 1652-6880
ISBN 978-91-86195-84-7

Print: Repro, Uppsala 2009

Pigs for Organic Production - Studies of sow behaviour, piglet-production and GxE interactions for performance

Abstract

Pigs in organic production are in most cases of the same genetic material as in conventional production. These animals are bred for high production in conventional production environments. The question therefore arises: Are these animals suitable for organic production? We investigated sow behaviour, piglet production and GxE interactions for performance traits of pigs in commercial organic and conventional herds and in SLU's Research herd.

When sows farrowed outdoors in huts they started their nest-building activities earlier in relation to farrowing start and performed a higher frequency of nest-building behaviour, than they did when they farrowed indoors in pens. Farrowing duration was shorter and still-birth frequency was lower when sows farrowed in huts rather than in pens. When sows and their piglets were group-housed outdoors during lactation, the sows' and piglets' natural weaning process was already well advanced when the herdsman separated sows and piglets. This weaning process was influenced by sow's body condition and the number of nursing piglets.

Piglet mortality was higher in the organic compared with the conventional environment. High levels of piglet mortality reduce piglet welfare why efforts to reduce piglet mortality are required. Oestrus during lactation occurred among group-housed sows in organic herds but not among single-housed sows in conventional herds. Lactational oestrus was more common in fatter sows.

Herdsmen in both organic and conventional herds praised sows with good nursing behaviour, weaning large and heavy litters with low piglet mortality.

We found weak GxE interactions for growth rate and carcass leanness in organic and conventional pig production environments indicating that with regard to these traits, an organic breeding index based on the existing conventional breeding evaluation would be feasible.

Keywords: Organic production, sow behaviour, piglet production, piglet mortality, lactational oestrus, selection, GxE interaction

Author's address: Anna Wallenbeck, SLU, Department of Animal Breeding and Genetics, Box 7023, 750 07 Uppsala, Sweden
E-mail: Anna.Wallenbeck@hgen.slu.se

Scouts learn through doing, and if it's not fun it's not scouting
Robert Baden-Powell

Till Pappa

Contents

List of publications

This thesis is based on the work included in the following papers, referred to by Roman numerals in the text:

I Wallenbeck, A., Thodberg, K., Rydhmer, L. Nest-building and farrowing behaviour in sows: comparing farrowing outdoors in huts and indoors in pens (Manuscript).

II Wallenbeck, A., Rydhmer, L., Thodberg, K. 2008. Maternal behaviour and performance in first-parity outdoor sows. Livestock Science 116, 216–222.

III Wallenbeck, A., Gustafson, G., Rydhmer, L. Sow performance and maternal behaviour in organic and conventional herds. (Submitted).

IV Wallenbeck, A., Rydhmer, L., Lundeheim, N. 2008. GxE interactions for growth and carcass leanness: Re-ranking of boars in organic and conventional pig production. Livestock Science, In Press, doi:10.1016/j.livsci.2008.11.003.

Papers II and IV are reproduced with the permission of the publisher.

Abbreviations and explanation of concepts

AI	Artificial Insemination
CAP	Common Agricultural Policy within the EU
EU	European Union
EBV	Estimated Breeding Value
GxE interaction	Genotype by Environment interaction
IFOAM	International Federation of Organic Agriculture Movements
pp	post partum

Artificial insemination	Fresh semen delivered from boar station to piglet-producing herds where sows are inseminated by the herdsmen.
Farrowing crate	Farrowing pen where sows are kept in crates or tethered; sows can stand up and lie down, but not turn around.
GxE interaction	When a trait is partly influenced by different genes in different environments.
KRAV	A Swedish certification organization for organic production.
Organic farming	Farming according to some set of regulations for organic farming. Sometimes expressed as ecological or biological farming.
Plasticity	When a genotype's phenotypic expression is the same across several environments.
Reaction norm	Describes the phenotype as a function of the environment.
'The Swedish concept'	Pig production according to Swedish legislation, which includes high standards for animal health, animal welfare and food safety.

Introduction

My journey through this PhD project started with a statement: conventional pigs are used in organic pig production! This made me wonder: what distinguishes a conventional pig and a pig labelled organic? What are the differences between conventional and organic production, and why? During my PhD journey, I have found some answers, and several new questions have arisen.

Several alternative farming methods were joined under the term 'organic farming' when IFOAM (International Federation of Organic Agriculture Movements) was founded in 1972. The development of organic farming was a reaction to the industrialized farming methods developing in post-war Europe and an effect of the increased environmental awareness in the 1960s (Padel *et al.*, 2004). Organic food production aims at sustainable, secure and environmentally friendly food production including good animal welfare and good working conditions for those working within the food chain (IFOAM, 2005). The development of organic farming mainly focused on crop production during the 1970s and 1980s, though animals' role in the agro-ecosystem has been considered important since the early days of organic farming. Consequently, research on organic farming has also focused on crop production, and scientific studies on organic animal husbandry have been scarce.

Organic animal production has grown in Europe over the last few decades with increased demand for organic food from consumers in combination with pro-organic political decisions. Developing a growing organic animal production towards the principles of organic farming requires improved knowledge of organic animal husbandry among herdsmen, farming advisers, government workers, policy makers and scientists. The search for such knowledge should be based on a holistic and systemic approach (Watson *et al.*, 2008), covering both the biological aspects of keeping animals in organic production systems and the role of animal husbandry in the agro-ecosystem and in society.

The animals used in organic animal husbandry today are in most cases based on the same breeds and genetic lines as those used in conventional animal husbandry. They are bred for high production in an intensive, conventional production environment that often includes a heavy input of external recourses. However, in organic animal husbandry the implementation of the principles of organic farming supplies these animals with a less intensive production environment, including less external input than is usual in the production environment they are bred to produce in. The simple question is: Are conventional pigs suitable for organic production? My attempt to answer this enquiry is this thesis.

The purpose of this thesis is to gain knowledge about pigs in organic production which can contribute to the development of sustainable production systems and breeding strategies for organic pig production. Specifically, the thesis focuses on piglet production, sow behaviour and GxE interactions for performance traits in organic and conventional production environments.

General background

Aims for pig production in Europe

The aims of agricultural production in Europe have changed over time. The aim during the 1950s and 1960s was solely to secure the supply of food for the citizens by increasing production and productivity. Now it additionally includes improvements in food quality, food safety, environment protection and animal health and welfare (EC, 2007a). When the supply of food was secured in Europe during the 1970s and 1980s the Common Agricultural Policy (CAP) changed, according to the satisfied demand of food, leading to reduced subsidies for agricultural products. Consequently, market competition started to affect European agriculture to a larger extent. Besides CAP, pig producers follow national legislation which is in some cases stricter than European Union (EU) legislation. This is the case in Sweden. Swedish animal welfare legislation prohibits preventive use of antibiotics and includes requirements of generous space allowance for pigs, restricted use of sow crates, prohibition of solely slatted floors and strict environmental requirements (e.g. regarding lighting, manure handling and ventilation). This stricter legislation has raised the costs accruing to Swedish pig producers and thereby decreased the Swedish supply of pig meat. This has in turn increased retail consumer prices and lowered demand for Swedish pig meat (Liljenstolpe, 2008) due to cheaper import meat. Strict animal welfare legislation is the basis of 'the Swedish concept' of pig production, characterized by high standards of animal health, animal welfare and food security. Current policy on pig production in Europe is set out in CAP and national legislation. The producers are also influenced by consumer demand and market competition between and within countries. This is reflected in the aim of the Swedish pig producers' association to "create improved power of competition for the individual pig producer".

Organic production

Alternative farming methods using holistic and sustainable approaches were developed in many countries during the first half of the twentieth century: for example, Steiner (1929) in Austria and Balfour (1943) in UK. Interest in these methods increased with the increased environmental awareness of the 1960s, and several of the methods were conjoined under the term ‘organic farming’ when IFOAM was founded in 1972 (Padel *et al.*, 2004). IFOAM is today a global umbrella organization for organic agricultural organizations around the world.

Principles of organic animal husbandry

Organic farming is based on four basic principles: health, ecology, fairness and care. Organic food production strives to have a holistic and systemic approach, aiming towards environmental, social and economical sustainability (IFOAM, 2005). IFOAM’s general principles of organic animal husbandry (Table 1) emphasize that animal husbandry should be an integrated part of the agro-ecosystem and embrace good animal welfare and health.

Certification of organic production

Organic production is in most cases certified, and organic products are in most cases labelled according to some set of regulations governing organic production. The purpose of certification is to ensure the quality of the products, and to guarantee and communicate the way products are produced through the entire chain running from producers to consumers; this defends the premium prices of these products. The basic standards of IFOAM, which were originally published in 1980, are criteria which the regulations of certification organizations accredited by IFOAM must fulfil (Padel *et al.*, 2004). Additionally, since 1991 the EU has set up regulations for organic production in order to ensure fair competition on the market and a functioning internal market for organic products within the EU (EC, 2007b). Regulations for organic animal husbandry were introduced in an EU regulation governing organic production in 1999. The EU regulation is a law within the EU, and thus within the EU this regulation must be followed if products are to be labelled organic.

Table 1. *General principles for organic animal husbandry (extracted from IFOAM's basic standards) (IFOAM, 2005)*

General principles
Overall
• Organic agriculture develops a viable and sustainable agro-ecosystem, by working compatibly with natural living systems and cycles.
• The whole farm, including livestock, is converted to organic management practices according to the standards over a period of time.
• The establishment of organic animal husbandry requires an interim period, the conversion period. Animal husbandry systems that change from conventional to organic production require a conversion period to develop natural behaviour, immunity and metabolic functions.
Management
• Organic livestock husbandry is based on the harmonious relationship between land, plants and livestock, respect for physiological and behavioural needs of livestock and the feeding of good-quality organically grown feedstuff.
• Organic animals receive their nutritional needs from organic forage and feed of good quality.
• Organic management practices promote and maintain the health and well-being of animals through balanced organic nutrition and stress-free living condition.
Breeding
• Genetic engineering is excluded from organic production and proceeding.
• Organic animals are born and raised on organic holdings.
• Breeds are adapted to local conditions.
• Organic management practices promote and maintain the health and well-being of animals through breed selection for resistance to diseases, parasites and infections.

The main certification organization for organic production in Sweden is KRAV, which was founded in 1985 and was one of the first certification organizations in the world to be accredited by IFOAM. Thus KRAV's rules for organic production follow both IFOAM basic standards and the EU regulations as a minimum. IFOAM's basic standards, the EU regulation of organic production and the regional or national regulations of certification organizations aim towards the principles for organic farming, but they are set according to what it is practically possible to achieve at present. All these regulations are regularly revised in order to develop organic production further towards the principles of organic production (Wivstad, 2004). For example, KRAV's first regulation in 1985 contained one page of rules. Today KRAV's book of regulations is well over a hundred pages.

Organic and conventional production environments for pigs

The main differences between organic pig production according to KRAV and conventional pig production according to 'the Swedish concept' (Swedish animal welfare legislation) are summarized in Table 2. Group-housing of sows in the later stages of lactation (2 weeks pp until weaning) is common practice in Swedish organic piglet production. However, this is not included in either EU or KRAV regulations for organic animal husbandry. The organic pig production is less than 1% (approximately 20000 slaughtered pigs per year) of the total pig production in Sweden at present.

Table 2. *KRAV regulation and the Swedish animal welfare legislation concerning housing and management in pig production*

Issue	Organic (KRAV)	Conventional
Feeding and medical care		
Feedstuff	Organically grown (≥85 – 100%)[1], home grown (≥50%), *ad libitum* roughage allowance	
Grazing	During the vegetative period	No grazing requirement
Weaning age	≥7 weeks[2]	≥4 weeks
Medical care	No preventive medication other than certain vaccinations	
	Withdrawal period x 2	Withdrawal period x 1
Housing, minima space allowance		
Gestation period (per sow)	Group and loose-housed during gestation, ≥2.5 m^2 indoor and ≥1.9 m^2 outdoor on concrete or on pasture in group huts[3]	Group and loose-housed during gestation, ≥2.5 m^2 indoor
Nursing period (per sow and litter)	Single and loose-housed first 2 weeks, ≥6.0 m^2 indoor or on pasture in hut[3], loose-housed 2 weeks pp until weaning , ≥7.5 m^2 indoor and ≥2.5 m^2 outdoor on concrete or on pasture in family huts[3]	Loose-housed from farrowing until weaning, ≥6.0 m^2 indoor
Growing/finishing period (per pig, 85 kg)	Loose-housed, ≥1.2 m^2 indoor and ≥0.8 m^2 outdoor on concrete	Loose-housed, ≥0.83 m^2

[1]Changing gradually towards the aim of 100% which will be fulfilled in 2012
[2]Weaning 40 days pp allowed for the youngest piglets in a group when batchwise piglet production is applied
[3]Spaces for sows in huts on pasture are not specified

Project Ekogris – an interdisciplinary research project

This PhD project was included in a larger research project called 'Ekogris' funded by the Swedish Research Council for Environmental, Agricultural Sciences and Spatial Planning (Formas). In project Ekogris researchers with expertise in different fields of animal science have investigated several aspects of organic pig production. The aim of project Ekogris is to attain an overview of organic pig production, to solve issues that limit the development of organic pig production and investigate new, presently not utilized opportunities. Regulations for organic animal husbandry mainly affect three areas: housing, feeding and medical care (Boelling *et al.*, 2003). Other sub-projects in project Ekogris cover growing/finishing pig feeding, housing and health (Høøk Presto, 2008; Svensson *et al.*, 2005), while this PhD project covers sow behaviour and performance in different housing environments. This PhD project also covers breeding in organic pig production, an area which so far has received little attention in the development of organic production and its regulations.

Piglet production and sow behaviour

When sows are kept in loose-housed farrowing and lactation environments, as compared with conventional crated environments, a larger part of the responsibility for the piglets shifts from the herdsman to the sow. When sows are kept in groups during lactation, or outdoors during farrowing and lactation, the herdsman's opportunities to supervise the piglets become even more limited, and sows have even more responsibility for the piglets. Different production environments place different demands on the sow's maternal ability.

During the last few decades, conventional piglet production has focused on improved litter size and piglet growth. This has been achieved through development of management, housing and breeding aiming towards improved productivity. However, increased litter size is unfavourably genetically correlated with piglet survival (Hellbrugge *et al.*, 2008; Knol *et al.*, 2002), and there are indications that the rapid genetic improvement in growth rate has had an undesired effect on sow reproduction (Holm *et al.*, 2004). Moreover, high sow removal rates, in the range of 50% per year, have been reported, and reproductive disorder is the most frequent reason for sow removal in both conventional indoor (Engblom *et al.*, 2007) and conventional outdoor production (Akos & Bilkei, 2004).

Reports on organic piglet production are scarce, but studies comparing outdoor and indoor production environments show that sow performance differs between these environments. Sows kept in outdoor environments seem to mobilize body reserves in favour of piglet growth to a greater extent than sows kept in indoor environments (Wülbers-Mindermann *et al.*, 2002). Akos and Bilkei (2004) reported a higher percentage of non-productive days, and that anoestrus was a significantly more common culling reason in conventional outdoor production than it was in conventional indoor production. Moreover, it has been reported that sows are more active (Johnson *et al.*, 2001) and spend a lower proportion of their time together with their piglets (Hotzel *et al.*, 2004) in conventional outdoor production environments than they do in conventional indoor nursing environments.

Sow behaviour

Animals' behaviour is partly inherited, but is also affected by environment and the experience of the individual animal (Jensen, 1993a). The sow's maternal behaviour develops over parities, and the environment affects this development (Thodberg *et al.*, 2002). Sows perform nest-building behaviour before farrowing in both semi-natural outdoor environments (Jensen *et al.*, 1993; Jensen, 1989) and indoor farrowing pens (Jensen, 1993b). The frequency and the pattern of nest-building behaviour is the same for wild boar-crossed sows as it is for sows of domesticated breeds (Gustafsson *et al.*, 1999). Sows' nest-building starts about 24 h before, and peaks about 12–6 h before farrowing starts (Castrén *et al.*, 1993). The provision of nest-building material affects the timing and quality of the nest-building behaviour (Thodberg *et al.*, 1999). Moreover, Damm *et al.* (2003a) found that loose-housed sows had a more varied and less fragmented nest-building behaviour, a shorter duration of nest-building, and a lower heart rate in the last hour before farrowing, than crated sows.

At the start of farrowing, sows are rather active, but within the first or second hour after farrowing onset the sow becomes passive; this is shown by low activity levels, with the sow spending most of her time lying laterally and being unresponsive to the piglets. Low sow activity and low sow responsiveness to piglets during farrowing are believed to be an evolutionary strategy that reduces the risk of crushing piglets during the first few hours after piglet birth (Pedersen *et al.*, 2003; Jarvis *et al.*, 1999).

There are indications of relationships between nest-building, farrowing behaviour and piglet mortality. Pedersen *et al.* (2006) suggested that a high still-birth rate is associated with slow parturition progress. They also suggested that a high frequency of piglets crushed is associated with sow passivity before farrowing, which in turn they found to be associated with low sow nest-building activity before farrowing. Andersen *et al.* (2005) found that loose-housed sows crushing none of their piglets performed a higher frequency of nest-building behaviour 8–6 hours before farrowing but a lower frequency of nest-building behaviour the last hour before farrowing start compared with sows crushing piglets.

High milk production and good sow nursing behaviour is essential for piglet growth. The sow's use of fat reserves during lactation is genetically correlated with high piglet growth (Grandinson *et al.*, 2005). High nursing frequency (Valros *et al.*, 2002) and high sow weight loss (Valros *et al.*, 2003) is associated with high piglet growth. Nursing behaviour changes continuously during lactation, indicating an ongoing weaning process during lactation where nursing frequency decreases, piglets gradually initiate a larger proportion and sows gradually terminate a larger proportion of nursings over the course of lactation (Valros *et al.*, 2002; Gustafsson *et al.*, 1999; Bøe, 1991). Damm *et al.* (2003b) suggested that the pattern of the gradual weaning process varies between environments.

Pig breeding

Modern pig breeding

The aim of modern pig production is to produce plentiful meat of good quality at a low cost. Consequently efficient feed conversion, high growth rate and carcass leanness are important production traits in modern genetic evaluations. Heritabilities for production traits are often moderate to high, resulting in rapid genetic improvement when these traits are selected for. During the last 50 years, production traits have been praised and given considerable economic weight in breeding programmes, and this has resulted in the rapid genetic improvement of these traits. Unfortunately, production traits often have unfavourable genetic correlations with health traits (Rauw *et al.*, 1998) and reproduction traits (Rydhmer, 2000). Interest in health and reproduction traits has increased over the last few decades and such traits are now included in several breeding programmes. Reproduction and health traits generally have lower heritabilities than production traits, and therefore genetic improvement is generally slower here.

