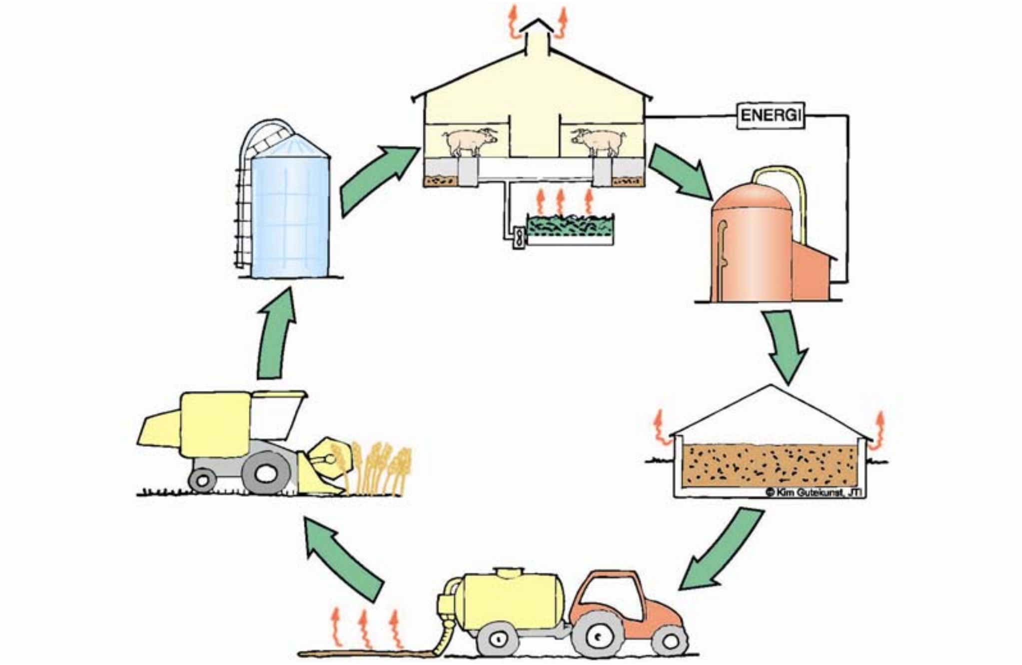
Measures to reduce ammonia emissions in pig production – Review

Åtgärder för att minska ammoniakavgången i grisproduktionen – en förstudie



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FOREWORD

Society makes more and more demands on how human food is produced and this is also valid for pig meat. Therefore, pig meat should be produced with so low environmental impact as possible, while the pig producers have to be able to compete economically with pig producers in other parts of the world. The national aim in Sweden is that ammonia emissions from pig production in 2010 should be 15 % lower than that of 1995. The aim in Scania is even higher: 20 %. These aims have already been reached, but this has mainly been due to a decrease in the number of animals in production. In other words: the environmental impacts as well as job possibilities are exported to abroad.

Probably, ammonia emissions will have to be reduced even more in the future, while even other nitrogen losses have to be reduced such as nitrogen leaching to the ground water and nitrous oxide emissions. At the same time pigs have to be produced according the Swedish animal welfare legislation, which includes more space for the pigs and access to straw or other rooting material. These special rules make it often more difficult to apply new techniques from abroad.

Even other issues are becoming more and more important such as: reduction of energy consumption, reduction of green house gas emissions, production of energy by biogas production, and reduction in odour and fine-dust emissions. So these issues have also to be evaluated when discussing ways to reduce ammonia emissions. Of course, new techniques have to be economically competitive so that Swedish pig production can compete internationally.

The aims of this report were to collect information, from both Sweden and abroad, about different techniques which could be used to reduce ammonia emissions, and to determine how these techniques could be used under Swedish circumstances. The entire chain with housing, slurry storage and slurry application was followed. The report was written by authors from the department of Rural Buildings (LBT-SLU, Alnarp) and the Swedish Institute of Agricultural and Environmental Engineering (JTI, Uppsala).

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TABLE OF CONTENT

Summary 6
Sammanfattning 9

1. Introduction 11
2. Limits of the literature review 13
3. Feed and feed technique
   3.1 Feedstuffs 14
   3.2 Dietary composition of the feed 17
   3.3 Multi-phase feeding 17
   3.4 Relation between feed and greenhouse gases 17
4. Management and health
   4.1 Pen cleanliness 19
   4.2 Production efficiency and health 20
5. Housing systems
   5.1 Ammonia emissions 21
   5.2 Measures to decrease ammonia losses 23
   5.3 Emissions of methane and nitrous oxide 29
   5.4 Discussion 32
6. Treatment of manure outside the pig house
   6.1 Lowering the pH of the manure 34
   6.2 Anaerobic treatment (digestion) for biogas production 34
   6.3 Aerobic treatment (wet composting) of slurry 35
7. Storage of manure
   7.1 Influencing factors on ammonia emissions from storage 36
   7.2 Ammonia losses from manure storage – emission factors for Sweden 36
   7.3 Measures to reduce ammonia losses from manure storage 37
8. Spreading of manure
   8.1 Influencing factors on ammonia emission after spreading 40
   8.2 Ammonia losses from applied pig manure – emission factors for Sweden 40
   8.3 Measures to reduce ammonia losses from field applied manure 42
   8.4 Other losses than ammonia 43
9. Organic pig production 45
10. Integrated systems 46
11. Conclusions 49
12. Recommendations for the future 51
13. Literature 52

Appendix 1 62
Appendix 2 63

SUMMARY

In this literature review, measures of reducing the ammonia (NH_3) emissions from pig production are described, with focus on systems that can be used under Swedish conditions. The entire production chain with feed, housing, manure storage and application on the field is described and taken into consideration. However, in order to limit the study, the production of crops for feed is not included.

As compared to many other countries, emissions of NH_3 in Swedish pig production are already low, due to low protein levels in the feed, housing systems with a small excretory area, and storage of slurry outside the building.

Lowering the crude protein level from 14.5 % to 12.5 % would reduce NH_3 emission by 20 % from the pig house. Including fiber in the feed, leads to a shift from nitrogen in the urine towards more nitrogen in the faeces. In combination with removing the manure daily from the pig house, this might give opportunities for reducing NH_3 emissions. A reduction in NH_3 emission of up to 50 % might be possible. However, using fiber leads to higher methane (CH_4) emissions (from animal and housing), and therefore this should be combined with biogas production. More research is needed in this field. Adding acids or salts to the feed could reduce NH_3 emission by up to 40 %, while also improving feed conversion efficiency. Of course, good practice when preparing the feed must be followed. By applying multi-phase feeding and feeding according to the sex of the animals, NH_3 emissions could be reduced by 5-15 %. By reducing feed spillage, offering a good environment for the pigs and maintaining good pig health, nitrogen losses could also be reduced with about 5 – 15 %.

The importance of having clean pens is also discussed in this literature survey. Swedish housing systems, having a relatively high percentage of solid flooring (with some bedding) and a small excretory area in the pen, provides an opportunity for reducing NH_3 emissions from the housing system. However, one prerequisite for this is that the pigs keep the pens clean, and therefore the room temperature should not be too high. This means that during hot periods, the air has to be conditioned before entering the pig house, *e.g.*, by taking in the air via channels under the building. Removing manure daily by means of scrapers (reduction up to 40 %) and cooling the manure under the slats (reduction up to 50 %) are measures that are already implemented in Swedish pig production. The effect of air temperature, air flow and ventilation system are also discussed. Cleaning the exhaust air using bio-filters (up to 65 % reduction), bio-scrubbers (up to 70 % reduction) and chemical scrubbers (up to 96 % reduction) is also an option. By only purifying the exhaust air from the manure channels, the costs for this method can be reduced substantially.

The emissions of CH_4 and nitrous oxide (N_2O) from the housing system are also discussed. Removal of the manure under the slats appears to reduce CH_4 emission from the building. The use of deep-litter bedding may in many cases result in high N_2O emissions. More research is needed in this field.

Treating the manure with sulphuric acid, in combination with aeration and re-circulation in the pig house, can reduce NH_3 emissions by up to 70 %. Pumping slurry between different compartments in a pig house is not allowed according to the Swedish Welfare Legislation. Therefore it is not certain that the acidification of slurry, inside the pig house, can be applied in Sweden.

Anaerobic treatment of biogas production, as another treatment of manure, may not reduce NH_3 emissions when storing and spreading the manure, but it results in increasing the

nitrogen availability for the crops. In that way nitrogen losses can be reduced since less nitrogen has to be spread per hectare. Besides, biogas production reduces odour problems as well as emissions of green house gas (GHG) by the production of energy and lower CH_4 emissions. Aerobic treatment of manure, can reduce the emissions of NH_3 and GHG. However, poorly controlled aeration processes can have the opposite effect.

Storage of slurry in a tank having a cover lid has been pointed out in many investigations, to be the easiest and most effective way of reducing NH_3 and CH_4 emissions. The straw used for fattening pigs is mainly consumed by the pigs, and it is rare that a naturally stable crust will be developed on the slurry. However, within piglet production a crust on the slurry tank is often found. This crust can cause problems when the slurry tank is covered. Technical solutions have to be developed to solve this problem.

On pig farms, the main crops are cereals, and the slurry is mainly applied either in the spring during tillage work, or band spread in the early summer on growing cereals. Incorporation of the slurry, *e.g.*, by harrowing in the spring, effectively reduces the NH_3 losses if it takes place as soon as possible after spreading, preferably directly or at least within 4 hours after spreading. Another possibility is to band spread the slurry onto the growing cereals because the canopy provides a microclimate which reduces the NH_3 losses, as compared to spreading on a bare field. Late application during the vegetation period or spreading before the autumn sowing, often results in lower nitrogen utilization by the plants, and thereby higher risks of nitrogen leakage.

Due to interactions between different sources on a farm, reduction in NH_3 emission from the individual sections of the livestock production system cannot be simply added to give the net reduction in emission from the total system. Thus a whole farm system approach is needed for devising control strategies for reducing NH_3 emission. Four scenarios were evaluated in this report. Scenario 1 consists of: Reduction of the crude protein in the feed from 14.5 % to 12.5 %, relatively simple technique inside the pig house to reduce NH_3 emission, covering the slurry tank and new technique when spreading manure. Scenario 2 consists of: Using biproducts from industry (16.5 % crude protein instead of 14.5 %) and cleaning of exhausting air, covering the slurry tank and new technique when spreading manure. Scenario 3 comprises conditions similar to those of Scenario 1, including high dietary feed fiber content in combination with biogas production. Scenario 4 comprises conditions similar to those of Scenario 2, including high dietary feed fiber content and in combination with biogas production. Preliminary calculations indicate that the scenarios may reduce emissions by 47-68 %. It should be pointed out that the calculations are still very uncertain. The calculations show that Scenario 3 appears to be the most effective way of reducing NH_3 emissions. So the combination of using low protein feed with high fiber content together with the production of biogas appears to be a promising method for future development. Even Scenario 1, which used only simple techniques, has a significant result: lowering the protein content affects the entire chain from feed to the field.

From the literature review, it can be concluded that one should consider whole farm systems when trying to reduce NH_3 emissions. Having a roof on the manure storage, using band spreading together with incorporation, *e.g.* harrowing, within a few hours after spreading, are the most important and easiest ways of reducing NH_3losses. When discussing the method of animal keeping, feeding and housing, a low protein level in the feed has a positive effect along the entire production chain, and appears to be the most effective means of reducing NH_3 emissions. Using more fiber or acids/salts in the feed will reduce the NH_3 emission even more. When biproducts from industry are used in the pig feed, cleaning the exhausting air from the manure channel may be an option. More research is needed before recommendations can be given.

SAMMANFATTNING

I denna litteraturgenomgång beskrivs åtgärder för att minska ammoniakavgången i grisproduktionen under svenska förhållanden. Hela kedjan från foder, inhysning, gödsellagring och gödselspridning ingår i studien. För att begränsa studien, ingår inte själva odlingen av fodermedel.

Jämfört med många andra länder, är emissionen av NH3 i Svensk grisproduktion låg. Detta på grund av låga halter av protein i fodret, små gödsel-ytor samt lagring av gödsel utanför stallet.

En minskning av råproteinmängden från 14.5 % till 12.5 % skulle minska emissionen av ammoniak från stallet med omkring 20 %. Inblandning av mer fiber i fodret leder till att mer kväve utsöndras via avföringen och mindre via urinen. Tillsammans med att gödsla ut dagligen från stallet skulle detta kunna ge möjligheter att minska ammoniakavgången från stallet med upp till 50 %. Fiber kan emellertid leda till höga emissioner av metan både från djur och stallet och därför bör inblandning av fiber kombineras med biogastillverkning. Mer forskning behövs för att klargöra hur mycket metan som kommer från grisarna och hur mycket som kommer från stallet. Inblandning av syror och salter i fodret kan minska ammoniakemissionen med upp till 40 %, samtidigt som foderutnyttjandet förbättras. Genom att tillämpa multifas-utfodring, eller utfodring efter kön, kan man minska ammoniakemissionen med 5 – 15 %. Genom att förhindra foderspill, genom att ge en bra närmiljö till grisarna och genom en hög hälsostatus kan man minska ammoniakemissionen med 5 – 15 %.

Vikten av rena boxar behandlas i litteraturgenomgången. De svenska inhysningssystemen med mycket fast golv, med strömedel och med en relativ liten gödselyta skapar bra möjligheter för att minska ammoniakemissionen. En förutsättning för detta är dock att grisarna håller rent på den fasta delen i boxen. Därför ska rumstemperaturen inte vara för hög. Detta innebär att luften måste bli konditionerad under varma perioder, t.ex. genom att föra luften genom kanaler under stallet, innan den kommer in i stallet. Teknik som redan används mycket i Sverige är skraputgödsling (reduktion 40 %) och kylning av gödsel i kulverten (reduktion upp till 50 %). Effekten av lufttemperatur, luftflöde och ventilationssystem är beskriven. Rening av den utgående luften med biofilter (upp till 65 % reduktion), bio-scrubber (upp till 70 % reduktion) och kemisk-scrubber (upp till 96 % reduktion) är möjligt. Genom att enbart rena den utgående luften från gödselkulverten, skulle man kunna sänka kostnaderna för denna teknik.

Emissioner av metan och lustgas diskuteras också. Att dagligen föra bort den gödsel som ligger under spalten, verkar minska metanemissionerna från stallet. Djupströbäddar leder i många fall till höga emissioner av lustgas. Mer forskning behövs i detta forskningsområde.

