Comparative environmental assessment of three systems for organic pig production in Denmark

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1. Background

Organic pig production has emerged as an alternative to the intensive conventional pig production in Europe with the animals confined indoors and often an imbalance between livestock and land for feed production and manure utilisation. The organic systems aim at improving animal welfare by supporting the pig's natural behaviour (Hermansen et al., 2003), and improving soil fertility by better linking crop and livestock production from an agro-ecological point of view.

The differences between organic and conventional pig production is more fundamental than for example differences between dairy production systems, which may be why the share of pig herds within the organic holdings is considerably lower than the percentage of pig herds in conventional agriculture in both the UK (ADAS, 2001), Germany (Willer, et al., 2002) and Denmark (Plant Directorate, 2004b). However, the recent development has seen a dramatic increase in demand for organic pig meat in Denmark, Germany and the UK and present production cannot meet demand. Besides regulation on use of feedstuffs, the organic pig production has a main challenge in the regulation for housing. The sows need access to grazing in the summer time, and growing pigs need as a minimum requirement access to an outdoor run. In addition, the area requirements for indoor housing are higher than for conventional production.

These requirements have a major impact on what systems to consider, both from economical and agro-ecological points of view. And therefore, efforts to improve organic pig production should focus on the integration of livestock production and land use, but considering environmental impacts on local and global scales.

The most commonly used system in Denmark is to combine an outdoor sow production all year round with rearing growing pigs in barns with an outdoor run (Hermansen & Jakobsen, 2004). The type of stable most commonly used by full time producers in Denmark is a system with deep litter in the entire indoor area or deep litter/straw bed in half the area while the outdoor area consists of a concrete area. The use of a concrete covered area, from which the manure can be collected, is a way to comply with the environmental regulations stating that the outdoor run should be constructed in a way that prevents leaching.

Research shows that very good production results can be obtained in such systems in terms of litter size, daily gain, feed consumption and health (Hermansen et al., 2003). However, two possible drawbacks exist. First, the space requirement per growing pig in housing facilities is considerable and, thus, capital demanding. For fattening pigs of 85-100 kg live weight, the indoor space required is equivalent to 1.3 m^2/pig (of which at least 0.65 m^2 must consists of a solid floor) and 1.0 m^2 outdoors run (Council Regulation, 1999). In addition, each lying zone, i.e. straw bedding area, must be able to accommodate all pigs at a time. This put a heavy burden on costs of buildings (money and resource use) and at the same time it can be questioned if such rearing systems comply with the consumer expectations. Second, the outdoor sow production has been connected with high environmental burden in the form of N losses (Larsen et al., 2000; Eriksen et al., 2002).
This made us to consider two alternatives to the organic pic system most often used presently. A system where all pigs were reared outdoors on grassland (and saving buildings) and a system where sows and growing pigs were kept in a tent system placed upon a deep litter area in order to reduce risk for N leaching. Both have been used under commercial conditions. In order to assess the possible trade-offs between environmental impacts on the one hand and the assumed advantages of these alternative systems (animal welfare, low investment) on the other hand an Environmental Impact Assessment was needed. Environmental assessment of livestock farming systems can be done on an area basis (e.g. nutrient losses per ha) or on a product basis (e.g. Green House Gas emission per kg meat or milk; Haas et al., 2001; van der Werf & Petit, 2002; De Boer, 2003; Halberg et al., 2005). The area based assessment is relevant for locally important emissions such as nitrate leaching but a product based assessment is more relevant for emissions, which have a less localised impact (acidification) or even a global character (Green House Gasses). Moreover, since the organic production is often considered a more sustainable alternative to conventional intensive pig production, from a consumer point of view it might be interesting to compare the eutrophication per kg meat produced from different organic and compared to conventional systems.

The objective of this paper is to compare the environmental impact and green house gas emission of organic pig production systems with different levels of integration of livestock and land use.

2. Methods

Three models of organic pig production systems were established based on a synthesis of empirical data from on-farm studies and experimental production systems as explained in detail below. The emissions per ha from each farm type were modelled using state-of-the-art methodology for nutrient balances, ammonia volatilisation and green house gasses. Finally, the environmental impact per kg pork produced was assessed using standard Life Cycle Assessment methodology combining the emissions from the farm level with emissions from imported feed, transport and the construction of stables.