Modern pig breeding programmes are based on the crossbreeding of three or four breeds. Purebred animals are kept in nucleus herds, crossbred gilts are produced in multiplying herds, and growing/finishing pigs are born and raised in commercial herds. Data collection, genetic evaluation and selection of breeding animals are performed in the nucleus herds and to some extent in multiplying herds. Thus this is where the genetic improvement is obtained. The genetic improvement is passed on from the purebred population to hybrids and slaughter pigs. The advantage of crossbreeding is the effect of heterosis, where offspring with parents of different breeds generally perform better than the mean performance of both parents. The effect of heterosis is especially good for health and reproduction traits.

Gene flow into Swedish organic pig production with current breeding strategy

Most organic pig producers in Sweden today use the same genetic material as used in conventional pig production. In organic production according to KRAV's regulation it is, at present, permissible to buy 10% of the gilts needed for replacement externally from gilt producers (KRAV, 2008). In the EU regulations for organic production this proportion is 20% (EC, 2007b). If there are no organic replacement gilts available on the market, it is permissible to recruit gilts from conventional gilt producers. The majority (80–90%) of replacement gilts in organic production are raised and selected for breeding in the herd where they later will produce. It is common for such replacement gilts to be the result of two-breed rotational crossing. The gene flow into organic pig production in Sweden is thus through the 10–20% of the gilts recruited externally and AI Landrace (L) and Yorkshire (Y) boars as sires of the gilts recruited within the herd and AI or serving Hampshire (H) or Duroc (D) boars as sires of the growing/finishing pigs (Figure 1).

Animal breeding for organic production

The general principles for organic production stress that in organic production, breeds should be selected for improved disease resistance and be adapted to local conditions (IFOAM, 2005). Longevity, vitality, fertility, high feed efficiency, foraging ability and temperament are suggested as important traits for animals in organic production (Hörning, 2006; Pryce *et al.*, 2004). Production traits are also important in breeding objectives for organic animal production, because they promote economic profitability (Pryce *et al.*, 2004). Robust animals with the ability to adapt to a variety of environments are sought in organic production, since there is environmental variation both within organic farms (e.g. between seasons) and between organic farms (Hirt *et al.*, 2001).

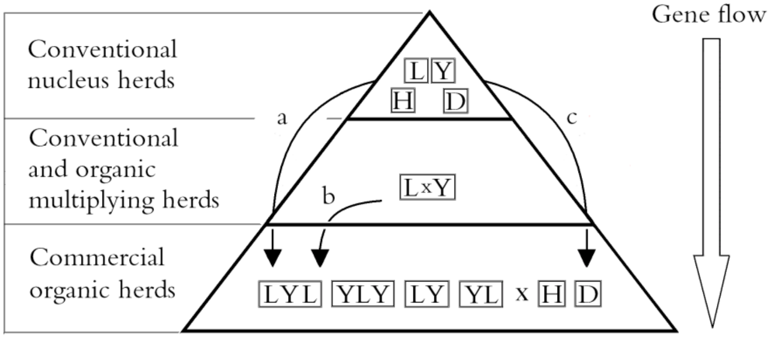

Figure 1. Breeding structure in pig production and gene flow into commercial organic herds (Swedish example): a) AI- Landrace (L) and Yorkshire (Y) boars as sires of the gilts recruited within the commercial herd, b) 10–20% externally recruited replacement gilts and c) AI or serving Hampshire (H) or Duroc (D) boars as sires of the growing/finishing pigs.

Where a trait is partly influenced by different genes in different environments, GxE interactions occur. Strong GxE interactions result in large over-prediction of economic outputs if they are not accounted for in the breeding programme (Dominik & Kinghorn, 2008). If there are strong GxE interactions for important traits in organic and conventional production environments, genetic evaluation specifically for organic herds will be a suitable breeding strategy for organic producers. If no GxE interactions exist, or if they are negligible, an organic breeding index provided from the conventional genetic evaluation, but adapted to organic circumstances, would be a suitable breeding strategy for organic producers (Pryce *et al.*, 2004).

IFOAM's general principles for organic production cover organic animal breeding. However, there are no generally accepted regulations for organic animal breeding at present (Nauta & Roep, 2008). Today the animals used in organic production are in most cases based on the same breeds and lines as those used in conventional production. Local breeds are used in some cases, where premium prices for special products can be charged, e.g. the Iberian breed in Spain and the Saddleback breed in UK (Pryce *et al.*, 2004). Nauta & Roep (2008) suggest three main strategies for organic dairy cattle breeding, and these could be applied also for other species:

- Adaptation of a conventional breeding programme, including alternative 'organic' breeding indices based on the insights of GxE interactions, and including relative weights between traits according to the specific needs of organic producers;
- A separate organic breeding programme based on an organic population (national or international);
- Improved natural breeding (farm- or region-based).

Different organic breeding strategies might be appropriate depending on which reproduction techniques and which traits are desired for animals in the specific production system, and on whether there are GxE interactions for those traits (Pryce *et al.*, 2004). However, few scientific investigations into suitable traits for organic animal husbandry, or into GxE interactions in organic and conventional production environments, have been reported.

Aims of the thesis

The purpose of this thesis was to acquire knowledge concerning pigs in organic production which can contribute to the development of sustainable organic pig production systems and breeding strategies.

The specific aims were to investigate:

- differences in sow behaviour before and during farrowing and their relation to piglet mortality when sows farrow loose-housed outdoors and indoors;
- the maternal ability of outdoor, group-housed sows during 7 weeks of lactation;
- relationships between sow maternal ability and reproduction in organic and conventional piglet production environments;
- differences in sow performance between organic and conventional piglet production environments;
- differences between herdsmen's judgement of sow maternal ability and behaviour in organic and conventional piglet-producing herds;
- GxE interactions for pig growth and carcass leanness in organic and conventional production environments.

Summary of investigations

Material and methods

This thesis includes a study performed at the Research station of the Swedish University of Agricultural Sciences (SLU), Funbo-Lövsta, and two studies of commercial herds. Sow and piglet registrations included in the thesis are summarized in Table 3. In addition to the studies of sow and piglet traits, the growth rate and leanness of 1850 growing/finishing pigs from organic herds were recorded at slaughter (Paper IV). All studies were performed in accordance with Swedish regulations governing animal use in experiments.

Sow and piglet study at Research station (Papers I and II)

The study was performed at SLU's Research station at Funbo-Lövsta, outside Uppsala, at the latitude 60 degrees north. This herd was not certified as organic, but IFOAM's basic standards were followed in the experiment with three exceptions; the sows were treated with anthelmitics, sows and piglets did not have access to outdoor areas when they were kept in the indoor group-housed farrowing environment and the feed ingredients were not organically grown. However, the feed composition was adequate for pigs in organic production.

Animals, housing, feeding and management

Forty Yorkshire x Swedish Landrace sows and their four first litters were included in the study. The sires of the litters were AI boars of the Hampshire breed. The sows were born and raised outdoors. These sows gave birth to their first and third litters outdoors in individual huts on pasture with individual grazing paddocks (Figure 2 & 3) during spring and summer (approximately April–September). In their second and fourth parities, all sows farrowed indoors in conventional Swedish farrowing pens (Figure 2 & 4) without crates during autumn and winter (approximately October–March). In the first and third parity, sows were moved into family paddocks at 2 weeks pp, where they stayed until weaning at 7 weeks pp. Each family paddock (Figure 5) contained 1 hut, 1 sun shed and 1 mud bath. In the second and fourth parity sows and piglets were moved into family boxes with deep straw bedding where they stayed until weaning at 7 weeks pp. Generally, 4–5 sows and their piglets were kept in each family paddock or box. During gestation sows were loose-housed on deep straw bedding in an uninsulated building from December to May and outdoors on pasture with access to group huts with deep straw bedding and sun sheds from June to November. The first sows farrowed in April 2003; the last litters were born in March 2005.

Table 3. *Registrations included in the thesis by study, parity and paper (I to III) (d4 = day 4, w4 = week 4)*

	Research station study		Field studies	
Production environment:	Organic outdoor	Organic indoor	Organic herds	Conventional herds
Piglet weaning:	7 weeks	7 weeks	7 weeks	5 weeks
Parity:	1 and 3	2 and 4	1 to 3	1 to 3
Number of sows:	31–40	25–36	50–69	61–75
Piglet mortality	Until d4 pp [I] & until weaning [III]	Until d4 pp [I] Herdsmen's judgement	Until weaning [III] Herdsmen's judgement	
Piglet weight and growth	d4, d14 pp & weaning /piglet [II]	–	Birth & weaning/litter [III]	
Sow weight and fat status	Farrowing, d14 pp & weaning [II]	–	Herdsmen's judgement at farrowing & weaning [III]	
Reproduction	–	–	Lactational oestrus [III] Return to oestrus after weaning litter 1 & 2 [III]	
Nest-building behaviour	Videotaped [I]	Videotaped [I]	Herdsmen's judgement [III]	
Farrowing behaviour	Videotaped [I]	Videotaped [I]	Herdsmen's judgement [III]	
Nursing behaviour	Video d4 pp direct obs. w4 & w6 pp [II]	–	Herdsmen's judgement. [III]	

[I] Paper I, Parities 1–4, [II] Paper II, Parities 1, [III] Paper III, Parities 1–3

When farrowing outdoors in huts, sows had access to the amount of straw necessary to keep the bed dry inside the hut and additional access to approximately 10 kg of straw and tree-branches outside the hut. When farrowing indoors in pens sows were provided with approximately 2 kg of straw per day. The outdoor family huts were provided with the amount of straw needed to keep the bed dry. Sows were fed according to the feeding standards applied in Sweden (Simonsson, 1994) which are based on sow weight and fat status. Sow feed intake in the first 2 weeks pp was measured as the feed given in the individual trough, since sows were not given new feed or an increased ration until the previous feed ration was consumed. From week 2 pp until weaning these sows were fed *ad libitum* from an automatic feeder. Piglets had access to the sow feeder during this period. When sows were kept outdoors they could graze at all times, and when they were kept indoors they were allowed approximately 0.5 kg hay per sow per day. Water was provided through 1 water nipple in each farrowing paddock, 1 in each farrowing pen and 2 in each family paddock.

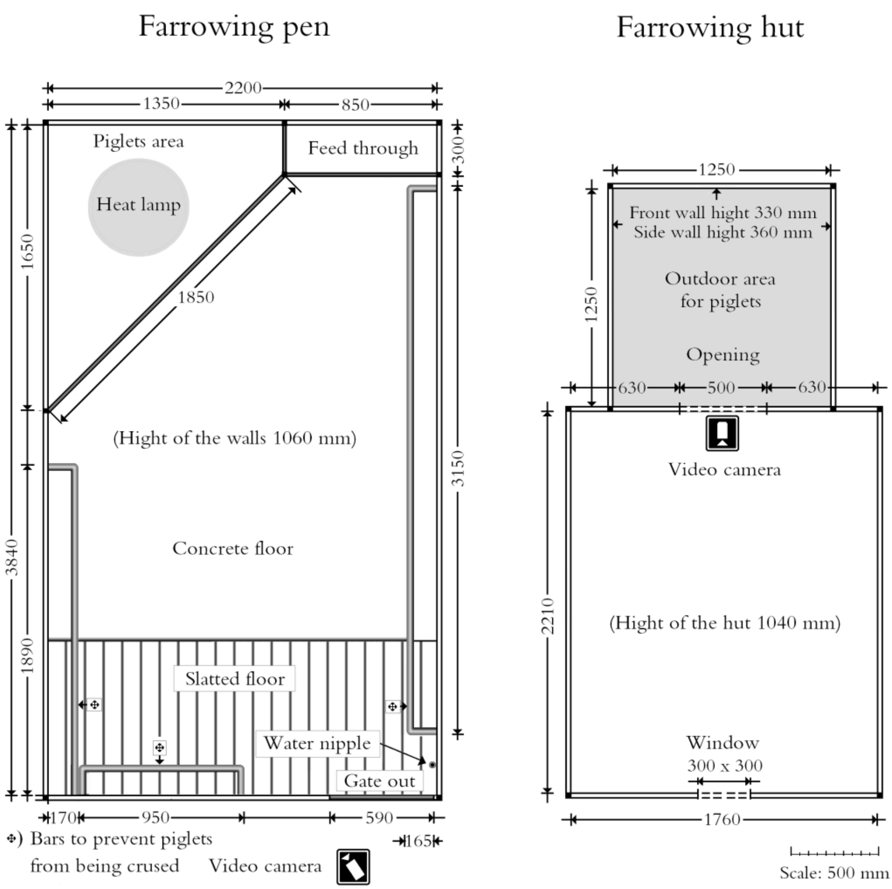

Figure 2. Design of farrowing pen and hut.

Figure 3. Farrowing huts in individual paddocks. Photo: Anna Wallenbeck.

Figure 4. Farrowing pen. Photo: Anna Wallenbeck.

Figure 5. Direct observation of sow behaviour in the family paddock. Photo: Kjell Andersson.

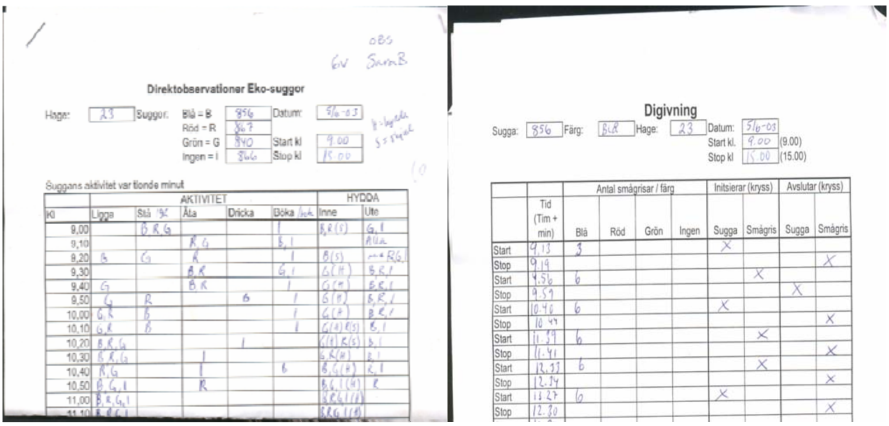

Figure 6. Check sheets used during direct observations at weeks 4 and 6 pp.

Piglets were ear-tattooed with a unique identity number, and all male piglets were castrated at approximately day 4 pp. Cross-fostering was not applied. The piglets did not receive iron supply and their teeth were neither clipped nor grated. Sows were treated with anthelmitics 2 weeks before farrowing.

Behaviour registrations

The sows and their litters were time-lapse videotaped 24 hours per day inside the farrowing hut or in the farrowing pen from day 112 of gestation until at least 2 hours after last piglet was born; and in parity 1 the sows and their piglets were additionally videotaped at day 4 pp for 24 hours. Cameras with infra-red (IR) lamps were positioned in the roof above the entrance of the hut and on a stand outside the farrowing pen (Figure 2 & 3). All videotapes were analyzed visually using the programme TASTX created by Decker (2003). The videotape recordings before and during farrowing were analyzed for the behaviour parameters presented in Table 4. The time that sows spent outside the hut when farrowing outdoors was included in the upright duration.

During the first parity, videotapes recorded during day 4 pp were analyzed for nursing duration, nursing frequency, nursing terminator (sow or piglet) and milk letdown (yes or no). A nursing was defined as suckling continuing for more than 60 seconds and including more than 50% of the litter. If the sow stood up or rolled over on her belly, making her udder unavailable for the piglets, she was considered the terminator. If more than 50% of the litter left the available udder or fell asleep at the udder, the piglets were considered terminators. Milk letdown was registered when all the piglets in the litter suddenly changed their suckling pattern from manipulating the teat and moving their heads quickly up and down, to suckling movements of the mouth and holding the head still. Sow lying duration, number of postural changes and duration of outdoor visits were also analyzed.

During the first parity, individual sow behaviour was directly observed in the family paddock (Figure 5) between 9 am and 3 pm during 1 day in week 4 pp and again during 1 day in week 6 pp. Nursing duration, nursing frequency and nursing terminator were continuously observed and sow activity (standing or lying) was scanned every 10 minutes according to a check sheet (Figure 6).

Table 4. *Behaviour parameters calculated, based on registered behaviours*

Behaviour parameters	Definition
Lateral duration	Time from lateral recumbency until any other posture
Outdoor duration	Time from outdoor exit until next indoor entry
Upright duration	Time from standing up/walking until any other posture
Postural change	Change between any of the postures
Nest-building events	Rooting or arranging material
Farrowing start	First piglet born (live-born or still-born)
Farrowing stop	Last piglet born (live-born or still-born)
Farrowing duration	Duration from farrowing start until farrowing stop
Latency between first piglet born and first teat in mouth	Duration from farrowing start until first teat in mouth
Longest duration of lateral recumbency during farrowing	Maximum single duration in lateral recumbancy after farrowing start (without any postural changes)
Latency between farrowing start and last postural change	Duration from farrowing start after until last postural change before the longest duration of lateral recumbancy during farrowing

Sow and litter performance registration

Litter size was registered on the day of farrowing, and piglets were individually weighed on the day of castration, which was approximately day 4 pp, at day 14 pp and at weaning (approximately 7 weeks pp). Piglet mortality was registered from farrowing until weaning in parity 1 and from farrowing until day 4 pp in parities 2, 3 and 4. Cause of death was judged by the herdsmen. Piglets considered still-born were examined by a simple autopsy (floating of the lung in water). Sows were weighed and measured for back-fat 5 days before expected farrowing. This was repeated at day 14 pp and at weaning.

Field studies in commercial herds (Papers III and IV)

Field studies were performed in commercial organic and conventional pig production herds (Figure 7 & Table 5). Maternal traits were studied during the 3 first parities of 144 sows from 3 organic and 3 conventional piglet-producing herds during the period 2003–2006. These sows were Swedish Landrace x Yorkshire crosses bought from conventional gilt producing herds. The sires of the piglets were Hampshire boars, and all herds used a combination of AI and natural mating. However, during the period from February 2003 until August 2004, 174 sows from the 3 organic piglet-producing herds were inseminated with unmixed semen (standard semen doses used in commercial piglet production blend the semen of several boars) from 37 AI-Hampshire boars according to an insemination scheme designed for this study. AI-doses were provided by the Swedish breeding organization Quality Genetics.