Genom att blanda in svavelsyra i gödseln, i kombination med luftning och recirkulering genom stallet, kan man minska ammoniakemissionerna med upp till 70 %. Att pumpa gödsel mellan olika avdelningar i ett stall är dock inte tillåtet i Sverige och därför är det tveksamt om denna teknik får användas i Sverige.

Att behandla gödseln i en biogasanläggning leder inte till lägre emissioner av ammoniak i samband med lagring och spridning, men det gör kvävet lättare tillgängligt för växterna. Därför behöver mindre gödsel att spridas per hektar vilket leder till lägre kväveförluster genom utlakning. Tillverkningen av biogas leder dessutom till en rötrest som luktar mindre än

gödsel i samband med spridning. Dessutom minskar man emissionen av växthusgaser genom produktion av förnyelsebar energi och reducerad emission av metan.

Att lufta gödsel (aerobisk behandling) kan minska emissionen av både ammoniak och växthusgaser. Om processen inte styrs tillräkligt bra kan det emellertid ge en motsatt effekt.

I många undersökningar nämns tak över flytgödselbehållaren som det enklaste och mest kostnadseffektiva sättet att minska ammoniak- och metan emissionen. Halm som används till slaktgrisar äts till största delen upp av grisarna och det är inte ofta att ett naturligt svämtäcke bildas av halmen. Inom smågrisproduktionen bildas dock oftast ett svämtäcke i gödselbehållaren. Detta svämtäcke kan skapa problem vid uppblandning av gödsel i samband med utkörning av gödsel. Tekniska lösningar måste utvecklas för att lösa detta problem.

På många grisgårdar är spannmålsodling en stor del av växtföljden, och den mesta av gödseln sprids strax innan sådd, eller med slangspridning på våren i den växande grödan. Genom att harva direkt efter gödselspridning, och senast inom 4 timmar, minskar man emissionen av ammoniak avsevärt. Att slangsprida gödsel i en växande gröda som inte är allt för lång ger också en lägre emission. Att slangsprida i en växande gröda senare i växtsäsongen eller gödselspridning före höstsådden leder till lågt kväveutnyttjande av växterna och ökar därmed risken för kväveläckage till grundvattnet.

Eftersom olika delar av ett produktionssystem påverkar varandra, kan man inte enkelt summera effekterna av olika delar i ett produktionssystem. Istället måste man titta på hela produktionssystemet för att kunna bedöma hur stor reduktion i ammoniakemission man kan uppnå. Fyra scenarior för slaktsvinsproduktion blev evaluerade i rapporten. Scenario 1: En minskning av råproteinhalten från 14.5 % till 12.5 %, relativt enkla förbättringar i stallet, ett tak på gödselbehållaren och den nyaste tekniken vid utkörning av gödsel tillämpas. Scenario 2: Utfodring med rester från industrin (16.5 % i stället för 14.5 % råprotein), rening av den utgående stalluften, ett tak på gödselbehållaren och den nyaste tekniken vid utkörning av gödsel tillämpas. Scenario 3: som scenario 1 samt inblandning av fiber i fodret (i kombination med biogasproduktion). Scenario 4: som scenario 2 samt inblandning av fiber i fodret (i kombination med biogasproduktion). Det måste understrykas att beräkningarna fortfarande är osäkra. Preliminära beräkningar indikerar att ammoniakemissionerna möjligtvis kan sänkas med 47-68 %. Beräkningarna visar att scenario 3 verkar vara det effektivaste sättet att minska ammoniakemissionen. Det verkar alltså som att kombinationen av en låg proteinhalt och hög fiberhalt i fodret, i kombination med biogas, kan vara en intressant utvecklingsväg för framtiden. Även scenario 1 med relativt enkel teknik hade en betydande effekt: genom att minska proteinhalten i fodret påverkar man hela produktionskedjan.

Man kan konkludera från denna litteraturgenomgång, att man behöver bedöma hela produktionskedjan för att få ett intryck av hur mycket man kan minska ammoniakemissioner från grisproduktionen. Att ha ett tak på gödselbehållaren, att använda slangspridning och snabb nedmyllning inom några timmar är de viktigaste och snabbaste sätten att minska ammoniakförluster. När man diskuterar djurhållningen, utfodringen och inhysningen så verkar en låg proteinhalt i fodret vara det effektivaste sättet att minska ammoniakemissioner från hela produktionskedjan. Inblandning av fiber eller syror/salter kan ytterligare minska ammoniakemissionen. När restprodukter från industrin används i foderblandningen kan det vara intressant att rena den utgående ventilationsluften från gödselkanalerna. Mer forskning behövs dock innan rekommendationer kan ges till grisproducenter.

1. INTRODUCTION

In recent decades pig production has been intensified in most European countries. By importing feedstuffs from other parts of the world, pig production has grown. At the same time, pig production has been concentrated to fewer but much larger pig units. This has resulted in a surplus of manure and a serious concern about the effect of ammonia (NH_3) emissions on environmental acidification and the pollution of ground and surface water (van der Peet-Schwering, 2003).

Atmospheric NH_3 causes acute toxic injuries to vegetation close to the source and contributes to the large scale nitrogen eutrophication and acidification of ecosystems by long range atmospheric transport of ammonium. The most important source of anthropogenic NH_3 in Europe is agriculture, mainly from livestock production and fertilizer application. The contribution from agriculture is on average 92 %, and about 25 % of the nitrogen in animal excretion is lost to the atmosphere. In Southern Sweden the ammonium nitrogen (NH_4-N) deposition is about 10 kg/hectare, about 80 % imported from surrounding countries. The total nitrogen deposition in Southern Sweden is about 20 kg/hectare, clearly influencing nature and biodiversity. The problem with eutrophication is not only a problem for the nature and biodiversity in Sweden but also in the countries around the Baltic Sea. Moreover, the eutrophication of the Baltic Sea is one of the major problems of the Baltic Sea, due to the fact that the average depth is only 55 m, as compared to the Mediterranean, with an average depth of 1 500 m.

Although dairy- and beef production stands for the largest part of the environmental impact on nature, intensive pig and poultry production contributes also to this environmental impact (Table 1). Cattle production has the highest NH_3 emissions (57 %), followed by pig production (13 %). As shown in the Table, the NH_3 emission from pig production consists of: 47 % from buildings, 25 % from manure storage and 28 % from manure spreading.

Besides the NH_3 emissions, society is also concerned about the release of greenhouse gases (GHG) from animal production. Within pig production, the release of GHG is largest from feed production, especially when imported soya from South America is used. Emissions of methane (CH_4) and nitrous oxide (N_2O) from pig houses, manure handling and animals, and the use of energy for ventilation are also of importance (Berglund *et al.*, 2009). Therefore it is necessary to take into account GHG when evaluating techniques that reduce NH_3 emissions.

Besides the emissions of NH_3 and greenhouse gases, pig production also faces problems with emissions of odours and dust from the housing system, manure storage and in connection with manure spreading. At the same time, pigs have to be kept under ‘good’ environmental circumstances with enough space for them to move, and to have access to rooting material or other materials for exploration. Sweden is the only country within the EC which oblige the use of straw for pigs and prohibit tail-docking. In Sweden, pigs have in general 30-50 % more space and more solid flooring as compared to that in other EC countries. So the circumstances are different from other EC countries and therefore not all technical solutions from abroad are applicable.

Table 1: Emission of ammonia in Sweden for year 2005, in tons (SCB MI 37 SM 0701)

	Species			Sum
	Cattle	Pigs	Other farm animals	Total
From manure				
- Ventilation	5 450	3 150	-	10 050
- Storage	9 300	1 700	-	14 650
- Spreading	12 100	1 850	-	15 750
- Total from manure	26 850	6 700	6 850	40 450
Grazing	3 150	0	750	3 900
Total animal production	30 000	6 700	7 600	44 300
Fertilizers				1 900
Sum agriculture				**46 250**
Sum horticulture				**100**
Sum forestry				**50**
Industry				2 650
Burning				1 200
Transport				1 400
Others				900
Total				**52 400**

A study concerning methods of reducing nitrogen pollution from Swedish pork production was done by Kumm (2003). He identified the following measures to reduce NH_3 emissions and N-leaching: reducing protein level in the feed, Specific Pathogen Free (SPF) pig production, spreading all the manure in the spring and rapid incorporation of the manure, using catch crops and halving N-input in feed grain production. A combination of best manure handling, catch crops and low protein feeding could reduce N-leaching plus NH_3 emissions by 50 %. Although not considered in our literature review, the location of a pig farm has a large impact on nitrogen leaching (Kumm, 2003). Farms situated on clay soil are better in taking care of the nitrogen than are farms situated on sandy soil. N-leaching from pig production on clay soil was only one third of that on sandy soil. According to the author, establishment and increase of pig production should take place in regions with clay soil.

The present review will go describe different techniques of reducing NH_3 emissions, those of GHG, and odour. The applicability of these techniques will be evaluated not only as just a part of the production system but also in a larger context looking at the entire farm system (Sommer & Hutchings, 1995).

2. LIMITS OF THE LITERATURE REVIEW

The literature study is limited to pig production and although it will primarily deal with NH_3 emissions, energy consumption and the emissions of N_20, CH_4, dust and odour will be mentioned. To limit the study, the production of crops for feed is not included. However, the use of different feeds for pigs and the spreading of manure are included in this study.

The study will deal with both conventional and organic pig production for both sow herds and growing-finishing pig production. The focus will be on systems that can be applied under Swedish circumstances, which means good animal welfare with enough space for the pigs, relatively much solid flooring and straw or other rooting material available on the floor for the pigs. The European Community is going into the direction of high-welfare systems for pigs and the challenge is to combine a good animal welfare with low environmental pollution.

3. FEED AND FEED TECHNIQUES

3.1 Feedstuffs

3.1.1 Type of protein source

One way to reduce NH_3 emissions from pig production is by lowering the crude protein level in the feed. An advantage of this method is that the input of nitrogen into the entire production chain will be lower, resulting in both lower NH_3 emissions, and those of N_2O, from the entire chain.

About 70 % of pig feed consists of cereals. Although cereals have lower concentrations of amino acids and crude protein than protein-products, such as, extracted soya bean meal, cereals will be responsible in many cases for the major part of the crude protein in the feed. The ileal digestibility of amino acids in cereals (65-80 %) is in general lower than that of protein-products (80-90 %), resulting in more protein in the dung originating from cereals.

There are relatively more non-essential amino acids in cereals than in a protein-product like extracted soya bean meal (Table 2). This means that the total crude protein level will increase in the feed when cereals are used, and that it will exceed the needs of the pigs. The use of protein-feedstuffs will match better the pigs' requirements and will lower the crude protein level. Besides, the distribution of amino acids in cereals differs more from that of ideal protein than the distribution of amino acids in extracted soya bean meal does (Table 2). Especially lysine levels are low in cereals. Ideal protein is the constitution of amino acids that is optimal for meat deposition (Whittemore, 1998).

The use of energy sources other than untreated cereals, such as, fat or starch, may help to reduce the dietary crude protein level. However, pure starch (from gluten production) is not available to all pig producers. Energy sources, *e.g.,* soya oil, rape oil and fat from the slaughterhouse are difficult to obtain since they are in demand for the production of food and energy. When using fat in the pig feed, one also has to be careful how these fats affect the fat in the slaughter carcass; some fats give too hard pig meat fat or some fats result in pig meat with a bad taste.

So, in practice, the main part of the energy in the feed will originate from cereals. Therefore the best thing is to use cereals with low crude protein levels, like mould barley, feed wheat and triticale. Cereals with low crude protein levels make it easier to balance the feed with protein-feedstuffs and artificial essential amino acids, like synthetic lysine, without impairing the financial result per pig. Research has shown that it is possible to produce a balanced growing-finishing pig feed with 11 g crude protein per MJ metabolic energy (13.5 % crude protein in solid feed) by using cereals with low crude protein levels (Göransson, 2008).

Table 2: Amino acid distribution in ideal protein (g/ kg crude protein) (Whittemore, 1998) and the distribution of ileal digestible amino acids in barley and extracted soya bean meal (g/kg digestible crude protein) (data: central veevoederbureau)

Amino acid	**Ideal protein**	**Barley**	**Extracted soya bean meal**
Histidine	25	23	26
Isoleucine	40	34	44
Leucine	75	71	72
Lysine	70	33	60
Methionine + cystine	40	40	27
Phenylalanine + tyrosine	75	84	84
Threonine	45	30	35
Tryptophan	15	11	12
Valine	50	48	45
Total essential amino acids	435	374	405
Other, non-essential	565	626	595

Cystine, tyrosine and arginine are semi-essential; non-essential are glumatic acid, proline, serine, glycine, aspartic acid and alanine.

Hayes *et al.* (2004) reported NH_3 emissions of 3.11, 3.89, 5.89 and 8.27 g/d/animal with 13.0, 16.0, 19.0 and 22.0 % CP respectively. In addition, odour emissions were lower in these experiments in feeds with low CP. No differences in daily feed intake or daily weight gain were detected between the four treatments. Cahn *et al.* (1998a) tested 16.5, 14.5 and 12.5 % CP for pigs of 55 kg live weight. They concluded that NH_3 emission was reduced by 10-12.5 % for each percent decrease in dietary CP, and many reports from other researchers showed similar results. Beside the positive effect of lower NH_3 emissions, the use of synthetic amino acids, together with reduced intact protein levels in the diets, significantly reduced odour production (Sutton *et al.*, 1999). However this was not at all confirmed by Fink Hansen *et al.* (2006).

According to Lenis and Schutte (1990), the CP level of a typical swine ration can be reduced by 3 percentage points (*e.g.* from 16 to 13 %) by replacing soybean meal with synthetic amino acids and corn without negative effects on animal performance.

Every 1 % lower dietary CP level results in 9 % lower N excretion (Ferket et al, 2002) and 10 % lower NH_3 emission (Aarnink *et al.*, 1993). This agrees very well with the findings of Kendall *et al.* (1999); reductions from 16.7 to 12.2 % CP in the feed lead to a reduction in NH_3 emission of 40 %. It was pointed out in their investigation that performance was impaired and that 12.2 % CP might have been too low for practice under commercial circumstances.

In Sweden, CP levels in pig feed have been low since 1990, after finding the positive effects of low CP feeds on animal health, indoor climate and NH_3 emissions. A standard growing-finishing feed in Sweden contains traditionally 14.5 % CP, which means that the potential to reduce NH_3 emission is limited. A reduction to 12.5 % CP would mean a reduction of 20 %.