2.1 Models of organic pig production

Three different systems were considered. The point of departure was the most commonly used system today in Denmark, where the sow herd is kept on grassland with access to small huts for protection, and the fattening pigs are kept in indoor facilities (system I) which allows collection of a part of the manure in liquid form. As one alternative, also slaughter pigs were reared on grassland all year round, i.e. reducing housing facilities to movable steel huts, no collection of manure, but moving pigs in the crop rotation from year to year (system II). The other alternative considered was a one unit pen system as described in principle by Andersen et al. (2000) and Jensen & Andersen (2005) (system III). In this system climate tents – containing 4 pens- are placed upon a deep litter area on a floor of seashells on the soil surface. From this area pigs have access to grazing when suitable.

2.2 Bio-technical results in different organic pig production systems

Very few baseline data from commercial organic pig production have been published. Whereas litter size is not expected to be different in organic systems from conventional systems, number of farrowing per sow and year are reduced due to the longer lactation period in organic systems, and this affects the number of weaned piglets per sow and year. I.e. Lauritsen et al. (2000) observed 1.9 litters per sow a year in organic production compared with 2.26 in conventional pig production.

Regarding efficiency in finisher production both a higher (Millet et al., 2004) and a lower daily gain (Hansen et al., 2001) has been observed compared with conventional production. In both references feed conversion was slightly poorer in the organic systems. This probably reflects a two-sided effect, where the more space in the organic housing system stimulates growth compared to conventional production, but the poorer possibilities to adjust feed composition in the organic system results in a higher feed consumption per kg gain.

From an overall point of view we found that the results observed under commercial Danish conditions by Strudsholm (2004) – daily gain 740 g/d and feed consumption per kg gain 3.0 SFU (Barley equivalents) - would be an reasonable assumptions to use in the model.

Based on these bio-technical results we established three models of different organic pig production systems, Table 1. All three systems had the same total production of 1800 fattening pigs (100 kg live weight) per year; from a total of 100 sows with own replacement and a total land area of 84 ha.

The area with grassland for outdoor keeping of livestock was calculated according to Danish public rules for free range organic pig production (European Commission, 2000; Ministry of Environment, 2002), which allow a stocking rate expected to deposit 280 kg N/ha every second year. This determined the crop rotation to a large extent and – as a consequence – grassland accumulated to 48% of the area in system II. Next, crops were chosen in order to best fulfil the feed requirements of the herd under the restrictions of maximum 15% of the total land grown with rapeseed and peas – respectively - in the crop rotation due risks of soil borne pathogens. The rest of the feed requirements for the herd were assumed imported from outside the farm, which resulted in type II importing a higher percentage of feed due to the limited area with cereals.

Table 1: Housing, production and feed use in three modelled types of organic pig production. Might be useful to use first 10 lines of the table in the text of "methods"

Characteristic of system	I Free range sows	II All free range	III Tent system
No. of sows	100	100	100
No. pigs delivered	1800	1800	1800
Sow housing	38 farrowing huts, 31 huts for group housing of pregnant sows	38 farrowing huts, 31 huts for group housing of pregnant sows	14 Tents for group housing of pregnant sows
Fattening pigs housing (from 17-100 kg)	68 pigs pens in stables, with outdoor area in concrete	Free range, 55 huts similar to huts for pregnant sows	16 tents (one-unit pens), 20 t blue shells, straw
Feed use, SFU			
- per sow, including recruitment	2200	2200	2200
- per piglet, 18-30 kg	30	30	30
- per grower, 30-100 kg	217	217	217
Feed composition, %			
- cereals/protein rich fed	57/33	57/33	57/33
- silage/grazed grass	7/3	4/6	10/1
Area use, ha	84	84	84
- grain cereals, %	52	39	55
- pea and lupine, %	14	6	15
- winter rape, %	14	7	13
- grass/clover/alphalpha, %	20	48	18
Manure on crops, kg N ha^{-1}			
- grain cereals	116	0	142
- pea and lupine	0	0	70
- winter rape	230	0	240
- grass/clover/alphalpha	195	260	214
Average over all crops	132	124	157
Crop yields			
- grain cereals, kg ha^{-1}	4343	3625	4592
- pea and lupine, kg ha^{-1}	2592	2770	2642
- winter rape, kg ha^{-1}	2610	1482	2922
- grass/clover/alphalpha, SFU ha^{-1}	4088	1707	4491
Average over all crops, SFU ha^{-1}	3856	2381	4053

