Welfare, performance and emissions in a stationary housing system for organic growing-finishing pigs; A holistic approach

Anne-Charlotte Olsson

Faculty of Veterinary Medicine and Animal Science
Department of Biosystems and Technology
Alnarp

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Cover: Concrete outdoor area outside the organic barn
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Abstract

High standards of animal welfare and health and providing animals with a natural environment and organic feed are primary objectives in organic pig farming. However, housing solutions in organic pig farming are not uniform. Stationary systems have permanent buildings with concrete areas outdoors and/or pasture, mobile systems have outdoor huts on pasture, and mixed systems have both stationary buildings and huts. This thesis examined the pros and cons of stationary housing systems for organic growing-finishing pigs in studies carried out at Odarslöv Research Farm, SLU, Alnarp. The uninsulated and naturally ventilated building was fitted with eight pens (8 x 16= 128 pigs), four with a deep straw system and four with a 'straw-flow' system. Each pen had access to an outdoor concrete area and, depending on the experimental set up, also to pasture.

No difference in health, daytime pig activity, or pen hygiene was detected between the deep straw and straw-flow systems. Pigs with access to pasture were not more active during daytime behaviour studies than pigs without access to pasture. However, the pigs with access to pasture occupied themselves more on the pasture than on the concrete outdoor area. Pigs from straw-flow pens had higher carcass meat percentage at slaughter than pigs from deep straw pens, but there was no difference in performance between pigs with and pigs without access to pasture. Nitrogen losses from the organic pigs were estimated to be 26-27% of N excreted. This gives approximately three to four times higher ammonia emission than standard values from conventional pigs when assuming that all losses consist of ammonia. A larger fouled area, particularly outdoors, may partly explain this result.

Measures to improve hygiene, reduce fouling and decrease nitrogen emissions from the outdoor concrete area were tested. The intention was to direct the excretory behaviour of the pigs by introducing rooting yards with attractive rooting material. Our investigations on rooting yard design revealed that a larger rooting yard (8.4 m^2) with one high wall (LH) was a more optimal option than a smaller (5.3 m^2) one. In the LH-design it was revealed that any rooting material of wood shavings, peat, peat + feed pellets was more attractive than the control yard without rooting material. Visual hygiene evaluations showed improved hygiene for all rooting materials tested. However, to reduce ammonia emission, peat was clearly in favour compared to wood shavings.

Keywords: organic pigs, stationary housing, rooting material, ammonia emission, hygiene, performance, mass balance

Author's address: Anne-Charlotte Olsson, SLU, Department of Biosystems and Technology, P.O. Box 103, 250 53 Alnarp, Sweden
E-mail: anne-charlotte.olsson@slu.se

Dedication

To my first academic mentor, Jørgen Svendsen. Thanks for giving me a bit of all your knowledge about pigs!

The good life is one inspired by love and guided by knowledge

The trouble with the world is that the stupid are cocksure and the intelligent are full of doubt.

Bertrand Russell

Contents

List of Publications

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

I Botermans, J.A.M., Olsson, A.-C., Andersson, M., Bergsten, C. & Svendsen, J. (2015). Performance, health and behaviour of organic growing-finishing pigs in two different housing systems with or without access to pasture. *Acta Agriculturae Scandinavica, Section A - Animal Sci*ence 65, 158-167.

II Olsson, A.-C., Jeppsson, K.-H., Botermans, J., von Wachenfelt, H., Andersson, M., Bergsten, C. & Svendsen, J. (2014). Pen hygiene, N, P and K budgets and calculated nitrogen emissions for organic growing-finishing pigs in two different housing systems with and without pasture access. *Livestock Science* 165, 138-146.

III Olsson, A.-C., Botermans, J., Andersson, M., Jeppsson, K.-H. & Bergsten, C. (2016). Design of rooting yards for better hygiene and lower ammonia emissions within the outdoor concrete area in organic pig production. *Livestock Science* 185, 79-88.

IV Olsson, A.-C., Botermans, J., Andersson, M., Jeppsson, K.-H. & Bergsten, C. (2016). Use of different rooting materials to improve hygiene and to lower ammonia emission within the outdoor concrete area in organic growing-finishing pig production. *Livestock Science* 191, 64-71.

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Abbreviations

DFI	Daily feed intake
DWG	Daily weight gain
FCR	Feed conversion ratio
GHG	Greenhouse gases
NH_3	Ammonia
CO_2	Carbon dioxide
CH_4	Methane
N_2O	Nitrous oxide
N	Nitrogen
P	Phosphorus
K	Potassium

1 Introduction

1.1 The pig as a domestic animal

The pig is one of the oldest forms of livestock and pig husbandry has a very long tradition (Lega *et al.,* 2015). It has been shown that wild boars were domesticated several times and at different locations in Europe and Asia over 10,000 years ago (Groenen *et al*., 2012). According to Rowley-Conwy *et al*. (2012), the pig is the domesticated farm animal with which man has had the best success, based on the geographical spread of pig rearing in the world's agricultural systems.

Pork is currently also the most commonly eaten meat in the world (Worldwatch Institute, 2013). Important explanations of the popularity of the pig as a meat source are its adaptable nature and its omnivorous diet. Pigs have a good ability to adapt to various housing systems and environmental factors (for example pen design, feeding systems, ambient temperature, access of rooting material *etc*.), but housing and factors in the environment have a considerable influence on pig welfare, behaviour and performance.

Even though the pig is adaptable, it has a strong need to root and explore, to live and act in social groups with a clear hierarchy, and to choose resting areas according to the most optimal ambient temperature. Therefore differences in health, skin lesions, daytime pig activity and performance between different housing systems and pen designs, can be observed.

1.2 Organic pig production

1.2.1 Development and regulations

Conventional pig production is characterised by increasingly larger herds and more intensive housing systems. There has also been a trend towards separation of crop and livestock production. The introduction of organic farming and livestock production has partly occurred as a reaction to developments within conventional production (Alarik *et al.*, 2000). The International Federation of Organic Agriculture Movements (IFOAM) has basic norms and principles for organic livestock husbandry (IFOAM, 2014). Important issues are integration between land and animal production, optimal animal welfare including loose housing (Lund & Algers, 2003), possibilities for the animals to express normal behaviour and access to rooting material for exploration and foraging. Moreover the pigs have to be given organic feed produced with biological processing methods (IFOAM, 2014).

As a consequence of these principles, animals in organic production must have access to outdoor areas and to organic feed, preferably produced on land belonging to the farm and according to organic regulations, *i.e.* without artificial fertilisers, herbicides and pesticides. Furthermore, use of synthetic amino acids or enzymes, such as synthetic lysine and phytase, is prohibited. These products are often produced by fermentation (Isberg *et al.*, 2012), and the ban is due to the fact that the fermentation process may be performed by genetically modified organisms (Blair, 2008).

Due to these standards and principles, organic farming is often believed to be more environmentally friendly than conventional farming (Costa *et al.*, 2014; Reganold & Wachter, 2016). Consumers also seem to be willing to pay extra for organically produced meat (Dransfield *et al.*, 2005), although differences in meat quality are difficult to prove (Millet *et al.*, 2005).

In Sweden, as in many other European countries (Früh, 2011), the first organic pig herds were established in the early 1990s. In 2007, the total number of organic pig herds in Sweden was 41, of which 17% had only sows, 44% had both sows and fattening pigs and the remaining 39% had only fattening pigs (COREPIG, 2011). In 2011, around 40 000 pigs were produced as organic in Sweden, which was slightly lower than the number of organic pigs in *e.g.* the UK. The greatest numbers of organic pigs in Europe can be found in Germany, Denmark and France, each of which produced around 170 000 organic pigs in 2011 (European Commission, 2013). In 2014 there were 43 organic pigs herds in Sweden (Swedish Board of Agriculture, 2014).

1.2.2 Housing systems and design of pens and huts

Although the minimum standards for organic production are the same throughout the EU (EU, 2007; EU, 2008), housing systems for organic pigs vary in different European countries (Früh *et al.*, 2014; COREPIG, 2011). Certain organic labels and private schemes may have stricter rules than the minimum standards. As an example, the Soil Association in UK requires organic pigs to be kept on pasture all the year when possible according to ground conditions and weather. Therefore, pigs in the UK are housed in movable huts on the pasture. In contrast, pigs in Austria, Germany and Switzerland only require access to an outdoor concrete yard (Früh, 2011). In Sweden, the organic label KRAV has set the specific requirement that organic pigs must have 4 months access to pasture during the grazing period in summer (KRAV, 2014).

The housing systems in organic pig farming can be divided into three categories. Stationary systems have permanent buildings with concrete areas outdoors and/or pasture. Mobile systems have outdoor huts, which are moved on the pasture land and mixed systems have both stationary buildings and huts (Früh, 2011). In Sweden, all three categories exist (Benfalk *et al*., 2005; Lindgren *et al*., 2008).

Furthermore, the huts, the pens within the buildings and the layout of the outdoor area can be designed in many different ways (Aarestrup Moustsen *et al*., 2004; Früh, 2011; Salomon *et al*., 2005; Svensson *et al*., 2005). Pens with deep litter are common in organic pig farming (Svensson *et al*., 2005). This solution is based on the availability of large amounts of straw. Deep litter allows the animals to root in the bedding, but also means that the pigs will excrete in the bedding. Thus large amounts of straw are needed to absorb urine and faeces from the pigs (Gentry *et al*., 2002). To keep straw consumption at a lower level, 'straw-flow' systems may be an alternative (Philippe *et al*., 2012).

1.2.3 Welfare

Since housing systems and the design of huts and pens vary a great deal within organic pig production, it is difficult to make specific statements about welfare, behaviour and performance. However, some general findings can be presented.

The access to bedding and rooting material is of importance for pig welfare in organic pig farming (Bracke *et al*., 2012). Numerous studies show that a barren environment is negative for pigs, leading to aggression, tail-biting and pen-mate directed oral behaviour (Beattie *et al*., 1998; Pedersen *et al*., 2014). Other studies show that certain amounts of litter and roughage can reduce such behaviours and improve performance (Bodin *et al*., 2015; Høøk Presto *et al*., 2009; Olsen *et al*., 2001). In comparison with conventional pig production, stocking density is much lower in organic pig production. High stocking density and an environment without rooting material are mentioned in several studies as reasons for aggression between pigs and social stress (Cornale *et al*., 2015; Turner *et al*., 2000; Spoolder, 2007). According to organic EU rules (von Borell & Sørensen, 2004), a finishing pig must have an area of 1.3 m^2 indoors and 1.0 m^2 outdoors. In the Swedish KRAV rules these requirements are slightly higher; 1.5 m^2 indoors and 1.0 m^2 outdoors (KRAV, 2014). According to the equation that specifies the minimum floor area per conventional growing finishing pig in Sweden (total area $m^2 = 0.17 + (weight/130)$; Swedish Board of Agriculture, 2010) a conventional pig of 110 kg requires an area of 1 m^2. Thus organic pigs have a 2.5 fold larger individual area than conventional pigs. Consequently, negative behaviours and injuries, such as aggression, tail biting and bite injuries, are higher in conventional pig production than in organic (Lindgren *et al*., 2014). This suggests that animal welfare in organic production is better in the aspect of area per pig.

Because housing solutions are more extensive in organic than in conventional pig production, group sizes are often larger (Benfalk *et al*., 2005) and climate conditions vary more widely. There is conflicting information on how group size affects animal welfare. McGlone & Newby (1994) found a negative impact in terms of injuries and morbidity when group size increased from 10 or 20 to 40 animals, while Samarakone & Gonyou (2008) found no such differences when comparing groups of 18 and 108 pigs. Meyer-Hamme *et al*. (2015) observed more negative social behaviour and dirtier pigs in larger groups of pigs than in smaller groups (group size <15, 15-30, >30 pigs), but still concluded that pig welfare level was not influenced by group size in their study. An explanation for these conflicting results might be that it is difficult to treat group size as a separate factor, since there are interactions with feeding systems, area per animal, management *etc*. Overall, the more extensive housing solutions in organic rearing and thereby more varying and sometimes more extreme climate conditions may influence pig welfare in a negative way (Edwards, 2005).

Good health and few injuries in the animals are other important factors in good welfare. Organic pigs are generally healthy. For example, pigs housed outdoors most often have less respiratory diseases than pigs housed indoors (Guy *et al*., 2002) and tail biting is seldom reported among organic pigs (Lindgren *et al*., 2014). However, rearing outdoors increases the risk of contact with other animals that can carry disease, such as birds, rats and foxes (Leirs *et al*., 2004). The risk of parasitic infections, such as *Ascaris suum* infection, also increases when pigs have outdoor access (Lindgren *et al*., 2014). *Ascaris suum* infection causes liver lesions and reduced welfare and performance (Katakam *et al*., 2016). Furthermore, locomotion problems have been reported in pigs on pasture and are possibly associated with *Erysipelothrix rhusiopathia* infection (Kugelberg *et al*., 2001) or osteochondrosis (Etterlin *et al*., 2015). Specific design features in the housing system, such as large differences between indoor and outdoor floor level, are suggested to be related to osteochondrosis (Heldmer & Ekman, 2009).