3.1.2 Fiber

By increasing the non-starch polysaccharide (NSP) in the diet, more microbial growth will take place in the large intestines, leading to a shift towards more nitrogen being excreted in the dung and less in the urine (Urinary N:fecal N ratio from 3.83 towards 1.21). The pH of the slurry has been observed to be 1.13 units lower when NSP were included in the diet (30 % sugar beet pulp) (Cahn *et al.*, 1997). The nitrogen in the dung is held by bacteria (Kendall *et al.*, 1999), and it will take much longer time to convert this to NH_3 as compared to urea in urine. By removing the slurry from the pig house daily, only NH_3 from the urine can emit. The low pH of the slurry will also lead to a slower production of NH_3 in the slurry when NSP are used in the diet. Other studies by Canh *et al.* (1998c) show that a diet with 30 % sugar beet pulp reduces NH_3 emissions by 53 % from the slurry, using a laboratory setup for 7 days at 20^0C. Besides, the use of NSP and specific oligosaccharides in the diets significantly reduces odour production (Sutton *et al.*, 1999).

3.1.3 Products that lower pH in the manure

In swine, reducing the pH of urine is the most effective means of reducing NH_3 emission because most of the NH_3 is derived from the urine (Aarnink *et al.*, 1998). Canh *et al.* (1998b) have demonstrated that NH_3 emission can be reduced by 30, 33, and 54 % by replacing $CaCO_3$ (Limestone) in the diet with $CaSO_4$ (gypsum), $CaCl_2$ (calcium chloride), or calcium benzoate, respectively. Urine pH has dropped 1.3 pH units with $CaSO_4$ and $CaCl_2$, and 2.2 pH units with calcium benzoate in the diet. Den Brok *et al.* (1997) have shown that benzoic acid in the feed decreases NH_3 emission by 40 %, while also improving the feed conversion rate from 2.93 to 2.83. Urine pH and NH_3 emission can also be reduced by the dietary addition of adipic acid and phosphoric acid, which can substitute for other P sources in the diet (Kim et al, 2000).

3.1.4 Other additives to the feed

The use of *Yucca schidigera* extract in the feed resulted in 30 % lower concentrations of NH_3 in the air (Colina *et al.*, 2001). However in these studies air flow was not measured. No effect of Yucca was found by Panetta *et al.* (2006).

3.2 Dietary composition of the feed

In general, nutrient excretion may be reduced by avoiding the overfeeding of specific nutrients or by enhancing nutrient utilization in the animals (Ferket *et al.*, 2002). Therefore the dietary composition should be well balanced with regard to the animal needs. When preparing the feed, rules for good feed preparation have to be followed. For instance, comprehensive information about the ingredients used is necessary.

In addition, a good standard of feed preparation should be followed. Overheating has to be avoided since it reduces protein digestibility up to 50 % (Whittemore, 1998). Grinding into too large particles, as well as the presence of anti nutritional factors, would result in poor digestion (Whittemore, 1998). Of course diets should be formulated based on nutrient availability instead of nutrient content. Using ileal digestibility instead of faecal digestibility would be a good example. As mentioned previously, a reduction of the amount of crude protein in the feed would not only reduce NH_3 emission but also emissions and the leakage of nitrogen in general. Lower levels of nitrogen in the environment would reduce the emission of N_2O in the whole integrated system (housing, manure storage, spreading, and plant production). Feed additives, such as, direct-fed microbials, organic acids, microbial enzymes (i.e., phytase, carbohydrases, and proteases) could be used to increase the digestibility and absorption of nutrients or to modulate the microflora (Ferket *et al.*, 2002).

3.3 Multi-phase feeding

Van Kempen (2002) reported a reduction in N excretion by 17.5 % when feeding pigs between 25 and 115 kg with three phases as compared to one phase. Van der Peet-Schwering and Voermans (1996) reported that multiphase feeding reduced urinary N excretion by 14.7 % and NH_3 emission by 16.8 %. In addition to significant reductions in mineral emissions, feed costs per pig decreases (Bell, 1998). Multiphase feeding is easy to achieve with liquid feeding systems, but is also possible with the modern dry feeding systems. Feeding programs specific for sex and strains of animals have also been developed. For example, barrows could be fed with a feed with lower protein content as gilts. In that way, 5-8 % lower N excretion could be achieved (Ferket *et al.*, 2002).

3.4 Relation between feed and green house gasses

Not only NH_3 emission but also emissions of green house gases have to be considered when evaluating the feed. The feed can affect CH_4 emission from animals, and from the housing and manure handling systems. One example is the fiber content in the feed. Although fermentable carbohydrates reduce NH_3 emission, an increase in the amount of fermentable carbohydrates in the feed increases the risk of CH_4 production during storage (Aarnink & Verstegen, 2006). Therefore including fiber in the feed may be combined with biogas production from the slurry, and in that way may improve the efficiency of the biogas plant. Another example is the use of salts (H3PO4 + CaSO4) in the feed leading to a reduction in CH_4 emission by 14 % (Kim *et al.*, 2004).

Feed that results in low NH_3 emission could also give higher emissions of N_2O. When pigs were housed on deep-litter beds, feeding low protein feed resulted in much higher N_2O emission, as shown by Philippe *et al.* (2006). In their experiment, growing-finishing pigs (26-111 kg live weight) on deep litter (47 kg straw/pig) were fed either low protein feed (14.7 % CP) or high protein feed (17.8 % CP). The low protein feed resulted in 26 % lower NH_3 emission (10.6 vs. 14.4 g NH_3 per pig per day), 13 % lower CH_4 emission (13.1 vs. 15.0 g CH_4 per pig per day) but 2 times higher N_2O emission (1.02 vs. 0.52 g N_2O per pig per day) (Philippe *et al.*, 2006). So the relationship between nitrogen losses and N_2O emission to the environment is not so clear. On the other hand, one should expect that a reduction in the amount of nitrogen in the system/nature should lead to less N_2O production.

4. MANAGEMENT AND HEALTH

4.1 Pen cleanliness

The importance of having clean pens was shown by Aarnink *et al.* (2006). When the pigs started to excrete on the solid floor, the NH_3 emission increased. In their experiments, the pigs had access to 1.0 m^2 per pig. In other experiments done by Aarnink *et al.* (2006) it was clearly shown that above a specific temperature, the pigs changed their lying and excretory behaviours. When the temperature increased, the pigs started to lie more on the excretory area (slatted flooring), and above a specific temperature, the pigs started to excrete on the solid floor. When 30 % of the slatted floor in the excretory area was covered by the pigs, they started to excrete on the solid lying area. This appeared at 25 ^{0}C for 25 kg pigs and at 21 ^{0}C for 80 kg pigs.

Experiments done by Botermans and Andersson (1995) showed that already at low temperatures pigs started to lie on the excretory floor. They also showed that the change of behaviour due to heat was dependent on the housing system. In an insulated pig house with slatted flooring on the excretory area, pigs started to lie on their side first, and then later on they started to lie on the slatted floor. However, in an uninsulated pig house with a solid concrete floor in the excretory area, pigs started to lie first on the excretory area and then later on they started to lie on their side. So the solid concrete floor in the excretory area resulted in earlier fouling of the pens and at the same time the pigs also became dirtier as compared to housing with slatted flooring in the excretory area. This will lead to higher NH_3 emissions and therefore it can be concluded that slatted flooring is more appropriate than solid flooring in the excretory area. The total pen area was 1.2 m^2 per pig. Pigs 20 kg of weight started to lie on the excretory area at 18 ^{0}C in the insulated pig house, and at 23 ^{0}C 10 % of the pigs were lying on the slatted flooring. In the uninsulated pig housing, at 16 ^{0}C 20 kg pigs started to lie on the excretory area, and at 23 ^{0}C 10 % of the pigs lay on the excretory area. Pigs 55 kg of weight started to lie on the excretory area at 15 ^{0}C in the insulated pig house and at 23 ^{0}C, 40 % of the pigs lay on the excretory area. In the unisulated pig house, 55 kg pigs started to lie on the excretory area at 8 ^{0}C and at 23 ^{0}C 60 % of the pigs lay on the excretory area. Pigs 85 kg of weight spent much of their time lying on the excretory area. In the insulated pig house, 18 % of the pigs were lying on the excretory area at 13 ^{0}C and at 24 ^{0}C 60 % of the pigs lay on the excretory area. In the uninsulated pig house 30 % of the pigs were lying on the excretory area at 13 ^{0}C and at 24 ^{0}C 60 % of the pigs lay on the excretory area.

So the studies above show that the room temperature in pig houses should not be too high when pigs have access to a solid floor in the lying area. This means in practice that the air has to be conditioned before entering the pig house during hot periods. One way of conditioning the air is by leading the air trough channels under the ground.

Another factor affecting pen cleanliness is the health of the pigs. Pigs with diarrhoea will defecate all over the pen, resulting in dirty floors. Liquid feeding may result in more liquid faeces, which will lead to a higher risk of having dirty pens.

4.2 Production efficiency and health

The easiest way to reduce nitrogen losses is by reducing feed spillage (Ferket *et al.*, 2002). When feed spillage increases by 10 %, the nitrogen losses increases by 17 % (Botermans & Olsson, 2004), which automatically increases the risk for higher NH_3 emissions.

By offering a good environment to the pigs, feed utilization will in most cases improve, resulting in lower nitrogen losses. By not stressing the pigs (offering enough space, not mixing the pigs, having low competition for feed, not too large groups of pigs, and so on) nitrogen losses will usually be 5-15 % lower as compared to pigs that are stressed. Housing pigs in uninsulated houses results in 7-15 % higher nitrogen losses (Botermans & Olsson, 2004).

When discussing production efficiency, health is the most important factor. Herds with severe health problems will automatically have high nitrogen losses. It has been found that herds with high health status (SPF-herds) had a 8 % lower nitrogen output as compared to herds with a normal health status (Botermans & Olsson, 2004).

5. HOUSING SYSTEMS

Swedish animal housing and manure handling systems differ in certain respects from those in other countries as a result of tradition, climate and animal welfare standards. This means that some of the measures recommended internationally cannot be used in Swedish systems. Furthermore, a number of the animal housing and manure handling systems that exist in Sweden are already designed in such a way that they produce lower NH_3 emissions than conventional systems in other countries.

5.1 Ammonia emissions

Measurements of NH_3 emissions from different animal housing systems and manure handling systems for pigs have been carried out in a number of countries. Some of these measurements have been assessed and compiled by an international expert group (Expert Group on Ammonia Abatement), which acts within the UNECE's work on the Gothenburg Convention. The results are contained in a document describing measures to counter NH_3 emissions (Guidance Document on Control Techniques for Preventing and Abating Emissions of Ammonia) (ECE, 2007). A review is also provided in a Best Available Technique (BAT) reference document on intensive animal rearing of poultry and pigs (BREF 07.06, 2003).

One complication with the international assessments of NH_3 emissions from animal houses is that they are based on reference systems that are common in other countries but that are not used, or are not permitted, in Sweden, for example fully slatted pens for pigs. Therefore the reference systems in the international assessments often have higher NH_3 emissions than the traditional Swedish systems.

In Sweden, LBT has carried out measurements in conventional fattening pig rearing in the traditional Swedish pen with long-trough and partly slatted floor.

5.1.1 Fattening pig section

The traditional fattening pig pen in Sweden is a long-trough crate consisting of an eating and lying area with a solid floor, and an excretion area with concrete slats. The slurry is removed from the house by scrapers or by vacuum suction. There are versions with cross-troughs and automatic feeders. Large pens with straw bedding or 'straw-flow' also exist. Measurements at the LBT experimental house for fattening pigs, Alnarps Södergård, show that NH_3 emission from a house with a traditional long-trough pen, concrete slats and mechanical ventilation are between 1.4 and 1.6 kg NH_3 per pig place and year.

Internationally, NH_3 emissions from various animal housing systems for fattening pigs are compared with a building that has mechanical ventilation, is fully slatted and has slurry storage under the slatted floor in a culvert. Ammonia emissions for these systems in Europe lie between 2.4 and 3.0 kg per pig place and year. Animal housing systems with partly slatted floor, concrete slats and mechanical scrapers give 40 % lower NH_3 emissions, *i.e.* 1.4-1.8 kg per pig place and year (ECE, 2007). Partly slatted floor, concrete slats and vacuum slurry extraction reduce NH_3 emissions by 25 %. Straw bedding in pens can increase NH_3 emissions by 0-33 % compared with the reference pen (BREF, 2003). Ammonia emissions from pens with straw-flow have been studied in Austria by Amon *et al.* (2007) and have been found to be 2.2 kg per pig place and year, *i.e.* around 25 % lower than those from the fully slatted reference system.

5.1.2 Weaner pig section

Weaner pens are generally designed with a lying area of solid flooring and an excretion area of self-draining flooring. The self-draining floor consists of either concrete or plastic slats. The slurry is extracted by scrapers under the slats. The pens are designed either as small pens for one litter or as large pens for 2-3 litters. There are also systems where newly weaned piglets are kept in straw-flow pens accommodating 8-10 litters. No measurements have been made in weaner pig sections in Sweden.

Internationally, fully slatted pens with slurry storage under the pens represent the reference system. Ammonia emissions from this system are estimated to be between 0.6 and 0.8 kg per place and year. A system with partly slatted floor and scrapers under the slats, similar to the Swedish system, is estimated to reduce NH_3 emissions by 35-70 % compared with the reference system (ECE, 2007). Pens with vacuum slurry extraction reduce NH_3 emissions by 25-35 % compared with the reference pen (BREF, 2003).

5.1.3 Farrowing section

Floor surfaces in farrowing pens consist of a lying area of solid floor and an excretion area, which may be separate from the pen. The excretion area is usually a self-draining floor (plastic slats) but can also be a solid floor. The farrowing section can also consist of straw bedding with separate farrowing pens. There are no empirical data available from farrowing sections in Sweden.

Internationally, the reference pen for farrowing is a fully slatted pen (metal or plastic slats) with slurry storage under the slats. This pen has NH_3 emissions of 8.3-8.7 kg per sow place and year (ECE, 2007). A farrowing pen with partly slatted floor and slurry scraper can give a 35-52 % decrease in NH_3 emissions compared with the reference system (BREF, 2003). There are no international results available regarding farrowing pens on straw bedding.

5.1.4 Mating section and pregnancy section

Common pen systems in mating and pregnancy sections are straw-bedded pens with individual feeding crates, pens with trickle feeding (biofix-system) and an excretion area, pens with an individual feed area, excretion area and lying area (three-roomed), and straw-bedded pens with slatted floor and transponder feed release. Excretion areas can either have a self-draining floor or a solid floor. There are no empirical data available on NH_3 emissions from mating and pregnancy sections in Sweden.