[1)] kg feed kg live weight $gain^{-1}$

2.3 Estimation of crop yield in the system

The grain yields per ha were estimated to be in average 3410 kg cereal (*Avena Sativa L., Hordeum vulgare L., Triticum aestivum L.*), 1890 kg winterrape (*Brassica napus L.*) and 2770 kg peas (*Pisum sativum L.*). Lupines (*Lupinus luteus L.*) were grown in order to increase the supply of essential amino acids. These yields correspond to recordings from 598 Danish organic farms on sandy soils (less than 10% clay, corresponding to USDA (1990) soil texture classes loamy sand and sandy loam) and mostly no irrigation. They used an average input of 70 kg N per ha from animal manure. The grain yields differed in the three model farms due to differences in the percent of manure, which was collected and available for redistribution to cereal crops.

2.4 Estimating emissions from the pig production model farms

Based on the import of feed and straw and the export of live pigs and cash crops, farm gate Nitrogen (N) and Phosphorus (P) balances were established following methods described in Halberg et al. (1995) and Kristensen et al. (2005).

Losses of NH_3 were estimated as a coefficient of the N surplus of the grazed area and based on available literature, it was set to 23% of the N surplus (Eriksen et al. 2002, Gustafson & Svennson 2003,Williams et al. 2000). Denitrification was estimated using the SimDen model (Vinther & Hansen, 2004) based on added N and soil type.

SimDen also estimated the proportion of Dinitrogen monooxide (N_2O) in total denitrification (N_2O+N_2).

SimDen does not account for the N_2O emissions from manure management and storage and the indirect N_2O emissions in recipients of the ammonia and nitrate emissions from the farm. This was estimated according to IPCC principles using the fractions 0.025 and 0.01 of Nitrate-N (NO_3-N) leached respectively NH_3-N volatilised (IPCC, 2000). In systems I and III emission factors of 0.001 and 0.1 of N in slurry and deep litter straw bedding respectively were used (IPCC, 2000).

Ammonia loss from indoor growing pigs were estimated using Danish standards: Loss of 15% NH_3-N in slurry and 10% denitrification in deep litter (Poulsen et al., 2001). In system III the total N-losses of deposited manure N has been estimated to 25%. This was based on replicates of mass balances in the system. It was assumed that denitrification accounted for 4% of the N attributed to losses from the deep litter and the rest was equally allocated as NO_3 leaching and NH_3 losses.

The emissions of NO_3 through leaching from the fields was estimated from the soil balance after deducting airborne emissions and soil N change. Changes in soil-N were calculated on the basis of the C-inputs from manure and crop residues and the current soil C/N, using a dynamic model, (C-tool) which is outlined in Gyldenkærne et al. (2007). The change in soil-N used here is that which is predicted to occur after 10 years. The initial soil C/N was set at 16 and the total Soil-C and -N in root profile was set to 175 and 11 tons per ha based on 700 representative Danish soil samples (Heidmann et al., 2002).

2.5 Product based environmental assessment of pork from 3 model farm types

In order to calculate the aggregated resource use and environmental impact through the production chain for organic pigs in the three systems Life Cycle Assessment methodology was applied (Wenzel et al., 1997; Anonymous, 2006). The functional unit was defined as one kg of live weight pig delivered from the farm. The system was defined as the production on farm (herd and crops), the production and transport of feed off farm and the production of the building material for housing and of energy for electricity and traction.