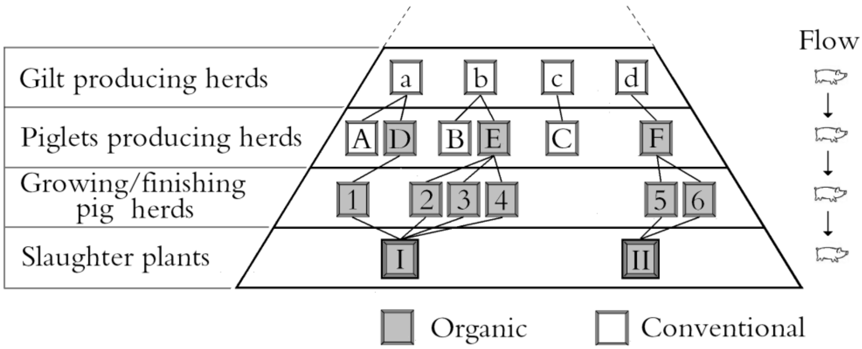

Figure 7. Herds and slaughter plants involved in the field studies.

Table 5. *Number of sows per piglet-producing herd*

		Parity		
Environment	Herd	1	2	3
Conventional	A	25	21	17
	B	25	25	24
	C	25	23	20
Organic	D	24+8[1]	22+7[1]	15+6[1]
	E	25+13[1]	24+9[1]	22+3[1]
	F	20	19	13

[1]Sows with only one litter included in the study

Suitable piglet production herds for these studies were selected by production advisors based on herd size, the herdsmen's skills in documenting production results, and interest in participating in this research project. Growing/finishing pig herds connected with the participating piglet-producing herds were also included. Altogether 5 of the 6 piglet-producing herds and 2 of the 6 growing/finishing herds had run pig production for more than 30 years. The other herds had approximately 10 years of pig production experience. The organic herds had followed KRAV's regulations for organic production (KRAV, 2005) for approximately 3–4 years when these studies started. The number of employees varied from 1 (the farmer himself) in some of the growing/finishing pig herds to 6 in one of the conventional piglet-producing herds, but labour in most herds consisted of the herd owner and

1 part-time employee. The piglet-producing herds were financially compensated for extra work related to the study per registered litter, while growing/finishing herds were compensated with a single sum. Before the study started a written agreement including details of financial compensation and the herd owner's right to read manuscripts before publication was signed. The duration of participation in these studies varied between the herds from approximately 1.5 to 3 years.

Piglet-producing herds

The conventional piglet-producing herds had on average 305 sows (250–350) in production. In all conventional herds, sows farrowed indoors in individual farrowing pens without crates, where they stayed with their litter until weaning approximately 5 weeks pp. During mating and gestation the sows were kept in groups on deep straw bedding in uninsulated buildings.

Organic pig production systems depend on the specific local conditions of the farm. Thus production environments varied more between organic herds than between conventional herds. The organic piglet-producing herds had on average 77 sows (55–96) in production. The production in these herds corresponded to approximately 10% of the organic piglet production in Sweden at that time. Sows farrowed indoors in individual farrowing pens without crates in two of the organic herds. In these two herds, sows and their litters were group-housed (6–10 sows) indoors in pens with deep straw bedding with outdoor access on concrete flooring and access to roughage from 2 weeks pp until weaning (approximately 7 weeks pp) during the non vegetative season (approximately September–May). During the vegetative season, sows and piglets in one of these two herds had additional access to pasture connected to the group pens, whereas in the other herd sows and piglets were kept in huts on pasture 2–7 weeks pp. In the third organic herd sows and piglets were kept outdoors on pasture throughout the year. The sows farrowed in individual paddocks with farrowing huts and were kept in family groups with access to family huts during weeks 2–7 pp. During mating, sows in all organic herds were group-housed on deep straw bedding in uninsulated buildings. During gestation, sows in two of the organic herds were group-housed on deep straw bedding in uninsulated buildings with outdoor access on concrete flooring and with access to roughage during the non vegetative season. During the vegetative season, sows in one of these two herds had additional access to pasture connected to the building during gestation, whereas in the other of the two herds sows were kept in huts on pasture during gestation. In the third organic herd sows were kept in huts outdoors on pasture during gestation throughout the year.

All 6 piglet production herds applied batchwise piglet production. Piglets in all herds and sows in two of the herds were fed *ad libitum* during the nursing period. In the other 4 herds sows were fed according to the feeding standard practiced in Sweden (Simonsson, 1994) during the nursing period, but the feed allowance was regulated according to the herdsman's judgement of the sows' need. Sows and piglets had additional *ad libitum* access to roughage in the organic herds. The general health situation was good in all piglet-producing herds during the study period according to the herd veterinarians.

Growing/finishing pig herds and slaughter plants

The growing/finishing pigs were raised in 6 commercial organic growing/finishing herds, which sent on average 993 pigs to slaughter every year (Figure 7). The production in these herds corresponded to approximately 30% of the organic pig meat production in Sweden at that time. The slaughter plants were certified by KRAV to slaughter organic pigs (KRAV, 2005). The growing/finishing pigs were fed restrictively, following the SLU norm, according to weight. They had access to pasture during the vegetative season. During the non-vegetative period they were kept indoors with outdoor access on concrete and had access to roughage.

Behaviour registrations

We visited all herds and instructed the herdsmen as to how to make registrations and judgements. They collected all the information on sows and their litters included in this study.

Using 3 questionnaires, herdsmen judged maternal ability and the behaviour of each sow during 3 periods: during farrowing, from farrowing until 2 weeks pp and from 2 weeks pp until weaning (Table 6). These questionnaires were based on work described by Vangen *et al.* (2005).

Sow and litter performance registrations

Birth date, number of live-born and number of still-born piglets were registered at the day of farrowing. Cross-fostering (number of piglets moved in and out of the litter), the date of the piglet move and piglet mortality, including cause of mortality and date of death, were registered throughout the nursing period. Litter weight and number of piglets weighed were registered at castration, approximately day 4 pp, and at weaning. As weaning age differed between the production systems, piglets in organic herds were about 2 weeks older than those in conventional herds when weighed at weaning. At the weighing at 4 days pp, piglets moved into the litter were excluded, since this weight should reflect foetal growth rate in the uterus. The weighing at weaning included all piglets nursed by the sow.

Sow fat status was judged at the day of farrowing and the day of weaning according to a grade scale (Figure 8). Sow birth date, insemination date and number of inseminations after weaning the first and the second litter were registered. Oestrous signs during lactation (standing oestrus and reddening and swelling of vulva) and the date on which these signs were observed were registered.

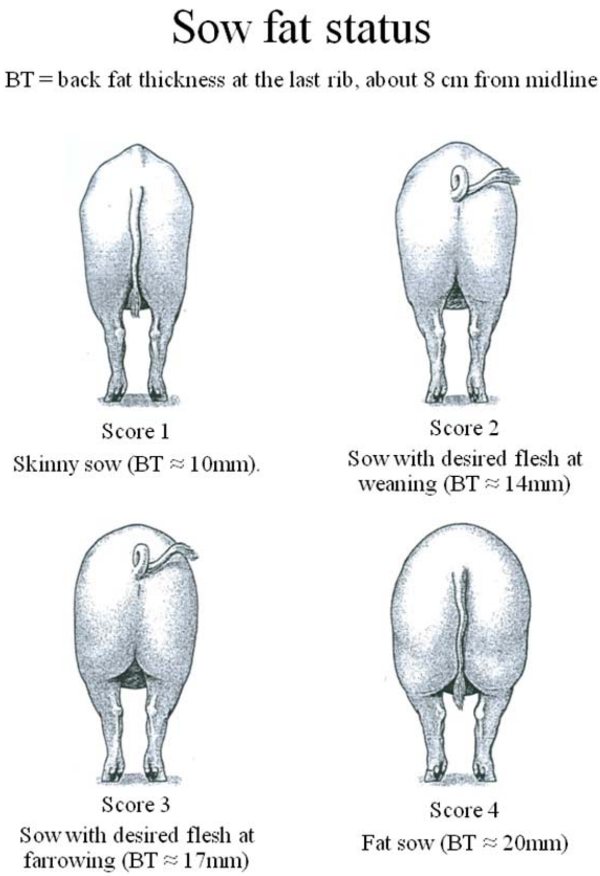

Figure 8. Judgement scale for sow fat (Lantmännen, 1995).

Table 6. *Questions about sow maternal ability and behaviour during farrowing, from farrowing until 2 weeks pp and from 2 weeks pp until weaning*

Judgement period Question	Reply scale
Farrowing, first questionnaire	
Approximate time of farrowing onset	Time of the day
Approximate farrowing duration (hours)	Hours or Do not know
Sow nest-building behaviour before farrowing [1]	1=No to 7=Much
Sow restless behaviour during farrowing [1]	1=Very restless to 7=Very calm
Do you think that the sow have squeezed or trampled piglets to death? [1, 2]	1=Much to 7=None
How much aggressive behaviour does the sow show towards the piglets during farrowing? [1, 2]	1=Much to 7=None
Do you suspect that the sow has bitten piglets to death?	Yes/No
Farrowing until 2 weeks pp, second questionnaire	
How often is the sow incautious around the piglets? [1]	1=Always to 7=Never
Do you think that the sow have squeezed or trampled piglets to death?	Yes/No
How good is the sow at nursing her piglets? [1]	1=Very bad to 7=Very good
How often does the sow show fear for you when you work around her?	1=Always to 7=Never
How often is the sow aggressive towards you? [1, 2]	1=Always to 7=Never
What do you think of the sow's maternal ability? [1]	1=Very bad to 7=Very good
2 weeks pp until weaning, third questionnaire	
How good is the sow at nursing her piglets? [1]	1=Very bad to 7=Very good
How often does the sow show fear for you when you work around her? [1]	1=Always, to 7=Never
How often is the sow aggressive towards you? [1, 2]	1=Always to 7=Never
How often is the sow aggressive towards other sows? [1](only organic herds)	1=Always to 7=Never
What do you think of the sow's maternal ability? [1]	1=Very bad to 7=Very good

[1]Answers on scale: 1------2------3------4------5------6------7 or tick box: Do not know
[2] Low variation on the continuous scale, transformed into a bivariate variable where 0=occurrence and 1=no occurrence

Organic breeding values for growth and carcass leanness

Piglets were ear-tagged (4 days pp) and tattooed on their back (2–7 weeks of age) with a litter-sex identity number. Both ear-tag and tattoo were used to identify the carcasses of these pigs at the slaughter line. The pigs were slaughtered between November 2003 and August 2005. Birth date, slaughter date and slaughter weight before sanitary carcass discard were recorded. Additionally, back-fat thickness was measured at slaughter line applying the Hennesy grading instrument to the last rib, about 8 cm from midline. Organic breeding values for growth rate and back-fat thickness were estimated for 37 Hampshire AI-boars using this information. Pedigrees for the AI-boars were collected from the breeding organization Quality Genetics.

Conventional breeding values for growth and carcass leanness

Conventional breeding values for growth rate until 100 kg and back-fat thickness at 100 kg were collected from Quality Genetics for the 37 Hampshire AI-boars used in the study. These values were estimated in December 2005 on the basis of records collected from the boars and their relatives raised in conventional nucleus herds. Records of growth rate and back-fat thickness from an ultrasonic test in nucleus herds, together with records of growth rate and carcass leanness from a station test, were used in the conventional genetic evaluation.

Interviews with farmers

When the study was finished the owners of the organic piglet production herds were interviewed by telephone. The herd owners were forewarned about the interview in a letter, and the same person carried out all of the interviews. Each interview (approximately 15 min) covered the following questions:

- What were your expectations when you converted to organic pig production?
- What were your concerns when you converted to organic pig production?
- What works better than your expectations?
- What works worse than your expectations?
- After the conversion to organic production, what was the next large change on the farm (or in the company)?

Statistical analyses

The statistical analyses were performed using the SAS package, version 8.2 or 9.0 (SAS institute, Inc. Cory, NC). All dependent variables were tested for normal distribution using procedure UNIVARIATE, considering skewness, kurtosis, Shapiro-Wilks test for normality and a normal probability plot. Variables differing significantly from normality were either log-transformed or converted to ordinal or bivariate variables and analyzed as such.

Various SAS procedures were used in the statistical analyses; the choice of model depended on the type of input (predictor) and outcome (response) variables.

Variables are one of the following:

- continuous
- categorical (nominal: classes without order (e.g. gender), or ordinal: classes with order from least to most).

Input variables are one of the following:

- fixed (would not change in a new data sample)
- random (unique for this data sample).

Procedure GLM assumes normal distribution of the outcome variable and handles fixed input variables. It is suitable for analyzing models with normally distributed continuous outcome variables and non-random input variables. Procedure GENMOD differs from GLM in that normal distribution of the outcome variable is not assumed, but the outcome variable can follow some of the exponential family distributions. It is suitable for analyzing models with categorical outcome variables and non-random input variables. Procedure MIXED assumes normal distribution of the outcome variable and differs from GLM in that, besides fixed input variables, it also handles random input variables. It is suitable for analyzing models with normally distributed continuous outcome variables and fixed and random input variables. Procedure GLIMMIX differs from MIXED in that normal distribution of the outcome variable is not assumed, but the outcome variable can follow some of the exponential family distributions. It is suitable for analyzing models with categorical outcome variables and both fixed and random input variables. All of these procedures handle both continuous and categorical input variables.

Paper I

Nest-building during farrowing and percentage of time lying on the belly during farrowing were log-transformed and number of still-born piglets in the litter was transformed into a bivariate variable (presence or not of still-born piglets in the litter) before these parameters were analyzed.

Least square mean differences between farrowing environments were estimated for nest-building parameters, farrowing parameters and sow and litter performance parameters using procedure MIXED for continuous variables and procedure GLIMMIX for the bivariate variable presence or not of still-born piglets in the litter.

The following statistical model was applied:

y = farrowing environment + parity (farrowing environment) + season (farrowing environment) + litter size + sow + residual,

where farrowing environment had 2 classes (hut or pen), parity had 4 classes (parities 1–4), season of farrowing had 4 classes (spring outdoors, summer outdoors, autumn indoors and winter indoors) and litter size (total number of piglets born) had 3 classes (<10, 10–12, >12 piglets). Sow was included as a random effect and the other predictor variables were included as fixed effects. Litter size was excluded from the statistical model when number piglet born alive was analyzed. When analyzing piglet weight and piglet growth, age at weighing (number of days) was included in the statistical model.

Residual Pearson correlations were estimated using procedure CORR to investigate relationships between nest-building and farrowing parameters. The following GLM model was applied to estimate the residual of the response variables:

y = farrowing environment + parity (farrowing environment) + season (farrowing environment) + litter size + residual,

where all these factors are included as fixed effects.

Relationships between sow behaviour around farrowing and piglet mortality (percentage dead of live-born piglets until day 4 pp) were investigated by regression analysis using procedure GLM. Regression analysis was performed separately for each behaviour parameter with the behaviour parameter as a covariate using the following statistical model:

Piglet mortality = farrowing environment + parity (farrowing environment) + season (farrowing environment) + litter size + covariate + farrowing environment ^{x} covariate + residual, where the covariate was a behaviour trait. When the interaction between farrowing environment and the behaviour parameter was not significant, the interaction was excluded and the analysis was performed again.

Paper II

Only first parity sows farrowing outdoors were studied in Paper II. Residual correlations between variables were estimated using procedure GLM. The fixed effects of litter size day 4 pp (3 classes; <9, 9–10, >10) and nursing group (5 classes) were studied for all dependent variables and included in the statistical model if significant. Nursing group is the group of sows that were in the family paddock together. Nursing group includes the effects of group, season (spring or summer) and the person recording behaviour.

When analyzing nursing frequency week 4 and 6 the following statistical model was applied:

y = litter size + nursing group + residual

When analyzing sow weight at weaning, sow back-fat at farrowing and at weaning the following statistical model was applied:

y = litter size + residual

When analyzing piglet growth from week 2 to weaning, nursing duration day 4 and week 6, percentage lying day 4, week 4 and week 6, number of postural changes day 4 pp, time spent outdoors day 4, sow weight at farrowing and week 2 and sow back-fat week 2, the following statistical model was applied:

y = nursing group + residual

Relationships between some class and continuous variables were investigated by including the class variable as a fixed effect in the above statistical models and estimating least square mean differences for the continuous variables between classes.

Correlations between different measuring occasions of the same behaviour were estimated for nursing frequency, nursing duration and percentage lying applying the same fixed effects as in the above models but applying procedure MIXED with REPEATED statement (unstructured covariance structure) and including sow as random subject.

Paper III

Some of the continuous variables were transformed into bivariate variables since there was too little variation on the continuous scale: day or night for farrowing time; still-born piglets or not, piglets squeezed or trampled piglets to death during farrowing or not, aggressive behaviour towards piglets during farrowing or not, aggressive behaviour towards humans from farrowing until 2 weeks pp or not and from 2 weeks pp until weaning or not, sow fat loss (reduced fat score between farrowing and weaning or not).

Least square means between organic and conventional environments were estimated using procedure MIXED for continuous variables and procedure GLIMMIX for bivariate variables. The following statistical model was applied:

y = environment + parity number + litter size + herd (environment) + sow (environment and herd) + residual,

where sow was included as a random effect and the other predictor variables were included as fixed effects.

Residual correlations were estimated to investigate relationships between variables. Response residuals were estimated using procedure GLM for continuous variables and procedure GENMOD for bivariate variables. The following statistical model was applied:

y = environment + parity number + litter size + herd (environment) + residual,

where all predictor variables were treated as fixed effects. Residual Spearman rank correlations were estimated with procedure CORR.

Least square means for sow performance traits between organic sows that did or did not show oestrous signs during lactation were estimated using procedure MIXED. The following statistical model was applied:

y = oestrus (yes/no) + parity number + sow (herd) + residual, where sow (herd) was included as a random effect and the other predictor variables were included as fixed effects.

In all of the above models, environment had 2 classes (organic or conventional), parity had 3 classes (parities 1–3) and litter size (number of piglets born alive) had 3 classes (<10, 10–12, >12). Litter size was excluded when least square means were analyzed for number of piglets born alive, still-born and number of weaned. When litter weight and mean piglet weight at day 4 pp were analyzed, piglet age at weighing (days) was included in the model. When variables with 1 registration per sow (kg weaned piglet per year, weaning to insemination interval after first and second litter) were analyzed, parity number, litter size and the random effect of sow were excluded from the statistical model. When weaning to insemination intervals were analyzed, the season of weaning previous litter (4 seasons; January–March, April–June, July–September and October–December) was included in the statistical model.

Paper IV

The DMU package (Madsen and Jensen, 2008) was used to estimate genetic variance and covariance components and to estimate organic breeding values. All 37 Hampshire AI-boars were included in the genetic analysis. However, only boars with more than 20 offspring resulting in 29 boars (range 20–110 offspring) were included in the rank correlation calculations. Spearman rank and Pearson correlations between organic and conventional breeding values were calculated using procedure CORR.