If recommended by a veterinarian, it is permitted to vaccinate against *Erysipelothrix rhusiopathia* in KRAV-production, However, the frequency of vaccination is lower in organic than in conventional pig (Ström, 2010). Preventive treatment against parasites and worm disease is not allowed according to the KRAV-rules. Therefore, careful management of pasture rotation is of great importance (Wallgren, 2001).

1.2.4 Behaviour

In general, the behaviour of pigs is influenced by a variety of environmental factors, such as location of feed and water, stocking density, freedom of movement, access to bedding and rooting material, ambient temperature, group size, group dynamics *etc*. Thus, to some extent, it is possible to 'influence' the behaviour of pigs by manipulating various factors in their housing environment.

Activity and preference of location are influenced by housing, feeding and management features in the immediate environment of the pigs. Benfalk *et al.* (2005) showed this in a comparison of the behaviour of organic growing-finishing pigs during daytime in two different systems of organic production; one with huts on pasture and one where the pigs were housed in a stationary system with access to pasture. Water and feed were provided outside the huts and inside the building, respectively. It was found that the pigs with huts were more often outside than the pigs in the stationary system. In another study, where organic pigs were offered only 80% of their recommended feed ration they were found to spend more time rooting than those which had 100% feed supply (Stern & Andresen, 2003). Other examples of how features in the environment influence pig behaviour are placement of additional roughage (Høøk Presto *et al.*, 2009) and rooting material (Vermeer *et al.*, 2015) in the outdoor area. The excretory behaviour of pigs was also influenced by the housing system (Benfalk *et al.*, 2005) and the feed ration (Stern & Andresen, 2003).

1.2.5 Feed composition, feeding system and performance

Organic pig production is based on organically grown feedstuffs, preferably grown on-farm. Since it is a challenge to grow certain high-quality protein feed stuffs organically, the organic production regulations make it difficult to optimise organic diets in the same way as conventional diets. This often results in organic feedstuffs with a lower essential amino acid (AA) level than recommended, which may compromise pig performance (Sundrum *et al.*, 2011) or not (Høøk Presto *et al.*, 2008; Millet *et al.*, 2005). Pig performance can be expressed as growth rate, feed conversion ratio (FCR), meat percentage *etc*.

Large variations in ambient temperature, more often a colder climate and the greater freedom of movement compared with in conventional pig production, are other factors influencing performance in organic pig production. According to Kool *et al*. (2009), feed consumption was 20-30% higher in organic pig production than in conventional.

It was shown by Strudsholm & Hermansen (2005) that organic pigs fed *ad libitum* had higher feed consumption when reared on pasture than if they were housed with access to an outdoor area. Similar findings have been reported by Kelly *et al. (*2007). In their investigation, pigs were housed on pasture with a shelter or housed in indoor straw-bedded accommodation with an outdoor concrete exercise area and all pigs were fed *ad libitum*. Pigs on pasture had higher feed intake and higher feed conversion ratio, but the same daily weight gain and lean percentage. This shows that pigs on pasture may use more energy for locomotion. Energy may also be used for maintenance of homeothermy during periods with ambient temperatures below the lower critical temperature of the pigs (Kelly *et al.*, 2007). Pigs can partly compensate for this by grazing and rooting. However, in one study a 20% reduction in the feed allowance resulted only in about 5% higher nutrient intake from the herbage, showing that grower-finisher pigs have only limited possibilities to cover their feed uptake requirement using herbage (Stern & Andresen, 2003). In another study where concentrate was made available *ad libitum* to growing pigs, the intake of grass-clover sward contributed only 4% of daily organic matter intake (Mowat *et al*., 2001).

Feed supply system is another important factor for pig performance. The housing system in use determines possible feed supply systems (Schiöler & Alarik, 2002). In systems with huts that are moved around between different locations outdoors, more advanced feeding systems are impossible in practice. Therefore, pigs in huts outdoors are most often fed dry feed *ad libitum* in feeders of different kinds. In such systems, feed spillage may be a problem (Edwards, 2007; Sikala, 2012). *Ad libitum* feeders are also common when group sizes are large both outdoors and indoors, since trough feeding then becomes difficult to resolve in a practical way. The specific effect of feeding system on feed efficiency in this situation is not easy to determine, since other factors such as group size, space allowance, nutrient content in the feed *etc*. may interact in different ways (Douglas *et al*., 2015). However, *ad libitum* feeders have the disadvantage that the possibility to restrict feeding towards the end of the rearing period is limited. This may affect lean meat percentage in a negative way (Strudsholm & Hermansen, 2005).

In housing systems with stationary houses and smaller group sizes, automated solutions with feeding of the pigs in troughs is possible. Wet feeding systems are also a possibility if the system can be kept free from freezing in some way. Feeding in troughs provides better opportunities to feed the pigs restrictively towards the end of the finishing period and achieving a better control of feed rations.

1.2.6 Water

It is important to have a safe water supply for the pigs. In movable systems outdoors, water is most often provided in simple water troughs. During winter time this can cause problems with freezing (Andersen & Pedersen, 2014). In stationary systems, water is given indoors and permanent water systems are used. To frost-proof the water supply in such buildings, the solution is either to use circulating heated water or to put a heating coil in the water bowl (Svensson *et al*., 2005).

According to the KRAV rules (KRAV, 2014), organic pigs also should have access to a mud bath (wallow) or some other water cooling solution during the warm season.

1.2.7 Environmental impact

One of the goals of organic farming is to minimise the environmental impact of agricultural production (Hansen *et al.*, 2001). However, a number of scientific studies have shown that emissions, *e.g.* of nitrogen, from organic pig production systems are higher than those from conventional pig production (Kool *et al*., 2009; Carlsson *et al.*, 2009).

The environmental impact of organic and conventional pig production has been compared in various studies using the method of Life Cycle Assessment (LCA). Within a LCA, the environmental impact of a product is followed from “cradle to grave”. Thus, when comparing different pig production systems, feed production is also included in the analysis. This means that the differences between organic and conventional production systems concerning the use of artificial fertilisers and chemical herbicides and pesticides (Basset-Mens *et al*., 2003) are included in the LCA calculations. Despite this, the results of calculations on carbon footprint, acidification and eutrophication do not show a difference in favour of organic production systems, but rather the opposite (Basset-Mens *et al*., 2003; Carlsson *et al*., 2009; Halberget *et al*., 2007; Kool *et al*., 2009).

1.3 Environmental impact generally in livestock and pig production

All livestock production has a negative impact on the environment (Steinfeld *et al.*, 2006; Hermansen & Kristensen, 2011; Herrero & Thornton, 2013; Garnett, 2009; Garnett, 2011). Examples of such impacts are acidification, eutrophication and climate change through release of greenhouse gases (GHG). Environmentally harmful substances originate either from the animals themselves or from their manure (Halden & Schwab, 2008).

Nitrogen excretion from animals and the associated ammonia emission is one reason for acidification. Eutrophication is influenced by both nitrogen and phosphorus excretion. Livestock production also contributes in different ways to the GHG by carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). According to some calculations, livestock production is responsible for 14 to 18% of GHG and 64% of ammonia (NH_3) emissions in the world (Gerber *et al.*, 2013; Steinfeld *et al.*, 2006). In Europe, as much as 94% of all ammonia emission is considered be caused by agriculture and 71% are considered to be connected with manure management (Eurostat, 2016).

In pigs, nitrogen excretion is in the form of urine and faeces and is the result of the nitrogen input to the animal (feed, straw *etc.*) minus the nitrogen retained in the animal (Eurostat, 2011). Thus, feed type, feed utilisation and production efficiency are of great importance for nitrogen excretion (Kool *et al.*, 2009). When making comparisons between conventional and organic pig production, pros and cons can be found for both production systems (Tuomisto *et al.*, 2012).

In organic production, the relationship between crop and livestock production is better optimised than in conventional production (Halberg *et al.*, 2010). This ensures that there is no major transport of nitrogen or phosphorus, for example in the form of feed, from one area to another. However, such transport often occurs in conventional production and consequently concentration of animal production in certain geographical areas results in point loads of nitrogen in these areas.

On the other hand, feed efficiency in organic pig production is most often less good than in conventional production (Kool *et al.*, 2009). One reason is that the environment of organic pigs, at least in the Nordic countries, is colder than that of conventional pigs in insulated buildings. In a cold environment, pigs use more feed to keep themselves warm (Kelly *et al.*, 2007). Moreover, pigs in organic production use more energy for movement than pigs in conventional production (Kool *et al.*, 2009).

To get optimal feed utilisation, an optimal level of nitrogen in feed and efficient use of this nitrogen in the animal is of great importance. Within an optimal feed regime (for optimal growth and feed utilisation) to pigs, the ratio between specific amino acids (primarily lysine, threonine and methionine) and energy has to reach certain values (Göransson *et al*., 2010). In conventional pig feed, this goal can be achieved without increasing the total level of protein (crude protein) within the feed by introducing synthetic essential amino acids (Verstegen *et al.*, 1993; Dourmad & Jondreville, 2007). This is a successful method for reducing the impact of pig production on greenhouse gas emissions, acidification and eutrophication (Garcia-Launay *et al*., 2014). However, in organic pig production the use of synthetic essential amino acids is prohibited. To secure sufficient amounts of essential amino acids for optimal growth, the crude protein level in organic feed therefore has to be higher than in feed for conventional pigs. This is another reason for the higher nitrogen excretion in organic pig production.

Nitrogen may manifest itself as various nitrogen compounds (ammonium (NH_4^+), ammonia (NH_3), nitrate (NO_3^-) or nitrous oxide (N_2O) (Philippe *et al*., 2011). The housing and manure systems determine which nitrogen compound is most likely to occur. In intensive indoor housing with solid or slatted floors and slurry collection, emission of ammonia is the main problem (Aarnink *et al*., 1997; Aarnink *et al*., 1996; Philippe *et al*., 2011; Jongebreur & Monteny, 2001). In more extensive systems, such as deep litter systems with or without access to a solid concrete yard outdoors, the nitrogen emissions comprise varying levels of ammonia but also nitrous oxide (Eriksen *et al*., 2002; Rigolot *et al*., 2010). In outdoor systems on land, the nitrogen emissions occur both to the air (ammonia, nitrous oxide) and as leaching to the soil (ammonium, nitrate; Williams *et al*., 2005; Halberg *et al*., 2010; Salomon *et al*., 2012; Webb *et al*., 2014).

In addition to the relationship between manure system and nitrogen compounds, the manure system influences the level of ammonia emission. In extensive deep litter systems, the ammonia emission is higher than in slurry systems. According to the computer-based templates used by the Swedish Board of Agriculture (2012, 2016), the ammonia emission from deep litter systems is 25% of nitrogen excreted compared with 14% in slurry systems (Sannö *et al*., 2005). Different ammonia emission factors are used to calculate ammonia emissions from animal houses with different kind of livestock and different systems for manure handling *etc*. The emission factor indicates the percentage of excreted nitrogen that will most likely disappear as ammonia.

Phosphorus is another nutrient related to pig production that can give environmental problems. Phosphorus is a vital nutrient for the pig, but the degree to which pigs can utilise phosphorus in the feed is limited, since most of the phosphorus in plant feed ingredients is bound within phytate molecules

(Jongbloed & Kemme, 1990). For pigs to be able to use phosphorus bound as phytate, they need the enzyme phytase. Grain, especially wheat, contains endogenous phytase, which is activated when the feed is soaked. Therefore, the digestibility of phosphorus is higher when pigs are fed wet feed than when they are fed dry feed (Lyberg, 2006). Another solution is to add phytase to the feed (Lyberg, 2006). By adding phytase to a conventional cereal-soybean pig feed, the digestibility of phosphorus can be increased from 30% to 60-70% (Dourmad & Jondreville, 2007). However, similarly to the ban on synthetic amino acids, phytase may not be used in organic pig feed. Thus the digestibility of phosphorus is lower in organic feed than in conventional feed containing synthetic phytase. Consequently, organic pigs excrete more phosphorus than conventional pigs with feed supplemented with phytase.

The greenhouse gases carbon dioxide and methane are produced by pigs during respiration and by bacteria in the digestive tract of the pig, respectively (Philippe & Nicks, 2015). Carbon dioxide, methane and the third GHG nitrous oxide are also released from the manure (Philippe & Nicks, 2015). The carbon dioxide emissions coming directly from the pigs and the manure are most often excluded from GHG calculations, since similar amounts of carbon dioxide are assumed to be consumed during photosynthesis by the plants used as feed sources (Philippe & Nicks, 2015). According to Pedersen & Sällvik, (2002), a fattening pig produces 1.70 kg respiratory carbon dioxide per day. Smaller, more uncertain amounts of carbon dioxide are also produced in the manure due to hydrolysis of urea and anaerobic fermentation, as well as aerobic degradation of organic matter (Philippe & Nicks, 2015). In solid manure, aerobic processes dominate. Methane is produced under anaerobic conditions, as mentioned in the digestive tract but also by bacteria in the manure. The Intergovernmental Panel on Climate Change (IPCC) has estimated that methane production from enteric fermentation amounts to 1.5 kg/pig/year and that from manure to 9-12 kg/pig/year in countries in Western Europe with mean annual temperature of 10-14 °C (IPCC, 2006). Since methane is a more potent greenhouse gas than carbon dioxide, this amount of methane has to be multiplied by 21 to convert it to carbon dioxide equivalents.