Internationally, fully slatted pens with slurry storage underneath are used as the reference system, with NH_3 emissions between 3.12 and 4.2 kg per sow place and year (ECE, 2007). Pens with partly slatted floors and slurry scrapers under the slats give a 30 % reduction in

NH_3 emissions. Partly slatted flooring and vacuum slurry extraction give a 25 % reduction in emissions compared with the reference pen. Straw-flow pens without separate excretion areas are reported to have 0-67 % higher NH_3 emissions and straw-flow pens with excretion areas and transponder feed release have 38 % lower NH_3 emissions compared with the reference pen (BREF, 2003).

In Holland, measurements have been made in a transponder system with 60 % straw-bedded area, 17 % slatted floor and 23 % solid floor. The total floor area was 2.25 m^2 per sow. Ammonia emissions from the house were 8.7 g per sow and day, which is equivalent to 3.2 kg per sow place and year (Groenestein *et al.*, 2007).

5.2 Measures to decrease ammonia losses

Ammonia emissions from manure are the result of a complex process, which is affected by a large number of factors. The factors affecting NH_3 losses from animal houses include the amount of nitrogen in the manure, manure temperature, enzymatic activity, manure pH, absorption capacity of straw bedding, oxygen and water content of the manure, C/N-ratio in the manure, manure surface area, exposure time, air temperature, air flow, air speed and air movement over the manure. When a measure to reduce NH_3 emissions is introduced in an animal house, one or more factors within the house are altered.

5.2.1 Manure handling systems

Studies on different lengths of emptying intervals for slurry under slats in fattening pig houses have shown that the NH_3 concentration only begins to increase at intervals longer than one day. Slurry removal 1-2 times per day is therefore sufficient to prevent an increase in NH_3 emissions due to slurry storage in pig houses (Gustafsson, 1988). After three days of storage, NH_3 emissions increase by approx. 40 % (Gustafsson, 1988).

According to BREF (2003), vacuum extraction gives higher NH_3 emissions than mechanical scrapers under slats. Animal housing systems with straw-flow (Amon *et al.*, 2007) or fully straw-bedded pens give higher NH_3 emissions than systems with partly slatted floors and mechanical scrapers (BREF, 2003).

5.2.2 Pen design

Pens should be designed so that the pigs keep the lying area and the slats as clean as possible. In pens for fattening pigs, the pen area should not be too square, since that increases the risk of the pigs defecating in one or more corners of the lying area. For the pigs to keep their pens as clean as possible, the excretion area should be greater than the minimum requirement and comprise at least 25 % of the lying area. The lying area, on the other hand, should never be made larger than the minimum requirement, since a large lying area increases the risk of pigs defecating in the lying area. In order for any urine excreted in the lying area to drain away, the floor should have a slope of 2-3 % towards the self-draining floor (Olsson & Ascárd, 2008).

The fences in the excretion walkway should be as open-mesh as possible so that the pigs have contact with each other. This leads to more activity on the slats and keeps them cleaner. In pens with automatic feeders, these should be placed on the dividing wall on the side towards the opening to the excretion walkway. Bite valves with permanent water supply should be placed in the excretion walkway in such a way that the pigs turn into the defecation walkway to prevent manure collecting at the entrance to the pen (Olsson & Ascárd. 2008).

Underfloor heating can be installed in the entire lying area and should be used to control defecation and lying behaviour (Olsson & Ascárd, 2008). Heat for the underfloor heating can *e.g.* be extracted from the slurry in the slurry culvert by a heat pump (see section 5.2.4).

Long-trough pens with split excretion walkways give a smaller slatted floor area (~25 % of pen area) and therefore smaller slurry channel area than if the pen had a full excretion walkway (~40 % of pen area). With a split excretion walkway the slatted floor area is around 0.24 m^2 per pig, compared with around 0.40 m^2 with a full walkway. If the lying area is kept equally clean, the NH_3 emissions should be lower from pens with split excretion walkways. Studies in Holland have shown that NH_3 emissions can be reduced by 20 % if the slatted floor area for weaner pigs is decreased from 50 % to 25 % of pen area. The corresponding reduction in NH_3 emissions for fattening pigs is 10 % (Aarnink *et al.*, 1996).

Lying areas in weaner pens should also not be over dimensioned. An adequately large excretion area is also good for pen hygiene. Under floor heating in the entire lying area can be used to control the lying behaviour of the pigs and thus also pen hygiene. In order for the self-draining floor to be kept clean, the fences in excretion walkways must be open-mesh so that contact exists between pens, which increase the number of trampling on the slats (Olsson & Ascárd, 2008).

For weaner pigs in small pens (10 pigs) it is generally better to have narrower pens in order to have good pen hygiene. If the pen has an automatic feeder, the position of this is very important in achieving good pen hygiene. It must be placed approx. two-thirds of the way down the pen on the side where there is an opening out to the excretion walkway. Automatic feeders in large pens should be placed on a dividing wall near the excretion area. Bite valves for supplementary water access should be placed above the slats (Olsson & Ascárd, 2008).

5.2.3 Design of slurry culvert and slats

Ammonia emissions from a pig house with slatted floor originate partly from the slurry channel and partly from the floor surfaces in the house, including the slatted floor. The amount originating from the slurry channel probably varies with conditions in the house, for example the slatted floor area and the air movements in the house. Measurements in a fattening pig house with 40 % slatted floor area and scrapers under the slats have shown that 47 % of NH_3 emissions come from the slurry channel with high evacuation. This proportion appears to increase with increasing air flow through the house (Jeppsson & Gustafsson, 2006). In international systems where the slurry is stored under the slats, the majority of the NH_3 emissions (approx. 80 %) come from the space under the slats (Aarnink *et al.*, 1996).

A measure described internationally (BREF, 2003; ECE, 2007) is to decrease the slurry surface area in the slurry channel. This is achieved by having a V-shaped slurry culvert, which decreases the slurry surface area. The V-shaped sides must have a smooth surface so that the slurry does not adhere to them. For fattening pig pens the specification is that the sloping side facing the pen lying area must have at least 45^o slope and that the other sloping side on the opposite side must have at least 60^o slope. This decreases slurry surface area in the slurry channel to max. 0.18 m^2 per pig. This is a possible alternative for pens with a full excretion walkway (40 % slatted floor area) but practical trials should first be carried out to test the function and verify that NH_3 emissions are decreased. Internationally, it is reported that this measure gives a 60 % reduction in NH_3 emissions compared with the reference pen (ECE, 2007).

There is also an alternative with urine drainage in the slurry culvert and slurry extraction with mechanical scrapers (ECE, 2007). However, there are no data available on how much urine drainage decreases NH_3 emissions.

A 10 mm layer of oil (mineral oil) on slurry surface has been tested in a fattening pig house with 25 % slatted floor area and NH_3 emissions were found to be reduced by 31 % during a three-week measuring period (Aarnink & Wagemans, 1997). In laboratory studies, a thin (6 mm) surface layer of oil has been shown to reduce NH_3 emissions from slurry by up to 98 % (Pahl *et al.*, 2002). In practical trials carried out in a fully slatted house for weaner pigs, a 5 mm layer of vegetable oil reduced NH_3 emissions by around 50 %, while at the same time decreasing odour by more than 50 %. However the oil layer disintegrated and after 25 days the NH_3 emissions increased markedly. A thicker layer or addition of new oil would probably have reduced NH_3 emissions over a longer period. A disadvantage that emerged was that CH_4 emissions increased by 60 % (Pahl *et al.*, 2002).

In general, plastic and metal slats give lower NH_3 emissions than concrete slats at the same percentage opening. The reason is that it takes a longer time for manure and urine falling on concrete slats to reach the culvert and this causes more NH_3 emissions (ECE, 2007).

In a study on the effect of slat openings on NH_3 emissions carried out in a fattening pig house with three sections, with 18 mm, 20 mm and 22 mm slat openings respectively, the different slat openings gave rise to no differences in NH_3 emissions (Fabbri et al., 2007). However, odour emissions were higher with the 18 mm slat opening due to the pen floor and the pigs being fouled with manure.

5.2.4 Manure cooling

In the LBT experimental house, Alnarps Södergård, trials have been carried out on cooling of the slurry channels in a fattening pig house with the help of cooling pipes and a heat pump. The cooling pipes were inserted at 0.06 m depth with a c-c spacing of 0.27 m into the floor of a 1.09 m wide slurry channel. Cooling the floor of the slurry channel from 9 ^oC to 5 ^oC reduced NH_3 emissions by 47 % (Andersson, 1998). Another study showed that NH_3 emissions decreased by 35 % with a temperature decrease of 2 ^oC (Carlsson & Nilsson, 1999). In Denmark there are similar systems in which cooling has been reported to reduce NH_3 emissions by around 30 % if the system is designed so that the pipes lower the temperature by 5 ^oC (Dansk landbrugsrådgivning, 2004a).

In Holland a system has been developed where cooling plates float on the surface of slurry under slats. These cooling plates are 0.14 m wide and 0.01 m thick, and float on the surface at a 60^o angle and at spacings of 0.10-0.15 m. They are cooled with groundwater (den Brok & Verdoes, 1996). The system has been developed for use in pig houses with slurry storage in channels under the slats. In a house with partly slatted concrete floor, slurry storage under slats and cooling plates, NH_3 emissions were reduced by 50 % compared with the reference system (BREF, 2003, ECE, 2007).

5.2.5 Additives to decrease manure pH

The effectiveness of a pH-lowering additive is dependent on its capacity to neutralise the basic character of the slurry (Husted *et al.*, 1991). Additives that lower the pH are divided into acids and salts. Acids are more effective in lowering slurry pH than salts and the pH decrease is more long-lasting (Husted *et al.*, 1991).

A number of acids have been used in experiments to reduce NH_3 emissions, *e.g.* sulphuric acid, hydrochloric acid, nitric acid, phosphoric acid, lactic acid and acetic acid (McCrory & Hobbs, 2001; Rodhe *et al.* 2005). Phosphoric acid is relatively expensive but is not influenced by microbes (Rodhe *et al.* 2005). Sulphuric, hydrochloric and nitric acid are strong irritants and thus dangerous to handle. They are also very corrosive (McCrory & Hobbs, 2001). The effect of sulphuric and nitric acid can decrease due to microbial activity. Lactic and acetic acid are less corrosive but they can also be broken down by microorganisms (Rohde *et al.*, 2005). Addition of nitric acid to slurry causes large amounts of dinitrogen gas to be released (Berg *et al.*, 2006). There is also a risk of acids promoting production of toxic gases, for example hydrogen sulphide on addition of sulphuric acid.

In Denmark a system has been developed for houses with slurry collection where the pH is lowered with the help of sulphuric acid. The acid is added automatically to the slurry in a container outside the house. Aeration prevents dangerous hydrogen sulphide being formed in the slurry. The slurry, with a pH of 5.5, is then returned to the slurry channels of the house. The system uses 4-6 kg concentrated sulphuric acid per ton of manure. With this system NH_3 emissions are reduced by 70 % (Dansk landbrugsrådgivning, 2004b).

Soluble salts with acidifying effect, for example calcium chloride, magnesium chloride, calcium sulphate and copper sulphate, can be used to lower the pH in slurry. Superphosphate, which is found in some additives, also has an acidifying effect (Rodhe *et al.*, 2005). Addition of a salt gives a temporary lowering of the pH in the slurry. To achieve a long-lasting pH decrease and a reduction in NH_3 emissions, salts must be added repeatedly (McCrory & Hobbs, 2001).

For example, addition of a product consisting of superphosphate and copper sulphate has been shown to reduce NH_3 emissions from slurry. One day after incorporation of the product into the slurry, NH_3 emissions were 50 % lower than from slurry without additive. After 1 week, the reduction was 60 % but after three weeks the effect had begun to decline and NH_3 emissions were 30 % compared with the control without additive (Andersson, 1994).

5.2.6 Addition of peat to deep litter beds

A number of properties render peat (sphagnum peat) a suitable litter material for deep litter beds. Peat has a high water-binding capacity, low pH and above all, the ability to chemically bind NH_3. Peat can bind four times more NH_3 per unit dry matter than straw. A study by Kemppainen (1987) showed that peat (sphagnum peat) absorbs 2.7 % NH_3 per unit mass of dry matter at 70 % water content. Other types of peat bind only 0.26-0.86 % of dry matter mass (Peltola, 1985). Studies have shown that a bed for fattening pigs that contains 60 % peat and 40 % chopped straw decreases NH_3 emissions by 35 % compared with a bed of long straw (Jeppsson, 1998).

5.2.7 Indoor climate (air temperature)

Pigs are clean animals that like to distinguish between the areas they lie in and the areas they excrete in. In comfortable ambient temperatures, pigs like to lie together on a warm and insulated floor area. The area chosen for excretion is as far as possible from the lying area. Above a certain ambient temperature pigs alter their behaviour and like to lie separately on a cooler area, so they then start lying on the slatted floor. They therefore begin to excrete in other places in the pen. This has been studied by Aarnink *et al.* (2006) in pens with 40 % slatted floor area. The results showed that below a certain air temperature, the number of excretions on the lying area remained at a constant 13 % of the total number of excretions. Above a certain air temperature, the number of excretions increased by 10 % with every one degree increase in temperature. The ambient temperature, at which their excretory behaviour changed, decreased with pig weight, from approx. 25 ^{o}C at 25 kg body weight to approx. 20 ^{o}C at 100 kg body weight (Aarnink *et al.*, 2006). The ambient temperature at which behaviour alters probably also depends on production level, floor temperature, ventilation system, air movements and the speed of incoming air.

The risk of lower cleanliness in the pens, and thus larger fouled area, increases during the summer months when air temperature is higher and also increases towards the end of the fattening pig period (Aarnink *et al.*, 1995). The larger the fouled area, the greater the effect of air flow and temperature on NH_3 emissions (Ni *et al.*, 1999).

5.2.8 Air flow

At constant temperature in the house, NH_3 emissions decrease with decreasing air flow through the house. This is because air flow over the surface of the manure influences the concentration gradient between the NH_3 in the manure and in the surrounding air. With increased air flow, NH_3 release gradually approaches a maximum value.

By cooling incoming air on warm days and thus decreasing air flow and lowering air temperature, NH_3 emissions can be decreased. This has been studied by Müller *et al.* (2005), who cooled the air for a farrowing house with a soil heat exchanger. The results showed that NH_3 emissions can be reduced by at least 25 % in a farrowing house.

5.2.9 Ventilation system

Most houses with mechanical ventilation have exhaust ventilation. The ventilation fans extract air from the house and thus create a negative pressure, which causes external air to enter the house. If manure extraction and urine drainage systems are not airproofed to external air, they act as air inlets. This air carries NH_3 into the house, causing the NH_3 concentration inside the house to increase so that NH_3 emissions increase. The NH_3 concentration in the air from manure or urine systems can be very high. Air supply via manure and urine removal systems is unfortunately much too common. This can be prevented by having air-tight valves, u-bends or extractor fans in outgoing culverts. In systems that have pipes for urine drainage leaving the house, shut-off devices are also required in these.