A genetic bivariate analysis was performed for growth rate up to 100 kg and back-fat thickness at 100 kg. The pedigree included the sires' pedigree over two generations. The identities of the growing/finishing dams were included but their pedigree was unknown. Thus all dams were regarded as unrelated. The following animal model was applied:

y = sex + litter size + growing/finishing herd + herd-year-season + birth litter + animal + residual,

where the fixed effect of sex included 2 classes, litter size at 2 weeks pp included 3 classes (<10, 10–12, >12 piglets) and growing/finishing herd included 6 classes. Herd-year-season, birth litter and animal were included as random effects.

Comments on study design

In Paper I we studied sow behaviour around farrowing during the sows' first 4 parities. The gilts entering the study were born and raised in an outdoor environment at the Research station. The insemination of the gilts was planned so that the 40 gilts farrowed in two batches, one in April–June and the other one in July–September. These 40 sows farrowed in the outdoor environment during spring and summer (parities 1 and 3) and in the indoor environment during autumn and winter (parities 2 and 4). The aim was to study the same sows over several parities. The economic limits and time-frame of this project did not permit use of a larger number of sows. Thus we would have decreased the amount of data collected from each environment if we had aimed for outdoor and indoor farrowing in all parities. Consequently, parity was nested within farrowing environment. This means it is possible that sows' previous experience of the other farrowing environments biased the results concerning sow farrowing behaviour. However, parity was included in the statistical model when the data were analyzed and had in most cases no significant effect on the analyzed behavioural variables.

Paper II was the first Paper written in this PhD project. The analyses were initiated in 2004, when some sows had only farrowed once; thus only first parities are included.

In Paper III, the analyzed measurement of sow behaviour was the herdsman's judgement of sow behaviour. It is important to appreciate that these registrations therefore involve judgements that are affected by the knowledge and experience of the individual herdsman. In this study such effects were not measured, and consequently they were not accounted for in the statistical analyses of the data.

In Paper IV, GxE interactions were investigated with an EBV rank correlation approach. The rank correlations of boars' breeding values estimated are assumed to be in close relationship with the corresponding genetic correlations. McLaren *et al.* (1985) showed that genetic and boar rank correlations are closely related. They investigated purebred and two-crossbred offspring of Hampshire, Duroc and Yorkshire raised in the same environment. The genetic and rank correlations were 0.67 and 0.69, respectively, for growth rate, and 0.86 and 0.82, respectively, for back-fat thickness. The accuracy of rank correlations is dependent on the accuracy of both ranks included. In the present study, the conventional breeding values were based on much more information and many more relatives, leading to a high level of accuracy as regards boars' rank. By contrast, the organic breeding values were based on less information and fewer relatives, leading to a relatively lower level of accuracy as regards boars' rank. By using as much information as possible in the ranks included in the rank correlation, the overall accuracy of the correlation was increased. An alternative to this rank correlation approach would have been a bivariate trait approach, estimating genetic correlations for these traits between production environments. To achieve this it would have been necessary to collect data from commercial conventional herds as well. However, this alternative would have reduced the accuracy of boars' conventional rank and made the study twice as expensive.

The rank correlations estimated in the Paper IV are influenced by crossbreeding, since the organic breeding values are based on the performance of crossbred offspring and the conventional breeding values are based on the performance of the boars and their purebred relatives. Brandt and Taubert (1998) estimated genetic correlations between purebred Duroc and their crossbred (Duroc x (Landrace x Large White)) relatives raised in the same environment to 0.97 for growth rate and 0.98 for back-fat thickness. Using two different Duroc lines, Zumbach *et al.* (2007) reported genetic correlations between purebred Duroc from nucleus herds and their crossbred (Duroc x (Landrace x Large White)) relatives in commercial herds at 0.60 and 0.79 for growth rate and 0.83 and 0.89 for back-fat thickness. Since the correlations between purebred and crossbred relatives found in the present study are considerably lower than those reported in previous studies, we conclude that the correlations here do indicate GxE interactions between organic and conventional production environment.

Main results

Sow and litter performance (Papers I, II and III)

Sow and litter performance differed to some extent depending on the production environment. Least square means for organic and conventional herds in Paper III are summarized in Table 7. In Paper I the probability of still-born piglets in the litter was lower when loose-housed sows farrowed outdoors in huts than it was when sows farrowed indoors in pens. According to the herdsmen's judgement, the most common cause of piglet death was that the sow had crushed the piglet to death, and this held in the organic outdoor environment (10.9% crushed to death, of live-born until day 4), organic indoor environment (7.5% crushed to death, of live-born until day 4) (Paper I), organic herds (8.3% crushed to death, of live-born until weaning) and conventional herds (6.7% crushed to death, of live-born until weaning) (Paper III). Piglet mortality was higher in organic than in conventional herds. However, there was a large variation in the level of piglet mortality among herds showing that organic herd F (outdoor farrowings) had higher piglet mortality specially during the first 14 days pp than all the other organic and conventional herds ($p<0.05$). Organic herd D (pasture access from the group pen) tended to have higher piglet mortality during the later part of lactation (day 14 to 35 pp) than all the other herds ($p<0.1$).

Relationship between sow appetite, body reserves and litter performance (Paper II)

Only few of the first parity sows farrowing outdoors consumed feed according to their recommended intake during the first 2 weeks of lactation, and sows with large litters tended to consume a lower percentage of recommended intake than sows with small litters. Sow feed consumption during the first 2 weeks of lactation was correlated with sow back-fat-depth week 2 pp, indicating that fat sows eat a lower proportion of their recommended intake in early lactation than thin sows do. Compared with sows with a low feed intake, sows with high feed intake until 2 weeks pp had piglets with higher growth rates during this period and during the period from 2 weeks pp until weaning at 7 weeks pp. During the first 2 weeks pp, piglets of heavy sows grew faster than piglets of light sows.

Sow reproduction (Paper III)

Oestrous signs during lactation were observed in all organic herds (4%, 20% and 32% of sows in parities 1, 2 and 3 respectively) and in none of the conventional herds. Approximately 40% of the sows that showed oestrus during lactation did so in week 5 of lactation. Sows showing oestrus during lactation in the organic herds had higher fat score at weaning than sows not showing oestrus (score 2.4 vs. 2.2, $p = 0.045$).

Table 7. *Least square means for sow and litter performance in parities 1 to 3 in organic and conventional herds*

	Org. herds	Conv. herds	
Piglet weaning age:	7 weeks	5 weeks	
Number of sows:	50 – 69	61 – 75	p
Litter size			
Number of piglets born alive	11.9	11.8	0.811
Probability of at least one still-born piglet in litter[1]	0.43	0.33	0.054
Number of piglets weaned per litter	9.9	10.3	0.054
Number of piglets weaned per year	20.2	23.5	0.001
Piglet mortality (% of live-born ± cross fostering)			
From farrowing until weaning	15.2	11.2	0.003
From farrowing until day 35 pp	14.8	11.5	0.018
Piglet age at death (days)	10.6	6.9	0.003
Piglet weight and growth			
Litter weight day 4 pp (kg)	23.0	21.7	0.013
Litter weight at weaning (kg)	138	85	0.001
Mean piglet weight day 4 pp (kg)	2.5	2.4	0.004
Mean piglet weight at weaning (kg)	15.5	9.3	0.001
Piglet growth from day 4 pp until weaning (g/day)	277	246	0.001
Kg weaned piglet per year	308	213	0.001
Sow body reserves			
Sow fat judgement score at farrowing (score 1= thin to score 4=fat)	2.81	2.77	0.439
Sow fat judgement score at weaning (score 1= thin to score 4=fat)	2.21	2.34	0.104
Sow fat loss (probability to reduce fat judgement score from farrowing until weaning)	0.03	0.04	0.469

[1]Low variation on the continuous scale, transformed to bivariate variable where 0=occurrence and 1=no occurrence

Sow nest-building and farrowing behaviour (Papers I and III)

Sow activity and nest-building behaviour differed depending on the production environment (Table 8) and changed over the last 24 hours before farrowing start (Figure 9a–c).

Table 8. *Least square means for the sows' nest-building and farrowing behaviour*

	Research station study			Field studies		
Production environment:	Organic outdoor	Organic indoor	p	Organic herds	Conventional herds	p
Nest-building						
Sow behaviour before farrowing [III] (1=No to 7= Much)				4.4	4.3	0.48
Nest-building (events/hour pre-partum)[I]:						
12–10 h	5.3	1.9	0.004			
9–7 h	5.4	3.4	0.007			
6–4 h	5.6	4.8	0.407			
3–1 h	3.5	4.9	0.102			
Upright duration (minutes/hour pre-partum)[I]:						
12–10 h	27.5	28.3	0.828			
9–7 h	23.6	36.2	0.001			
6–4 h	16.6	33.4	0.001			
3–1 h	8.8	21.4	0.001			
Farrowing						
Approximate farrowing duration (hours)[III]				4.2	3.7	0.089
Farrowing duration first piglet born until last piglet born (hours)[I]	3.5	5.2	0.001			
Sow behaviour during farrowing (1=Very restless to 7=Very calm)[III]				6.0	5.8	0.227
Nest-building, frequency during farrowing (events/hour)[I]	0.7	0.2	0.027			

[I] Paper I, Parities 1–4

[III] Paper III, Parities 1–3, Answers on scale: 1------2------3------4------5------6------7 or tick box: Do not know

Sows in the organic herd in which sows and piglets were kept outdoors on pasture throughout the year had lower ($p<0.05$) scores for nest-building behaviour than sows in the other two organic herds (Paper III).

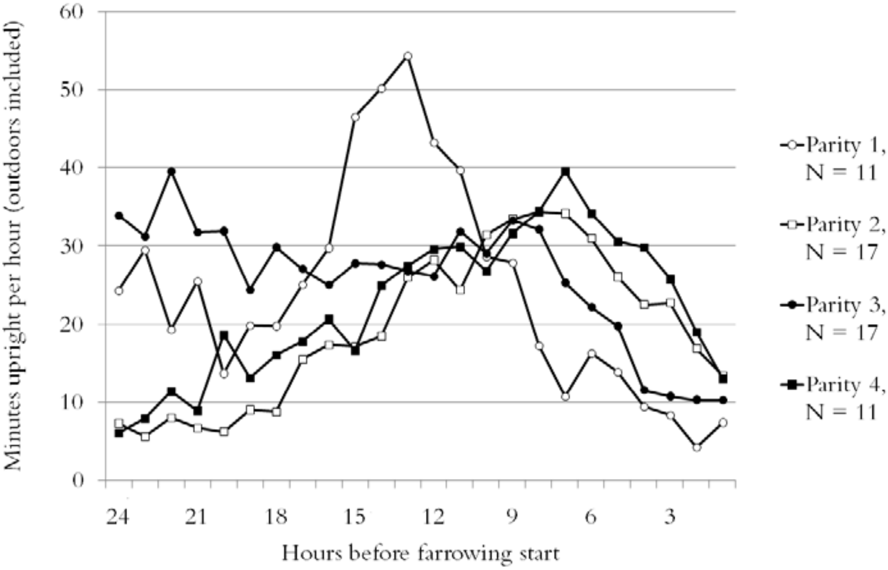

Figure 9a. Minutes per hour the sow spent in upright posture (standing or walking) during the last 24 hours before farrowing start, by parity. Time spent outdoors, outside the hut, is included in the time spent in upright posture in parities 1 and 3.

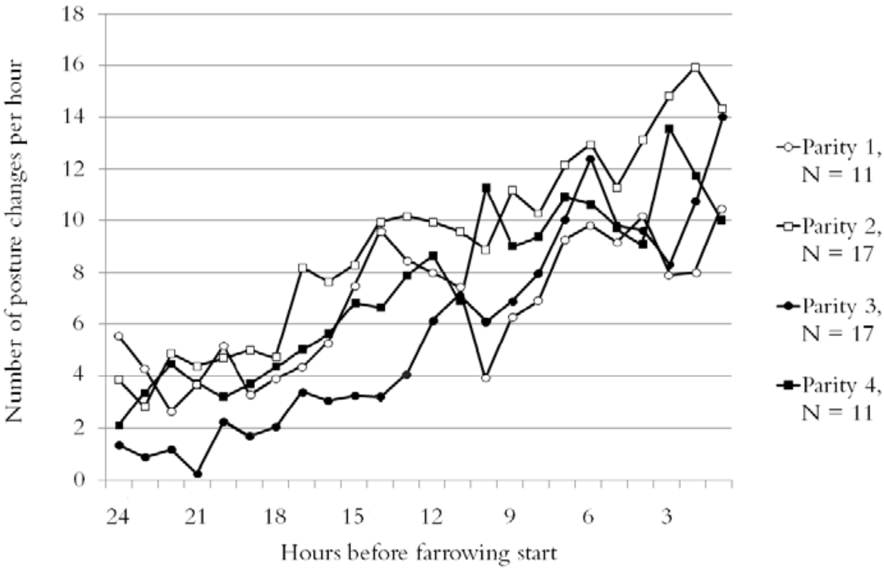

Figure 9b. Number of postural changes per hour during the last 24 hours before farrowing start, by parity.

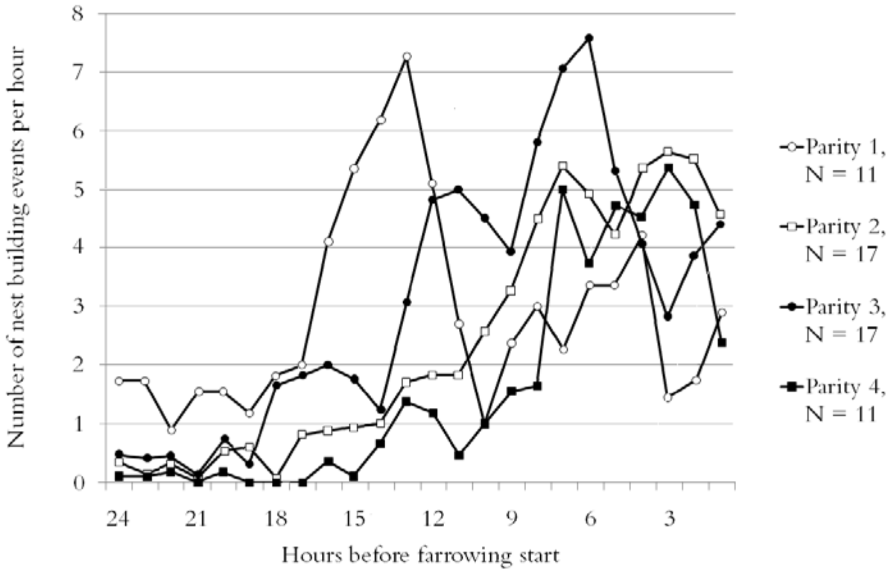

Figure 9c. Number of nest-building events per hour during the last 24 hours before farrowing start, by parity.

Relationships between sow behaviour before farrowing start and sow behaviour during farrowing (Paper I)

When sows farrowed indoors in pens, how much of the time they spent in upright posture during hours 12–10 before farrowing was associated with calm behaviour during farrowing (i.e. short time spent in upright posture, few postural changes and few nest-building events). In contrast, much time spent in upright posture during the last 3 hours before farrowing was associated with restless behaviour during farrowing (i.e. long time spent in upright posture, many postural changes and many nest-building events). These correlations were weaker and in most cases non-significant when sows farrowed outdoors.

Relationships between sow behaviour during farrowing and piglet mortality (Papers I and III)

The regression coefficient for piglet mortality (until day 4 pp) on sow behaviour during farrowing differed between farrowing environments, indicating that prolonged adoption of an upright posture and many postural changes led to high piglet mortality when sows farrowed in huts, but did not affect piglet mortality when sows farrowed in pens. Moreover, longer period from first piglet born until first teat in mouth was associated with increased piglet mortality when sows farrowed outdoors but did not affect piglet mortality when sows farrowed indoors.

According to the herdsmen's judgement of sow behaviour in the commercial herds, calm behaviour during farrowing was associated with a low probability of squeezing and trampling piglets during farrowing. In organic herds, calm behaviour during farrowing was associated with cautiousness among piglets during the first 2 weeks pp, but no such relationship was found in conventional herds.

Sow nursing behaviour (Papers I, II and III)

For first parity sows kept outdoors, nursing frequency, nursing duration and percentage lying decreased over lactation, as shown in Table 9. Sows terminated a higher proportion of the nursings in late lactation than they did in early lactation, terminating 32%, 84% and 91% of all nursings at day 4, week 4 and week 6 pp, respectively.

Sows in organic herds were judged to show better nursing behaviour, to be more cautious among their piglets, and to have better maternal ability in early lactation, than sows in conventional herds. Moreover, sows in organic herds were judged to show fear of the herdsman more frequently than sows in conventional herds (Table 9).

In first parity sows farrowing outdoors (Paper II), the number of postural changes correlated negatively with nursing frequency at day 4 pp, indicating that calm sows nursed more frequently than restless sows. Time spent outdoors at day 4 pp was not correlated with number of nursings. Percentage lying (time per sow) correlated with nursing duration and tended to correlate also with number of nursings in week 4 pp, indicating that calm sows nursed longer each time and more frequently than restless sows. Sow nursing was not correlated with percentage lying in week 6 pp.

Among these first parity sows, 22 of 37 sows had alien piglets at the udder during at least 1 nursing in the course of the observation in week 4. Three of these sows had alien piglets at all nursings. 13 of 37 sows had alien piglets at the udder during at least 1 nursing in the course of the observation in week 6 and 1 of these sows had alien piglets at all nursings. This indicates that cross-suckling decreases in late lactation. Just 30% of the sows had their whole litter at the udder at all nursings in week 4, and 19% had their whole litter at the udder at all nursings in week 6.

Table 9. *Least square means for sow nursing behaviour parameters*

	Research station study			Field studies		
Production environment:	Organic outdoor	Organic indoor		Organic herds	Conventional herds	
Piglet weaning age:	7 weeks	7 weeks	p	7 weeks	5 weeks	p
Duration from farrowing start until first teat in piglet mouth (min) [I]						
	31.8	49.1	0.019			
Nursing frequency [II] (events/hour):						
Day 4	1.5^a		0.001			
Week 4	1.0^b					
Week 6	0.9^c					
Nursing duration [II] (min/nursing):						
Day 4	6.7^a		0.001			
Week 4	3.3^b					
Week 6	3.7^b					
Lying part of total time [II] (percentage):						
Day 4	85^a		0.001			
Week 4	40^b					
Week 6	43^b					
How good is the sow at nursing her piglets? [III] *(1=Very bad 7=Very good):*						
From farrowing until day 14 pp				6.2	5.8	0.001
From farrowing day 14 pp until weaning				5.9	5.9	0.993
How often does the sow show fear of you when you work around her? [III] *(1=Always, 7=Never):*						
From farrowing until day 14 pp				6.3	6.5	0.020
From farrowing day 14 pp until weaning				6.2	6.6	0.001
How often is the sow incautious around the piglets? [III] *(1=Always, 7=Never):*						
Farrowing until day 14 pp				6.0	5.5	0.001
What do you think of the sow's maternal ability? [III] *(1=Very bad, 7=Very good):*						
Farrowing until day 14 pp				6.0	5.8	0.027
Day 14 pp until weaning				5.9	5.8	0.368

[I] Paper I, Parities 1–4, The p value corresponds to the effect of the farrowing environment, values of the trait with different subscripts differ from each other ($p<0.05$)
[II] Paper II, Parities 1, The values marked with different superscripts within behaviour parameter differ from each other ($p<0.05$)
[III] Paper III, Parity 1–3, Answers on scale: 1------2------3------4------5------6------7

Correlations between repeated measurements of nursing frequency, nursing duration and percentage lying were estimated for first parity sows farrowing outdoors. The correlations were low or negative between day 4 pp and observations later in lactation, but high and positive between measurements from weeks 4 and 6 pp.