The most potent greenhouse gas is nitrous oxide, which is multiplied by 298 to convert it to carbon dioxide equivalents. Nitrous oxide originates from animal manure and is produced by microorganisms during incomplete nitrification and denitrification processes (Philippe & Nicks, 2015). Alternating aerobic and anaerobic zones are favourable for the production of nitrous oxide. Such conditions are more common in deep litter than in slurry (Philippe & Nicks, 2015). However, production of nitrous oxide is very random, which makes the rate of emissions difficult to predict. IPCC (2006) suggests 1% nitrous oxide emission of nitrogen excreted when using deep litter systems.

1.4 Methods for measuring ammonia emission

The main focus in this thesis on emissions was that of ammonia. Therefore, a short description of different methods for measuring ammonia emission is presented in the following.

Ammonia emission from an animal house *i.e.* floor surface can be measured and calculated in a number of different ways. A common approach is to measure the ammonia concentration in representative air samples (for example in inlet and exhaust air) and combine this with measurements of air flow/ventilation rate. However, obtaining representative air samples is a complicated task since ammonia concentration varies at different places in an animal house. In addition, ammonia concentration has temporal, seasonal and diurnal variations, which makes sampling even more difficult. It is also important to adjust for background concentration (in the surrounding environment), air temperature and air pressure when measuring ammonia concentration. Air temperature and air pressure have to be considered, since ammonia is a gas and the volume of a gas is influenced by air temperature and air pressure. Air samples can be taken in closed sampling chambers, either static or dynamic, as point samples at various locations within a house or by means of open-path sampling devices (Ni & Heber, 2008). Use of static closed sampling chambers represents a special case, since there is no exchange of air between the inside and the outside of the chamber (= no air flow), while dynamic closed sampling chambers have both air inlets and outlets. Dynamic closed sampling chambers are suitable for measuring ammonia emission from a certain release surface. On the other hand, point sampling at different heights over this area is preferable when evaluating *e.g.* the amount of ammonia to which animals and their care takers are exposed.

The actual measurement of ammonia concentration may also be performed in a variety of ways. In so-called ‘wet’ methods, ammonia is captured in distilled water or in an acid and the concentration can then be analysed by various methods such as titrimetry, photometry, pH paper *etc.* When using ‘dry’ methods, ammonia is analysed in its gas phase. Examples of measuring equipment used for this are different brands of gas detection tubes, infrared analysers and electrochemical sensors (Ni & Heber, 2008).

However, as mentioned earlier, it is necessary to measure not only ammonia concentration, but also air flow/ventilation rate in order to calculate ammonia emission from an animal house. In mechanically ventilated buildings, the ventilation rate can be measured with hot wire anemometers or specially developed measuring fans placed in the ventilation shafts. In naturally ventilated buildings, the ventilation rate is much more difficult to determine, since ingoing and outgoing air are not concentrated to certain shafts. In some cases, measurements of pressure differences between inside and outside can be used instead. Another method is to inject and monitor ventilation by means of a tracer gas. However, factors such as method used for injection and monitoring, as well as type of tracer gas, also have to be considered in that case. A particular case is to use carbon dioxide as a tracer gas. This does not require carbon dioxide injection, but is based instead on information about how much carbon dioxide the animals produce, applied in a mass balance method. This use of carbon dioxide is sometimes referred to as an indirect tracer gas method. If the predictions of carbon dioxide production are in good agreement with reality, this is an applicable method in animal houses without deep litter beds/manure beds. However, in extensive systems with deep litter this is not a method that can be recommended, since there might be significant carbon dioxide production also from the litter (Jeppsson, 2000).

Obviously, when it comes to measurement of ammonia concentration and air flow, the type of housing in which the measurements have to be performed and the choice of method used have a great influence on the accuracy of the results. According to Ozcan *et al.* (2007), the uncertainty in measurements can be 8 to 40% when using carbon dioxide as an indirect tracer gas in animal houses without deep litter. In houses with deep litter, the uncertainty may be even higher.

Another method that can be used to measure ammonia emission, or more correctly total nitrogen emissions from an animal house, is to use a mass balance approach (Eurostat, 2011; Hassouna & Eglin, 2015). The mass balance method can also be used to check the relevance and reliability of ammonia emission measurements made according to the methods described above. In a mass balance calculation, the input (*e.g.* nitrogen content in rearing pigs and in feed and straw used) and output of a nutrient (*e.g.* nitrogen content in the manure, in slaughter pigs and in straw leftovers at slaughter) is quantified. If the nutrient can assume a volatile nature, the difference between input and output is interpreted as emissions (Hassouna & Eglin, 2015).

1.5 Sustainability

In the context of environmental impacts of livestock production, the concept of sustainability is often debated and a change towards more sustainable agriculture is frequently recommended (European Commission, 2012, 2016).

Conventional and organic farming in livestock production are often compared in terms of environmental aspects of sustainability (Kool *et al*., 2009), but other considerations must be included in the full definition of sustainability.

The expression 'sustainable development' is defined in many ways and different stakeholders (companies, governments and individuals) have their own definitions (Hay et *al*., 2007). Within different science disciplines the interpretations also differ, *e.g*. natural and social scientists often have differing perspectives on the definition of sustainable development (Blank, 2013).

The origin of the expression can be found in the Brundtland Report, published by the United Nations in 1987 (Word Commission of Environment and Development, 1987). An often quoted sentence from this report states that "Humanity has the ability to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs" (*ibid*, page 16).

When introducing the concept, the intention was to design a "frame" and vision for future development and governance within the world. Since 1987, different interpretations and re-interpretations of 'sustainable development' have been made within various topics. In a speech to the European Commission (European Commission, 2012), the European Commissioner for Agriculture and Rural Development concretised what the concept means for EU agricultural policy by listing eight different visions for sustainable agriculture within the EU. These are: 1) increasing productivity without affecting the capacity of soil and water to regenerate and to be maintained in good condition, 2) producing high quality, safe and healthy food, 3) generating enough income for farms to keep them going, 4) delivering ecosystem services (preserving valuable habitats, biodiversity, genes), 5) improving quality of life in rural areas, 6) strengthening the economy, 7) contributing to balanced territorial development and 8) ensuring animal welfare.

These eight visions are aims within sustainable farming in EU and reflect a good balance between: 1) social acceptability, 2) environmental benefits and 3) economic viability. These three dimensions are known as the three "pillars" of sustainability (Bonneau *et al*., 2014). Drawings of the three pillars bearing up the concept 'sustainability' are often used to visualise that sustainability consists of at least three different dimensions.

Thus, sustainability is a concept with a complex meaning, comprising a combination of various heterogeneous targets. In words of pig production, sustainability means a production of healthy pigs in housing systems giving the pigs possibilities to root and to perform their natural behaviour in combination with an efficient production with low environmental impact as well as happy and satisfied pork producers with sufficient income for a good life.

2 Aims and hypotheses

The overall aim of this thesis was to improve current knowledge about stationary housing systems for organic finishing pig production in relation to behaviour, health and performance, as well as hygiene in the pens and mass balances of nitrogen, phosphorus and potassium.
The objectives of the studies were:

- To describe and evaluate the health, activity and performance of pigs with deep straw or straw-flow pens during different seasons of the year and with or without pasture during the summer period (Paper I).

- To describe and evaluate the activity and performance of pigs with different designs of rooting yards or with different rooting materials in the concrete outdoor area during different seasons of the year (Papers III and IV).

- To calculate nitrogen, phosphorus and potassium balances and nitrogen emissions in a stationary system for organic growing-finishing pigs and to examine the correlation to hygiene in the pens. Another objective was to compare the emissions with standard values of ammonia emissions used in conventional pig production (Paper II).

- To describe and evaluate specific measures to reduce ammonia emission *i.e.* improving hygiene on the outdoor concrete area (Papers III and IV).

- To consider 'sustainability' in stationary solutions for organic growing-finishing pig production in relation to other systems for organic or conventional pig production.

The hypothesis of Paper I was that there are differences in health, daytime pig activity and performance between deep straw and straw-flow housing systems and with or without access to pasture.

The hypothesis of Paper II was that there are differences in pen hygiene, nitrogen, phosphorus and potassium balances and nitrogen emissions between deep straw and straw-flow housing systems and with or without access to pasture.

The hypothesis of Paper III was that addition of a rooting yard in the outdoor concrete area and the design of such a yard influence hygiene and excretion behaviour of the pigs in this area.

The hypothesis of Paper IV was that different rooting materials differ in their attractiveness to the pigs and in their effect on ammonia emission.

3 Material and Methods

3.1 Research farm, animals and housing

All studies (Papers I-IV) were carried out at Odarslöv Research Farm at the Swedish University of Agricultural Sciences (SLU) in Alnarp. The Research Farm herd comprises 50 sows (Swedish Landrace x Yorkshire crosses), recruitment animals and finishing pigs. The finishing pigs (three-race crosses, so called PigHam) were produced by inseminating the sows with sperm from Hampshire boars. The sows were loose at farrowing (farrowing pen 7.0 m^2) and the pigs were weaned at 4.5 weeks of age as intact litters in rearing pens (4.0 m^2). Both farrowing pens and rearing pens had a straw-bedded lying area and a slatted dunging area and the pigs were undocked throughout their whole life time. At 11 weeks of age and a weight of about 20-27 kg, the pigs were either moved to an insulated building for conventional pigs or to an uninsulated building for organic pigs. All pigs were individually numbered with plastic tags in the ears.

In total nine different batches of organic growing finishing pigs were studied during a period of four years. The different rearing batches of about three - four months through the four years were categorized by season (Fig. 1).

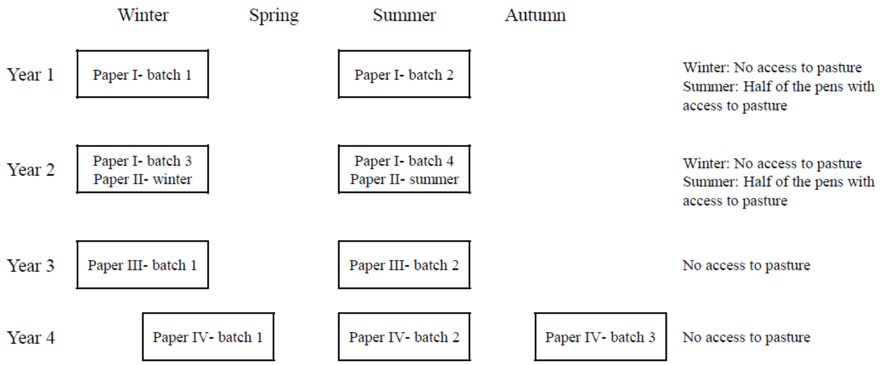

Figure 1. Summary of production batches used in the different papers (I-IV) during year 1, 2, 3, and 4 and seasons winter, spring, summer and autumn.

3.2 The organic pig house

The same organic pig house was used in all studies (Papers I-IV) The uninsulated building with natural ventilation (space boarding and open ridge in the roof) accommodated eight pens (in total 128 pigs; Fig. 2, 3). Each pen kept 16 pigs and measured 3.6 x 7.0 m indoors (1.5 m^2/pig exclusive troughs). The pen was divided in a lying area, feeding/activity area and a dunging area.

For the experiments described in Papers I-II the lying area in four pens had a deep straw system (A) and four pens had a 'straw-flow' system (B; Figures 4-6). The lying area in the straw flow pens (C) were slightly smaller than the deep straw (C) and covered by a roof. All pens had access to a similar outdoor concrete pen 3.6 x 5.0 m (1.1 m^2/pig; Fig. 7, 8) directly connected to the indoor pen. During the grazing period in summer, four treatments were compared (A and B with access to pasture (pasture area 96 m^2/pig) or without access to pasture; *i.e.* KRAV or EU rules; Fig. 9). During the housing period in winter, the pigs had no access to pasture and only the two housing systems were compared.