The function and positioning of air inlets affect NH_3 emissions by affecting air movements around surfaces that are fouled with manure. In choosing and placing air inlets, the aim should therefore be to have as low air speeds as possible around fouled surfaces. It is the animals that need fresh outdoor air, not the slurry.

The depth of the slurry channels affects air movements over the slurry surface. A channel that is 1.20 m deep gives up to 30 % lower NH_3 emissions than a channel that is 0.45 m deep (Andersson, 1995).

In Sweden the extraction fans are normally placed in the ceiling or walls (HE – high evacuation). If the house has a slatted floor with slurry channels, there is good potential to decrease NH_3 concentrations in the house through extracting outgoing air via the slurry channel (LE – low evacuation). However, this type of slurry gas ventilation increases air movements down in the slurry channel, which increases NH_3 emissions. At the LBT experimental farm, Alnarps Södergård, the difference in NH_3 emissions between HE and LE has been investigated for different ventilation flows. At high air flows, higher NH_3 emissions were found with LE than with HE, but at low flows (approx. 30-40 % of maximum flow) NH_3 emissions were at the same level as for HE. Since LE means lower NH_3 concentration in the house, there are improvements in the working and animal environment. The outgoing air from low evacuation can preferably by purified in *e.g.* a biofilter (see section 5.2.10).

5.2.10 Air purification

The outgoing air can either be purified in a biobed or scrubber, an option for mechanically ventilated animal houses. If all outgoing air has to be purified, in most cases this requires collection of the outgoing air in one place, but there are examples of systems where the air from each extractor fan is purified in a biobed. There are also systems where the outgoing air drums consist of scrubbers that purify the air.

Purification of outgoing air is a measure with high installation costs but the running costs also increase since the fans must be able to handle the pressure drop through the biobed or scrubber. One option to decrease the costs is to only purify part of the outgoing air. By purifying approx. 30 % of the outgoing air capacity (minimum ventilation), NH_3 emissions are decreased by around 70 % if the efficiency of purification is 95 %. If the efficiency of the air purifier is approx. 50 %, NH_3 emissions are decreased by around 40 % (Kai et al., 2007).

Biofilters

A biofilter consists of organic material in which the purification is carried out by micro organisms. The air passes through the material and is captured by the moisture and micro organisms present in a biofilm around the organic material. Biofilters are efficient at purifying large flows of air with low concentrations of air pollutants. Well-designed biofilters in agriculture can decrease the content of moisture and hydrogen sulphide by 95 % and that of NH_3 by 65 % (Nicolai & Lefers, 2006). Examples of organic material are peat, soil, compost, sawdust, straw or a combination of two or more materials (Nicolai & Janni, 2001).

Scrubbers

Purification of outgoing air with scrubbers is a method for reducing NH_3 emissions that is mainly used in Holland, Germany and Denmark. In Holland there are more than 200 establishments that purify the outgoing air from pig and poultry houses (Melse *et al.*, 2006).

A scrubber consists of a reactor with a filter of an inert or inorganic material (for example a plastic) with a large pore volume and surface area. The material is moistened with liquid that is applied to one of the sides of the bed with a sprayer or sprinkler system. A fraction of the liquid is recycled and a fraction is separated out and replaced with new water. Air from the house is forced horizontally or vertically through the filter, which leads to good contact between air and liquid. The NH_3 present in the outgoing air dissolves in the liquid. The liquid removed can be used as a liquid fertilizer.

The scrubber is usually designed to handle the maximum air flow from the house. In order to decrease the costs, one option can be to not purify all the air. Calculations show that if the scrubber is designed to handle 50 % of maximum flow, only 10-20 % of NH_3 emissions do not pass through the scrubber (Melse *et al.*, 2006).

In Holland, five chemical scrubbers and six bioscrubbers have been evaluated (Melse & Ogink, 2005). On average, the NH_3 content in the air was reduced by 96 % by chemical scrubbers and by 70 % by bioscrubbers.

5.3 Emissions of methane and nitrous oxide

Methane is formed by microorganisms during anaerobic decomposition of carbohydrates in *e.g.* feed and manure. Methane gas production from animals is primarily determined by animal species, size, feed intake, production level and feed digestibility (Wilkerson *et al*., 1994; Jungbluth *et al*., 2001). As well as being produced in the digestive tract of animals, CH_4 is also produced from anaerobic decomposition of slurry in houses and in storage units. Methane gas production from slurry is mainly determined by carbon availability, oxygen availability, pH, temperature, storage duration, chemical composition of the slurry and the presence of compounds that inhibit CH_4 gas formation (Zeeman, 1991; Hüther *et al*., 1997; Gonzalez-Avalos & Ruiz-Suarez, 2001). In practice, since the microorganisms and essential ingredients are present in the slurry, it is temperature and storage duration that determine CH_4 gas production (Monteny *et al*., 2001). Values of CH_4 emissions from pig houses cited in the literature vary between 0.9 and 4.5 kg per (fattening pig) place and year depending on the composition of the diet and the production level (Jungbluth *et al*., 2001). Around 35 % of CH_4 emissions originate from the pigs themselves (Monteny *et al*., 2001).

Nitrous oxide (dinitrogen oxide) is formed by microorganisms during denitrification in oxygen-deficient environments. Denitrification is preceded by nitrification, where ammonium is transformed by nitrifying bacteria (aerobic) to nitrite/nitrate. High concentrations of NH_3 and low C/N ratio inhibit nitrification. Production of dinitrogen oxide in slurry depends mainly on denitrifying bacteria, the availability of oxygen and nitrite/nitrate and access to readily degradable organic material. Ammonification of urea must occur before N_2O is released from the slurry. The ammonium formed is converted to nitrite/nitrate by aerobic nitrifying bacteria. High concentrations of NH_3 and low C/N ratio inhibit the conversion of ammonium to nitrate. Production of N_2O in slurry is affected by denitrifying bacteria, oxygen, nitrite/nitrate, and readily degradable organic material (Monteny *et al.*, 2001). Nitrous oxide emissions from pig houses vary between 0.02 and 0.31 kg per place and year for animal housing systems without litter and between 0.05 and 3.73 kg per place and year for deep litter beds (Jungbluth *et al.*, 2001).

Animal housing and slurry handling systems affect emissions of CH_4 and N_2O. Comparative studies have been carried out in Belgium on fattening pigs in fully slatted pens and deep litter beds, and on fattening pigs on full slats and straw-flow. The experiments had 5 and 3 replicates respectively and were performed by comparing two large pens with 16 pigs in each (Table 3). The amount of straw used was 47 kg per pig in the deep litter pen and 34 kg per pig for straw-flow. In the experimental system with straw-flow the solid manure was stored inside the house, which probably affected the results.

Table 3. Emissions of ammonia, methane and N_2O from fattening pig production in fully slatted pens, deep litter beds and straw-flow

	Ammonia g/animal, day	Methane g/animal, day	Nitrous oxide g/animal, day	Reference
Fully slatted pen	6.2	16.3	0.54	Phillippe *et al.*, 2007a
Deep litter bed	13.1	16.0	1.11	Phillippe *et al.*, 2007a
Full slats	4.98	15.2	0.67	Phillippe *et al.*, 2007b
Straw-flow	13.31	8.88	0.68	Phillippe *et al.*, 2007b

Since slurry is not stored inside the pig house in Sweden, emissions of CH_4 and N_2O are expected to be lower in Sweden as compared to the fully slatted systems in Phillippes investigation (Phillippe *et al.*, 2007a). Monteny *et al.* (2001) measured CH_4 and N_2O emissions from both animals and manure. The emission of CH_4 from growing-finishing pigs (enteric fermentation) was 1.5 kg/place/year. The emission of CH_4 from indoor storage of slurry was 9.6 kg/place/year in fully slatted housing systems for growing-finishing pigs. It might be expected that the emission of CH_4 from slurry is low in pig houses without any storage of slurry in the pig house, as in Sweden (Osada et al, 1998; Hilhorst et al, 2002). Measurements in Sweden by Ngwabie *et al.* (2010) in a partly slatted fattening house with daily scraping under the slats during three fattening periods show that the mean CH_4 emission for a fattening period is between 7.9 and 38.9 g/pig/day (2.9 – 14.2 kg CH_4/place/year). The highest emission was during the summer period. These Swedish figures show that more research has to be done before clear figures are available. The advantage of not having storage of manure inside might be enraged by higher CH_4 emissions from the slurry storage outside the pig barn. Therefore it might be even more important to reduce emissions of CH_4 from the slurry storage by using the slurry for biogas production.

The mean emission of N_2O from the fattening house was low in the Swedish study, between 0.003 and 0.11 kg/place/year (Ngwabie et al, 2010). This is significantly lower as the emission of N_2O from pig houses with manure storage inside (0.25 kg N_2O per growing-finishing pig place per year which means 75 CO_2eq per pig place and year). Electricity consumption is about 64 kWh per growing-finishing place which would mean 6 kg CO_2eq per place/year (Vattenfall, 91 g carbon dioxide per kWh). A summary of this is given in table 4.

The greatest reduction of nitrious oxide emission is achieved by matching fertiliser application rates to the crop requirements (Hellebrand & Munack, 1995). Here, biogas production might be important, since digestate from biogas production contains nitrogen which is better utilizable by the crops (Baltic Sea, 2010).

Table 4: Emissions of carbon dioxide equivalences (CO_2eq) in kg per growing-finishing pig place per year from housing with or without slurry storage under the building (exclusive the storage outside the building)

	Housing with slurry storage inside	Housing with slurry storage outside	References
Methane from enteric fermentation (kg CO_2eq /place/year)	37	.	Monteny *et al.*, 2001
Methane from manure indoors (kg CO_2eq /place/year)	240	180 [1)]	Monteny *et al.*, 2001 Ngwabie *et al.*, 2010
Nitrous oxide from pig house (kg CO_2eq /place/year)	75	18	Monteny *et al.*, 2001 Ngwabie *et al.*, 2010
Carbon dioxide from energy consumption (kg CO_2eq /place/year)	6	6	Hörndahl, 2008
Total (kg CO_2eq /place/year)	358	204	

[1)] Both from pig and housing

5.4 Discussion

We detected only two comparative studies of different housing and slurry handling systems for pigs, both carried out in Belgium by Philippe *et al.* (2007, 2007b). The studies show that a slurry system with fully slatted pens gives considerably lower NH_3 emissions than deep litter beds and straw-flow. The advantage with straw-flow is that emissions of CH_4 are much lower than for the slurry system. Emissions of N_2O are much higher for deep litter beds than for the slurry system. Amon *et al.* (2007) have also studied straw-flow and report considerably lower emissions of NH_3, CH_4 and N_2O. Further comparative studies are needed to produce reliable data on differences in emissions between different housing and slurry handling systems.

Animal housing and slurry handling systems in Sweden differ from those in other countries due to tradition, climate and animal welfare. In addition, many of the housing and slurry handling systems that exist in Sweden are already designed in such a way that they give lower NH3 emissions than the traditional systems in other countries. However, there is a lack of data and results from several of the Swedish systems in terms of emissions of NH3 and GHG. Table 5 shows the status of Swedish animal housing and slurry handling systems compared with traditional international systems and the systems with the lowest NH3 emissions according to ECE (2007) and BREF 07.06 (2003). Measures with the greatest potential for decreasing NH3 emissions in Swedish pig houses are estimated to be:

- Planning for good pen function and clean pens
- Preventing incoming air from passing through the slurry handling system
- Cooling the slurry in the culverts with heat pump and cooling pipes
- Purifying outgoing air by biofilter or scrubber
- Using peat in deep litter beds
- Designing deep litter pens for dry sows with combined floor areas instead of a full deep litter area.

Table 5. Ammonia emissions from the reference system, a system equivalent to the traditional Swedish system and the system with the lowest NH_3 emissions according to ECE (2007) and BREF 07.06 (2003)

Animal category	Description of system	NH_3 emissions kg NH_3/place & yr	Reduction %
Fattening pig house			
Reference system	Fully slatted pen, slurry storage under slats	2.4 – 3.0	
Swedish system	Partly slatted floor, scrapers, concrete slats		40 [1)]
System with lowest NH_3 emissions	Partly slatted walkway, V-shaped culvert, vacuum slurry removal, metal slats		65
Air purification	Chemical scrubber		90
Weaner house			
Reference system	Fully slatted pen, slurry storage under slats	0.6 – 0.8	
Swedish system	Partly slatted floor, scrapers		40 – 70 [2)]
System with lowest NH_3 emissions	Partly slatted floor with cooling of slurry surface		75
Air purification	Chemical scrubber		90
Farrowing house			
Reference system	Fixed sows, fully slatted pen, slurry storage under slats	8.3 – 8.6	
Swedish system	Partly slatted floor, scrapers		35 [2)]
System with lowest NH_3 emissions	Fully slatted floor, cooling of slurry surface		70
Air purification	Chemical scrubber		90
Dry sow house			
Reference system	Fully slatted pen, slurry storage under slats	3.2 – 4.2	
Swedish system	Deep litter bed		0 – +67 [2)]
System with lowest NH_3 emissions	Partly slatted floor, separation of manure, back-rinsing with liquid fraction in gutters		70
Air purification	Chemical scrubber		90

[1)] Agrees with Swedish data; [2)] Swedish data lacking

6. TREATMENT OF MANURE OUTSIDE THE PIG HOUSE

6.1 Lowering the pH of the manure

Lowering the pH of the slurry can be one way to reduce NH_3 emissions from storage and spreading of slurry. In most cases the treated slurry is even used inside the pig houses to reduce NH_3 emissions from the pig house as well. In Denmark a system has been developed for houses with slurry collection where the pH is lowered with the help of sulphuric acid. The acid is added automatically to the slurry in a container outside the house. Aeration prevents dangerous hydrogen sulphide being formed in the slurry. The slurry, with a pH of 5.5, is then returned to the slurry channels of the house. The system uses 4-6 kg concentrated sulphuric acid per ton of manure. With this system NH_3 emissions are reduced by 70 % (Pedersen, 2004).

6.2 Anaerobic treatment (digestion) for biogas production

It is well known that anaerobic digestion for biogas production from animal slurry is one of the most cost-effective end-of-pipe methods of reducing emissions of GHGs from animal husbandry. Additional GHG benefits are achieved when the evolved biogas is used for energy supply that would otherwise have come from fossil fuels (Weiske, *et al*., 2006). How the anaerobic digestion process affects NH_3 emissions is however less well understood and there are few studies carried out comparing pig slurry/manure management processes with and without anaerobic digestion as a treatment option.