Herdsmen's judgements of sow behaviour in early and late lactation correlated positively with each other (Nursing behaviour: r = 0.3; Fear of human behaviour: r = 0.3; Maternal ability: 0.4) in both organic and conventional herds.

Relationship between nursing behaviour, sow activity and sow and litter performance (Paper II)

Sows that terminated a low proportion of nursings on day 4 tended to be fatter at 2 weeks pp. Sows spending a long time nursing and lying down a large proportion of the observation time during week 6 pp were heavier at weaning than sows lying less and with short nursings. Furthermore, sows that were fat at weaning had longer nursing duration on the observation day in week 6 pp. Back-fat thickness at weaning was thinner in sows terminating all nursings in week 6 pp than it was in sows terminating less than 100% of the nursings.

Sows with large litters gave longer nursings on day 4 pp and fewer nursings during weeks 4 and 6 pp. Litter size was not related to the percentage of nursings terminated by the sow. Piglet growth was not significantly different for different litter sizes; nor was it related to nursing frequency or nursing duration.

Good maternal ability according to herdsmen (Paper III)

Herdsmen's judgement scores of good maternal ability in early lactation correlated with good nursing behaviour and a low probability of squeezing or trampling piglets to death in both organic and conventional herds and in all 3 parities. In organic herds, as compared with conventional herds, the herdsmen's judgements of good maternal ability in early lactation were more strongly correlated with calm behaviour during farrowing, cautiousness among piglets, a low level of fear of humans, and lower piglet mortality.

Herdsmen's judgements of good maternal ability in late lactation were associated with good nursing behaviour and low piglet mortality in both organic and conventional herds. Moreover, a large and heavy litter at weaning was an important factor in the herdsmen's judgement of good maternal ability in both production systems. In organic herds, judgements of good maternal ability in late lactation correlated more strongly with mean piglet weight at weaning, high piglet growth and low sow fat status at weaning than they did in conventional herds.

GxE interaction for growth rate and carcass leanness in organic and conventional production environments (Paper IV)

Of the 2750 ear-tagged and tattooed piglets from the organic piglet-producing herds included in the study, 66% were identified at the slaughter line and included in the genetic evaluation. Based on the performance of the boars' offspring in organic herds, heritability (h^2) was estimated to be 0.30 and 0.36 for growth rate until 100 kg and back-fat thickness at 100 kg, respectively. The genetic correlation (r_g) between the two traits was estimated to be -0.11. Litter effect (c^2) was estimated to be 0.15 and 0.11 for growth rate and back-fat thickness, respectively.

Spearman rank correlations between organic and conventional breeding values for the 29 boars included in the re-ranking evaluation were 0.48 for growth rate and 0.42 for back-fat thickness. Both correlations differed significantly from 0 and 1.

Interviews with organic piglet producers

A short interview with the organic piglet producers was performed when the field study was finished. The interview suggested that the producers' expectation, when they started organic pig production, was that they would either simply continue with the established and profitable production they had taken over or increase profitability compared with their current conventional piglet production. The producers' concerns when they took on organic piglet production were about issues related to the keeping of pigs outdoors, such as heavy workload, poor pig health status and low production levels. After running organic pig production for some years they concluded that outdoor pig production worked better than their expectations during the summer period, and that the pigs' health was better than they had expected. However, they also found that getting pigs to defecate in the right places and keeping pigs outdoors during wet and cold periods was much harder than they had expected at the start of organic production. In one of the herds no substantial changes in production had been performed after converting to organic production. In the second herd, they had turned from integrated pig production to specialized piglet production to improve productivity. In the third herd, the owners had decided to quit organic pig production because it involved too much hard labour.

General discussion

The purpose of this thesis was to gain knowledge of pigs in organic production which can contribute to the development of suitable production systems and breeding strategies in organic pig production. Piglet production and sow behaviour were investigated in organic and conventional production environments in Papers I–III, and GxE interactions for growing/finishing pig growth and carcass leanness in organic and conventional production environments were investigated in Paper IV. In the following discussion the main results of papers I-III are first considered in detail; there follows a more general discussion of these results in relation to the principles of organic production. Then the results of papers IV are considered in detail, followed by a more general discussion of suitable breeding strategies for organic pig production.

Piglet production and sow behaviour

Piglet mortality

The probability of still-born piglets in the litter was lower when sows farrowed loose-housed outdoors in huts than it was when they farrowed loose-housed indoors in pens (Paper I), but it was higher for sows in organic herds than it was for sows in conventional herds (Paper III). Lack of oxygen is considered a main cause of still-birth (Herpin *et al.*, 2001) and piglet still-birth is associated with a slow parturition progress (Pedersen *et al.*, 2006). Thus the shorter farrowing duration observed by herdsmen when sows farrowed outdoors in the Paper I and the shorter approximate farrowing duration observed in conventional herds (p=0.09) in Paper III is one possible explanation of the lower still-birth frequency found outdoors as compared with indoors, and in conventional as compared with organic herds. We had assumed that the low frequency of still-born piglets reported from outdoor hut systems (Leufvén, 2004) might be due to still-born piglets becoming concealed in the straw, or in the corners of the hut, and thus not being recorded. However, the ratio between the number of still-born piglets observed on the videotapes and the number of still-born piglets recorded by the staff was the same outdoors as it was indoors. Thus still-born frequency really does seem to be lower when sows farrow outdoors. Factors contributing to the lower still-birth frequency require further investigation.

Piglet mortality was higher and the piglets died at a higher age in litters of sows in organic herds than in litters of sows in conventional herds (Paper III). This finding is in agreement with Hultén *et al.* (1997), who found late piglet mortality in litters of group-housed sows in conventional herds to be higher than it was in litters of single-housed sows. Piglets are less protected in group-housed lactation environments than they are in single-housed lactation environments. Sows can walk away from their piglets and avoid nursing, and other sows can harm the piglet in the group-housed environment. In the farrowing pen piglets are protected from crushing by the sow by bars and have constant access to the sow and to a heat lamp. Neither EU nor KRAV regulations for organic production state that sows should be group-housed during the later part of lactation (KRAV, 2008; EC, 2007b). However, this is common practice in Swedish organic pig production and also accords with the organic principles, since this resembles the natural social grouping for sows and piglets. Piglet mortality was higher in the organic herd where sows and piglets were kept outdoors in huts than in any of the other herds (both organic and conventional). This finding is possibly explained by the harsher environment, e.g. more extreme temperatures, for the piglets in the hut compared with the pen.

The most frequent cause of piglet mortality according to herdsmen's judgement was that the piglet was squeezed or trampled to death by the sow; this was the case both when loose-housed sows farrowed outdoors in huts and indoors in pens (Paper I), this was seen and in organic as well as in conventional herds (Paper III). Thus sow behaviour after farrowing is important for piglet survival. This emphasizes the importance of keeping sows with suitable behaviour in loose-housing lactation environments. Moreover, when analyzing production data from all 4 parities of the sows in the Research station study, we found that high sow weight and back-fat loss during lactation is related to low piglet mortality in both the indoor and the outdoor environment (Wallenbeck & Rydhmer, 2008). This relationship accords with earlier findings in indoor farrowing pens (Grandinson *et al.*, 2005; Valros *et al.*, 2003) and underlines the importance of the sows' ability to produce much milk.

High still-birth frequency and high piglet mortality are not only unethical but also lead to low productivity and low economic profitability. As a consequence, efforts to reduce piglet mortality trough suitable housing, management and breeding are important in both organic and conventional piglet production.

Piglet growth

Sows in organic herds gave birth to heavier piglets and litters than sows in conventional herds. There was no difference in sow fat score at farrowing between sows in organic and conventional herds; thus the heavier piglets and litters in organic herds are probably not effects of sow energy intake during gestation (Paper III). However, there are indications that the feed level, fat and energy content of the sow's diet during gestation can affect foetus growth (Whittemore, 1998). Another possible explanation of the higher foetus growth in sows from organic herds can be found in the outdoor gestation environment. The relationship between gestation environment and foetus growth needs to be confirmed in further studies, and the relevant causal factors need to be identified.

Sow feed consumption in early lactation was correlated with piglet growth from birth until weaning (Paper II). This emphasizes the importance of good sow appetite during lactation. Sow feed consumption over the first 14 days pp was estimated at 65% of the recommended feed intake. Accordingly, Heyer *et al.* (2005) found low feed intake during the first 10 days pp (76% of the recommended feed intake) in Yorkshire x Landrace primiparous gilts farrowing outdoors. This low feed consumption might be because the sows had to leave the hut and their piglets to get to the feed trough. Alternatively it might be because the sows had enough body reserves at farrowing, and thus had low motivation for feed intake during early lactation.

Sows in organic herds weaned approximately 100 kg more piglet per year than sows in conventional herds, as a result of the longer nursing period in organic herds. However, sow body condition at weaning did not differ between organic and conventional herds (Paper III), indicating that sows did not use their body reserves to feed piglets during the longer nursing period. During lactation sows must handle a parent-offspring conflict. Each sow has to prioritize among her own needs, her present litter's and her future litters' needs (Manning & Stamp-Dawkins, 1998). Sows need enough energy reserves for the next litter, but they also have to produce and provide enough milk for the current litter to survive until the piglets have changed to solid feed. These trade-offs are affected by both litter size and lactation environment. Sows with large litters lose more weight and fat during lactation than sows with small litters (Wülbers-Mindermann *et al.*, 2002). When analyzing production data from all four parities of the sows in the Research station study we found that the relationship between litter size and sow back-fat loss was stronger in outdoor lactation environments than it was in indoors (Wallenbeck & Rydhmer, 2008). Moreover, in these analyses we found that the outdoor environment stimulates sows to mobilize energy reserves to produce milk to a greater extent than the indoor environment does. This result accords with earlier findings by Wulbers-Mindermann *et al.* (2002). However, in the field study we observed that the sows from organic herds were not thinner at weaning than sows in conventional herds, and that the body condition at weaning was quite good for sows in both production systems (Paper III). Bøe (1991) found that piglets' solid feed intake increases considerably from week 3 until week 6 of a 10 week lactation, and that piglets' solid feed intake is important for the weaning process. Thus the sows included in Paper III did probably not produce milk for 100 kg extra piglet per year, but rather had piglets that developed a strong appetite for, and good ability to utilize, solid feed. One of the motives for the longer nursing period in organic production is that the nursing provides the piglets with a substantial feed. However, a large proportion of the piglets' energy intake appears not to come from sow milk during the later stages of the 7-week lactation. The gradual weaning process over this long nursing period provides a gradual change from milk to solid feed, and this seems to be favourable for piglet growth after weaning (Eriksson, 2006). Perhaps the sow's ability to stimulate her piglets to change to solid feed is an important maternal trait in organic piglet production. However, according to herdsmen in organic herds, good maternal ability includes the sow's ability to use her body reserves during lactation and they praised sows with low body-fat score at weaning. Thus herdsmen want their sows to produce and provide milk for their piglets throughout lactation in the group-housing system. Piglets' solid feed intake and their change from milk to solid feed would be interesting to investigate in group-housed and outdoor lactation environments.

Oestrus during lactation

Lactational oestrus was observed among sows in all three organic herds but not among sows in any of the three conventional herds, and the frequency of lactational oestrus increased with parity (Paper III). Oestrus during lactation is a common phenomenon in production systems where sows are group-housed during lactation. As mentioned earlier, no organic regulations state that sows should be group-housed during the latter stages of lactation. Nevertheless, this is the common practice in Swedish organic pig production, and it resembles the natural social grouping for sows and piglets during lactation. Lactational oestrus often leads to logistical problems in the batch wise production system if sows do not come into oestrus within the first week after weaning as desired (Hultén *et al.*, 2006; Hultén *et al.*, 1995). However, in Paper III there was no apparent difference in the frequency of repeated mating, or in weaning to first insemination interval, between sows showing and sows not showing oestrus during lactation. A possible reason for this is that approximately 40% of the sows that showed oestrus did so in week 5 of lactation; these sows probably came into oestrus again 3 weeks later, i.e. during the first week after weaning, when herdsmen want the sow to come into oestrus. When lactational ovulation was investigated among the sows involved in the Research station study of this thesis (Hultén *et al.*, 2006), it was found that sows ovulated during lactation in 47% of lactations (parities 1–4) and that only half of these ovulations were accompanied by oestrous signs detected by the herdsmen. Thus the actual proportion of sows ovulating during lactation was probably higher than the proportion of sows herdsmen reported as showing oestrous symptoms in Paper III. In Paper III we found that the frequency of lactational oestrus increased with parity, which is in accordance with the increased frequency of lactational ovulation found among the sows in the Research station study over parities (Hultén *et al.*, 2006). In that study we also found that the ovulation frequency was higher during winter and spring than it was during summer and autumn, and that the majority of the sows ovulating during lactation did so during weeks 6 and 7 of lactation. Moreover we found that ovulation during lactation was associated with short nursings, a low number of piglets suckling, rapid piglet growth, and high litter weight, and that the weaning-to-ovulation interval was delayed when sows had ovulated during lactation (Hultén *et al.*, 2006).

Sows in organic herds showing oestrus during lactation were significantly fatter at weaning than those not doing so (Paper III). Hultén *et al.* (1995) found that group-housed sows gained back-fat thickness during lactation while single-housed sows lost back-fat thickness, and that the frequency of lactational ovulation was much higher among group-housed sows. However, they did not find the direct relation, observed in the present study, between oestrus during lactation and sow fatness. Our finding indicates that, in the organic production environment, where sows are group-housed and have the opportunity to control nursing by walking away from the piglets, and when sows have more energy resources than are needed by the current litter, sows can prioritize the next litter and thus come into oestrus. The relationship between fat sow body conditions and ovulation during lactation in group-housing lactation environments requires further investigation.

Sow nest-building behaviour

There was no difference in herdsmen's judgement of sow nest-building behaviour between organic and conventional herds, and herdsmen did not consider much nest-building to be important for maternal ability (Paper III). However, the herdsmen observed sows performing nest-building behaviour before farrowing in both production systems. All sows in the conventional herds, and the majority of the sows in the organic herds, farrowed in the same type of pens, thus no difference in nest-building behaviour were expected. In one of the organic herds sows farrowed outdoors in huts, and herdsmen's judgements indicate that these sows performed a lower frequency of nest-building than the indoor, penned sows in the other two organic herds. However, the results of Paper I show that sows start their nest-building activities earlier, and perform a higher frequency of nest-building, when they farrow outdoors in huts than they do when they farrow indoors in pens. Moreover, sows spent less time in upright posture over the last 9 hours before farrowing when they farrowed outdoors in huts than they were when they farrowed indoors in pens. Nest-building behaviour was investigated through videotape recordings in Paper I and by herdsmen's observations during routine management in Paper III. If the herdsmen attending to the organic herd, where sows farrowed in huts, observed the sows during the last few hours before farrowing start, this result in Paper III is in agreement with that of Paper I. But the Paper III result could also be sensitive to the difficulty of observing sows' behaviour inside the hut.

The results of Paper I show that sows perform a high frequency of nest-building behaviour during the period 12–7 hours before farrowing start when they farrow outdoors in huts. This accords with earlier reports of peaks in nest-building behaviour about 12–6 hours before farrowing onset in both loose-house pens (Castrén *et al.*, 1993) and more extensive loose-house get-away pens (Thodberg *et al.*, 1999). However, the increase in nest-building frequency before farrowing appeared to occur later when sows farrowed indoors. A difference between the loose-housed outdoor and indoor farrowing environments in respect of nest-building behaviour was expected, since differences in nest-building performance have been reported between other farrowing environments. Damm *et al.* (2003a) reported a higher frequency of nest-building behaviour when sows farrowed in the more extensive get-away Scmidth pen than in sows farrowing in the conventional crate. The difference in the sows' timing of nest-building activity observed between loose-housed sows farrowing outdoors and indoors in Paper I was probably caused by different environmental stimuli. The outdoor farrowing environment resembled pigs' natural farrowing environment to a greater extent than the indoor farrowing environment – specifically, the fact that the farrowing site separated the farrowing sow from other sows. Thus sows were more isolated from, and less disturbed by, other sows when they farrowed outdoors in huts and probably less stressed during their preparation before farrowing.

High piglet mortality following crushing by the sow has been found to be related to sow passivity and low nest-building frequencies before farrowing (Pedersen *et al.*, 2006; Andersen *et al.*, 2005). In Paper I we did not find such relationships, but we found relationships between sow behaviour before farrowing and during farrowing. When sows farrowed indoors in pens, much time in upright posture (standing or walking) 12–10 hours before farrowing was associated with calm sow behaviour (i.e. short periods in upright posture and low frequency of postural changes and nest-building) during farrowing. By contrast, much standing and walking during the last 3 hours before farrowing was associated with restless sow behaviour (i.e. a longer time spent in upright posture and high frequency of postural changes and nest-building) during farrowing. These relationships were not as strong when sows farrowed outdoors in huts. The farrowing environments investigated in Paper I probably offered the sows satisfactory opportunities to nest-build, which resulted in relatively low levels of stress during sows' preparation for farrowing. Thus the sow's behaviour before farrowing did not have a substantial impact on her tendency to crush piglets during and after farrowing. However, sows' behavioural need to perform nest-building behaviour seemed to be satisfied to a higher degree and sows seemed to be less stressed when they farrowed outdoors in huts than when they farrowed indoors, since the relationships between sow behaviour before and during farrowing was weaker when sows farrowed outdoors.