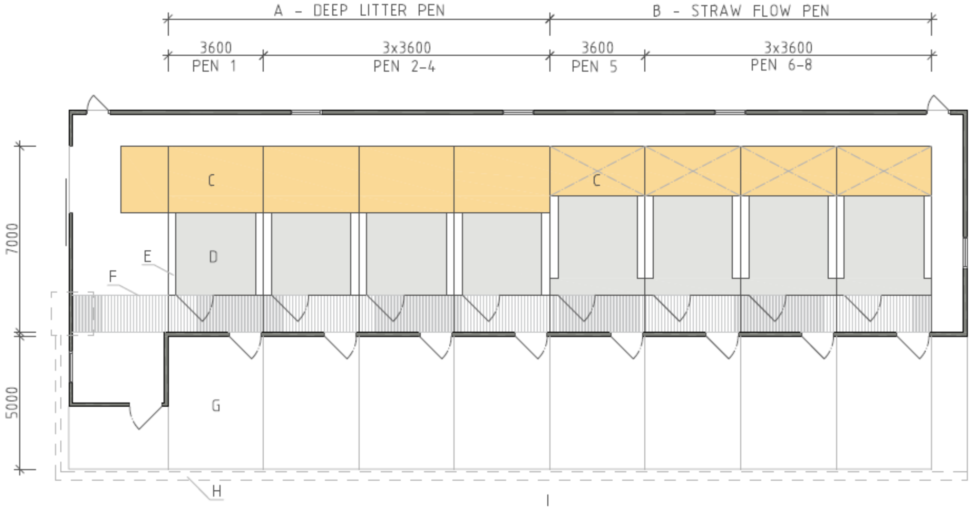

Figure 2. Pen design in the organic growing-finishing pig house with deep straw pens (A, pens 1-4) and straw-flow pens (B, pens 5-8). Each pen had a lying area (C), a concrete feeding and activity area (D), two feeding troughs (E), a slatted dunging area indoors (F), an outdoor concrete area (G) and an outdoor manure channel (H). Four pens (pen 1, pen 4, pen 5 and pen 8) had access to pasture (I). The outdoor areas are described in Fig. 7 and 8.

Figure 3. The exterior of the organic pig house.

Figure 4. The interior of the organic pig house.

Figure 5. View of the deep straw pen (A).

Figure 6. View of the straw-flow pen (B).

Figure 7. Frontal view of the outdoor concrete area.

Figures 8. Side view of the outdoor concrete area.

Figure 9. View of the alley and the pasture area.

3.2.1 Rooting yards

In Paper III, four different designs of rooting yards: i) LH = large area (8.4 m^2) with one high wall (1.0 m); ii) LL = large area (8.4 m^2) with low walls (0.3 m); iii) SH = small area (5.3 m^2) with one high wall (1.0 m); and iv) SL = small area (5.3 m^2) with low walls (0.3 m)), all filled with peat, were introduced in the concrete outdoor area. The rooting yards were compared with an outdoor concrete reference pen (R) without a rooting yard (Fig. 10). The pigs had no access to pasture in this comparison.

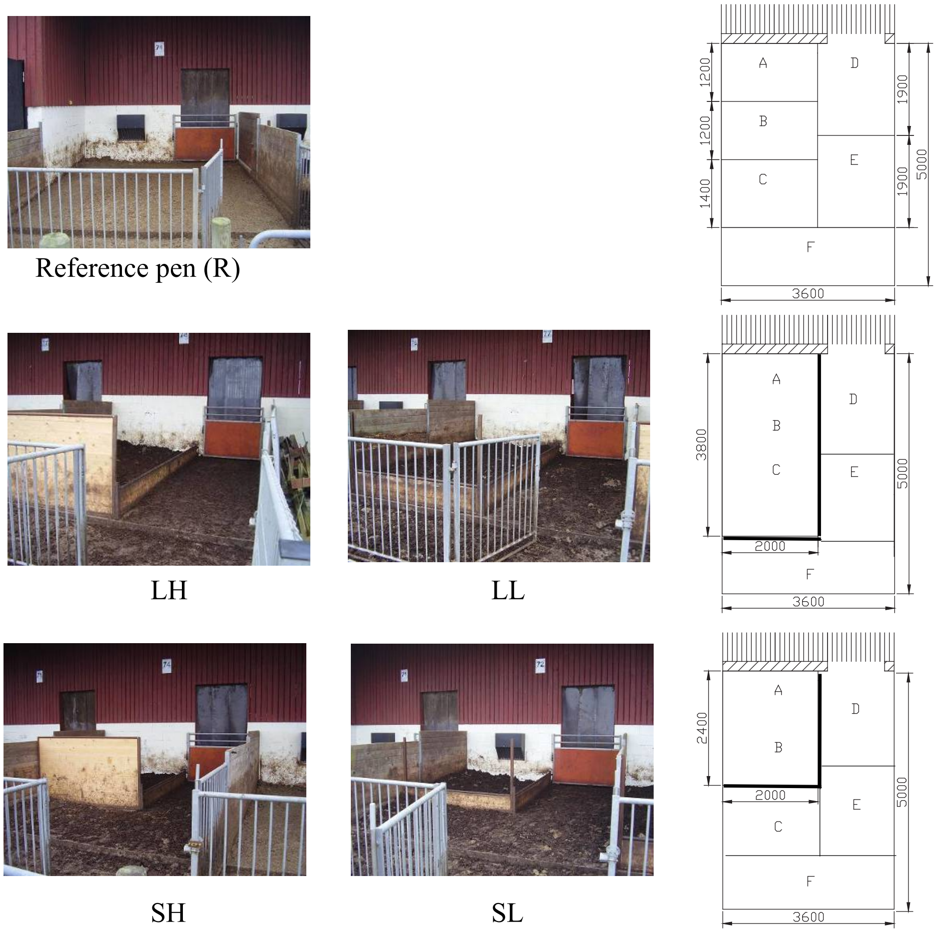

Figure 10. Illustration of the outdoor concrete area with the reference pen (R) and LH (large area and one high wall), LL (large area and low walls), SH (small area and one high wall), and SL (small area and low walls). Hygiene studies and ammonia emission measurements were performed in six different zones (A–F) in the outdoor area. The walls between pens adjacent to zones A–E, were solid, while gates divided the pens adjacent to zone F.

In Paper IV, the most optimal rooting yard design according to the results from Paper III (the LH design), was chosen for six of the eight outdoor pens and different rooting material was studied. Two of rooting yards were filled with wood shavings, two with peat and two with peat + feed pellets. The two other outdoor areas, without rooting yards and rooting materials, were used as control treatments. The pigs had no access to pasture in the study described in Paper IV.

3.2.2 Feed/water allocation and feed recording

In all Papers (I-IV) and all treatments, the pigs were fed simultaneously twice a day, in troughs inside the organic pig house. The daily feed supply was recorded per pen, based on feed volume per pen and volume weight. The values obtained were checked daily against data from load cells under the feed silo. Up to a live weight of 65 kg the pigs were fed semi-*ad libitum*, while thereafter they had restricted access to the feed (2.75 kg/pig/day). All the pigs had permanent access to roughage from the straw bedding and pigs on pasture also had access to grass and roots. Roughage, straw and grass uptake was not recorded.

Water was available for 20 minutes per feeding session via nipples (1 nipple per 2 pigs) placed above the troughs. In addition, water was available for 24 h per day in a drinking bowl in the dunging area indoors.

3.2.3 Feed

In Papers I-II, the pigs were given the same commercial organic pelleted feed for growing-finishing pigs in parallel in all treatments. However, there were some differences in the feed mixture between the pig batches due to seasonal variations in deliveries from the feed company, *e.g.* the metabolisable energy content varied from 12.1-12.7 MJ/kg and the crude protein content from 16.3-17.5%.

In Papers III-IV, the pigs were given a commercial conventional pelleted feed. This was done for economic reasons. Some small differences between different feed deliveries occurred due to seasonal variations. The feed given to the pigs in the batches in Papers III and IV had an average metabolisable energy content of 12.4 MJ/kg and a crude protein content of 14.5%.

3.2.4 Straw

Before introduction of the pigs, straw was spread on the lying area. Additional straw was given once a week in the deep straw pens and twice a week in the straw-flow pens, based on the needs of the pigs. Therefore, more straw was given during the cold periods.

3.3 Observations/recordings

3.3.1 Health, diseases and treatments

The same principle for recording of health and treatments was used in all papers (I-IV). During the entire growing-finishing period, the occurrence of new diseases and treatments were recorded for each pig (Svendsen *et al.*, 1998). If a disease of the same kind was identified more than once in the same pig, there had to be at least a three-week period before the disease was recorded as a new case.

At slaughter, the presence of disease (including carcass and organ inspection) was recorded for each pig at the slaughter house. All pigs that died or were euthanised during the study period were examined *post mortem* and the cause of death/reason for euthanasia, was diagnosed and recorded.

3.3.2 Skin lesions

Skin lesions were recorded in Paper I at 6 and 10 weeks after introduction (17 and 21 weeks of age, respectively). The pigs were examined for the presence of skin lesions, defined as wounds and bruises that could easily be detected by visual inspection in the daytime using a flashlight. The lesions were scored at four positions: head, ears and neck; shoulder and front legs; body; and hams and hind legs, for each pig using a scale from 0-3 (0=no lesion, 3=severe lesion; (Svendsen *et al*., 1992)). The maximum sum of scores (four positions) for an animal was 12 and the maximum mean lesion score for an animal was 3. An average lesion score was calculated for each pen as an average value of all pigs in the pen.

3.3.3 Location and activity of pigs

In Paper I, manual daytime recordings (07.30-16.30 h) of pig location and pig activity were made when the pigs were 17 and 21 weeks old. Recordings of lying or standing/sitting/walking and locations (indoors; lying area, eating/activity area, slatted flooring or outdoors; concrete area, pasture area) were made by two observers (one indoors and one outdoors) at 5-minute intervals.

In Paper III, location, activity and rooting behaviour of the pigs were recorded during a whole 24-h period when the pigs were about 17 weeks old. As in Paper I, the recordings were made by two observers, one indoors and one outdoors. In Paper IV, the manual recording of location and activity of the pigs (no rooting behaviour was recorded in this study) was replaced by 24-h videotaping in the different pens. From the videotapes, the location and activity of the pigs were decoded manually every 5^{th} minute.

3.3.4 Pen hygiene

Studies of hygiene in the whole pen (Paper II) or limited to the outdoor area (Papers III and IV) were carried out once a week during the rearing period. The area studied was divided into smaller observation zones, which were scored subjectively for cleanliness according to a scale from 0 to 2, where 0 = without urine and faeces, 1 = some urine and faeces and 2 = much urine and faeces.

3.3.5 Performance

The same principle for recording performance was used in all papers (I-IV). Individual live weight at introduction and individual calculated live weight at slaughter were recorded. The pigs were sent to slaughter at an average live weight of 115 kg. Live weight at slaughter was calculated using the carcass weight at slaughter, with a dressing percentage of 75.2%. The individual commercial carcass weight and carcass meat percentage were recorded at the slaughter house. The daily feed supply recorded per pen was corrected for dead and euthanised pigs. The performance (daily weight gain and feed conversion ratio (FCR)) was calculated for each pen as an average value for all pigs in the pen.

3.3.6 Temperature

Air temperatures indoors and outdoors were recorded every 10^{th} minute in all studies by means of Tinytag loggers[1)].

3.3.7 Nutrient balances and nitrogen emissions

In Paper II, an entire nutrient balance was calculated for nitrogen, phosphorus and potassium. In order to perform calculations of nutrient balances, all inputs and outputs to and from the system were recorded. Inputs recorded were weight of piglets, total amount of feed and total amount of straw introduced into the individual pens. In the pens with access to pasture, the amount of pasture consumed was determined based on calculations of the amount of potassium in the manure and in the commercial feed ratios and the potassium concentration in the pasture dry matter. Outputs recorded were weight of slaughtered pigs, weight of manure produced (faeces and urine) and weight of left-overs in the pens (deep straw, straw *etc*.). In the pens with access to pasture, manure on pasture was estimated by comparing with pens without access to pasture.

[1)] Gemini Data Loggers Ltd, Scientific House, Terminus Road, Chichester, West Sussex, PO 19 8UJ, UK (www.geminidataloggers.com)

The total amount of feed in the individual pens was determined as described in section 3.2.2. Amount of manure was calculated by collecting and weighing all manure (indoors and outdoors) produced in individual pens during 48 hours every fortnight (eight collections in total). The total amount of faeces and urine produced during the rearing period was then calculated by means of linear regression between the eight sampling values.

Finally, representative samples of manure, feed, straw and pasture and the remaining bedding material were analysed for dry matter, total nitrogen, ammonia-nitrogen, nitrate-nitrogen, total phosphorus and total potassium by a laboratory [2)] certified to ISO 9001:2000 & ISO 14001:2004.

In Papers III-IV, the environmental impact of the organic pig production was limited to ammonia emission from the outdoor area. In those studies, ammonia emission from different zones of the outdoor area were compared by means of a ventilated chamber technique, where ammonia emission were calculated according to a mass balance method using a standardised, equal air flow for all measurements (Jeppsson, 1998). This technique is widely used (Ferm *et al.*, 2000), but has the disadvantage that the ‘real’ air movements (and thereby emissions) are altered when the chamber is placed over the area from which emissions are measured. However, when comparing ammonia emission from different surfaces under the same conditions, it is an advantage that air movements over the area are standardised. Thus, the technique is handy and useful when comparing emission from different surfaces (Jeppsson, 2000).