The environmental impact categories considered were Eutrophication, Acidification, Global Warming Potential (GWP), ozone depletion, photochemical smog and land use following the principles of EDIP 97 (Wenzel et al., 1997, updated version 2.3). Eutrophication was calculated as NO_3 equivalents with the relative eutrophication potential of PO_4 and NH_3 to NO_3 being 10.45 and 3.64 respectively. Acidification used Sulfur Dioxide (SO_2) equivalents with SO_2, NH_3 and (Nitrogen Oxides (NO_x) assigned factors of 1.0, 1.88 and 0.7 respectively. The Green House gasses CH_4 and N_2O were converted into Carbon Dioxide (CO_2) equivalents using the factors 25 and 320 respectively and assuming a 100-year time span.

3 Results

Table 2 shows the N balances (kg N ha^{-1} $year^{-1}$) on herd, land and farm level in a coherent set up, which accounts for the total internal and external N flows. The N balances of the three organic pig production systems differed mainly with respect to the amount of imported protein in feed due to the different land use. System I imported 140 kg N ha^{-1} with cereals and concentrates, which accounted for 61% of the 229 kg N ha^{-1} in total feed protein and straw supplied to the herd. System II had a higher feed N import - 73% of total N to herd - due to a larger grassland area and, therefore, a lower total cereal production. In system III the feed import was comparable with system I, but due to the need for straw for the bedding the total N input from outside the farm was higher. System II had the highest N surplus per ha (land and farm level) and the highest denitrification due to the dominant grazing area. The total emission of NH_3 per ha was at comparable levels in all systems but in system II, there was a relatively high emission of NH_3 from manure and urine excreted on the outdoor area. After deduction of gaseous losses and net soil N changes from the N-surplus the resulting NO_3 leaching was highest in system II and lowest in system I.

Table 3 also shows the aggregated emissions of NH_3 and the NO_3 and PO_3 leaching and denitrification in kg substance at farm level used as input to the LCA models. The different models of pig production represent trade offs between emissions. The tent system (III) had lower ammonia loss compared with system I but higher denitrification loss and Nitrate leaching. System II had highest N losses due to the overall higher N-surplus. Methane emissions in system I were four times higher than in system II and III due to the slurry.

Systems I and III had higher diesel use (which contributed to CO_2 emission in the LCA) for traction and other farm operations due to the larger area with seasonal crops and the manure handling (results not shown).

Results of the LCA combining the farm level emissions and traction with emissions from production and transport of imported feeds and construction of sow and pig housing are presented in Table 4. The contribution to Global Warming in kg CO_2 equialents per kg pig was significantly higher (according to the Monte Carlo simulations) in system II compared with systems I and III mainly due to the higher emission of N_2O in the free range system (Table 4) and the higher feed import (due to lower crop yields). The production and transport of imported feed accounted for 33% of total GHG emission in system II compared with 27 and 26% in systems I and III respectively (data not shown). Traction for crop production and fodder handling on the farm accounted for 12% of GHG in all systems while emissions from housing and electricity were relatively small. In all systems N_2O linked to the N-cycling on the farm contributed by far the larger part of the total GHG emission because of the higher characterisation factor (320, see above).

Table 2 Nitrogen balances at herd, land and farm level in three modelled, organic pig production systems

System	*Herd level*			Land level[1]			Farm gate		
I = Free range sows II = All free range III = Tent system	I	II	III	I	II	III	I	II	III
	(Kg Nitrogen ha^{-1} $year^{-1}$)			(Kg Nitrogen ha^{-1} $year^{-1}$)			(Kg Nitrogen ha^{-1} $year^{-1}$)		
Inputs									
Imported cereals	99	124	96				99	124	96
Concentrates	41	41	41				41	41	41
Straw-bedding	5	5	28						23
Seeds				2	1	1	2	1	1
Biological fixation				40	45	39	40	45	39
Deposition				16	16	16	16	16	16
Home-grown cereals and legumes	53	29	57						
Home-grown forages	21	10	27						
Grazing	9	18	2						
Collected manure				97		122			
Deposited manure[2]				51	167	27			
Total input[3]	229	227	251	205	229	206	197	228	216
Outputs									
Home-grown cereals				53	29	57			
Home-grown forages				30	28	29			
Cash crops				12	3	12	12	3	12
Live pigs	60	60	60				60	60	60
Straw				5	5	5			
Total output	60	60	60	100	65	103[4]	72	64	72
Balance	169	167	190	105	164	102[4]	125	164	144
Losses									
Denitrifikation	2		7	12	17	10	14	17	17
NH_3 losses									
Stable and storage	19		18				19		18
Grazing				12	37	6	12	37	6
Spreading and crops				11	4	11	11	4	11
Soil change				24	25	38	24	25	38
Leaching			16[5]	46	80	37	46	80	53