Sow farrowing behaviour

Sows were equally calm during farrowing when they farrowed loose-housed outdoor in huts as when they farrowed indoor in pens (Paper I). Herdsmen in both organic and conventional herds judged their sows to be calm during farrowing (Paper III). These observations suggest that sow farrowing behaviour is controlled mainly by internal factors in these loose-house farrowing environments, and that external factors have at most a minor impact on sow farrowing behaviour. However, farrowing duration was shorter when sows farrowed outdoors rather than indoors, and litter size had no significant effect on farrowing duration. A possible explanation for this is that the sows were less disturbed by the surrounding environment, and thus calmer and less stressed. Sows also had more opportunity to exercise during the last few days before farrowing when they farrowed outdoors than they had when they farrowed indoors, and this may have influenced the progress of parturition (Paper I).

Farrowing durations, as judged by herdsmen, were longer in organic than conventional herds (Paper III). Since the majority of the sows in both organic and conventional herds farrowed in pens, and since the judgement of farrowing duration made by herdsmen who were probably guided in part by litter size, it is difficult to relate the result reported in Paper III to the result reported in Paper I. Jarvis *et al.* (2004) investigated farrowing duration in sows farrowing loose-housed in pens and confined in crates. They found no difference in farrowing duration between these two farrowing environments, but they did establish that the provision of straw prolonged farrowing in both pens and crates. They offered no explanation of this finding, but their results in combination with ours indicate that farrowing environment does affect the progress of parturition. Overall these findings need to be confirmed in further studies. Factors in the environment potentially affecting parturition progress need to be investigated and identified.

We found that active sow behaviour during farrowing was associated with high piglet mortality when sows farrowed loose-housed outdoors in huts, but not when sows farrowed loose-housed indoors in pens (Paper I). The difference between farrowing environments in this relationship between sow behaviour during farrowing and early piglet mortality was probably caused by differences in the environment and differences in the herdsmen's management. In the indoor farrowing environment, the temperature was more stable, the piglets had access to a heating lamp, there were bars to prevent piglets from being crushed, and herdsmen supervised the piglets more frequently than they did in the outdoor farrowing environment. Thus piglets may have had more chance of surviving careless sow behaviour in the indoor farrowing environment. The herdsmen's judgements of sow behaviour presented in Paper III show that herdsman in both organic and conventional herds associate calm behaviour during farrowing with low frequencies of squeezing and trampling of piglets during farrowing. Thus herdsmen's perceptions of sow behaviour during farrowing seem to be in accordance with the association we found between sow farrowing behaviour and piglet mortality in the outdoor hut farrowing environment in Paper I.

In Paper I we found that calm sow behaviour during farrowing was associated with short duration from first piglet born until first teat in mouth, and that this association was stronger when sows farrowed outdoors compared with indoors. Likewise, short duration from first piglet born until first teat in mouth was correlated to low mortality outdoors, but not indoors. Thus calm sow behaviour during farrowing seems more important for piglets' colostrum intake and survival when sows farrowed outdoors. It has been reported that exposure to cold decreases piglets' colostrum intake (Le Dividich *et al.*, 2005). Lack of colostrum intake and the risk of being crushed by the sow are the primary causes of early piglet mortality (Whittemore, 1993).

Sow behaviour during lactation

Nursing frequency, nursing duration, and percentage lying, all decreased over lactation, and sows terminated a higher proportion of the nursings in late lactation than they did in early lactation (Paper II). This indicates an ongoing weaning process, as others have suggested (Valros *et al.*, 2002; Gustafsson *et al.*, 1999). Our finding is also in agreement with Hotzel *et al.*(2004), who reported that, in sows kept outdoors in individual paddocks with farrowing huts, the proportion of time sows spent with their litters reduced from 86% on day of farrowing to 30% just 2 weeks later. However, we found that sow nursing behaviour is repeatable within late lactation, during the group-housed period. Thus sow nursing behaviour is an individual character of the sow, as stated by Valros *et al.* (2002). In Paper II that sows with larger litters allowed less frequent nursings in late lactation. Cross-suckling, where a piglet suckles a sow other than its own mother, was observed, and it decreased over lactation. Cross-suckling can be either habitual or occasional. It is related to low milk production by the piglet's own mother and high milk production by the cross-suckled sow (Olsen *et al.*, 1998). Sows with high back-fat thickness at weaning were more willing to nurse than sows with low back-fat thickness. High nursing frequency (Valros *et al.*, 2002) and high sow weight loss (Valros *et al.*, 2003) have been reported to be associated with high piglet growth, and the sow's use of fat reserves during lactation is genetically associated with high piglet growth (Grandinson *et al.*, 2005). However, piglet growth was not significantly correlated with nursing frequency or nursing duration in Paper II. Bøe (1991), who reported that piglets' solid feed intake increased considerably from week 4 pp until weaning at 10 weeks, suggested that a piglet's solid feed intake is an important factor in the weaning process. Thus our results are likely to be explained by piglets' solid feed intake during weeks 2–7 pp in the group paddocks. Piglets' feed consumption was not recorded in Paper I, since in that situation piglets shared a trough with the sows. However, piglets were often seen at the feed trough during the behavioural observations at weeks 4 and 6 pp. The sow's willingness to nurse is associated with sow body condition and litter size. The ongoing weaning process through lactation is driven by the constant mother-offspring conflict and sows can control the allocation of resources by restricting nursing. In a nursing environment where several sows and their piglets are kept in groups, and where piglets have *ad libitum* access to feed, sows do restrict nursing when necessary, and piglets find feed elsewhere.

Herdsmen's judgement of sow maternal ability

According to the herdsmen's judgements of sow behaviour presented in Paper III, herdsmen working with organic herds, as compared with those working with conventional herds, gave higher scores to their sows across a range of traits, indicating that their sows had better nursing behaviour, were more cautious among their piglets and had better maternal ability in early lactation. Moreover, sows in organic herds were judged to show fear of the herdsman more frequently throughout lactation than sows in conventional herds. During late lactation, sows in organic herds have the opportunity to express a wider range of behaviours than sows in conventional herds (Hotzel *et al.*, 2004; Johnson *et al.*, 2001). This might explain some of the differences in herdsmen's judgement of sow behaviour. Another way to explain these contrasts would be to point to differences in the amount of information that herdsmen included in their judgements. The organic herds had fewer sows in production and a lactation period that was 2 weeks longer than that of the conventional herds. This meant that herdsmen in the organic herds spent more time managing, and thus observing each sow than their colleagues in conventional production.

Herdsmen in both organic and conventional herds scored most of their sows as good mothers. Herdsmen's judgement of good sow maternal ability was associated with low piglet mortality, good nursing behaviour and large and heavy litters at weaning in both organic and conventional herds. These findings are in line with the aim of profitable piglet production, common to all production systems. However, in the organic herds, herdsmen's judgements of good maternal ability also included calm behaviour during farrowing, cautiousness around piglets during the first 2 weeks pp and low fear of humans. Thus, in organic herds, a wider range of maternal traits seem to be important in herdsmen's judgements of sow maternal ability. On the other hand, also these traits are related to low piglet mortality and high piglet growth. In the same investigation (Paper III) herdsmen considered that sows judged to be calm during farrowing did, according to the herdsmen, less often squeeze or trample piglets during farrowing. However, no significant correlation was found between calm behaviour during farrowing and low piglet mortality. In Paper I, calm sow behaviour during farrowing was found to be important for piglet survival when sows farrowed outdoors in huts; and previous studies have shown that calm behaviour during farrowing (Jarvis *et al.*, 1999) and responsiveness to piglets (Wechsler & Hegglin, 1997) reduce the risk of crushing piglets, thereby reducing piglet mortality. Moreover, low levels of fear of humans are genetically related to low piglet mortality (Grandinson *et al.*, 2003). High levels of fat loss and weight loss during lactation are genetically related to high piglet growth and high piglet survival (Grandinson *et al.*, 2005). Herdsmen in organic herds consequently included high probability of sow fat loss during lactation, and low sow body condition score at weaning among the traits important for good maternal ability.

The repeatability of herdsmen's judgements of sows nursing behaviour, fear of human behaviour and maternal ability between early and late lactation found in both organic and conventional herds (Paper III) indicates that these traits are individual characteristics of the sows. These findings are in accordance with those reported by Vangen *et al.* (2005), who estimated heritabilities for herdsmen's judgement score of sow nursing behaviour (0.07–0.08), fear of humans (0.14–0.17) and maternal ability (0.02). The correlations between herdsmen's judgements of sow nursing behaviour and sow maternal ability in early and late lactation calculated in Paper III were stronger in conventional than organic herds. This is probably explained by the change in environment 2 weeks pp in organic herds, together with the fact that, in these herds, the interval between judgements was 2 weeks longer than in conventional herds.

Piglet production and sow behaviour in relation to the principles of organic animal husbandry

Conflicts and tradeoffs between different organic principles

According to IFOAM's general principles for organic production, organic animal husbandry should be based on natural living systems and cycles, a harmonious relationship between land, plants and livestock, and respect for physiological and behavioural needs of the animals (Table 1, page 13). Organic production should also apply a holistic approach, aiming for environmental, social and economical sustainability (IFOAM, 2005). Such a holistic approach leads to conflicts, and so requires tradeoffs, among the various principles and stakeholders involved in the practical conduct of organic farming (Padel *et al.*, 2004). Conflicts and tradeoffs are a natural consequence of the ambitious aims of organic production. They lead to a constant revision and development of organic production systems. The results of the studies included in this thesis highlight a few such conflicts. Some of the more important of these are: the sows' opportunity to perform sufficient nest-building behaviour *versus* the herdsmen's working conditions; and the chance for sows and piglets to live outdoors throughout lactation and in natural social groups *versus* piglet survival and production efficiency (piglet mortality and lactational ovulation).

Paper I shows that, compared with when they farrowed loose-housed indoors in pens, sows started their nest-building activities earlier, performed a higher frequency of nest-building behaviour, and were calmer when farrowing started when they farrowed in loose-housed outdoors in huts. Thus sows performed more, and more optimally timed, nest-building activity when they farrowed outdoors in huts. With regard to the aim of organic animal husbandry to fulfil sow's behavioural needs, outdoor huts would be preferable to indoor pens. However, the answers in the simple interview performed with organic piglet producers included in this thesis showed that these producers found that the most challenging part of organic piglet production was keeping pigs outdoors during cold and wet periods. Piglet production in outdoor huts is associated with a heavy workload for the herdsmen, and this is the main reason why this system has become less common in Swedish organic piglet production over the last decade (Alarik, 2009). Thus there is a conflict between the sows' ability to perform sufficient nest-building behaviour (animal welfare) and the herdsmen's working conditions (social and economic sustainability).

In Paper III, we found that piglet mortality was higher in organic than in conventional herds. Piglets' environment in the outdoor hut, e.g. extreme temperatures, and the group-housing lactation environment in the organic herds explain this difference. High piglet mortality leads to impaired piglet welfare and productivity in the production system, which should be weighed against pigs' possibility to live outdoors and in their natural social groups. As mentioned earlier, it is common in Swedish organic pig production to keep several lactating sows and their piglets together. This is in accordance with organic principles, since it resembles the natural social grouping of sows and piglets. In Paper III we found that piglets died at a higher age in organic herds than in conventional herds. High piglet mortality might not be in opposition to good animal welfare in organic production. One of the general principles of organic farming is to work with natural living systems and cycles. Considering the reproduction strategy of the pig, which is to give birth to many relatively small offspring, expecting only a few of them to grow up and reproduce themselves (Edwards, 2002; Jensen, 1993a), piglet mortality can indeed be considered a part of a natural cycle, and thus an acceptable phenomenon in organic production. On the other hand, according to the more conventional view of animal welfare, high piglet mortality is unethical and destructive of animal welfare. Consumers associate organic animal husbandry with improved animal welfare (Åkerfeldt, 2009), so consumers would probably reject organic pig meat if high piglet mortality was routine in this production system. One way to ensure consumers good animal welfare in organic animal husbandry is to apply output norms for organic products. One such output norm could involve a threshold value for piglet mortality level (percentage or frequency) above which the herd would not be certified as organic (Spoolder & Padel, 2008). Moreover, high piglet mortality results in decreased productivity and profitability which in the long run affects economic sustainability. Thus, there is a conflict between the sow's and her piglets' ability to live in what is, for them, natural social groups (sow and piglet welfare) and piglet survival (piglet welfare), and this is in turn associated with profitability (economic sustainability).

Lactational ovulation is a phenomenon occurring when sows are group-housed during lactation and it often leads to logistic problems in batchwise production. This is a recognized problem among organic piglet producers in Sweden. It leads to a conflict between the opportunity of the sows and piglets to live in a natural social group, on the one hand, and production efficiency and economic sustainability, on the other.

Animal welfare and animals' natural behaviour

Organic animal husbandry should encourage good animal health and welfare, as pointed out in several different contexts both in IFOAM's basic standards (IFOAM, 2005) and EU regulations on organic production (EC, 2007b). Animal welfare is often used in the marketing of organic animal products. The opportunity to perform natural behaviours is often used as a benchmark of good animal welfare, and one of the general principles of organic animal husbandry is that the ethological needs of the animals should be respected. This is stressed in IFOAM's basic principles and EU regulations governing organic production and is referred to as the animals' right to perform their natural behaviours. The definition of natural behaviour varies among scientists. During evolution, the pig developed a number of specific behaviours associated with the habitat they lived in and their reproductive strategy. Even after intensive breeding focusing on increased productivity in intensive production environments during the last century, domesticated pigs are negatively affected when their ability to perform certain behaviours is restricted. Examples of such behaviours include: sow isolation from the family group during farrowing, nest-building behaviour, nursing behaviour and the differentiated social behaviour of sows in their family groups (Hörning, 2006; Jensen, 1993a). According to Jensen & Toates (1993), such lists of animal behavioural needs are in many cases useless when comparing animal welfare in different production systems, since the behavioural needs will vary with an animal's situation, i.e. the environment the animal lives in and the experiences of the individual animal. The 'natural behaviour list' approach was used in many places in this thesis (Paper I, II, III). However, our results show the variation in sow behaviour over environments and over time. Segerdahl (2007) suggests that the concept of natural behaviour is not only biological concept, but also a philosophical tendency initiated by a moral reaction. He argues that this explains the feeling that natural behaviour is something "very-very-important-but-we-don't-know-exactly-what-it-is". He also argues that domesticated animals exist within a human/animal culture, and that natural behaviours in this context develop with the experience of the individual humans and animals within the culture. Segerdahl (2007) suggests that an animal's physiological welfare could be used as an indication of which behaviours should be considered natural in a specific physical and cultural environment rather than the other way around.

GxE interactions for growth rate and carcass leanness

The calculated correlations between organic and conventional breeding values for growth rate and carcass leanness in Paper IV were positive and significantly different from both 0 and 1. The positive correlations mean that boars ranked highly as regards their conventional breeding value are in many (but not all) cases also ranked highly as regards their organic breeding value. The significant difference from 1 indicates that GxE interactions exist for growth rate and carcass leanness in the organic and conventional production environments included in this study. However, the significant difference from 0 indicates that these interactions are weak. To our knowledge, no studies of GxE interaction in organic and conventional pig production environments based on estimated breeding values or genetic parameters for growing/finishing traits had been reported before Paper IV. Merks & Van Kemenade (1989) reported GxE interaction for carcass leanness, but not for growth rate in conventional nucleus and commercial herds. Werner *et al.* (2007) found GxE interactions for both growth rate and carcass leanness when comparing different breeds in organic and conventional environments, but they observed no re-ranking of breeds. The heritability of growth rate and back-fat thickness, at 0.30 and 0.36 respectively, and the favourable but weak genetic correlation (-0.11) between these traits estimated in the organic environment investigated in Paper IV is in line with previous reports for both crossbred and purebred animals in conventional environments (Zumbach *et al.*, 2007; Brandt & Taubert, 1998; Clutter & Brascamp, 1998).

Boelling *et al.* (2003) argue that if there are weak GxE interactions in organic and conventional production systems, it is possible to combine data from both systems and operate a shared breeding programme. However, if there are strong GxE interactions, information from one system would be of little value when applied to the other, and separate breeding programmes should be preferred. Thus, the results of Paper IV indicate that with regard to growth rate and carcass leanness, an organic breeding index based on conventional data using alternative economic weights is a feasible breeding strategy for organic pig producers.

Animal breeding in organic production

Animal breeding in organic production has received relatively little attention in the development of organic animal husbandry, and at present there are no generally accepted rules for organic animal breeding (Nauta & Roep, 2008). However, aims appropriate for organic animal breeding are included in IFOAM's general principles of organic production. According to these, animals in organic production should be born and raised on organic farms, not be the result of genetic engineering and be adapted to local conditions. Breeds should be selected for disease, parasite and infection resistance (IFOAM, 2005).

Traits important in organic production environments

Beside the traits described as important in IFOAM's general principles, longevity, vitality, fertility, high feed efficiency, foraging ability and temperament are suggested as important traits for animals in organic production (Hörning, 2006; Pryce *et al.*, 2004). Organic production should be economically sustainable, and thus production traits need to be included in breeding objectives also for organic animal production (Pryce *et al.*, 2004). Organic pig producers in Sweden consider strong legs and joints, good maternal abilities when sows are group-housed during lactation, and good meat quality to be very important traits in their production system (Alarik *et al.*, 2009).

Robust animals with the ability to adapt to a variety of environments are sought in organic production. There is environmental variation both within (e.g. between seasons) and between organic farms (Hirt *et al.*, 2001). The ability to perform equally well in several environments is called plasticity; it can be measured through, for example, reaction norms. A reaction norm describes the phenotype as a function of the environment. Normally the environment is described, or quantified, on a continuous scale (de Jong, 1995). Robust animals have flat reaction norms (Knap, 2005), thus one way to select robust animals is to estimate breeding values on the basis of the slope of the reaction norm.

The relative importance of traits in a breeding evaluation is traditionally determined by the economic return associated with the genetic gain for each trait. Hence different traits are valued differently in the final breeding index. However, in breeding programmes with ethical priorities the introduction of non-market values has been suggested (Olesen *et al.*, 2000). Gourdine *et al.*(2009) performed a simulation study of an outdoor dam line selected for improved welfare. Market values for production traits were combined with non-market values for traits that were important for welfare. They found that a breeding goal emphasizing high welfare (including leg conditions, piglet mortality and weaning-to-mating interval) could improve welfare without introducing any dramatic change in production traits. The rate of genetic progress in production traits did, however, decrease. Such non-market values, based on principles of organic production, could be used in combination with market values in organic breeding indices.

GxE interactions in organic and conventional production environments

Where a trait is partly influenced by different genes in different environments, GxE interactions occur. GxE interactions that result in re-ranking are of considerable economic importance to producers if the genetic evaluation is based on information from only one of the environments. If there are strong GxE interactions for organically important traits in organic and conventional production environments, genetic evaluation specifically for organic herds will be a suitable breeding strategy for organic producers. If no GxE interactions exist, or if they are weak, an organic breeding index provided from the conventional genetic evaluation but adapted to organic circumstances ought to provide a suitable breeding strategy for organic producers (Pryce *et al.*, 2004).