3.4 Statistical analyses

Most of the statistical analyses were performed using PROC GLM (General Linear Model) in SAS 9.3 for Windows (SAS, 2009). All calculations in SAS were made with pen as the independent unit of observation and the residuals were tested for normal distribution (PROC UNIVARIATE).

Treatment (housing system, pasture/no pasture, design of rooting yard, kind of rooting material) and batch were used as independent factors in the model after tests of non-significant interactions.

[2)] AnalyCen, Estrids Väg 1, 291 65 Kristianstad

4 Results

4.1 Effect of pen design in the pig house

Somewhat more locomotor problems were recorded among the pigs in the deep straw pens than among the pigs in the straw-flow pens. No major differences were detected between the two pen systems with respect to skin lesions. The average skin lesion score was larger at 17 than at 21 weeks of age. No remarks of tail biting or respiratory disease were recorded at slaughter (Paper I).

There were no significant differences in pig activity or pen hygiene between the two pen systems. The hygiene in batches of both pen systems impaired during winter compared to summer (Papers I and II).

Comparison of performance between the two indoor pen systems (deep straw and straw-flow) revealed only minor differences. Pigs from deep straw pens had a significantly ($p=0.029$) lower carcass meat percentage at slaughter than pigs from straw-flow pens. No differences in other performance parameters (DFI), (DWG) and (FCR) were found between the housing systems.

The calculated nitrogen, phosphorus and potassium balances showed similar results in both pen systems. The average amount of nitrogen excreted was 6.0 kg per pig during the growing period in the winter and 4.2 kg per pig during the growing period in the summer. The calculated nitrogen loss (*i.e.* nitrogen emission factor) varied between 26 and 27 % of nitrogen excreted. There was no significant difference in the emission factor between pen systems and between winter and summer periods. Comparisons with standard figures used in conventional pig production indicated three to four times higher nitrogen emissions in the organic system. The amount of phosphorus excreted was 1.2 kg per pig during winter and 1.1 kg per pig during the summer. The amount of potassium excreted was on average 2.0 kg per pig during the winter period and 1.7 kg per pig during summer (Paper II).

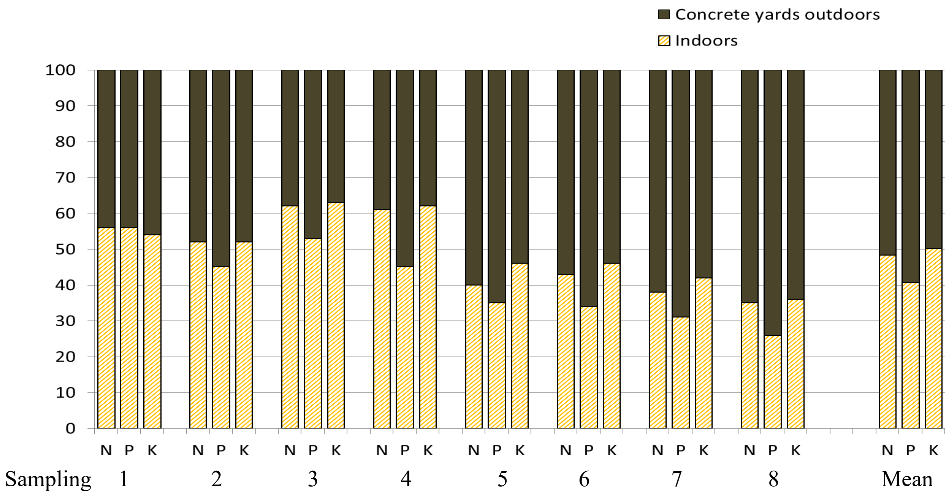

Figure 11. The proportion of N, P and K in total excreted manure, indoors and outdoors at eight fortnight samplings and the mean during the winter period (Paper II).

Nitrogen, phosphorus and potassium distribution varied between indoor and outdoor areas over the rearing period. The proportion of nitrogen, phosphorus and potassium indoors was generally higher in the first part of the rearing period than in the latter part (Fig. 11). Furthermore, the proportion of nitrogen and potassium found indoors were generally higher than that of phosphorus, during both summer and winter periods (Paper II).

4.2 Effect of access to pasture compared with no access

Pigs with access to pasture had a significantly higher prevalence of diarrhoea ($p<0.01$), but no other differences in health and injury observations were observed between pigs with or without access to pasture (Paper I).

At 17 weeks of age, there was no difference in total activity between pigs with or without access to pasture. However, pigs with access to pasture spent more active time outdoors than pigs without access to pasture, and more of time outdoors on pasture compared to on the concrete area (Paper I). At 21 weeks of age, the pigs with pasture access were less active than pigs without access to pasture. The air temperature during these observations was on average 22°C in batch 2 and 16°C in batch 4 and it was observed that the pigs had been active on the pasture already before the behavior studies started at 7.30 h (Paper I).

There was a tendency for better total pen hygiene in summer when the animals had access to pasture, and the size of the fouled area on the outdoor concrete area was significantly smaller when the pigs had access to pasture.

No significant differences in performance were observed between pigs given access to pasture and pigs with no such access (*i.e.* KRAV compared with EU rules). However, there was a trend for pigs with access to pasture to eat less feed and to have higher carcass meat percentage.

The amount of phosphorus that reached the pasture was estimated to 0.6 and 0.3 kg/pig (average 0.5 kg/pig) in the deep straw pens and straw-flow pens, respectively. The corresponding figures for the amount of potassium were 0.9 and 0.2 kg/pig.

The amount of potassium from pasture was estimated to be 0.4 kg/pig in the deep straw pens and 0.1 kg/pig in the straw-flow pens. These figures can be interpreted as an average of 8-9 kg dry matter per pig that was consumed from pasture (Paper II).

The estimated average phosphorus load of 0.5 kg/pig represented a total phosphorus load of approximately 52 kg/ha of pasture for each rearing batch based on the fact that each pig was given a pasture area of 96 m^2.

4.3 Effect of introducing a rooting yard with rooting material in the outdoor area

In Papers III and IV, a rooting yard (Fig. 12) with rooting material was introduced as a measure to improve hygiene and to lower ammonia emission within the outdoor concrete area.

No significant differences were observed in total activity between pigs with a rooting yard outdoors or without (Papers III and IV). But in the pens with rooting yards, the pigs tended (p=0.109) to be more outdoors (Paper IV) and these pigs were significantly more active outdoors compared to pigs in the reference pens. In Paper III, pigs in pens with outdoor rooting yards were active outdoors 7.8 % of observations compared to 5.1 % when pigs had no rooting yard outdoors. In Paper IV, the corresponding figures were 5.8 % and 3.3 % respectively. There was also more rooting behaviour in the pens with rooting yards (Paper III) than in the reference pens. However, no significant differences were found for any behaviour category between large and small rooting yards or between low or high walls (Paper III), or between rooting yards filled with peat, wood shavings or peat+feed (Paper IV). The addition of small amounts of feed pellets in the peat, to make the rooting material more attractive to the pigs, gave no positive effect. Pigs in batches, when ambient temperature was within the thermoneutral zone (= comfortable for the pigs), chose not only to root, but also to lie and rest, in the rooting yard. This trend was observed in both Papers III and IV.

Hygiene was improved in the rooting yard areas compared with the corresponding area of the reference pens (Paper III, Fig. 12). There was also a significant interaction between yard size and wall height, with better hygiene in zone C (Fig. 12) in the pens with a large rooting yard and a high wall, and dirtier in the pens with a small rooting yard and a high wall. No significant differences were found between different rooting materials concerning hygiene in zone A+B+C (Paper IV, Fig. 12). The highest dirtiness scores were recorded in zone F in both Paper III and Paper IV.

The pig performance was not influenced by the introduction, the design of the rooting yards or the rooting material used (peat, wood shavings or peat+feed pellets).

However, daily weight gain was significantly lower in batches with colder (winter/spring) ambient temperature than in batches with higher (summer/autumn) average air temperature (daily weight gain of 775 and 816 g/day, respectively, in Paper III and 749 and 842 g/day, respectively, in Paper IV). In Paper IV, a significant difference in feed conversion ratio (FCR) was also observed between winter and summer batches (3.1 and 2.8 kg feed per pig and day, respectively).

Paper III
Rooting yard in A+B+C or A+B

Paper IV
Rooting yard in A+B+C

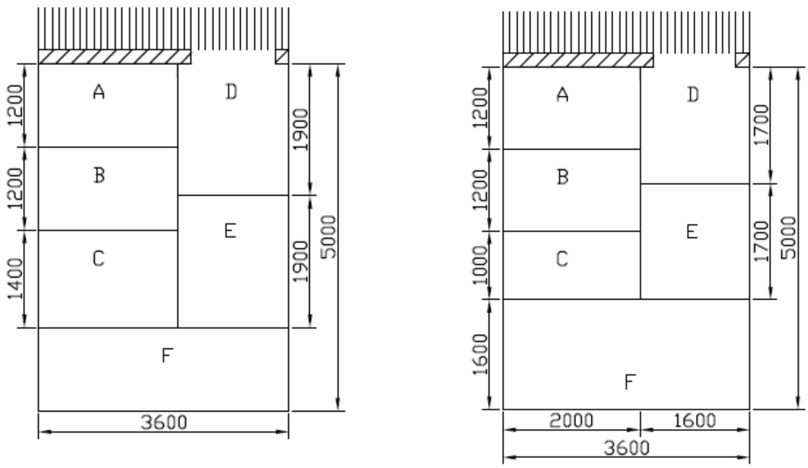

Figure 12. Outdoor concrete area divided into different zones A-F (Paper III and Paper IV).

In Paper III, there was a tendency (p=0.09) for lower ammonia emission in zone A+B (Fig. 13) in the pens with rooting yards, compared to the reference pens. For ammonia emission in zone C (Fig. 13) there was a similar interaction between size and wall height as for hygiene. Since the pigs displayed a preference to excrete behind the high wall, the lowest ammonia emission in zone C was recorded in the treatment with a large rooting yard (A+B+C) and a high wall (LH), while the highest ammonia emission in zone C was recorded in the treatment with a small rooting yard (A+B) and a high wall (SH). In zone F, significantly higher ammonia emission was found in the pens with a rooting yard than in those without. This general shift towards lower ammonia emission in zone A+B (and in zone C for the large rooting yards) and higher ammonia emission in zone F (Paper III) is illustrated in Fig. 13.

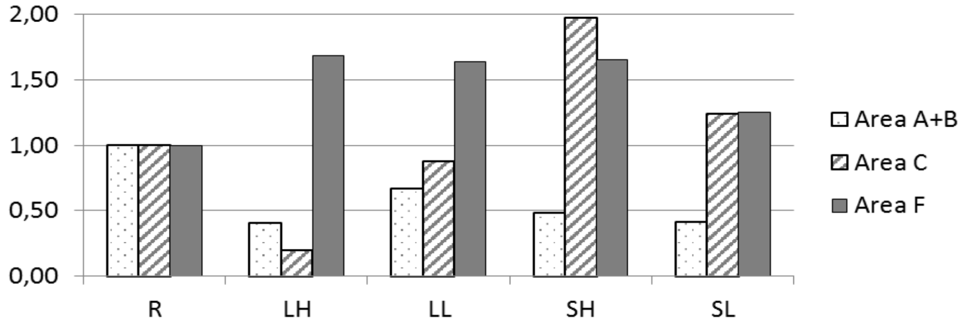

Figure 13. Mean values (uncorrected for size of zone area) of chamber ammonia (NH_3) emission (E_{CH}) of different zones (A+B, C and F) of the outdoor concrete pens with rooting yards of different designs; LH (large area and one high wall), LL (large area and low walls), SH (small area and one high wall) and SL (small area and low walls) expressed in relation to the values of the reference pen (R; Paper III).

In numerical terms, the lowest ammonia emission from the total outdoor concrete area (A+B+C+D+E+F) was found in the pens with a large rooting yard and one high wall (LH), but the difference compared with the reference pens without a rooting yard was not significant (Paper III). When comparing different rooting materials in the rooting yard, ammonia emission from zone A+B+C was significantly reduced when peat was used as the rooting material. When wood shavings were used, the ammonia emission from these zones was significantly higher compared with those from the corresponding zones in the reference pens (Paper IV).

Despite the fact that hygiene was better in summer batches, the ammonia emission data showed the highest values from these batches in both Paper III and Paper IV.

5 General discussion

In today's society, livestock is an increasingly challenged branch of agricultural production. Impact on the environment, animal welfare, and the use of antibiotics are examples of hot topics discussed. Production systems for animals are complex and the conditions provided for the animals during their rearing are vital for their welfare, performance and the utilisation of resources.

Organic production has developed as an alternative to an increasingly intense conventional production. Within organic production, good animal welfare and non-toxic production in harmony with nature are emphasised. Various solutions of organic pig production system exist, *e.g.* stationary systems or systems with huts. Within systems there are also variations in design of huts, pens, feeding arrangements *etc*. Therefore, no general statements on welfare, performance and emissions in organic pig production can be made. Each solution has its own pros and cons considering these parameters and for an even wider concept of 'sustainability'.