Laboratory studies, of thermophilic anaerobic digestion of artificial pig slurry (Strik *et al*., 2006), show NH_3 concentrations in evolved biogas of between 100 – 200 ppm for satisfactory biogas production. Though reducing the pH in the reactor reduced NH_3 concentration in biogas, the total biogas (and CH_4) production rate was also reduced. This reduction was due to the increased concentration of free volatile fatty acids (VFAs). Consequently it was concluded that it is impossible to control the NH_3 content of biogas by adjustment of pH whilst simultaneously maintaining a satisfactory biogas production. In the experiment the reactor was fed continuously for 160 days with maize silage and artificial pig manure during earlier stages, and solely pig manure for the last 58 days of the experiment.

Table 6 shows the results of pilot scale experiments on storage of cattle slurry with and without previous treatment in an anaerobic digester (Clemens, *et al*., 2006). The table shows that NH_3 losses from digested slurry were similar to those for undigested slurry during winter storage experiments, whereas during summer NH_3 emissions were about twice as high for biogas treated slurry as for untreated slurry. In general NH_3 emissions during the summer experiments were higher than during the winter experiments due the higher summer temperatures. The table also shows the effect of a solid cover and a straw cover on the slurry/digestate storage tank.

Table 6: Ammonia emissions due to cattle slurry/digestate during winter and summer storage experiments (Clemens *et al.*, 2006)

	Percent of total nitrogen given off as ammonia	
	Winter experiments (100 days)	Summer experiments (140 days)
Untreated slurry with crust	2.8	4.2
Untreated slurry with crust solid cover	2.0	2.3
Digestate	2.5	8.9
Digestate with straw cover	2.0	5.0
Digestate with straw and solid cover	1.9	3.1

Meanwhile, studies of NH_3 volatilisation after spreading (Sommer, *et al*., 2006) show a TAN loss of 9.7 % of total ammoniacal nitrogen (TAN) for digested pig manure (in 80/20 mixture with food waste) compared with 7.3 % for untreated pig manure. If the digested pig slurry also was subsequently separated by centrifugation the NH_3 losses after spreading was reduced to 4.9 % of TAN. These values are for surface application on sandy-loam soil. It is concluded from these studies that NH_3 volatilisation is greater for digested pig slurry due to its higher pH, 8.1 compared to pH 7.4 for untreated pig slurry. Meanwhile the reduced volatilisation of the separated, digested slurry (in spite of a pH of 8.2) was considerable due to the fact that separated slurry had a lower viscosity and therefore higher infiltration than the digested slurry that had not been separated.

Of interest to the current investigation of pig manure, is the body of literature concerning biogas production from cattle slurry. In experiments with surface application of differently-treated cattle slurry, (Möller and Stinner., 2009) found that 10.6 % of the total applied N is lost 96 hours after application for anaerobically digested cattle slurry compared to 8.9 % for untreated cattle slurry.

6.3 Aerobic treatment (wet composting) of slurry

A more comprehensive literature review was not possible in this limited review. Biological aerobic treatment can induce a nitrification and de-nitrification processes, which transforms the ammoniacal nitrogen in the raw slurry to nitrate and gaseous products, mostly di-nitrification (Burton *et al*., 1993). Nevertheless, poorly controlled aeration processes can also produce polluting gases including N_2O and NH_3. With intermittent aeration of pig slurry, Loyon *et al*. (2007) found a decrease of the GHGand NH_3 emissions compared to using storage alone.

7. STORAGE OF MANURE

7.1 Influencing factors on ammonia emissions from storage

The main influencing factors on the NH_3 losses from storages are manure properties (pH, dry matter content) temperature and wind conditions, filling technology, storage time, and for slurry storage ratio surface: volume, crust formation and mixing methodology (Svensson, 1991).

7.2 Ammonia losses from manure storage – emission factors for Sweden

There may be large losses of NH_3 when manure is stored, especially from solid manure or uncovered storages with urine water (Sommer *et al*., 1993; Karlsson, 1996a; Karlsson, 1996b; Smith *et al*., 2007). Petersen *et al*. (1998) measured a loss from solid pig manure of 23-24 % of total N. For slurry, the losses are less; Sommer *et al*. (1993) measured 8 % of total N for pig slurry, De Bode (1991) 5-15 % for cattle and pig slurry; Rom *et al*. (1999) 6-9 % for cattle and pig slurry. For cattle urine Karlsson (1996b) estimated a loss of 40 % of total N in full-scale storage, based on measurements in pilot scale. The Danish researcher Sommer (2000) made a review and set a loss of about 30 % of total N from urine storage. High NH_3 losses will also occur during storage of deep straw manure, where composting process take place with temperature rises up to 65°C. Karlsson and Jeppsson (1995) measured 19-35 % losses of total N from storage of deep straw manure from young cattle. Kirchmann (1985) showed the influence of carbon: nitrogen (C/N) ratio on NH_3 losses from solid manure heaps. The highest losses were in the short term (about the first 100 days) from the heap with C/N 16, while the losses from the heap with a C/N ratio of 40 were much smaller. However, in the long run (about 450 days storage) the losses were about the same from the two heaps.

Based on research made in Sweden and relevant research made in other countries, JTI together with The Board of Agriculture, have set up a Table of emission factors for NH_3 losses from manure storage (Karlsson & Rodhe, 2002), see Appendix 1. The losses are given for different types of manure (solid, semi-solid, slurry, urine and deep straw litter) from cattle, pig, hens, broilers, horses and sheep, respectively. The Swedish emission factors for storage of manure from dairy cows and pigs are: 1) 20 % of total nitrogen if stored as solid manure 2) 1 to 9 % of total nitrogen if stored as slurry and 3) 5 to 40 % of total nitrogen if it is urine (Karlsson & Rodhe, 2002). If the manure is composted, the emission factors are also high (30 %).

7.3 Measures to reduce ammonia losses from manure storage

7.3.1 Slurry

Based on the influencing factors on NH_3 emissions from slurry storages, Svensson (1991) gave a list of economical measures to reduce the NH_3 losses from the slurry storages. The measures related to slurry storage were:

- Minimize the storage time
- Minimize the quota slurry area to volume of storage
- Stimulate formation of stable crust
- Minimize air movement above slurry surface
- Minimize time for mixing

Since then these measures together with others have been implemented in Swedish agriculture as well as in many other countries (SJV, 2006).

Ammonia losses can be sharply reduced if the air directly above the slurry store is prevented from circulating. A method that efficiently reduces NH_3 losses is to cover the slurry stores with, for instance, a roof, a floating plastic cover or a stable natural crust (Sommer *et al*., 1993; Karlsson, 1996a; Smith *et al*., 2007). Sommer *et al*. (1993) found that in general, floating covers on pig or cattle slurry storage reduced NH_3 emissions with 60 % compared to no cover or crust. Karlsson (1996a) found in pilot scale studies that a good reduction in NH_3 emission could be obtained by covering pig slurry storage as well as urine pits. In the pig slurry storage a floating plastic foil as well as a peat layer were the most effective alternatives of the studied covering alternatives. They reduced NH_3 emissions by 85 % compared with the reference container. A wet surface crust (5 cm thick) was established in the reference container before the first measurement occasion. Leca pebbles (10 cm layer) reduced the losses with 47 % compared with reference. Finally, chopped straw (9 cm layer) reduced the emissions by 43 % compared with the reference. In cattle urine, chopped straw was not a reliable covering alternative as it after some time sank to the bottom and thereby had only a durability of 1-2 months. Also, the 0.5 cm cover with rapeseed oil on urine surface where very sensitive to wind and thereby not to be recommended.

If the slurry lagoon is filled underneath the cover, this can be kept intact even during filling, which reduces the risk of NH_3 emission (Muck *et al*., 1984). Karlsson (1996b) compared in full scale the losses from two pig slurry storages with top and bottom filling, respectively at five different times of the year. The NH_3 losses were low during the colder period November to January, with increased losses in March and April. In total, the losses did not exceed 3 % of the initial total N content, although no covers were used. Furthermore, hardly any difference in emission rate could be observed between the storage with pig slurry filled from the bottom and the storage with pig slurry filled from the top.

A method for reducing NH_3 emissions from stored slurry could be to change the properties *e.g*. by using additives. It is rather easy to mix an additive homogenously into slurry.

Addition of acid to slurry and thereby reducing the pH to around 5 is one method proved to reduce NH_3 emissions in storage (Rodhe *et al*., 2005). The method is today used in certain Danish farms (www.infarm.dk). Working environmental aspects, foam formation on slurry surface and investment costs are factors that so far have held back any more common use of it. Additives with mainly physically effects on the slurry are clay minerals and peat, which can adsorb and concentrate ammonium ions (Kirchmann & Witter, 1989; Al-Kanani *et al*., 1992). Another additive is an extract from Yucca, which also could adsorb NH_3 (Chapuis-Lardy *et al*., 2003). However, there are also research results not showing any effect, see review of additives in Rodhe *et al*. (2005).

7.3.2 Solid manure

From storages with solid manure, especially if composting takes place with high temperatures, the NH_3 losses could be high (Karlsson, 1994). The NH_3 volatilisation process could be delayed with a high C/N ratio of the manure (Kirchmann, 1985) as the microbes use nitrogen, as long it is carbon available. Peat included in the bedding material will also reduce the NH_3 losses during storage (Jeppsson *et al*., 1997; Rogstrand *et al*., 2004).

Jeppsson *et al*. (1997) composted deep straw manure from young cattle, based on beds with A) chopped straw, B) chopped straw + additive, C) 40 % chopped straw + 60 % peat (weight dry matter), and D) staw, not chopped. The total-N loss from the heaps during 46 days of storage were only 2 % from the compost C with bedding chopped straw + peat and highest (23 %) from pile D with straw, not chopped. In between, pile A gave 14 % losses and pile B 16 %. Rogstrand *et al*. (2004) showed in pilot scale studies that peat added to the straw bedding in tied cow barns or cover of the storage reduced the NH_3-losses with about 30 % compared to control. Applied to a full-scale barn, peat added reduced the NH_3-losses with 20 % compared to control, which meant a loss of about 14 % of total N coming into the storage (Rogstrand *et al*., 2005).

In the old days, there were also roofs on solid manure storages, but with increasing numbers of animals and thereby big amount of manure, it is nowadays not common. However, it could be an effective measure to reduce NH_3 losses from solid pig manure storages according to pilot scale measurements (Karlsson, 1996b). Additionally, a roof keeps rainwater away, which could prevent nutrient leakage from the manure pad if it has insufficient or lacking drainage.

The experiments by Karlsson (1996b) were made with pig manure (40.4 % DM) in 'static' storage, which means without everyday addition of new manure as in a full-scale storage. Under those conditions, the roof reduced the NH_3 losses during the first six days of storage with 79 % compared with no roof. Two weeks later, the NH_3 loss was very small from both of the storages. In a parallel study, semi-solid manure (anaerobic conditions, 'cold' manure) was stored with and without covers as straw (25-30 cm), peat (15 cm) and plastic cover. With the peat cover, no NH_3 emissions were detected. The other two covering materials also reduced the losses, with about 90 % compared to no cover. However, with aerobic conditions like in composts, where the temperature is high, Rodhe & Karlsson (2002) showed that a straw cover of about 30 cm also isolated the broiler litter pile well. Thereby, the average temperature in the covered pile stayed on a high level, around 50°C from October to May, which favoured NH_3 emissions. The conclusion was that covering the broiler manure heap with straw did not decrease the NH_3 losses during storage compared to no cover.

Techniques for converting solid manure to slurry in order to improve nitrogen utilisation (partly by reduced NH_3 emissions during storage) have been investigated by JTI (Karlsson &

Svensson, 1993). For ordinary farms, the studied methods were considered not economically or practically useful.

8. SPREADING OF MANURE

8.1 Influencing factors on ammonia emissions after spreading

The main factors influencing the NH_3 losses from applied manure are related to climate, manure properties, soil/crop conditions, application rate, and application method (Svensson, 1993; Sommer *et al*., 2001). In a review, Sommer & Hutchings (2001) compiled the factors directly affecting NH_3 volatilisation from field-applied manures into four groups: 1) concentration of NH_3 at manure surface, 2) transfer of NH_3 from surface to atmosphere, 3) area of manure exposed, and 4) the time manure is exposed to air. By incorporation of the manure into the soil immediately after spreading or simultaneously when spreading, the area and time of manure exposure can be minimised and therefore the influence from groups 1 and 2 can also be reduced. The concentration of NH_3 at the liquid surface is primarily a function of the chemical and physical conditions within the manure. Temperature, manure DM-content, pH and NH_4^+ concentration are important factors (Sommer *et al*., 1991; Bussink *et al*., 1994; Svensson, 1994; Vandré & Clemens, 1997). The transfer of NH_3 from the air at the surface to the atmosphere is mainly a function of the local meteorological conditions, *i.e*. wind speed, surface roughness of field, crust formation or crop canopy size and complexity (Sommer & Hutchings, 2001). In the UK, Misselbrook *et al*. (2002a) found in field experiments on ley that the most important variables influencing emissions were wind speed and slurry DM content. In addition, rainfall immediately following application reduced NH_3 emissions from cattle slurry applied to grassland by approximately 50 %. Huijsmans *et al*. (2001) found that the volatilisation rate increased with an increase in TAN content of the manure, manure application rate, wind speed, radiation or air temperature. The influencing factors identified and their magnitude differed with the application technique. Crop height affected NH_3 volatilisation when slurry was applied in narrow bands (Sommer *et al*., 1997; Huijsmans *et al*., 2001). Sommer & Jacobsen (1999) studied the influence of soil moisture content on infiltration of NH_4^+ and NH_3 volatilisation in coarse loamy sand in the laboratory and found that low soil water content enhanced the infiltration of slurry liquid and hence the mass transport of NH_4^+ into the soil, which meant a lower NH_3 emission.

The NH_3 volatilisation is highest during the first hours after application independent of spreading with broadcast spreader, band spreader or shallow injector (Svensson 1993; Huijsmans *et al*., 2001; Rodhe & Etana, 2005). As upwards of 50 % of total emission can occur within the first few hours following application to grassland, differences in emission rates during this period can lead to appreciable differences in total cumulative emission (Misselbrook *et al*., 2002b).

8.2 Ammonia losses from applied pig manure – emission factors for Sweden

Pig slurry applied on the soil surface in bands (band spreading), resulted in 19 % loss of the total ammoniacal nitrogen (TAN) in the slurry, when applied in spring and 17 % when applied in autumn (Svensson & Lindén, 1998; Weslien *et al*., 1998). No incorporation was used within 4 or 7 days, respectively and the experiments were conducted on a sandy soil in the county of Halland, Sweden.