1. Balance covering all farmland used on farm including grass-clover, cereals, pulses and cash crops
2. Manure deposited directly by livestock during grazing
3. Total herd input of feed protein is equal in all systems because protein norms were identical in the three models
4. Rounding off errors give small inconsistency of 1 kg ha^{-1}
5. Leaching from the deep litter bedding outside tents in averae of total farm area (equals 1440 by N total from tent area)

Table 3 Emissions of Ammonia, dinitrogen monooxide, Nitrate, Methane and Phosphate in kg year-1 from three modelled types of organic pig production

System Emissions	I, Free range sows	II, All free range	III, Tent system	Estimated CV, %[1]
Ammonia	4.164	4.183	3.548	22
Dinitrogen monooxide	692	843	793	29
Nitrate	17.183	29.767	19.785	15
Phospate	74	122	109	50
Methane	2.174	506	490	50

1) See methods for explanation

Table 4 Comparative Life Cycle Assessment of three modelled types of organic pig production, per kg live weight pig delivered from the farm[1)]

Impact category	Unit	I, Free range sows	II, All free range	III, Tent system
Global warming (GWP 100)	g CO_2-eg	2920 b	3320 a	2830 b
Ozone depletion	g CFC_{11}-eg	6.9 E-4 b	7.7 E-4 a	6.8 E-4 b
Acidification	g SO_2-eg	57.3 a	61.4 a	50.9 b
Eutrophication	g NO_3-eg	269 b	381 a	270 b
Photochemical smog	g ethane	0.96 a	1.0 a	0.96 a
Land use	M^2 year	6.9	9.2	8.5

1) Differences interpreted significant based on pair wise Monte Carlo simulations giving one system a higher outcome in more than 95% of 300 runs are indicated with small letters.
The free range system (II) caused approximately 30% higher Eutrophication per kg pig compared with system I and III (significant with 100% Monte Carlo runs higher for system II) primarily because of higher nitrate leaching from the grazed swards.

4 Discussion

The three modelled organic pig systems are all realistic commercial pig production farms. Tvedegaard (2005) compared the three systems' economic performance and found that system I with outdoor sow herd and fattening pigs kept in indoor facilities is the most cost efficient system. The costs are slightly higher in system II where also the fattening pigs are kept on grassland. Even though investment costs are lower in system II the overall cost efficiency was better in system I due to lower labour costs. In system III, with climate tents, the pig production is more expensive primarily due to the large amounts of straw to be imported from other organic farms.

Motives for free ranging the pigs include animal welfare, reduced environmental and economic costs from construction of stables and the - supposed - agro-ecological advantage of improved crop rotation with grass-clover leys (improved nutrient cycling, including BNF, increased soil fertility, higher crop diversity, reduction of cereal pests and diseases). However, as mentioned, the reduced investment costs in systems II and III with no stables were offset by higher labour costs. And the lower GHG emission from construction of housing in system II compared with system I was offset by the higher N_2O emissions from grazed fields and higher feed import. Moreover the higher Eutrophication in system II due to the Nitrate leaching from grazed swards may be considered as the major environmental cost of keeping freerange fattening pigs in the modelled system.

This is because the potentially improved nutrient cycling is difficult to establish in reality on sandy soils. The higher proportion of grass-clover in the rotation increases BNF and could improve the cereal yields as explained in the methods section. But the average effect on farm level was lower cereal and rapeseed yields per ha (Table 1) due to lack of manure for the second year cereal crops. This resulted in a higher feed import, which together with high BNF increased the surplus of the farm gate N balance (Table 2). However, most of this extra N-input was lost through leaching and N_2O-emissions according to experience documented in the Methods section. Therefore, the relatively high Nitrate leaching from freerange pig fattening would have to be reduced considerably for this system to be environmentally sustainable. One possible way for this could be to reduce the purchased feed and increase the pigs' forage uptake (which presently accounts for only 10% of feed intake, thus equal to systems I and III, Table 1), and this way increasing the immediate nutrient recycling during the grazing period. However, it remains to be documented that this in fact can be obtained and it can be foreseen that other crops than grass, i.e. root crops then need to be included in the crop rotation.