In this thesis, different pen systems with different access to outdoor facilities in a stationary production system for organic pigs were compared. The intention was to evaluate the system in a holistic way and to compare with experiences and data from mobile organic systems and from conventional systems. Before the start of the studies, existing experiences were reviewed, different solutions were considered and thorough discussions were made within the project group consisting of people with knowledge of animal husbandry. The project group concluded that an important requirement within an optimal system for organic pig production is the capacity to manage the pigs in an efficient way and to keep work effort and work load at low levels. This is the reason why a decision was made to study a stationary system. The final design of the organic pig house used in the studies reported within this thesis, was developed by the project group. Other important decisions taken by the project group were to work with rather small group sizes, which allowed synchronised feeding in the indoor troughs. Feeding in troughs also made it possible to restrict feed rations at the end of the rearing period to obtain better meat percentage. Therefore, the results in this thesis are linked to these conditions and cannot be extrapolated to *e.g.* larger group sizes with *ad libitum* feeders.

When comparing organic pig production with conventional, one conclusion is that the organic regulations, such as the requirement for the pigs to have outdoor access, to have litter for rooting and to be fed with feed produced organically without addition of synthetic essential amino acids, phytase *etc*., restrict the organic production system in certain ways. It is also quite obvious that welfare, activity, excretory behaviour and performance in pigs, as well as nitrogen emissions from the housing systems, are influenced by factors such as access to and type of rooting material, access to pasture, feeding and manure handling system, temperature *etc*. Examples of conflicting goals between different parameters also arise when a holistic approach is adopted. Such conflicts complicate the task of evaluating the 'sustainability' of a production system.

The original concept of sustainability is based on three pillars: 1) social acceptability, 2) environmental benefits and 3) economic viability. Animal welfare, which is an important ambition in organic pig production, is part of the first pillar, social acceptability. If the public does not accept a particular housing system, management, feeding *etc*., the production system will not be sustainable (Calker *et al*., 2005). However, in organic production animal welfare is often considered to be good, based on the fact that the stocking density is low and that the pigs have a high freedom of movement and access to rooting material (Spoolder, 2007; Lindgren & Lindahl, 2005). Rooting material and roughage are important resources that can influence activity and social interactions between pigs and reduce aggressive and harmful interactions (Petersen *et al*., 1995; Beattie *et al*., 2000; Olsen, 2001; Høøk Presto, 2008). In the studies reported in this thesis, good animal welfare was observed, with no records of tail-biting or respiratory disease at slaughter and skin lesion scores were reduced with age (Paper I). Moreover, the rooting need of the pig seemed to be fulfilled even without a rooting yard in the outdoor area, since the addition of rooting yards did not result in an increase in total rooting behaviour (Paper III). In the studies comparing pigs at 17 weeks of age with or without access to pasture (*i.e.* KRAV or EU rules), there were no differences in daytime activity of the pigs. However, pigs with access to pasture used more active time outdoors on pasture compared to outdoors on the concrete area and active time indoors (Paper I). Furthermore, the performance was not affected by the access to pasture or not. Thus it can be concluded that the energy from assumed pasture consumption appeared to be sufficient to cover possible extra energy expenditure by the walking, grazing and rooting on the pasture.

Compared with conventional pig production, the greater freedom for the animals and the increased opportunities for rooting provided in organic production can be taken to indicate that organic pigs have better welfare. Moreover, within Swedish organic production there is no major difference regarding area per pig and access to rooting facilities between stationary and mobile systems. However, animal welfare is not only influenced by the housing conditions, but also how the animals are managed. Good management is probably easier to maintain in a stationary system than in a mobile system when wind and weather and other conditions are harsh.

The sustainability pillar of social acceptability also involves parameters such as biosecurity, use of antibiotics, work load and work effort. Biosecurity includes both external (between the farm and the surroundings) and internal (between compartments within the farm) biosecurity (Boklund et al., 2004; Laanen et al., 2013; Ribbens et al., 2008). The success of biosecurity within an individual pig farm is affected by, among other factors, management principles, housing (Fablet et al., 2012) and density of animals on the farm (Tilman et al., 2002). The basic principles of internal biosecurity at the farm level include segregation, cleaning and disinfection. A production system according to these principles is often also called an “all in-all out” system or a batch system (Lurette et al., 2008) and such systems are equally common in organic and conventional production. However, because organic pigs have to be allowed outdoors, the external biosecurity is weaker than in conventional pig production since organic pigs come into contact with birds, foxes, wild boars *etc*. (Edwards, 2005; Collins et al., 2007). Therefore, external biosecurity in organic pig production must be characterised as doubtful, since it is impossible to keep the pigs out of contact with wild animals in nature (Edwards, 2005). Some differences between stationary systems and mobile systems in this regard can be identified, e.g. biosecurity is considered to be somewhat better if feed is given indoors. In closed conventional herds, it is possible to keep external biosecurity at a good level. On the other hand, the stocking density in organic herds is lower and no serious disease problems were observed either in this thesis or in other studies (Lindgren et al., 2014). The use of antibiotics also has to be kept to a minimum in organic systems, most often with a double withdrawal period prior to slaughter (KRAV, 2014) compared with in conventional herds.

In terms of work load and work time, Geng & Torén (2005) concluded that there is a higher risk of accidents and ergonomic load in a mobile system than in a stationary system. This is due to more manual work with feeding and watering, since automation is more complicated in mobile systems. A separate evaluation of workload and working time in the stationary system (studied but not published in the thesis) concluded that the values were acceptable (Olsson *et al*., 2007). On average, working time was calculated to be 32.6 min per pig during summer with access to pasture, 25.6 min per pig during summer without pasture and 26.5 min per pig during winter. Another Swedish study (Persson, 1998) estimated that the labour requirement in organic outdoor systems with huts was about 90 minutes per animal produced. In conventional pig production, the working time was estimated to be 10-14 minutes per slaughter pig (Mattsson *et al.*, 2004).

The second pillar of the sustainability concept is the environmental impact. The nutrient balance calculations in this thesis (Paper II) showed approximately three to four times higher nitrogen emissions in the organic system than the Swedish standard figures used for conventional pig production (Swedish Board of Agriculture, 2005). Three different reasons for this result were identified: 10% greater feed usage (factor of 1.2), 15% higher crude protein level (factor of 1.3) and a much larger fouled area, especially outdoors (factor of 2.3). The problem with poor hygiene in the outdoor area and measures to handle this have been described in other studies (Vermeer *et al*., 2015; Ivanova Peneva, 2006).

In conventional livestock production, nitrogen emissions from livestock housing mainly consist of ammonia (Jongebreur & Monteny, 2001). To make standard calculations of ammonia emission from different species, different types of manure and housing systems, all European countries use their own calculation models and national data (Eurostat, 2011). The models are often based on calculations of nitrogen flow and the use of so-called ammonia emission factors (Velthof *et al*., 2012) or conversion factors (IPCC, 2006). The models and ammonia emission factors have to be updated in line with improvements in production systems, feeding and manure handling *etc*. in each country. The most recently updated model in Sweden for calculation of ammonia and greenhouse gas emissions is called VERA (Swedish Board of Agriculture, 2016). In VERA, ammonia emission is calculated as percentage of total amount of nitrogen excreted by the animal. However, an even more accurate calculation method/model is to use the ammonia emission factor based on total ammoniacal nitrogen (TAN; ammonium-nitrogen + nitrogen compounds that are easily broken down to ammonium), instead of total nitrogen. Use of TAN is an improvement, since there is a better correlation between ammonia emission and TAN than between ammonia emission and total nitrogen content in excreta (Velthof *et al*., 2012). Models with TAN are currently used in the Netherlands (NEMA (Velthof *et al*., 2012) and to some degree in Denmark (Damgaard Poulsen, 2014).

The models for standard calculations of ammonia emission are based on many years of research under different conditions. However, in research reports the ammonia emission factor is rarely stated. Instead, a 'real' unit of ammonia emission is given, *e.g.* grams of ammonia per unit area and time. The ammonia emission can also be expressed over a certain period, *e.g.* kg ammonia per slaughter pig or per pig place and year. Use of these different units can lead to some confusion and recalculations are needed when trying to compare different figures. Thus based on the work in this thesis, it can be recommended that researchers reach some agreement about a 'standard' unit that is always used when reporting research.

In Paper II, the nitrogen balance was used to calculate a 'standard' ammonia emission factor for the stationary organic housing system tested. However, attempts were also made to recalculate this figure to ammonia emission per unit area and time. This resulted in an ammonia- nitrogen emission value of on average 4.5-5.6 g/day/m^2 floor area for the entire rearing period. This agrees well with findings in an investigation of nitrogen losses from organic pig production in the Netherlands (Ivanova Peneva *et al.,* 2006b), where ammonia-nitrogen emission from "clean" surfaces in the pens were found to be 1.9-2.7 g/day/m^2 and emission from "dirty" surfaces were 11.4-13.3 g/day/m^2.

The figures above reflect the importance of hygiene in pig pens (Aarnink *et al*., 1997). It is already a well-known fact that the emitting surface area is an important contributing factor for emissions (Philippe *et al*., 2011), but the importance of hygiene should be taken even more seriously and be used to guide management efforts in a more effective way in practice. The correlation between ammonia emission and fouled area in a pig pen could also be used as an important argument explaining why pen 'function' has to be considered and why it is important to have some knowledge about the excretory behaviour of pigs when designing pig pens. To some extent, hygiene studies could possibly also be used to predict ammonia emission.

In Paper III, a rooting yard with a rooting material was used as a measure to improve hygiene in the outdoor concrete area. Existing knowledge about where pigs want to excrete, in combination with knowledge about pig rooting behaviour, was used to formulate a hypothesis. The best solution was concluded to be the introduction of a large rooting yard with one high wall. The effort to improve the cleanliness outdoors and to direct the excretions of the pigs into a smaller sub-area in the outdoor area then proved successful.

However in Paper IV, it was found that hygiene studies are only a rough method to evaluate excretion of pigs in a pen. The measurements of ammonia emission indicated that the introduction of a rooting yard made it possible to direct the defecation, but not the urination to the same extent. Due to the chemical properties of the rooting material, the conditions in the outdoor area deteriorated when a rooting yard with wood shavings was introduced. This was an unpleasant surprise, but shows the complexity of different factors working together. On the other hand, a rooting yard with peat, a material with low pH and high water- and ammonia-binding capacity, seemed to be a good solution for reducing ammonia emission from the outdoor area. Thus, there is no clear-cut relationship between pen hygiene and ammonia emission. Depending on the choice of rooting material used to cover parts of the floor area in a pig pen, ammonia emission might be influenced to a large degree. The chemical properties of the rooting material provide a clue to their suitability in this aspect.

Introduction of a rooting yard in the outdoor concrete area or the rooting material chosen for this area did not influence performance, total activity or total rooting activity. However, when pens were enriched with the rooting material, the pigs tended to spend more time outdoors than when no rooting material was present.

An indication that the excretory behaviour of pigs has to be divided between defecation and urination was provided in Paper II, where it was concluded that pigs appeared to be more likely to walk farther away from the lying and eating area for defecation than for urination.

As already mentioned in the introduction, both ammonia and nitrous oxide emissions may occur from various kinds of litter systems (Eriksen *et al*., 2002; Rigolot *et al*., 2010). Measurements of nitrous oxide emissions were not included in this thesis, but were conducted in a pilot project performed in parallel with this thesis work. According to the results of that project, the nitrous oxide emission was higher from rooting yards with wood shavings than from rooting yards with peat or from reference pens without rooting yards (Botermans *et al*., 2010). Thus, even in this aspect wood shavings seem to be the least good alternative to use as rooting material from an environmental point of view. Therefore, use of wood shavings in outdoor rooting yards cannot be recommended to organic pig producers, even though waste wood chips from the farm is a possible alternative among farmers.

The third pillar in the sustainability concept is economic viability, which was not evaluated in this thesis. However, as in conventional production the financial return is the net result of the income from produced pork and the costs of feed, buildings and labour. Therefore, parameters such as feed conversion ratio, meat percentage, working time per pig produced *etc*. are equally important in organic as in conventional production. During the past forty years (Rhodes, 1995), conventional pork production has experienced major and tough changes. The global competition is harsh (Béranger, 2001), and price difference between conventional meat in relation to organic meat is considerable. One way for smaller pig producers to strengthen their economy and generate more income from the farm has been to find niche markets with better prices. Therefore, some pig producers perceive organic production as a more profitable option (von Borell & Sørensen, 2004). The price of organic pig meat in Sweden is good at the moment and the demand from consumers is increasing. On the other hand, the Swedish organic pig meat sector is very small (Swedish Board of Agriculture, 2014, 2015) which makes it uncertain and vulnerable to small changes. In an economic comparison some years ago, when the price of organic pig meat was lower, it was concluded that organic production according to EU rules was more profitable than production according to the Swedish KRAV rules (Botermans & Olsson, 2007). At that time, premium price paid for KRAV meat did not pay for the extra work with fences *etc*. when keeping pigs on pasture. Comparisons between organic pig productions according to EU or KRAV rules are also dependent on the farm-specific price of pasture, which can vary a great deal due to differing costs for land in different regions. The price placed on land and housing is another very relevant issue when comparing economic viability between stationary and mobile organic systems. However, as already mentioned, at the moment the price of organic pig meat is high and the KRAV price is better than in 2007.