Sommer *et al*. (1997) broadcast or band spread pig slurry to winter wheat in spring or later in June. In spring, when the crop was less than 10 cm high, there were no big differences in losses between broadcast and band spread slurry. When band spread in spring, the NH_3 losses were for three individual years 14, 28 and 17 % of TAN applied, respectively. Later application in June, when the crop heights were about 25 cm or more, the losses were 4, 10.5 and 9.6 % of TAN for the three years, respectively. The corresponding losses for broadcast spreading were 20, 20 and 18 % of TAN.

The NH_3 losses from pig urine applied in spring on bare soil resulted in a loss of TAN of 11 % after broadcast spreading, and 13 % after band spreading (Rodhe & Johansson, 1996). When the pig urine was applied in growing cereals in spring (10 cm crop height), the NH_3 losses were about 11 % of TAN after broadcast spreading and 6 % after band spreading.

Malgeryd (1996) measured a loss of 12 % of TAN in pig slurry after broadcast spreading on bare soil in spring. Broadcast spreading of pig slurry in the end of August, gave NH_3 losses of 102 % of TAN on stubble and on cultivated stubble 42 % of TAN. If band spread, the losses were lower with 42 % of TAN on stubble and 27 % of TAN on cultivated stubble.

Pig slurry applied in late winter on frozen soil, with a soil surface temperature of –2°C to 1.2°C resulted in a very high loss of 50 % of TAN explained by limited possibility for the slurry to infiltrate the soil (Sommer & Christensen, 1989).

Measurements of NH_3 losses from solid pig manure are rare. Malgeryd (1998) concluded that solid manure can give rise to substantially greater NH_3 emissions than slurry when applied at the same rate under identical environmental conditions. The nitrogen lost as NH_3 from broadcast spread solid manure (mixed) in spring was larger than the TAN-content (>100 %). Also, when spreading on crops, most TAN is lost (Rodhe *et al*., 1996). Svensson (1993) showed in lab-scale experiments that the NH_3 emissions from a solid manure (14.4 % DM content) had about 3 times higher NH_3 emissions compared with a slurry (5.4 % DM content) with the same nitrogen content. Good contact between soil and manure is necessary in order to get low NH_3 emissions.

Based on research made in Sweden and relevant research made in other countries, JTI together with The Board of Agriculture, have set up a Table of emission factors for NH_3 losses after spreading of solid manure, slurry or urine (Karlsson & Rodhe, 2002), see Appendix 2. The emission factors for spreading losses are expressed in percentage of total ammoniacal nitrogen (TAN) applied (% of TAN). These factors are used in the national inventory of NH_3 losses and in advisory service. The emission factors (EF) for NH_3 losses are in the range of 3 to 90 % and depends on manure type, time of spreading, and spreading methodology. However, the EF does not differ between animal species. The lowest losses are finding for slurry incorporated on open soil immediately after spreading in early autumn. On the other hand, almost all NH_4-N are lost if you spread solid manure on grassland in summer.

8.3 Measures to reduce ammonia losses from field applied manure

8.3.1 Choice of time for spreading

As temperature has a strong influence on the NH_3 losses, the choice of time for application is important. Choice of season, day and also time of the day influence the losses after spreading. Frick & Menzi (1997) showed that the losses could be halved by start of spreading at 8 pm instead of 6 am when spreading slurry to grassland. Gordon *et al*. (2001) found a 30 % reduction in overall NH_3 flux densities, primarily due to substantial reductions in NH_3 losses occurring within the first 10 h after manure application. The positive benefits of late-day manure spreading were more pronounced during warm, dry weather conditions. Positive linear correlations were observed between NH_3 emissions in the 10 h following spreading and solar radiation, wind speed, temperature and vapour pressure deficit (Gordon *et al.*, 2001).

When applying slurry in a growing crop, placing the slurry in the canopy bottom in bands (band spreading) gives a lower emission than broadcasting if the crop is higher than 25 cm (Sommer *et al*., 1997). The reduction occurs because the crop canopy changes the microclimate near the soil surface, lower wind speed, temperature and radiation, and increased relative humidity (Thompson *et al*., 1990). From pig urine, the NH_3 losses were less than 7 % with band spreading (Rodhe & Johansson, 1996).

8.3.2 Good contact between soil and manure - Spreading methodology

On the pig farms, the manure is mainly spread to cereal crops, either on open soil where it is possible to incorporate the manure by tillage or in growing cereal. Webb *et al.* (2006) concluded that rapid incorporation of manures into arable land is one of the most cost-effective measures to reduce NH_3 emissions. Also, they concluded that covering manure stores and applying slurry by band spreader or injection are more cost-effective than measures to reduce emissions from buildings. Their opinion was that these measures are likely to rank highly in most European countries.

Immediately incorporation after band spreading of pig slurry in spring, decreased the NH_3 losses from 19 % to 3 % of TAN applied (Svensson & Lindén, 1998; Weslien *et al*., 1998), a decrease of 84 %. When applied in August, the corresponding losses were 13.6 % without incorporation and 1.2 % with incorporation and thereby a reduction of more than 90 % was achieved with immediately incorporation. Ammonia emissions from pig urine were also reduced considerably with an immediately incorporation after spreading, with reduction of 80-90 % at spreading in spring tillage (Rodhe & Johansson, 1996). Malgeryd (1996) band spread pig slurry in growing barley with trailing hoses or trailing shoes. Band spreading with trailing shoes incorporate the slurry in the same time as the spreading. The NH_3 losses were 6-7 % of TAN in slurry applied with band spreading on the soil surface but only 0.6-0.7 % of TAN if band spread with trailing shoes (immediately incorporation).

Already since long time back, it is recommended to spread manure just before rainfall in order to reduce NH_3 emissions after spreading. Rainfall immediately following application of cattle slurry applied to grassland reduced NH_3 emissions by approximately 50 % (Misselbrook *et al*., 2002b). Today, with large quantities of manure to be spread in a period, the solution could be to irrigate immediately after spreading. McGinn & Sommer (2007) achieved a reduced NH_3 loss by 21-52 % by 6 mm irrigation after application of beef cattle manure and Rodhe *et al*. (1996) achieved a 30 % reduction of NH_3 emissions with 20 mm irrigation after application of semi-solid manure to grassland and less with irrigation of solid manure; 11 % reduction. The NH_3 emissions after broadcast spreading of pig slurry in growing cereal were reduced from 12 to 4 % of TAN by irrigating with 30 mm of water after spreading (Malgeryd, 1996).

In conclusion, good contact between soil and manure minimize the NH_3 losses after spreading of manure on field (Malgeryd, 1998).

8.3.3 Manure properties and application rate

Improving the ability of the slurry to infiltrate the soil could be a method to reduce NH_3 emissions. This could be achieved by dilution of the slurry or treating the slurry *eg*. by digestion. Klarenbeck & Bruins (1990) showed by dilution of 3 times a reduction from 65 % to 19 % of applied TAN. However, Elmquist *et al*. (1996) did not found any reduction in NH_3 emissions when diluting the pig slurry with 50 % of water, which was explained that the soil conditions did not promote a fast infiltration. With the higher degree of dilution is tanker spreading not realistic for economically and capacity reasons. Instead, injection of the slurry in the water flow from irrigation equipment could be the solution.

Svensson (1993) showed that by halved application rate, the losses were proportional reduced.

8.4 Other losses than ammonia

When adopting NH_3 emission abatement strategies there is a need to take into account all forms of N emissions from agricultural sources (including N_2O and NO_3) so as to ensure that the abatement of one form of emission does not lead to an increase in another and/or an increase in the same form of emission at another stage in an agricultural production system (Hyde *et al*., 2003). There are GHG from manure storage and from soil fertilised with manure or mineral fertilisers. From slurry storage, CH_4 is the main greenhouse gas, while from stored solid manure N_2O will occur. From fertilised soil it is mainly N_2O.

Measures in order to reduce NH_3 emissions may lead to an increased loss of GHG. Incorporation of manure may for instance increase N_2O emissions (Rodhe *et al*., 2005). However, type of incorporation could affect the N_2O losses. For example, closed slot injection of slurry into grassland, where the slurry was placed in cores reduced the losses from about 40 % of TAN applied with band spreading on the surface to zero, but generated a slightly increased N_2O emissions compared to band spreading (Rodhe *et al*., 2005). Velthof *et al*., (2003) found in lab-scale experiments that the placement of pig slurry at 5 cm depth in a row caused significantly greater emissions than when slurry was evenly placed at 5 cm depth or homogeneously mixed through the soil. In contrast, other studies have not found any difference in emission patterns of N_2O and CH_4 between injection and surface application techniques (Sommer *et al*., 1996; Clemens *et al*., 1997).

Excessive fertilizer N applications of mineral N or animal manure undoubtedly increase leaching and a N application adapted to the needs of the crop is a key factor to decrease N leaching. The timing is also important where autumn-applied manure on uncropped fields was found to be one of the most important sources of large nitrogen leaching loads (Djuurhus, 1992; Torstensson *et al*., 1992).

9. ORGANIC PIG PRODUCTION

Since it is not allowed to use synthetic amino acids within organic pig production, protein levels in the feed have to be high, as compared to feed used in conventional pig production. These high levels of protein in the feed increases the risk of higher NH_3 emission. Studies in housing systems with concrete outside yards at LBT (Olsson *et al.*, 2007) have shown that there were almost 4 times higher nitrogen emission of nitrogen as compared to that of conventional growing-finishing pig production. In these studies, evaluation of the important factors has been carried out. The high protein level in the feed accounts for a factor of 1.75, while the larger dirty areas account for a factor of 2.25. As long as synthetic amino acids are not allowed within organic pig production, the possibility of reducing NH_3 emission due to the feed is limited. One solution may be the use of fiber in the diet in order to reduce urinary NH_3 emission. However, the use of fiber will increase CH_4 emission from the manure, and therefore this option may be only a solution when the manure is used for production of biogas. Reduction of the size of the dirty area in the outside yard may also be another solution to reduce NH_3 emission (Olsson *et al.*, 2009). Daily removal of the manure or slatted flooring also reduces NH_3 emission, as compared to removal of manure from a solid floor twice a week (Ivanova-Peneva *et al.*, 2008).

In the more extensive production systems for organic production, the pigs are kept outside on the field with huts. Even here NH_3 emission from the field is a problem. Studies by Sommer *et al.* (2001) showed NH_3 emission of 5.8 kg/sow/year. In other studies, in outdoor pig farming systems, NH_3 emission was 4.9 kg/sow/year. A study of Williams *et al.* (2000) showed the importance of the green area being intact. As soon as the vegetation disappeared, large problems occurred with high losses of nitrate by leaching. Nitrogen in form of N_2O losses were estimated to be about 1 % of the total nitrogen excreted by the pigs, as compared to 0.1 % from slurry storage. Another problem is the fact that the minerals are unevenly divided over the field, since the pigs excreted on specific areas and feed might be spilled around the feeders. In a stationary system with a pig house, a nutrient management technique for collecting the manure on the preferred excretion areas on arable land has to be developed (Salomon *et al.*, 2006). Another solution might be a production system where the huts can be moved to different locations in the field. In the mobile outdoor system, the huts have to be moved regularly to solve the problems of an uneven distribution of excretion and feed spillage on the field (Salomon *et al.*, 2006).

In production systems with a stationary pig house and 24 h per day access to pasture, about 49 % of the dung (measured as P) was left on the field (Olsson *et al.* 2007). The manure will also be very unevenly distributed over the field (Salomon *et al.*, 2006), and therefore extra attention has to be paid to how this distribution over the field could be improved.

10. INTEGRATED SYSTEMS

Due to interactions between different sources on a farm, reduction in NH_3 emission from individual sections of the livestock production system cannot be simply added together to give the net reduction in emission from the total system. Thus a whole farm system approach is needed for devising control strategies for reducing NH_3 emission (Sommer & Hutchings, 1995). This has clearly been demonstrated in their experiment: Reducing the slatted area in the pig house has not reduced NH_3 emission at the farm level. Neither has placing a roof on the slurry store reduces the NH_3 emission at the farm level. Slurry injection has reduced NH_3 emission by about 35 % on farm level. However, reducing the slatted area, plus placing a roof on the slurry store, plus slurry injection has reduced the NH_3 emission by almost 60 % at the farm level. This shows that one has to think in entire systems. This is important since reduction in the NH_3 emission in one part of the production can lead to a higher emission later on in the system, and therefore the whole production chain has to be considered.

Sommer and Hutchings (1995) also point out in their review that there is a need to minimize any adverse side-effects of the measures to reduce NH_3 emissions. These can include the production of pollutants other than NH_3. For example, mixing deep litter in an animal house reduces NH_3 emission, but causes high emission of the green house gas N_2O (Groenestein and Faasen, 1996). Decreasing NH_3 emission will increase the addition of N to the soil, thus increasing the risk of nitrate leaching. Therefore it may become even more important to treat all manure in a biogas installation. The biproducts from biogas production contain less organic N and more inorganic N, as compared that of untreated manure. Therefore less N has to be spread per hectare, which results in a lower nitrate leaching to the groundwater, as compared to that of untreated manure (Baltic Sea, 2010; Birkmosse *et al.*, 2007).

An attempt to estimate the effect of different integrated systems is described below. Four different scenarios made to reduce NH_3 emissions (Table 7) have been studied. In all four scenarios the slurry tank is covered by a roof and the slurry band spread, either in the spring on arable land combined with incorporation within 4 h, or band spread in the early summer in growing cereals with a NH_3 loss of 7 % Total Available Nitrogen (TAN) applied (Karlsson & Rodhe, 2002). The content of TAN is set to 70 % of total-N at the time of spreading. The figures from Appendices 1 and 2 are used.

In Scenario 1, a simple technique is used to reduce NH_3 emission. The crude protein level is reduced from 14.5 % to 12.5 % by incorporation of synthetic amino acids to the feeding system. Extra effort is made to keep clean pens and pigs by using a good ventilation system, and manual daily cleaning of the pens has been used. Iron slats are used in the excretory area. The manure channels under the slats are cooled by a heating pump, and the energy used for heating the housing of piglets and weaners. The manure is removed daily by scrapers under the slats.

In Scenario 2, the cheapest type of housing and cheap feedstuffs are used (biproducts from the food and beverage industries). The feed contains a high level of crude protein (16.5 % instead of 14.5 %). The slurry is stored under the slats and removed every second week by a sewerage system (pipes under the building). So no effort is made to reduce NH_3 emission inside the building, and instead all air from the building is cleaned with a chemical scrubber.