Few genetic studies have been made of GxE interaction in organic and conventional animal production environments. One reason for this is that a large quantity of observations and good genetic relationships between the environments is required in order to generate reliable estimates. Nauta *et al.* (2006) reported moderate GxE interactions for yield traits in organic and conventional dairy production environments. Kelly *et al.* (2007) found no significant GxE interactions when comparing a traditional breed, a modern breed, and a cross between the two, in outdoor and indoor organic environments. In a genetic analysis of piglet survival under outdoor conditions, Roehe *et al.* (2009) recently found that the direct genetic effect of the piglet accounted for a larger proportion of the variation than what has been reported for piglet survival under indoor conditions, indicating GxE interactions for piglet survival in outdoor and indoor production environments.

Choice of breeding strategies for organic pig production

At present the genetic flow into Swedish organic pig herds runs through the gilts recruited externally (10–20%), through AI-Landrace or -Yorkshire sires of the within-herd recruited gilts, and through AI- or serving-Hampshire or -Duroc boars (Figure 1, page 19). This breeding strategy ought to be the starting point in the development of future breeding strategies aiming towards the principles of organic farming.

The majority of replacement gilts in organic piglet production are produced within the herd in accordance with both EU and KRAV regulations. Thus one part of the selection for improved maternal ability is carried out by the herdsmen on the farm. In this process the replacement animals will tend to be well adapted to the local environment on the farm according to the general principles of organic farming (IFOAM, 2005). However, the genetic improvement of low heritability traits, such as piglet mortality, will always be low when genetic evaluation is based only on data from the own herd. When choosing sires for the replacement gilts, whether with AI or serving boars, the breeding values of the boars should complement the performance of the dam (and her relatives). Thus careful documentation of replacement gilt dams and investigation of replacement sires' breeding values for individual traits are essential to successfully improve maternal traits in the herd.

The current breeding strategy in organic pig production is in most cases to use the same genetic material as that used in conventional production. This strategy, which is in conflict with many of the principles of organic production, is probably not one that all farmers would regard as an option of first choice. However, animals in organic herds do need to be replaced, and the alternatives to the current breeding strategy are scarce. Thus the need to develop suitable organic breeding strategies is currently urgent. The development of such strategies will require better knowledge of biological and genetic aspects of organic livestock production environments and a debate about organic principles for animal breeding (Nauta & Roep, 2008). To determine whether the current breeding strategy for organic pig production is sound, two factors needs to be investigated: first, whether the same traits are important in organic and conventional production systems; and second, whether there are GxE interactions for these traits in organic and conventional production environments (Boelling *et al.*, 2003). The data collection performed in the studies presented in Papers III and IV shows that the data needed for genetic evaluation in organic production environments can be registered in organic herds and at slaughter plants.

The results of Paper III show that whether they worked with organic or conventional piglet-producing herds, herdsmen praised sows weaning large and heavy litters with low piglet mortality which suggests that the same maternal traits are important in both production systems. Moreover, herdsmen in organic herds scored their sows as having good maternal ability, and thus organic herdsmen appear to be satisfied with the maternal breeds they use at present. However, housing, feeding and management are approached differently in organic and conventional production systems, and therefore the GxE interactions for these traits in organic and conventional production environments need to be investigated. In Paper IV we reported weak GxE interactions for growth rate and carcass leanness in organic and conventional pig production environments, indicating that, with regard to these two traits, an organic breeding index based on the existing conventional breeding evaluation may represent a suitable breeding strategy for the organic pig production system most commonly practiced in Sweden.

Conclusions

- Sows are stimulated to start nest-building activities earlier relative to farrowing start and perform a higher frequency of nest-building behaviour when they farrow loose-housed outdoors in huts than when they farrow loose-housed indoors in pens.
- Farrowing duration is shorter and still-birth frequency lower when sows farrow loose-housed outdoors in huts than when they farrow loose-housed indoors in pens.
- When sows and their piglets are group-housed outdoors during lactation, the natural weaning process is already well developed when separating the sow and her piglets. This weaning process is associated with the sow's body condition and the number of nursing piglets.
- Oestrus during lactation occurs among group-housed sows in organic but not among single-housed sows in conventional piglet production environments and is associated with fat sow body conditions.
- Herdsmen in both organic and conventional production environments praise sows with good nursing behaviour that wean large and heavy litters with low piglet mortality.
- There are weak GxE interactions for growth rate and carcass leanness in organic and conventional pig production environments, indicating that, with regard to these traits, an organic breeding index based on the existing conventional breeding evaluation is feasible.

Recommendations to organic piglet producers

- To reduce the occurrence of lactational oestrus in group-housing systems, avoid obese sows by restricting sow feeding during lactation in accordance with sows' body condition.
- Continue the development of housing, management and feeding systems that improve piglet survival during the whole lactation, both when sows are single-housed and when they are group-housed.
- Select sows with good maternal ability during both early lactation (single-housed) and during late lactation (group-housed) as mothers (dams) for the replacement gilts. Base the selection on careful documentation of sow performance and behaviour during the different stages of lactation.
- Select fathers (sires) for the replacement gilts on the basis of their breeding values for specific traits complementary to the dam's traits.
- Choose sires for the growing/finishing pigs according to their breeding values for the specific traits important in your herd (e.g. EBV for leg conditions) and not the overall index.

Future research

Future research into organic pig production should contribute to the sustainable development of this production. Ideally it will adopt a systemic approach. Interdisciplinary research should include, and link, several aspects of organic pig production together. Examples of such aspects are pig biology and the function of pig production in the agro-eco system and in the society.

Research focusing on organic piglet production should specifically examine:

- Environmental and nutritional factors during lactation affecting piglet mortality.
- The relationship between sow body condition and lactational oestrus and further develop feeding norms for sows during lactation and gestation.

Research focusing on pig breeding in organic production should specifically examine:

- Stakeholder (e.g. herdsman and consumer) perceptions as to which traits are important in organic production.
- GxE interactions for traits of importance in organic production, including leg and joint problems, disease resistance, meat quality and maternal traits.
- Methods for selection for disease, parasite and infection resistance in accordance with IFOAM's general principles (2005).

Svensk sammanfattning

Bakgrund

Intresset för ekologisk produktion har under de senaste åren ökat hos såväl konsumenter och politiker som lantbrukare. Ekologisk produktion strävar mot en uthållig, säker och miljövänlig matproduktion. Dessutom är god djurvälfärd och goda arbetsförhållanden viktiga mål. Grisarnas miljö skiljer sig delvis mellan ekologisk och konventionell produktion. De grisar som används i ekologisk produktion är i de flesta fall av samma avelsmaterial som de som används i konventionell produktion. Dessa djur är avlade för hög produktion i konventionella produktionsmiljöer. Passar sådana grisar i ekologisk produktion?

Utvecklingen av produktionssystem och avelsstrategier i enlighet med principerna för ekologisk produktion kräver ökad kunskap om hur grisar fungerar i ekologiska produktionssystem.

Sammanfattning av studierna

Vi studerade suggors beteende och smågrisproduktion i kommersiella ekologiska och konventionella smågrisbesättningar samt i SLU:s försöksbesättning på Funbo-Lövsta. Djurskötarna i tre ekologiska och tre konventionella smågrisbesättningar samlade information om totalt 144 suggor och deras tre första kullar. I försöksbesättningen studerade vi 40 suggor och deras fyra första kullar när suggorna hölls i en ekologisk utomhusmiljö under vår och sommar och i en ekologisk inomhusmiljö under höst och vinter. Suggorna i de ekologiska smågrisbesättningarna och suggorna i försöksbesättningen grisade i individuella grisningsboxar eller i individuella grisningshyddor. Från två veckor efter grisning fram till avvänjning hölls suggor och smågrisar i familjegrupper i storboxar inomhus eller i hagar med hyddor utomhus i de ekologiska besättningarna och i försöksbesättningen. I de konventionella smågrisbesättningarna hölls suggor och smågrisar i individuella grisningsboxar från grisning till avvänjning. Skötarna i de kommersiella smågrisbesättningarna registrerade kullstorlek, smågrisdödlighet och smågrisvikt samt bedömde suggornas hull och deras beteende under digivningsperioden. I försöksbesättningen samlade vi in samma information om suggan och kullen som i de kommersiella besättningarna, men mer detaljerat och suggornas beteende filmades under grisning och under dag 4 efter grisningen. Dessutom gjordes direktobservationer av suggans digivningsbeteende i familjegrupperna under den senare delen av digivningsperioden.

Resultaten visar att suggorna utförde mer bobyggnadsbeteende och påbörjade bobyggnadsaktiviteten tidigare när de grisade ute i hydda jämfört med när de grisade inne i box. Grisningen gick snabbare och förekomsten av dödfödda smågrisar var lägre när suggorna grisade ute i hydda jämfört med inne i box. När flera suggor och deras smågrisar hölls i grupp under digivningsperioden var suggornas och smågrisarnas avvänjningsprocess redan långt gången när skötaren separerade suggorna från smågrisarna ungefär 7 veckor efter grisning. Våra resultat visar att avvänjningsprocessen påskyndas av lägre hullstatus och större antal diande smågrisar.

Vi fann att smågrisdödligheten var högre i de ekologiska jämfört med de konventionella besättningarna. Brunst under digivningsperioden (dibrunst) förekom i ekologiska men inte i konventionella besättningar. Suggor som visade dibrunst var fetare vid avvänjning än de suggor som inte visade dibrunst.

Skötarna i både de ekologiska och de konventionella besättningarna ansåg att bra suggor karakterisera av bra digivningsbeteende och att de avvänjer stora och tunga kullar med låg smågrisdödlighet. Det visar att samma modersegenskaper är viktiga i båda produktionssystemen. Vi fann genotyp-miljösamspel för slaktgrisens tillväxt och köttighet i ekologisk och konventionell produktionsmiljö. Det innebär att dessa egenskaper delvis styrs av olika gener i de här två produktionsmiljöerna. Samspelet var dock svagt, vilket betyder att man kan använda det konventionella djurmaterialet även i den ekologiska produktionsmiljön, vad gäller egenskaperna tillväxt och köttighet.

Rekommendationer till ekologiska grisproducenter

- Förekomsten av brunst under digivningsperioden kan reduceras genom att undvika att suggorna blir för feta, t.ex. genom restriktiv utfodring av suggorna.
- Arbeta för låg smågrisdödlighet både tidigt (box/hydda) och sent (gruppbox/hage) under digivningsperioden i den fortsatta utvecklingen av inhysningssystem och skötselrutiner.
- Välj suggor med goda modersegenskaper under hela digivningsperioden (både i grisningsbox/hydda och i gruppbox/hage) som mödrar till rekryteringsgyltorna.
- Välj fäder till rekryteringsgyltorna med avelsvärden för specifika egenskaper som kompletterar mödrarnas förmågor.
- Välj fäder till slaktgrisarna baserat på deras avelsvärden för specifika egenskaper som är viktiga i din besättning, t.ex. högt avelsvärde för friska ben och leder.

References

Akos, K. & Bilkei, G. (2004). Comparison of the reproductive performance of sows kept outdoors in Croatia with that of sows kept indoors. *Livestock Production Science* 85(2-3), 293-298.

Alarik, M. (2009). Egen försäljning värdefullt. *Svensk Gris med Knorr* 1, 45.

Alarik, M., Arvidsson, C.J., Schörling, T.M., Karlsson, A., Engvall, A.M., Edsgård, B.P., Fransson, K., Dahlgren, D., Ekman, G.G., Anderson, C.A., Lundqvist, M., Ottosson, A., Davidsson, M. & Kinner, L. (2009). *Riskerna väger tyngre menar utvecklingsgruppen Ekogris öst - Uttalande angående import av avelsdjur och sperma från Danmark* [online]. (http://www.svenskgris.se/?p=20062). [Accessed 13 April].

Andersen, I.L., Berg, S. & Bøe, K.E. (2005). Crushing of piglets by the mother sow (Sus scrofa) - purely accidental or a poor mother? *Applied Animal Behaviour Science* 93(3-4), 229-243.

Balfour, E.B. (1943). *The living soil. Evidence of the importance to human health of soil vitality with special reference to post-war planning*. London : Faber and Faber, 24, Russell Square, W.C.I.

Boelling, D., Groen, A.F., Sorensen, P., Madsen, P. & Jensen, J. (2003). Genetic improvement of livestock for organic farming systems. *Livestock Production Science* 80(1-2), 79-88.

Brandt, H. & Taubert, H. (1998). Parameter estimates for purebred and crossbred performances in pigs. *Journal of Animal Breeding and Genetics-Zeitschrift Fur Tierzuchtung Und Zuchtungsbiologie* 115(2), 97-104.

Bøe, K. (1991). The process of weaning in pigs: when the sow decides. *Applied Animal Behaviour Science* 30(1-2), 47-59.

Castrén, H., Algers, B., de Passille, A.M., Rushen, J. & Uvnas-Moberg, K. (1993). Preparturient variation in progesterone, prolactin, oxytocin and somatostatin in relation to nest building in sows. *Applied Animal Behaviour Science* 38(2), 91-102.

Clutter, A.C. & Brascamp, E.W. (1998). Genetics of Performance Traits. In: Rothschild, M.F.*, et al.* (Eds.) *The Genetics of the Pig*. Cambridge: CAB International. pp. 427-462.

Damm, B.I., Lisborg, L., Vestergaard, K.S. & Vanicek, J. (2003a). Nest-building, behavioural disturbances and heart rate in farrowing sows kept in crates and Schmid pens. *Livestock Production Science* 80(3), 175-187.

Damm, B.I., Pedersen, L.J., Jessen, L.B., Thamsborg, S.M., Mejer, H. & Ersboll, A.K. (2003b). The gradual weaning process in outdoor sows and piglets in relation to nematode infections. *Applied Animal Behaviour Science* 82(2), 101-120.
de Jong, G. (1995). Phenotypic placticity as a product of selection in a variable environment. *American Naturalist* 145(4), 493-512.
Dominik, S. & Kinghorn, B.P. (2008). Neglecting genotype x environment interaction results in biased predictions from selection index calculations. *Livestock Science* In Press
EC (2007a). The Common Agricultural Policy explained
EC (2007b). European Communities Council Regulation (EC) No 834/2007 of 28 June 2007 on organic production and labelling of organic products and repealing Regulation (EEC) No 2092/91. *Official Journal of the European Union* 20.7.2007
Edwards, S.A. (2002). Perinatal mortality in the pig: environmental or physiological solutions? *Livestock Production Science* 78(1), 3-12.
Engblom, L., Lundeheim, N., Dalin, A.M. & Andersson, K. (2007). Sow removal in Swedish commercial herds. *Livestock Science* 106(1), 76-86.
Eriksson, M. (2006). Behavior and growth of piglets weaned at 5 and 7 weeks of age in an organic environment. *Master Thesis, Department of Animal Breeding and Genetics Swedish University of Agricultural Sciences*, 35.
Gourdine, J.-L., De Greef, K. & Rydhmer, L. (2009). Breeding for high welfare in outdoor pig production - a simulation study. *Annual Meeting of the European Association for Animal Production, Book of Abstracts*
Grandinson, K., Rydhmer, L., Strandberg, E. & Solanes, F.X. (2005). Genetic analysis of body condition in the sow during lactation, and its relation to piglet survival and growth. *Animal Science* 80, 33-40.
Grandinson, K., Rydhmer, L., Strandberg, E. & Thodberg, K. (2003). Genetic analysis of on-farm tests of maternal behaviour in sows. *Livestock Production Science* 83(2-3), 141-151.
Gustafsson, M., Jensen, P., de Jonge, F.H., Illmann, G. & Spinka, M. (1999). Maternal behaviour of domestic sows and crosses between domestic sows and wild boar. *Applied Animal Behaviour Science* 65(1), 29-42.
Hellbrugge, B., Tolle, K.H., Bennewitz, J., Henze, C., Presuhn, U. & Krieter, J. (2008). Genetic aspects regarding piglet losses and the maternal behaviour of sows. Part 1. Genetic analysis of piglet mortality and fertility traits in pigs. *Animal* 2(9), 1273-1280.
Herpin, P., Hulin, J.C., Le Dividich, J. & Fillaut, M. (2001). Effect of oxygen inhalation at birth on the reduction of early postnatal mortality in pigs. *Journal of Animal Science* 79(1), 5-10.
Heyer, A., Andersson, K., Leufven, S., Rydhmer, L. & Lundström, K. (2005). The effects of breed cross on performance and meat quality of once-bred gilts in a seasonal outdoor rearing system. *Archiv Fur Tierzucht-Archives of Animal Breeding* 48(4), 359-371.
Hirt, H., Bestmann, M., Nauta, W.J., Phillips, L. & Spoolder, H. (2001). Breeding for health and welfare. *the 4th NAHWOA Workshop*, 114-119.

Holm, B., Bakken, M., Klemetsdal, G. & Vangen, O. (2004). Genetic correlations between reproduction and production traits in swine. *Journal of Animal Science* 82(12), 3458-3464.

Hotzel, M.J., Pinheiro Machado, L.C., Wolf, F.M. & Costa, O.A.D. (2004). Behaviour of sows and piglets reared in intensive outdoor or indoor systems. *Applied Animal Behaviour Science* 86(1-2), 27-39.

Hultén, F., Dalin, A.-M., Lundeheim, N. & Einarsson, S. (1995). Ovulation frequency among sows group-housed during late lactation *Animal Reproduction Science* 39(3), 223-233.

Hultén, F., Lundeheim, N., Dalin, A.-M. & Einarsson, S. (1997). Pre- and post-weaning piglet performance, sow food intake and change in backfat thickness in a group-housing system for lactating sows. *Acta Veterinaria Scandinavica* 38(1), 119-133.

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

Hörning, B. (2006). Organic livestock husbandry and breeding. In: Kristiansen, P., Taji, A., Reganold, J (Ed.) *Organic Agriculture - A Global Perspective*. Ithaca, New York: Comstock Publishing Associates. pp. 151 - 163.

Høøk Presto, M. (2008). Organic pig meat production. *Acta Universitatis agriculturae Sueciae*. Uppsala: Deptartment of Animal Nutrition and Management, Faculty of Veterinary Medicine and Animal Science.

IFOAM (2005). The IFOAM basic standards for organic production and processing. International Federation of Organic Agriculture Movements.

Jarvis, S., McLean, K.A., Calvert, S.K., Deans, L.A., Chirnside, J. & Lawrence, A.B. (1999). The responsiveness of sows to their piglets in relation to the length of parturition and the involvement of endogenous opioids. *Applied Animal Behaviour Science* 63(3), 195-207.

Jarvis, S., Reed, B.T., Lawrence, A.B., Calvert, S.K. & Stevenson, J. (2004). Perinatal environmental effects on maternal behaviour, pituitary and adrenal activation, and the progress of parturition in the primiparous sow. *Animal Welfare* 13(2), 171-181.