To sum up, there are pros and cons with both organic and conventional pig production in all three pillars of sustainability. However, the weakness of organic pig production concerning higher ammonia emission (within the second pillar of sustainability) is troublesome. But, it should be borne in mind that the results on ammonia emission presented in this thesis only comprise pig rearing in a stationary system for organic growing-finishing pigs. An overall evaluation of the environmental impact of such a system should also include feed production. The fact that feed production in an organic system is performed without use of artificial fertilisers, herbicides and pesticides and with a "sustainable" relationship between livestock production and land is positive (Basset-Mens *et al*., 2003). Yet, despite this, several previous studies have not found any environmental benefits of organic pig production compared with conventional, but rather the opposite (Carlsson *et al*., 2009; Halberg *et al*., 2007; Kool *et al*., 2009; Tuomisto *et al*., 2012). In this thesis, measures to decrease the ammonia emission from concrete outdoor areas were tested. Introduction of rooting yards, filled with peat, showed positive results, reducing ammonia emission by about 20-40%, depending on if the ammonia emission figures were corrected for size of zone or not. However, this reduction was not statistically significant.

5.1.1 Methodological considerations

The behaviour studies carried out in this thesis were not of a detailed character, because behaviours such as redirected behaviour and aggression were not expected to be a great problem in organic pig pens with sufficient space and access to rooting materials. Instead, the purpose of the behaviour studies performed was to study the dynamics of pigs in pens providing different possibilities and choices (pen solutions/pasture or no pasture) and different rooting materials to occupy the pigs. This is why instantaneous scan sampling was performed instead of, for example, focal-animal sampling (Lehner, 1987). Scan sampling is efficient when the aim is to study many pigs in parallel. However, the methods used for the samplings varied in the different papers.

The behaviour sampling reported in Papers I and II were performed manually every 5th minute by two observers during daytime (07.30-16.30 h) and repeated twice during the rearing period (at 17 and 21 weeks of age). The advantage with this method is that it does not require too much planning in advance and that it is possible to cover large study areas (for example pasture fields outside). Similar methods have been used in other studies when studying standing, walking and lying (Benfalk *et al.*, 2005). However, this kind of behaviour study requires a great deal of man hours, which often precludes observations running over longer periods of time, such as throughout whole 24-h periods which was made in Paper III. The fact that there are some hours of darkness during each 24-h period is another problem for outdoor studies. When behaviour studies are not performed during whole 24-h periods, some information, that might be of great interest may be lost.

In Paper IV, the manual samplings on site were replaced by video recordings, which make it possible to save work hours during the studies. However, it requires quite a lot of time to set up, take down and move video cameras between pens, to save the recordings into the computer and finally to decode the material after the studies have been completed. Decoding of video recordings is time-consuming and monotonous work. There are also limitations on the number of cameras that can be used and the size of the study area that can be monitored. Video recording, when trying to follow pigs on pasture during bad rainy weather is another challenge. On the other hand, when pig behaviour is saved as video recordings, it is possible to go back and check different details more thoroughly.

Different methods were used to evaluate nitrogen emissions in Papers II-IV. The most comprehensive evaluation was performed in Paper II, when a so-called mass balance of nitrogen was generated. With this kind of evaluation an overall picture of the nitrogen flow in the system is provided, but the use of such a method in a housing system for pigs is demanding. Determining the total input of nitrogen to the system means calculating the nitrogen content in piglets, feed and straw used, in which access to accurate data is very important. Similarly, determination of the total nitrogen output means calculation of the nitrogen content in manure, slaughter pigs and straw leftovers at slaughter. Measuring the amount of nitrogen in faeces and urine produced by the pigs is not easy. In Paper II, this was done by collecting, weighing and sending samples for analysis to the laboratory every second week during the rearing period. To get accurate figures on how much nitrogen is produced in the manure, collection of urine and faeces in the pens, weighing, mixing of the different fractions and taking out representative samples for analysis must be performed very carefully. The difference between nitrogen input and output in a mass balance calculation then gives the nitrogen emissions. The same principle can be used for other compounds that may be of a volatile nature. Naturally, the precision of the calculations is dependent on the accuracy of input and output data, recording, sampling and laboratory analyses. As already mentioned, taking representative samples of manure for sending to the laboratory is a challenge and how well this task is performed affects the reliability of the results.

By making parallel mass balances for both volatile and non-volatile nutrients, it is possible to get more information about sampling and analysis errors (Hassouna & Eglin, 2015). Since mass balances for phosphorus and potassium were calculated in parallel with the nitrogen balance in Paper II, this possibility was exploited in this thesis. The precision in the mass balance calculations was estimated to be -6% for the growing period during the winter and +6 to +17% for the growing period during the summer. For the summer batch, this indicated a systemic error, which was possibly due to a portion of the phosphorus and potassium remaining on the concrete yards during the warm summer days where there was a high level of evaporation.

In Papers III and IV, the recordings of nitrogen emissions were limited to measurements of ammonia emission from the outdoor area. As described in the introduction to this thesis, ammonia emission from a surface or an animal house can be measured and calculated in a number of ways. In principle, by measuring the concentration of a compound in an air sample and then considering the air flow, the emissions can be calculated. In uninsulated buildings, determining air flow is complex. On the concrete area outdoors, air flow may vary widely between time and position. Therefore, the method with closed dynamic sampling chambers (see explanation in the introduction) was used in this thesis to measure ammonia emission from different zones in the outdoor area. In a closed dynamic sampling chamber, the air flow through the chamber is kept at a standardised, constant level. In the present case, the air flow through the chamber was set to 65 $m^3/m^2/h$. Use of a closed dynamic sampling chamber is suitable when the aim is to compare the ammonia emission from different emitting surfaces. However, since the “real” emission is not measured, only relative values for different surfaces can be assessed.

5.1.2 Practical implications

Use of a stationary housing system in organic pig production seems to be a good solution in regard to keeping the work load and work time at a reasonable level. For example, it allows feeding, checking and weighing of the pigs to be made indoors, which is practical and to some extent reduces the contact between feed and other living animals outside in nature. Furthermore, the meat percentage is an important economic parameter in organic pig production and there are better conditions for efficient feed management if feeding takes place indoors.

However, providing the pigs with access to pasture according to the Swedish KRAV rules may be more complicated with a stationary system than with a mobile system. A stationary system (*i.e.* pig house) has to be placed with access to different pasture areas in different years. In organic production according to the EU rules, no pasture area is needed.

To minimise ammonia emission from the system, it is as important in organic pig production as in conventional to strive for maximum efficiency in terms of feed conversion ratio. However, it is probably not possible to get the same FCR in organic pig production with or without pasture as in conventional, since organic pigs move over larger areas and live in a colder environment than conventional pigs. This will always result in a higher feed consumption per kg of growth, with larger differences in winter batches than summer batches.

Ammonia emission is also influenced by the higher crude protein content in organic feed compared with conventional feed. This is because use of synthetic essential amino acids, *e.g.* lysine, the first limiting amino acid in pig feed, is not allowed in organic production. Whether this rule within the organic regulations should be modified or whether synthetic lysine can be produced in a more ‘organic’ way in the future was an issue beyond the scope of this thesis. Nevertheless, changes in this direction would be desirable.

Giving organic pigs a larger area to live in also results in a larger area being fouled with faeces and urine. This is a particular problem with outdoor concrete areas. By making the outdoor area more fun and exciting for the pigs, this area can be used for more than excretion.

Introduction of a rooting yard with rooting material outdoors substantially improved the hygiene in all the outdoor area. However, measurements of ammonia emission from this area revealed an annoying discrepancy between the subjective perception of cleanliness and actual ammonia emission. The practical implication of this is that measures to direct the excretory behaviour of pigs have a significant effect on defecation, while it appears to be much more difficult to direct the urination of pigs. Instead, it was found that the chemical properties of the rooting material were the most important parameter for decreasing the ammonia emission from the outdoor area. When peat was used as a rooting material ammonia emission decreased, but when wood savings were used the ammonia emission was higher than in the reference pens without litter. Therefore, a practical recommendation from the work in this thesis is that wood shavings should not be used as a rooting material, even though they provide a good impression in subjective terms and may be ready available.

The problem with higher ammonia emission in organic pig production identified in this thesis is largely due to the fact that organic pigs have more space in which to move around. However, giving pigs more space and the possibility to move around more freely is one of the fundamental concepts within organic pig production. It is also undoubtedly positive for the animals. Thus, this is a good example of a complicated goal conflict that must be debated and resolved in future to promote the concept of sustainability.

To achieve economic viability in production, which is the third pillar of sustainability, it is as important in organic as in conventional production to keep feed, litter and labour costs low and get the highest possible price per kg pork produced. The preconditions for achieving these goals were assessed as good in the tested stationary system and two pen designs. However, it is generally considered difficult to get the feed conversion ratio in organic pig production as low as that in conventional production. Ambient temperature influences feed conversion ratio, *e.g.* the stationary organic system studied here showed higher feed consumption per kg of growth during winter than summer batches.

5.1.3 Summary in a holistic perspective

- Animal welfare in the stationary housing systems for organic pigs tested was considered good. No tail biting was recorded and there were few skin injuries from aggression. This is a positive finding within the sustainability pillar of social acceptability.

- The nitrogen emission factor in the stationary housing systems was calculated to be 26-27% of excreted nitrogen and was similar for winter and summer batches. This gives approximately three to four times higher ammonia emission than standard values from conventional pigs when assuming that all losses consist of ammonia and is a negative finding within the sustainability pillar of environmental benefits.

- To achieve economic viability in production, which is the third pillar of sustainability, it is as important in organic as in conventional production to keep feed, litter and labour costs low and get the highest possible price per kg pork produced. The preconditions for achieving these goals were assessed as good in the tested stationary system with either of two pen designs. However, it is generally considered difficult to get the feed conversion ratio in organic pig production as low as in conventional production. Ambient temperature influences FCR, *e.g.* the stationary organic system studied here showed a higher feed consumption per kg of growth of the winter than of the summer batches.

6 General conclusions

- No major differences were observed between deep straw and straw-flow pens regarding daytime pig activity, health, and pen hygiene. Pigs from deep straw pens had a significantly lower carcass meat percentage at slaughter than pigs from straw-flow pens.

- Under moderate temperatures, organic pigs given access to pasture and fed a commercial organic feed indoors were not more active during daytime than organic pigs without access to pasture. Pigs with access to pasture used more active time outdoors than pigs without access to pasture and on pasture compared to the concrete area.

- No difference in performance was detected between pigs with or without access to pasture. Thus, the energy from assumed pasture consumption appeared to be sufficient to cover possible extra energy expenditure by the pigs in walking, grazing and rooting.

- Calculations of nitrogen balance showed an average nitrogen excretion per pig of 6.0 and 4.2 kg during winter and summer batches, respectively.

- The nitrogen emission factor in the stationary housing systems was calculated to be 26-27% of excreted nitrogen and was similar for winter and summer batches. This gives three to four times higher ammonia emission than the standard values used in conventional pigs when assuming that all losses consist of ammonia.

- The higher ammonia emission in the organic system was explained by a 10% higher feed use (factor of 1.2), 15% higher crude protein level (factor of 1.3) and a larger fouled area (factor of 2.3), especially outdoors. The results from the nitrogen, phosphorus and potassium balance calculations suggested that pigs appeared to be more willing to walk farther away from the lying and eating area when they defecated than when they urinated.

- Introduction of a rooting yard in the outdoor area did not influence total activity, total rooting activity or performance. The rooting yard improved hygiene and the occupation of pigs in the outdoor area, especially when the rooting yard had a design with one high wall and enriched with rooting material. However, the variation was high and conditions such as outdoor temperature influenced the choice made by the pigs.

- There was a tendency for lower ammonia emission when peat was used as rooting material. When wood shavings were used, ammonia emission increased and was even higher than in the reference pens without rooting area.

7 Future research

This thesis provide new information about pig behaviour and performance, nitrogen, phosphorus and potassium balances and measures to reduce ammonia emission in a stationary system for production of organic growing finishing pigs. However, there are still questions to answer and new issues arose during the work. Some examples of questions to be answered in future work are:

- Would a different design of stationary system, for example a system with larger pig groups and a non-synchronised feeding system in *ad libitum* feeders, influence activity, performance, hygiene and ammonia emission?

- Does use of the "Circle of Sustainability" for comparing conventional and organic growing finishing pig production give a better overview of goal conflicts and result in a more systematic comparison?

- What differences are revealed by Life Cycle Analysis of acidification in a stationary system for organic pigs with rooting yards and peat in the outdoor area and a similar system without such enrichment in the outdoor area?