In Scenario 3, the same techniques as in Scenario 1 are used. Here, more fiber in the feed is used and the slurry is used in a biogas plant. The fiber in the feed will reduce NH_3 emission from the pig house and at the same time improve the gas production in the biogas plant. No differences in NH_3 losses from storage and spreading have been calculated due to handling of the digest from the biogas plant.

In Scenario 4, the same techniques as in Scenario 2 are used. Here, more fiber in the feed is used and the slurry is used in a biogas plant. The fiber in the feed will reduce NH_3 emission from the pig house and at the same time improve the gas production in the biogas plant. No differences in NH_3 losses from storage and spreading have been calculated due to handling of the digest from the biogas plant.

Table 7: Reduction in ammonia emission (in percent) with different scenarios (compared to conventional Swedish systems). The data are partly taken from the present literature review

	Standard	**Scenario 1:** **Simple technique**	**Scenario 2:** **Air cleaning of all air**	**Scenario 3:** **Simple technique + Biogas**	**Scenario 4:** **Air cleaning of all air + Biogas**
From Housing:					
Feed	14.5 % RP	Low protein -20 % Low fiber	High protein (cheap rest-products from industry) +20 %	Low protein -20 % High fiber -50 %	Fiber -50 % + high protein (cheap bi-products from industry) +20 %
Pen function / ventilation	Standard	Important with clean pens and clean animals -10 %	Less important with clean pens and clean animals 0 %	Important with clean pens and clean animals -10 %	Less important with clean pens and clean animals 0 %
Slatted flooring	Concrete	Iron -10 %	Concrete 0 %	Iron -10 %	Concrete 0 %
Cooling manure	No	Yes -30 %	No 0 %	Yes -30 %	No 0 %
System for manure handling	Scrapers	Scrapers 0 %	Slurry pipes +40 %	Scrapers 0 %	Slurry pipes +40 %
Air cleaning	No	No 0 %	Yes -90 %	No 0 %	Yes -90 %
Total-effect from housing		-45 %	-83 %	-78 %	-91 %
From storage of manure:	Straw cover	Roof -75 %	Roof -75 %	Roof -75 %	Roof -75 %
From spreading of manure:	Reference technique	Reference technique 0 %	Reference technique 0 %	Reference technique 0 %	Reference technique 0 %

Table 8: Flow of N (kg) per produced growing-finishing pig (25 to 120 kg live weight)

	Standard	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**
Piglet	0.50[1)]	0.50	0.50	0.50	0.50
Feed and straw	5.20[1)]	4.16	6.24	4.16	6.24
Slaughter pig, alive	2.70[1)]	2.70	2.70	2.70	2.70
Excretion	3.00[1)]	1.96	4.04	1.96	4.04
Emissions from the pig house	**0.40**	**0.22**	**0.07**	**0.09**	**0.04**
In manure storage	2.60[1)]	1.74	3.97	1.87	4.00
Emissions from manure storage	**0.10**	**0.02**	**0.04**	**0.02**	**0.04**
Available when spreading the manure	2.50	1.72	3.93	1.85	3.96
Emissions from spreading	**0.12**	**0.09**	**0.20**	**0.09**	**0.20**
Available for the plant	2.38	1.63	3.73	1.76	3.76
Total emission	**0.62**	**0.33**	**0.31**	**0.20**	**0.28**
Reduction in emissions	0 %	47 %	50 %	68 %	55 %

[1)] Figures from Simonsson (1990), Fernández (1996) and Greppa näringen, 2005.

The calculations show that Scenario 3 appears to be the most effective means of reducing NH_3 emission. So the combination of using low protein feed with high fiber content appears to be a promising way for future developments. Even Scenario 1, with simple techniques, has had a significant result: lowering the protein content affects the entire chain from feed to the field. The same effect on the entire chain may be expected of systems where the manure is acidified in the pig house by sulphuric acid, reducing NH_3 emission from the pig house, from the manure storage and at manure spreading (smellfighter from Infarm). Pumping slurry between different compartments in a pig house is not permitted according to the Swedish Welfare Legislation. Therefore it is not certain that the acidification of slurry can be applied in Sweden. In contrast to acidification, lowering the protein level of the feed may reduce the level of nitrogen in the environment, and in that way the N_2O emission from the soil may be reduced as well.

Using air cleaning has a large impact on the NH_3 emission from the pig house. However the higher emissions at spreading, reduces this advantage. This option may be most attractive when cheap feedstuffs with high protein levels are used.

11. CONCLUSIONS

As compared to many other countries, emissions of NH_3 in Swedish pig production are already low, due to low protein levels in the feed, housing systems with a small excretory area, and storage of slurry outside the building.

From the literature review it can be concluded that one should think in whole farm systems. Having covering the manure storage, using band spreading of manure together with incorporation, e.g. using a harrow, within a few hours after spreading, are the most important and easiest ways to reduce NH3 losses. When discussing the methods of animal keeping, feeding and housing, a low protein level in the feed has a positive effect along the entire production chain, and appears to be the most effective means of reducing NH3 emissions. Using more fiber in the feed will reduce the NH3 emission even more.

By altering the pig feed, NH_3 emission can be lowered substantially. The use of synthetic amino acids makes it possible to reduce the feed protein level. One must have in mind that feed protein levels are already low in Sweden (14-15 %), in comparison to other countries (16-18 %). So the potential of reducing NH_3 emission by reducing the protein level is only 10-20 %. However, a low protein level may even be important for maintaining a good indoor climate, and thus having both a good working environment and good environment for the pigs. The use of lower amounts of protein reduces the nitrogen in the entire chain and has therefore a strong potential. Fiber in the feed also reduces NH_3 emission from the pig house. However, fiber will also lead to higher CH_4 emission from the pigs and manure. More research is needed in this field. It seems to be important that having more fiber in the feed should be combined with biogas production. Adding salts to the feed that reduce the urinary pH is also a very effective way to reduce NH_3 emission, while at the same time feed utilization will improve.

With regard to housing, it can be concluded that few deep litter systems should be used as possible. Only deep straw beddings (with as little dung in it as possible) should be used for grouping/mixing sows after weaning. Nitrous oxide emission from deep litter beddings has been found to be up to ten times higher as compared to when slatted floor are used. With regard to area per pig, it is important that the pens are not too large for the number of pigs in the group, since it will result in large dirty areas, which give high NH_3 emission. However, the pens shall not be not too small, because this will result in crowding in the pen, the pigs will not use the dunging area, and then the entire pen will become dirty. When discussing area per pig, the Animal Welfare Legislation and the pigs needs also have to be taken into account. According to the Swedish Animal Welfare Legislation, pigs in Sweden have more solid flooring in the pen in comparison to pigs in most other countries. In addition, rooting material has to be present. These extra rules make it even more important that pigs should keep the pens clean. Therefore a good indoor climate has to be offered to the pigs.

The optimal pen appears to have a dry solid lying area with some bedding/rooting material and with the possibility of heating the floor. Pigs are fed in a trough which makes it possible to feed the pigs restrictedly, and in that way not over-feed them. Liquid feeding in the trough makes it possible to use biproducts products from the food and ethanol industries. The dunging area may consist of a well drained slatted floor (*e.g.*, iron for growing pigs, plastic for new born piglets). If there is need for heat for warming (*e.g.*, piglet production), the manure in the slurry channel can be cooled down using tubes in the floor under the channel with a heat exchanger, and the heat obtained be used for warming, when necessary.

The slurry channel should be about 1 m deep to minimize the air circulation at the manure surface. The manure- and ventilation system should be made to avoid air streams through the channel. Using scrapers under the slats would not only reduce NH_3 emission but also the production of CH_4 and H_2S from the slurry.

The measures above are not of great importance if all exhausting air from the pig house is cleaned by a scrubber or bio-filter. However, for maintaining a good working environment, according to the law, the indoors NH_3 concentrations should never exceed 10 ppm. This means in practice that some or several of the measures described above have to be implemented, especially during the wintertime when the air flow is low, even when all exhausting area is cleaned by a scrubber or biofilter.

Cleaning the air can be one solution for reducing NH_3 emission from the pig house. It may be especially interesting to use this technique when relatively high levels of protein are present in the feed, *e.g.*, when biproducts of the beverage industry and ethanol production plants are used. In order to reduce costs for air cleaning, systems which only clean the air from the manure channels are under development.

Biogas production is an effective method to reduce the emissions of GHG and odour. However, the emission of NH_3 may be higher from the digestate than from untreated slurry, especially during the summertime. Therefore, the use of a roof on the storage tank for digest, as well as using spreading techniques that reduce NH_3 emissions appears to be extremely important when the digest is handled.

Storage of slurry with a cover lid has been pointed out, in many investigations, as the being the easiest and most effective method to reduce NH_3 emissions. The straw used for fattening pigs is mainly consumed by the pigs, and it is rare that a naturally stable crust will be developed on the slurry tank. However, within piglet production, a crust on the slurry tank often develops. This crust can cause a problem when a cover lid is used on the slurry tank. Separation of straw from the manure, before pumping the manure into the slurry tank, may be necessary for this.

On pig farms, the main crops are cereals, and the slurry is mainly applied either in the spring during tillage work, or band spread in the early summer in the growing cereals. Incorporation of the slurry, *e.g.*, by harrowing in the spring tillage work reduces effectively the NH_3 losses if it takes place as soon as possible after spreading, preferably directly or at least within 4 hours after. Another possibility is to band spread the slurry in the growing cereals as the canopy provides a microclimate which reduces the NH_3 losses as compared when used on a bare field. Late application during the vegetation period or spreading before the autumn sowing, often results in a lower nitrogen utilization by the plants, and thereby higher risks of nitrogen leakage.

12. RECOMMENDATIONS FOR THE FUTURE

It can be recommended that slatted flooring is used within pig production and that as few deep litter systems should be used as possible. However, deep litter system might be used to improve the animal welfare of the pigs in certain parts of the production phase, such as, when mixing/grouping animals or in pen lying areas. The manure under the slats should be removed daily (by, *e.g.*, scrapers) to reduce the emissions of NH_3, CH_4 and H_2S. For this reason, the use of a sewer system (vacuum system) having two weeks slurry storage under the slats should not be recommended.

Altering the feed by lowering the protein level, including more fiber, salts or acids are also effective means of NH_3 emissions. However, it will be more difficult to check this method of reducing NH_3 emissions by the authorities in comparison to technical solutions like *e.g.* placing a roof on the slurry storage tank.

When inexpensive feeds are used which have higher protein levels, the use of air cleaning might be an interesting method of reducing NH_3 emissions. However, cleaning all the ventilation air might be costly, and therefore systems that only clean the ventilation air from the slurry pit should be developed. One prerequisite for a system like that will function is the fact that the pigs should keep the solid lying area clean from urine and dung. Therefore, more research is needed into how we can steer the lying and excretory behaviour of the pigs. Showering the pigs, cooling the incoming air and altering the ventilation system are interesting ways that should be developed and improved.

Slurry storage tanks should be built with covering. However, when large amounts of straw are used, as in Swedish sow herds, a crust can form under the covering, which is very difficult to remove if there is a roof on the tank. Therefore, techniques should be developed that can separate straw from the manure before the manure is pumped into the slurry tank.

Spreading the slurry should be done using techniques and routines that reduce NH_3 emissions. Lately, injectors for open soil have been sent on the market. However, the effect of these on the growing conditions for the cereals on different soils has not been studied. Here, research should be done in order to get an optimal use of these equipments.

The amount digested slurry from farm biogas reactors will increase in the future. The properties of the digest, *e.g.*, higher pH and soluble nitrogen (TAN), means that there is a need for even more careful handling methods, in order to avoid high NH_3 losses. There are still gaps in knowledge about best handling methods for the digest in order to minimize losses and to achieve highest possible nitrogen utilisation by the plants.

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AMMONIA LOSSES FROM MANURE STORAGE APPENDIX 1

Nitrogen losses as ammonia from manure storage in % of total content of nitrogen in storage. The emission factors (EF) are based mainly on national research in Sweden but also relevant studies made abroad. In some cases the default values have been interpolated (Karlsson & Rodhe, 2002). For definitions, see 'Glossary of terms on livestock manure management 2003', www.ramiran.net

	Animal species					
Manure type, handling method	Cattle	Pig	Layer and young hens	Broiler chicken	Horses	Sheep
Solid manure	20	20	12		25	25
Semi-solid manure	10	10				
Slurry, no cover						
Bottom filling	6	8	8			
Top filling	7	9	9			
Slurry, with cover						
Bottom filling:						
roof	1	1	1			
stable crust	3	4	4			
others	2	2	2			
Top filling:						
roof	1	1	1			
stable crust	4	5	5			
others	3	3	3			
Urine, no cover						
Bottom filling	37	37				
Top filling	40	40				
Urine, with cover						
Bottom filling:						
roof	5	5				
stable crust	17	17				
others	10	10				
Top filling:						
roof	5	5				
stable crust	20	20				
others	12	12				
Deep straw manure	30	30	20	5		33

AMMONIA LOSSES AFTER SPREADING OF MANURE APPENDIX 2

Nitrogen losses as ammonia from manure applied in % TAN in applied manure. The emission factors (EF) are based mainly on national research in Sweden but also relevant studies made abroad.

Spreading time and application technique	Incorporation	Solid manure*)	Urine	Slurry
Early spring				
Broadcast spreading	Spreading on frozen soil, late winter	20	40	30
Band spreading			30	20
Spring				
Broadcast spreading	Immediately	15	8	10
	After 4 h	33	14	15
	After 5-24 h	50	20	20
	Application on grassland	70	35	40
	Application to growing cereal		11	20
Band spreading	Immediately		7	5
	After 4 h		14	8
	After 5-24 h		20	10
	Application on grassland		25	30
	Application to growing cereal		10	15
Shallow injection, open slot	Application into grassland		8	15
Early summer & summer				
Broadcast spreading	Application on grassland	90	60	70
	Application to growing cereal		10	20
Band spreading	Application on grassland		40	50
	Application to growing cereal		10	7
Shallow injection, open slot	Application into grassland		15	30
Early autumn				
Broadcast spreading	Immediately	20	15	5
	After 4 h	35	23	18
	After 5-24 h	50	30	30
	No incorporation	70	45	70
Band spreading	Immediately		10	3
	After 4 h		18	9
	After 5-24 h		25	15
	No incorporation		30	40
Late autumn				
Broadcast spreading	Immediately	10	10	5
	After 4 h	15	15	8
	After 5-24 h	20	20	10
	No incorporation	30	25	30
Band spreading	Immediately		4	3
	After 4 h		11	4
	After 5-24 h		18	5
	No incorporation		25	15

*) Values are valid also for deep straw manure, semi-solid manure and sewage sludge