Jensen, P. (1989). Nest site choice and nest building of free-ranging domestic pigs due to farrow. *Applied Animal Behaviour Science* 22(1), 13-21.

Jensen, P. (1993a). *Djurens beteende och orsakerna till det*. Falköping: LTs förlag.

Jensen, P. (1993b). Nest building in domestic sows: the role of external stimuli. *Animal Behaviour* 45(2), 351-358.

Jensen, P. & Toates, F.M. (1993). Who needs behavioural needs? Motivational aspects of the needs of animals. *Applied Animal Behaviour Science* 37(2), 161-181.

Jensen, P., Vestergaard, K. & Algers, B. (1993). Nestbuilding in free-ranging domestic sows. *Applied Animal Behaviour Science* 38(3-4), 245-255.

Johnson, A.K., Morrow-Tesch, J.L. & McGlone, J.J. (2001). Behavior and performance of lactating sows and piglets reared indoors or outdoors. *Journal of Animal Science* 79(10), 2571-2579.

Kelly, H.R., Browning, H.M., Day, J.E.L., Martins, A., Pearce, G.P., Stopes, C. & Edwards, S.A. (2007). Effect of breed type, housing and feeding system on performance of growing pigs managed under organic conditions. *Journal of the Science of Food and Agriculture* 87(15), 2794-2800.

Knap, P.W. (2005). Breeding robust pigs. *Australian Journal of Experimental Agriculture* 45(7-8), 763-773.

Knol, E.F., Leenhouwers, J.I. & van der Lende, T. (2002). Genetic aspects of piglet survival. *Livestock Production Science* 78(1), 47-55.

KRAV (2005). *Regler för KRAV-godkänd produktion*. www.krav.se/regler.

KRAV (2008). *Regler för KRAV-godkänd produktion*. Available from: www.krav.se/regler

Lantmännen (1995). Maximera Mera! *Lantmännens nya MaximeraMera-system för suggor*

Le Dividich, J., Rooke, J.A. & Herpin, P. (2005). Nutritional and immunological importance of colostrum for the new-born pig. *Journal of Agricultural Science* 143, 469-485.

Leufvén, S. (2004). *Säsongsanpassad smågrisproduktion*. Diss. Swedish university of agricultural sciencis. Uppsala.

Liljenstolpe, C. (2008). Consumer valuation studies and structural modelling of the pig industry: a focus on animal welfare. . *Acta Universitatis agriculturae Sueciae*

Manning, A. & Stamp-Dawkins, M. (1998). *Animal behaviour*. Cambridge Cambridge University Press.

Merks, J.W.M. & Van Kemenade, P.G.M. (1989). Genotype x environment interactions in pig breeding programmes. V. Genetic parameters and sire x herd interaction in commercial fattening. *Livestock Production Science* 22(1), 99-109.

Nauta, W.J. & Roep, D. (2008). Principles and practicality of organic dairy cattle breeding: different options and implications. *Cultivating the future based on science. Proceedings of the Second Scientific Conference of the International Society of Organic Reserch, held at the 16th IFOAM Organic World Congress*

Nauta, W.J., Veerkamp, R.F., Brascamp, E.W. & Bovenhuis, H. (2006). Genotype by environment interaction for milk production traits between organic and conventional dairy cattle production in the Netherlands. *Journal of Dairy Science* 89(7), 2729-2737.

Olesen, I., Groen, A.F. & Gjerde, B. (2000). Definition of animal breeding goals for sustainable production systems. *Journal of Animal Science* 78(3), 570-582.

Olsen, A.N.W., Dybkjaer, L. & Vestergaard, K.S. (1998). Cross-suckling and associated behaviour in piglets and sows. *Applied Animal Behaviour Science* 61(1), 13-24.

Padel, S., Schmid, O. & Lund, V. (2004). Organic Livestock Standards. In: Vaast, M., Roderick, S., Lund, V., Lockeretz, W (Ed.) *Animal Health and Welfare in Organic Agriculture*. London: CAB International.

Pedersen, L.J., Damm, B.I., Marchant-Forde, J.N. & Jensen, K.H. (2003). Effects of feed-back from the nest on maternal responsiveness and postural changes in primiparous sows during the first 24 h after farrowing onset. *Applied Animal Behaviour Science* 83(2), 109-124.

Pedersen, L.J., Jorgensen, E., Heiskanen, T. & Damm, B.I. (2006). Early piglet mortality in loose-housed sows related to sow and piglet behaviour and to the progress of parturition. *Applied Animal Behaviour Science* 96(3-4), 215-232.

Pryce, J.E., Conington, J., Sørensen, P., Kelly, H.R.C. & Rydhmer, L. (2004). Breeding Strategies for Organic Livestock. In: Vaarst, M., Roderick, S., Lund, V. and

Lockeretz, W. (Ed.) *Animal Health and Welfare in Organic Agriculture*. Oxon: CABI Publiching. pp. 357 - 388.

Rauw, W.M., Kanis, E., Noordhuizen-Stassen, E.N. & Grommers, F.J. (1998). Undesirable side effects of selection for high production efficiency in farm animals: a review. *Livestock Production Science* 56(1), 15-33.

Roehe, R., Shrestha, N.P., Mekkawy, W., Baxter, E.M., Knap, P.W., Smurthwaite, K.M., Jarvis, S., Lawrence, A.B. & Edwards, S.A. (2009). Genetic analyses of piglet survival and individual birth weight on first generation data of a selection experiment for piglet survival under outdoor conditions. *Livestock Science* 121(2-3), 173-181.

Rydhmer, L. (2000). Genetics of sow reproduction, including puberty, oestrus, pregnancy, farrowing and lactation. *Livestock Production Science* 66(1), 1-12.

Segerdahl, P. (2007). Can natural behavior be cultivated? The farm as local human/animal culture. *Journal of Agricultural & Environmental Ethics* 20(2), 167-193.

Simonsson, A. (1994). Näringsrekommendationer och fodermedelstabeller till svin. In: *Swedish University of Agricultural Sciences Research Information Centre*. Uppsala:

Spoolder, H. & Padel, S. (2008). Performance of organic and low input livestock systems: a matter of sound design? *4th congress of the European project qualitylowinputfood*. Modena:

Steiner, R. (1929). Dornach: Selection for Natural Science of the Antrofiphofic Society. In: *Landwirtschaftlicher Kursus*.

Svensson, P., Botermans, J. & Olsson, A.-C. (2005). Technical solutions for the indoor housing of organic growing-finishing pigs -handbook-. *JBT Report 133*, 61.

Thodberg, K., Jensen, K.H. & Herskin, M.S. (2002). Nursing behaviour, postpartum activity and reactivity in sows: Effects of farrowing environment, previous experience and temperament. *Applied Animal Behaviour Science* 77(1), 53-76.

Thodberg, K., Jensen, K.H., Herskin, M.S. & Jørgensen, E. (1999). Influence of environmental stimuli on nest building and farrowing behaviour in domestic sows. *Applied Animal Behaviour Science* 63(2), 131-144.

Wallenbeck, A. & Rydhmer, L. (2008). Relationships between sow and piglet traits in organic production outdoors and indoors. *Cultivating the future based on science. Proceedings of the Second Scientific Conference of the International Society of Organic Reserch, held at the 16th IFOAM Organic World Congress*

Valros, A., Rundgren, M., Spinka, M., Saloniemi, H., Rydhmer, L., Hultén, F., Uvnas-Moberg, K., Tomanek, M., Krejci, P. & Algers, B. (2003). Metabolic state of the sow, nursing behaviour and milk production. *Livestock Production Science* 79(2-3), 155-167.

Valros, A.E., Rundgren, M., Spinka, M., Saloniemi, H., Rydhmer, L. & Algers, B. (2002). Nursing behaviour of sows during 5 weeks lactation and effects on piglet growth. *Applied Animal Behaviour Science* 76(2), 93-104.

Vangen, O., Holm, B., Valros, A., Lund, M.S. & Rydhmer, L. (2005). Genetic variation in sows' maternal behaviour, recorded under field conditions. *Livestock Production Science* 93(1), 63-71.

Watson, C.A., Walker, R.L. & Stockdale, E.A. (2008). Research in organic production systems - past, present and future. *Journal of Agricultural Science* 146, 1-19.

Wechsler, B. & Hegglin, D. (1997). Individual differences in the behaviour of sows at the nest-site and the crushing of piglets. *Applied Animal Behaviour Science* 51(1-2), 39-49.

Werner, D., Brade, W., Weismann, F. & Brandt, H. (2007). Performance and carcass quality of genetically different pigs under conventional and organic conditions. *Annual Meeting of the European Association for Animal Production, Book of Abstracts* 13, 277.

Whittemore, C. (1993). *The science and practice of pig production.* Essex UK: Longman Scientific and Technical.

Whittemore, C. (1998). Influence of pregnancy feeding on lactaion performance. In: Verstegen, M.W.A.*, et al.* (Eds.) *The Lactating Sow.* Wageningen: Wageningen Pers. pp. 350.

Wivstad, M., Milestad, R. och Lund, V. (2004). *Regelverk – möjligheter och hinder att uppnå målen för ekologiskt lantbruk.*

Wülbers-Mindermann, M., Algers, B., Berg, C., Lundeheim, N. & Sigvardsson, J. (2002). Primiparous and multiparous maternal ability in sows in relation to indoor and outdoor farrowing systems. *Livestock Production Science* 73(2-3), 285-297.

Zumbach, B., Misztal, I., Tsuruta, S., Holl, J., Herring, W. & Long, T. (2007). Genetic correlations between two strains of Durocs and crossbreds from differing production environments for slaughter traits. *Journal of Animal Science* 85(4), 901-908.

Åkerfeldt, Y. (2009). Vad förväntar sig konsumenterna och hur fungerear den ekologiska marknaden? *Svensk Gris med Knorr* 1, 36-37.

Acknowledgements

The work of this thesis was performed at the Department of Animal Breeding and Genetics, Swedish University of Agricultural Sciences (SLU). The project was funded by the Swedish Research Council for Environmental, Agricultural Sciences and Spatial Planning (Formas), the Department of Animal Breeding and Genetics at SLU, SLU:s financing of the Funbo-Lövsta Research station and SLU Ekoforsk. The Swedish Research School in Organic Farming and Food Systems (SwOFF) was financed by Formas. The SLU fund for internationalisation of postgraduate studies, Knut och Alice Wallenbergs jubileums fond, Sveriges Grisproducenters Forskningsstiftelse and SwOFF has provided travel grants for participation in conferences. Thank you for making my research and research education possible!

The years as a PhD-student have been a good period of my life. I have had fun from the start until the end, but naturally with periods of disbelief in myself and in the project. This has been a period of great personal development for me. What I have valued the most during these years are the people that I have worked with and the people who have shared these years with me. As most things in life, the performance of the studies included in my PhD project and the writing of this thesis have been a team effort and there are many people I want to thank.

My supervisors: Lotta Rydhmer (main supervisor), Nils Lundeheim, Gunnela Gustafsson and Fredrik Hultén. I want to thank all of you for supporting and encouraging me through the different stages of this PhD education. I also want to thank the group as a whole for all the stimulating and fun discussions helping me and the project forward.

Lotta Rydhmer (huvudhandledare, lärare och förebild) – Du såg mina starka och svaga sidor. Du hjälpte mig att hantera de starka sidorna och att utveckla de svaga sidorna till något bättre. Tack för alla kloka tankar du delar med dig av och för att du mycket sällan gör något av bekvämlighet. Jag imponeras av och avundas ditt tålamod.

Nisse Lundeheim (handledare, statistikidol, morgonkompis och chef) – Tack för all hjälp! Tack för alla vetenskapliga, icke vetenskapliga och underhållande diskussioner och din acceptans för mina och dina dumma frågor.

Gunnela Gustafsson (ekohandledare) – Tack för att du triggar mig till systemtänk, och för att du stannade med mig ”until the bitter end”.

Fredrik Hultén (reproduktionshandledare) – Tack för ett gott samarbete ute på Lövsta och för dina genomtänkta kommentarer som bidragit med struktur och ordning i mitt ofta alltför oplanerade arbetssätt.

Karen Thodberg (coauthor) – Thank you for sharing your knowledge about ethology, for your wise comments and questions and for the quick responses I got when I really needed them.

Kjell Andersson (tidigare chef, projektledare för Ekogrisprojektet och på senare tid mentor) – Tack för allt stöd, all hjälp, och för ditt tålamod.

Maria Alarik och Maria Neil (resurspersoner i doktorandprojektet) – Tack för alla kloka kommentarer och svar jag fått. Ert kunnande och er erfarenhet har bidragit mycket i avhandlingsarbetet.

Ulla Schmidt – Tack för allt ditt slit med grisarna, siffrorna och videobanden, du är ovärderlig. Tack för trevligt sällskap på rummet.

Försöksvärdarna i fältstudierna – Tack för att jag fått ta del av er kunskap och erfarenhet. Det är nytänkande entreprenörer som ni som för civilisationen framåt.

Stallpersonalen på Lövsta försöksstation: Eva Norling, Ulf Hermanson, Elin Eriksson, Ulrika Ehrnvall, Jessika Olsson, Linda Jakobsson och Lisa Ogden – Tack för allt ni lärt mig om grisar och för ert fantastiska arbete, speciellt med ute-suggorna. Tack för ett roligt samarbete och för alla snabba svar på mina frågor.

Arne Persson – Tack för all hjälp med ute-suggorna på Lövsta.

Rolf Grahm och Kristianstad slakteri –Tack för hjälpen med insamling av slaktdata från individmärkta ekoslaktgrisar.

Quality Genetics – Tack för spermadoserna och för att jag fick tillgång till Hampshiregaltarnas avelsvärden.

Sylvia Persson (Länsstyrelsen i Västergötland) och Eva Persson (SLU Skara) – Tack för hjälpen när fältstudierna sattes igång.

Paul Robinson – Tank you for their proof reading excellent. I really appreciate your late night efforts with my texts during the last week before submission.

Anders och Anna-Greta Karlsson (Tjulsta gård) – Tack för att ni så generöst delat med er av er kunskap och erfarenhet om grisproduktion i allmänhet och utegrisar i synnerhet.

Magdalena Høøk Presto (Den 'andra' doktoranden i Ekogrisprojektet) – Tack för ett fantastiskt samarbete på alla plan, med en förhoppning om fortsatt gott samarbete. Framöver försöker vi oss på lite mer brain och lite mindre storm. Som den goda förloraren jag är vill jag passa på och tacka motståndaren för en god match. Förra matchen vann du med 3 dagar, den här med ett halvt år.

Sara Björkner och Maria Eriksson (examensarbetare) – Tack för ett gott samarbete med grisobservationerna och för att ni lyste upp tillvaron på Lövsta.

Kristina Andersson – Tack för allt stöd och all hjälp! Du är som Alfons Åbergs kompis Målgan, du finns där när man känner sig lite trött och behöver någon som förstår. Du bidrar helt utan egen vinning när någon behöver hjälp – du är ett unikum i branschen. Tack för all läshjälp och för ett gott samarbete med GLIMMIX.

Anita Liljeholm – som hjälpt mig med den administrativa röra som lätt uppstår när två stora försök ska bedrivas parallellt. Tack för alla trevliga stunder på Lövsta och för allt stöd du gett mig.

Jörgen, Siw, Bian, Monica, Harriet, Helena, Stickan och Dan – Tack för att ni mött mina tråkiga frågor med glatt humör och hjälpt mig med krångliga resor, räkningar och datorer.

Ett stort tack till alla nuvarande och tidigare doktorander på Hgens svinavdelning som alla bidragit till den goda 'forskningsmiljön' på avdelningen: Katja Grandinson som övertygade mig om att jag ville doktorera; Linda Engblom, min modiga vän som stöttat mycket, men också tryck mig fram mot disputation med el-fösare under det sista året; Helena Lundgren och Helena Chalkias, som gett mig viktigt moraliskt stöd i både lätta och tunga stunder, som alltid tar sig tid för en lägesrapport och ett skratt; samt Monica Hansson som med glatt humör läst sida upp och sida ner i mina felstavade manuskript. TACK!

Laurianne Canario och Jean-Luc Gourdine (who did their post-docs at Hgen's pig-division) – Thank you for sharing your expertise and for bringing exotic French and Caribbean vibes to the pig-division.

Alla doktorander på Hgen – Tack för sammanhållningen. Hgens framgång ligger givetvis i det goda samarbetet mellan de perfekta individerna i Hgens starka doktorandgrupp. 'Snälla doktorander tar sig till disputationen – de andra tar sig hur långt som helst'.

Sara, Magdalena, Mathilda, Lotta, Therese, Mikaela och Nils (SwOFF:s husdjursdoktorander) – Tack för trevligt sällskap på vägen. Det var roligt att gå i skola och resa med er.

Marie Jansson Mörk, Magdalena Høøk Presto, Emma Löf och Sara Brännström (Agronom- & doktorandkompisarna) – Ni har länge varit, är och kommer nog alltid att vara ett väldigt viktigt stöd för mig på jobbet, lunchen, hemma och krogen. Extra tack till Marie för alla trevliga bilfärder, där vi löst ett och annat statistikproblem.

Alla mina fantastiska Veckholmsvänner (Veckholm och grannsocknar) – Tack för att ni pratar, fikar, pratar, bjuder på lunch, pratar, leker, pratar, bjuder på middag, pratar, räddar liv, pratar, föder barn, pratar, badar, pratar, dricker vin, pratar och grillar korv. Ni är min länk till verkligheten och utan er hade det här aldrig gått.

Min stora familj – Stort tack för ert ständiga stöd i livets alla situationer, där avhandlingsarbetet varit en ganska lång situation.

– Tack Mamma för dina fantastiska modersegenskaper och för att du är en så god förebild för oss 'yngre' kvinnor.

– Tack Pappa för att du oavsett allt, alltid finns här för mig. Tack för att du lägger in knuffarna där de behövs, även om du ibland lägger in knuffar där de inte behövs.

– Tack mina älskade systrar Stina och Karin för att ni smittar ner mesen i syskonskaran med ert mod, er kreativitet och ert självförtroende.

– Tack svärfar och svärmor för hjälpen med barnen och för att ni tillsammans med Fredrik strukturerat arbetet på gården efter mina 'avhandlingsbehov'.

Min lilla familj – Fredrik, min man, käresta och bästa kompis. – Tack för allt stöd och all hjälp, speciellt under slutspurten på avhandlingsarbetet. Tack för att du står ut med mig, och dessutom tycker om mig varenda, varenda dag.

Ludvig och Alma, mina kloka och vackra ungar. – Tack för att ni hanterar er mor med humor och skinn på näsan.