- Does introduction of rooting yards with peat in the outdoor area result in any methane and nitrous oxide emissions worthy of concern?

- Are there other rooting materials that can be produced on-farm and give similarly positive results as peat?

- Defecation of pigs can apparently be directed by housing arrangements, while urination appears to be more complicated to influence. Some studies of defecation/urination (excretory behaviour) in pigs have been performed, but more detailed studies in organic housing systems are needed to explain the effect of age, group size, ambient temperature, enrichment or not in the outdoor area, time during the 24-hour period, light in different areas, gender *etc*. on where in the pen pigs choose to urinate and defecate.

- Can lysine and phytase be produced in an "organic" way for use in organic feed?

- Can adjustment of the relationship between essential amino acids and energy in the feed between winter and summer batches (lower ratio in the winter than in the summer) influence organic pig performance and ammonia emission?

- Ammonia emission from solid concrete floors, both indoors and outdoors, seems to be a problem area not only in organic pig production. Therefore more efforts are needed to find cost-effective technical or management-related measures to improve hygiene and reduce ammonia emission from solid floors in conventional and organic livestock production (more frequent scraping, solar-driven cooling systems?).

8 Populärvetenskaplig sammanfattning

Det finns ett ökande intresse för ekologisk grisproduktion bland både producenter och konsumenter. Höga krav på djurens välbefinnande och hälsa i en naturlig miljö är primära mål i ekologisk grisuppfödning. Produktions- och inhysningssystem i ekologisk grisproduktion kan dock variera avsevärt och kan delas in i tre kategorier; stationära system med permanenta byggnader med betongytor och/eller betesmarker utomhus, mobila system i hyddor utomhus och blandade lösningar med både byggnader och hyddor.

I denna avhandling har ett stationärt system för ekologiska slaktgrisar undersökts ur olika perspektiv. Alla studier i avhandlingen (artiklarna I-IV) har utförts i ”Eko-stallet” på Odarslövs försöksgård för gris vid Sveriges Lantbruksuniversitet (SLU) i Alnarp. Eko-stallet bestod av en oisolerad byggnad med naturlig ventilation (glespanel och öppen nock) och 8 boxar à 16 grisar d v s totalt 128 grisar per uppfödningsomgång. Boxarna i stallet hade två olika utformningar. Fyra boxar hade djupströ av halm på liggytan medan liggytan i resterande fyra boxar utformats som en hydda med tak och halmströdd golvyta. Halmen i hyddan hölls kvar med en 20 cm hög tröskel. Utanför hyddan hade golvet en kraftig lutning så att den halm grisarna drog ut ur hyddan kunde ”flyta” mot gödselytan. Därför benämndes denna boxtyp för ”straw-flow”. Till var och en av de åtta boxarna fanns också en hårdgjord betongplatta med gödselkulvert utomhus. Under sommartid hade grisarna i hälften av boxarna (två djupströ-boxar och två straw-flow boxar) dessutom tillgång till beteshagar utomhus.

I artiklarna I-II gjordes jämförelser mellan de två boxtyperna samt om grisarna sommartid hade tillgång till bete eller inte. Resultaten visade att grisarna i djupströboxar hade en något lägre köttprocent i slaktkroppen jämfört med grisarna från straw-flow boxarna (56,6% mot 57,3%). Bland grisarna i djupströboxarna noterades också något fall av rörelseproblem, vilket inte registrerades i straw-flow boxarna (4,4% jämfört med 0%). Däremot sågs ingen skillnad i djurens aktivitet under dagtid (07.30-16.30) mellan boxtyperna.

I uppfödningsomgångar med måttliga utomhustemperaturer och vid tilldelning av det ekologiska fodret inne i byggnaden, påverkades inte grisarnas totala aktivitet under dagtid av om de hade tillgång på bete eller inte. Vid 17 veckors ålder var samtliga grisar aktiva ca 45% under dagtid. Grisarna utan tillgång till bete var aktiva inomhus 33% av tiden och på betongytan utomhus under 12%. Grisarna med bete var mer aktiva utomhus varav 21% på betet, och 4% på betongytan. Ingen skillnad i produktion registrerades mellan grisar med respektive utan bete. Detta tolkade vi så att energin från beteskonsumtionen kompenserade djurens eventuella extra energiåtgång för att röra sig och böka på betet.

Boxhygienstudier, N, P och K- balanser och beräkning av kväveemission utfördes under två uppfödningsomgångar; en vintertid och en sommartid. Det registrerades ingen signifikant skillnad i boxhygien mellan de två boxsystemen. Sommartid var dock betongytan utomhus renare när grisarna hade tillgång till bete. Emissionsfaktorn, d v s den procentuella förlusten av kväve i form av emission i förhållande till totalmängden kväve en gris utsöndrar under en uppfödningsomgång (=kväve ”bakom svans”), beräknades till 26-27%. Emissionsfaktorn var densamma under både vinter- och sommartid. Däremot var mängden kväve ”bakom svans” högre vintertid jämfört med sommartid (6,0 kg N jämfört med 4,2 kg N). Detta motsvarar ett kväveutsläpp av 1,5–1,6 kg N per gris under vintern och 1,1–1,2 kg N per gris under sommaren. Skillnaden beror främst på en högre foderkonsumtion och en större användning av halm under vintern. Om man antar att hela den beräknade emissionen utgörs av ammoniak, innebär detta en 3-4 gånger större ammoniakemission hos ekologiska grisar jämfört med schablonberäkningar för konventionella grisar. Vi kom fram till att en 10% högre foderförbrukning förklarade skillnaden i kväveutsläpp med en faktor av 1,2, en 15% högre råproteinnivå förklarade skillnaden med en faktor av 1,3 och en betydligt större gödselbemängd yta, särskilt på betongytan utomhus , förklarade skillnaden med en faktor av 2,3.

I artiklarna III-IV studerades åtgärder för att förbättra hygienen och minska ammoniakemissionen från betongytan utomhus. Genom att introducera böklådor med bökmaterial på denna yta var förhoppningen att grisarna skulle koncentrera sin gödsling och urinering till ett mindre område utanför böklådorna. Ett sådant förbättrat gödslingsbeteende skulle förhoppningsvis också leda till en lägre ammoniakemission.

Första steget var att utforma en optimal böklåda. I artikel III jämfördes fyra olika böklådor (LH = stor yta (8,4 m^2) med en hög vägg (1,0 m); LL = stor yta

(8,4 m^2) med låga väggar (0,3 m); SH = liten yta (5,3 m^2) med en hög vägg (1,0 m) och SL = liten yta (5,3 m^2) med låga väggar (0,3 m)) med en kontrollbox (R) utan böklåda. Samtliga böklådor i denna studie var fyllda med torv. Den stora böklådan med en hög vägg (LH) gav bäst resultat i hygienstudierna och även den lägsta uppmätta ammoniakemissionen.

I nästa steg (artikel IV) jämfördes betongytor utomhus försedda med stora böklådor med hög vägg (LH) och fyllda med olika bökmaterial (torv, spån och torv + foderpellets), med kontrollboxar utan böklådor och bökmaterial. Från beteendestudier konstaterades att grisarna uppfattade alla de testade bökmaterialen som attraktiva eftersom de oftare tenderade vara utomhus i boxar med böklådor. Den subjektivt värderade renheten konstaterades också betydligt bättre på utomhusytorna då det fanns böklådor med bökmaterial jämfört med i kontrollboxarna. Ammoniakemissionsmätningarna visade däremot inte på korresponderande resultat. Störst reduktion av ammonakemissionen registrerades då torv användes som bökmaterial, medan användning av spån resulterades i större emission jämfört med i kontrollboxarna. Tillsats av små mängder av foderpellets i torven, för att göra bökmaterialet mer attraktivt för grisarna, gav inte någon större positiv effekt.

Uttrycket ”hållbar utveckling” är ett populärt begrepp och används i en mängd olika sammanhang i dagens samhälle. Begreppet har sitt ursprung i den s.k. Brundtlandrapporten ”Our Common Future”, som utarbetades av FN:s Världskommission för miljö och utveckling år 1987. I denna rapport definierades en ”hållbar utveckling” som en ”utveckling som tillfredsställer dagens behov utan att äventyra kommande generationers möjligheter att tillfredsställa sina behov”. Sedan dess har begreppet vidareutvecklats och numera anses det innehålla minst tre olika dimensioner; 1) en social dimension, 2) en miljödimension och 3) en ekonomisk dimension. Begreppet “hållbarhet” har alltså en komplex mening och innebär en kombination av olika heterogena mål.

Appliceras begreppet på ekologisk grisproduktion kan en precisering vara att produktionen ska vara socialt accepterad med god djurvälfärd, god djurhälsa och säkra produkter, utförd av arbetskraft som trivs med sitt arbete och inte upplever för stor fysisk eller psykisk arbetsbelastning. Samtidigt ska produktionen bedrivas effektivt, ha en låg miljöpåverkan och ge tillräckliga inkomster så att även producenterna kan ha ett bra liv.

Hur hållbart kan då det studerade stationära systemet för ekologisk grisproduktion bedömas vara? På denna frågeställning går det att svara både positivt och negativt beroende på vilken dimension som beaktas. Grisarnas stora rörelsefrihet och tillgång till bökmaterial måste ses som positivt för djurens välfärd och för den sociala acceptansen av produktionsformen. Inga svansbitningsproblem, inga allvarliga hälsoproblem och få hudskador från aggressioner bland djuren är andra positiva resultat från det studerade systemet. Däremot innebär produktionsformen att det är problematiskt att upprätthålla ett optimalt smittskydd eftersom djuren vistas ute och därmed kommer i kontakt med fåglar och andra frilevande djur. Dock tilldelas foder och vatten inomhus, vilket ger ett visst skydd både mot smittor men även mot dåliga väderleksförhållanden. Foder- och vattentilldelning inomhus innebär också att dessa arbetsuppgifter kan mekaniseras, vilket underlättar arbetsinsatsen och minskar den fysiska arbetsbelastningen. De enklare, oisolerade byggnaderna och den därmed lägre omgivningstemperaturen resulterar dock i att ekologiska grisar i genomsnitt kräver mer underhållsfoder. Därmed blir foderförbrukningen högre än i konventionell produktion. Då råproteinhalten i ekologiskt foder, p g a förbud mot användning av syntetiska aminosyror, är högre än i konventionellt foder, blir mängden utsöndrat kväve per slaktgris också högre för ekologiska grisar än för konventionella. I system med fastgödselhantering, som i ekologisk produktion, är ammoniakemissionsfaktorn också högre jämfört med i flytgödselsystem, som i konventionell produktion. Tillsammans resulterade allt detta i en 3-4 gånger högre ammoniakemission än vad som beräknas från konventionella produktionssystem för gris. Detta är naturligtvis negativt för miljödimensionen i begreppet ”hållbarhet”. Det ska dock påpekas att någon helhetsbedömning mellan konventionell och ekologisk produktion, i vilken hänsyn även tas till hur fodret produceras m.m., inte har utförts i denna avhandling. Ekonomin i ekologisk grisproduktion uppskattas f. n. som relativt god i Sverige. Dock är ekologisk grisproduktion en liten nisch och är därmed mycket känslig för prisfluktuationer.

Sammanfattningsvis ger denna avhandling information om för- och nackdelar i stationära inhysningssystem för ekologiska slaktgrisar. Avhandlingen ger också viss kunskap om komplexiteten inom ett produktionssystem för grisar och vilka motstridiga mål som finns. Allmänt konstaterades att det testade stationära systemet och de två boxtyperna fungerade väl i praktiken. Introduktion av en böklåda med torv som bökmaterial på betongytan utomhus, visade positiva resultat i form av förbättrad hygien och minskade utsläpp av ammoniak från denna yta.

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Anita, Anne-Katrine, Anders och Ulf, mina fina systrar och trevliga svågrar. Vilken rikedom att ha en sådan familj när man behöver hjälp och stöd!

Mina kära syskonbarn: Gustav, Emil, Adrian, William och Alma! Även om jag nu kan sätta en lite finare akademisk titel på mitt visitkort vill jag att ni fortfarande tänker på mig som er vanliga lite virriga ”moster Lotta”! Ni vet att jag uppskattar praktiskt kunnande minst lika mycket som teoretiskt.

Teresia och Teodor, mina älskade vuxna barn. Ni är den stora lyckan i mitt liv. Hur gick det till att ni blev sådana intelligenta, tänkande och empatiska individer? Från att far och jag tidigare försökt lära er lite om livet är det nu ni som är vår stora kunskaps- och informationskälla.

Ingemar, min älskade livspartner. Tänk att vi lyckats hålla ihop i mer än 40 år! Kan det bero på att du är så tolerant och ger mig frihet att hålla på med mina diverse ”påhitt”? Din tolerans har visat sig vara en mycket viktig egenskap nu när arbetet med min avhandling inkräktat i lite för stor utsträckning på fritiden. Förhoppningsvis blir det något bättre framöver!