In the systems considered, sows and pigs were on grassland all year round, since this is feasible from the point of view of investment in facilities. However, situations where pigs are only on grassland in the plant growth period should be considered, since Eriksen et al. (2006) observed a reduced N surplus for growing pigs on pasture in this period, and in addition manure N could be taken up by autumn crops.

As explained, the results confirmed and have quantified the trade off between objectives for free range, outdoor pig production systems and the objectives of reducing emission with negative environmental impact. But the study also suggests that another compromise between these different objectives might be found. Thus, the emissions per kg live weight pig delivered from the tent system (III) were on the same level – or possibly lower -compared with system I. This demonstrates that it has been possible under practical conditions to reduce the N-related emissions (from system III) compared with system II by proper management of the deep litter bedding under the tent, ample supply of straw and a layer of blue shells beneath. The pigs in system III have only access to a limited grass-clover area, though these are larger than the outdoor runs in system I. But the integration of pig rearing and land use and the resulting crop rotation in system III might not seem different from system I from an agro-ecological perspective (Table 1). The feed import was slightly lower in system III compared with other systems. The most problematical aspects of the tent system are imports of straw and high labour costs. System I, using slightly modified stables with outdoor runs for fattening pigs in combination with free ranging sows seems to be the most competitive system. And the 20% grass-clover in the system I crop rotation still has an agro-ecological advantage over crop rotations with cash crops and cereals only.

The environmental impacts from the organic pig systems are higher than results from the comparable LCAs on conventional Danish pig production in the LCAfood database. Dalgaard et al. (2005) reported emissions from Danish conventional pig production corresponding to 2.7 kg CO_2-eq, 230 kg NO_3-eq and 43 kg SO_2-eg per kg liveweight pig ab farm, which were comparable with the conventional pig scenario assessed by Basset Mens & van der Werf (2005). Thus, the GHG emission per kg live weight pig in system I was 7% higher compared with conventional pig production and system II was 22% higher.

This comparison, however, does not take into account the different soil C-balances arising from differences in the crop rotations. The 24-39 kg N ha^{-1} net soil accumulation per year (Table 2) corresponds to approximately 240-390 kg net C sequestration in the three systems given a C/N proportion of 10. This C sequestration on the farm corresponds to -0.3, -0.4 and -0.5 kg CO_2-eq per kg liveweight pigs in the three organic systems or a reduction of approximately 11-19%. Thus, including this aspect the GHG emissions per ha and per kg pig from organic systems I and III were lower than from conventional pig systems where the net soil N and C changes were close to neutral (Dalgaard et al., 2006). The differences were larger for the Eutrophication, where systems I and III had 35 and 21% higher emissions compared with conventional system while system II had 65% higher emission, mainly due to leaching from the grasslands. All organic systems had 35-45% higher acidification per kg pig due to larger ammonia losses from outdoor runs (system I) respectively grasslands (system II) and the deep litter bedding (system III).

Conclusion

Of the systems considered system I with only grazing sows and fattening pigs in stables had a better economic and environmental performance compared with systems with all pigs on grassland and housed in huts (system II) or a tent with deep litter straw (system III). System II can be considered an attempt to minimise investment costs and the environmental burden of building concrete stables, to enhance animal welfare and to benefit from agro-ecological advantages of increased grass-clover area in the rotation. However, the present relations between feed uptake, pig production and crop rotation did not ensure an efficient recycling on the sandy soils in the all-grazing system and the nitrate leaching was therefore 50-60% higher compared with the other systems. If the grass-clover could contribute a larger proportion of feed uptake this would reduce the need for purchased feed and improve farm gate nutrient efficiency. The tent system might be a compromise between the pig grazing system and system with the stables because it allows the pigs a more natural behaviour and access to grazing while also reducing Nitrate losses. But the present version is disadvantaged by higher labour costs, and the yearly import of large amounts of straw and shells, which increases transport related emissions.

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