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Environmental Assessment of Future Pig Farming Systems

– Quantifications of Three Scenarios from the FOOD 21 Synthesis Work

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Summary

This report accounts for an environmental system analysis of three scenarios for future pig farming systems in Sweden. The three scenarios are focused upon A) Animal welfare; B) Environment and C) Product quality at low prices. The purpose of the study is to gain further knowledge about the environmental impacts of different future farm production systems of pig meat and to illustrate environmental benefits and disadvantages that are integrated in the production systems.

Life Cycle Assessment (LCA) is the principal method for the environmental assessment. The functional unit (FU) in the study is "one kg of bone-and fat free meat". The systems analysed include all phases in the life cycle of fertilisers, feed products, seed, diesel and pesticides. Transports steps are also taken into account. Buildings, machinery and medicines are not included. Allocation is done on an economic basis and in sensitivity analysis alternative allocation methods are tested. Data were collected for different future pig farming systems with the aid of expert opinion, yield trend data and application of future techniques in the production systems.

Chosen impact categories were: Use of energy, non-renewable resources and land; Toxicitiy (pesticide use), Climate change, Acidification, Eutrophication, Photo-Oxidant Formation.

The use of energy was 16.1 MJ/FU in scenario A, 14.7 MJ/FU in B and 18.4 MJ/FU in C. The lower energy requirement in A and B was mainly due to the difference in feeding strategy; in these scenarios more than 90 % of the protein feed was locally cultivated in contrast to scenario C where all protein feed was imported. The higher energy use in A in comparison with B was due to a lower piglet production per sow and higher feed consumption in A, and extra requirements for the field work associated with the sows´ outdoor grazing period.

A high proportion of the use of the resource phosphorous in scenarios A and C was explained by the consumption of mineral feed in these scenarios. By introducing the enzyme phytase in B, the consumption of new phosphorous could be kept at a very low level in this scenario. The positive effect of adding phytase in the feed was evident when evaluating the farm gate balances in the three scenarios; no P-surplus was found on farm B.

The total yearly land use varied between 11.3 – 13.5 m^2 per FU. Scenario A required the largest grass area due to the sows´ grazing period and B had the lowest land use.

In scenario B (environment), there was a very conscious strategy to reduce pesticide use by measures such as a diversified crop rotation (due to altered protein feeding in comparison with C) and the practice of mechanical weed regulation. The use of pesticides per hectare was halved on the pig farms in scenario B in comparison with C. In the whole life cycle of pig meat, the use of pesticides was only 40 % in B in comparison with C.

The total emissions of greenhouse gases varied between 3.6 – 4.4 kg CO_2-equivalents/FU and scenario B had the lowest output. Emission of nitrous oxide (N_2O) is the dominant greenhouse gas emission in pig production. The positive outcome for B was mainly an effect of the overall high nitrogen efficiency but also an effect of the lower need for fossil fuel in this scenario.

The total potential acidification of pig meat production is to a high degree correlated to ammonia emissions. The use of modern technique filtering the ventilation air in the pig houses as well as an efficient technique for manure spreading led to a significantly lower acidification potential for scenario B.

Nitrate leaching from arable land is the most important nutrifying emission. The calculated leaching per hectare was relatively low in the three scenarios. The leaching per FU was lowest in B due to a combination of high yields and high feeding efficiency.

Improving pig meat production from an environmental perspective is very much a question of improving feed production. When protein feed crops are cultivated in integration with grain crops, a diversified crop rotation can be created and this is an important preventive measure for keeping pesticide use at a low level. Locally/regionally produced protein feed reduce the use of fossil fuel and emissions of CO_2, NOx and SO_2. New techniques for pig manure handling and careful planning and application of the manure in the crop rotation can significantly reduce emissions of reactive nitrogen. A mixed farming livestock farming system with proper balance between animals and fodder crops has good opportunities to minimise nutrient losses and resource use while maintaining high yields and good production quality.

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1 Introduction

The Swedish research program Food 21 is aiming at a more sustainable Swedish food production. The long-term goals for Food 21 cover eight main sustainability aspects (Food 21, 2003): 1. Efficient use of natural resources, fossil and total energy use; 2. Low impact on the external environment, optimised use of phosphorous and nitrogen, low emissions of greenhouse gases; 3. Animal welfare, animal health, natural behaviour and low use of medicines; 4. Safe food products; 5. High product quality; 6. Ethics, accepted production forms; 7. Farmers; 8. Economy.

One important part of the Food 21 research program is to compile syntheses of on-going research within the different sustainability areas. Through system analyses, benefits of integrating systems as well as conflicts of interest, are made visible. In the synthesis work, scenario methodology is used to present solutions for future pig production (Stern *et al* 2004). The scenarios are deliberately constructed to be extreme in perspective to different goal visions for sustainability. The three scenarios presented for pig production focus upon animal welfare, environment and low prices-product quality respectively. This report presents an environmental evaluation of the synthesis work of future pig farming systems in Sweden. The method used for the environmental evaluation is Life Cycle Assessment (LCA).

LCA is a tool for assessing the environmental impact caused by a product or a service. The basic principle for LCA is to follow the product through its entire life cycle. The product system is delimited from the surrounding environment by a system boundary. The energy and material flows crossing the boundaries are accounted for as input-related (e.g. resources) and output-related (e.g. emissions to air) flows.

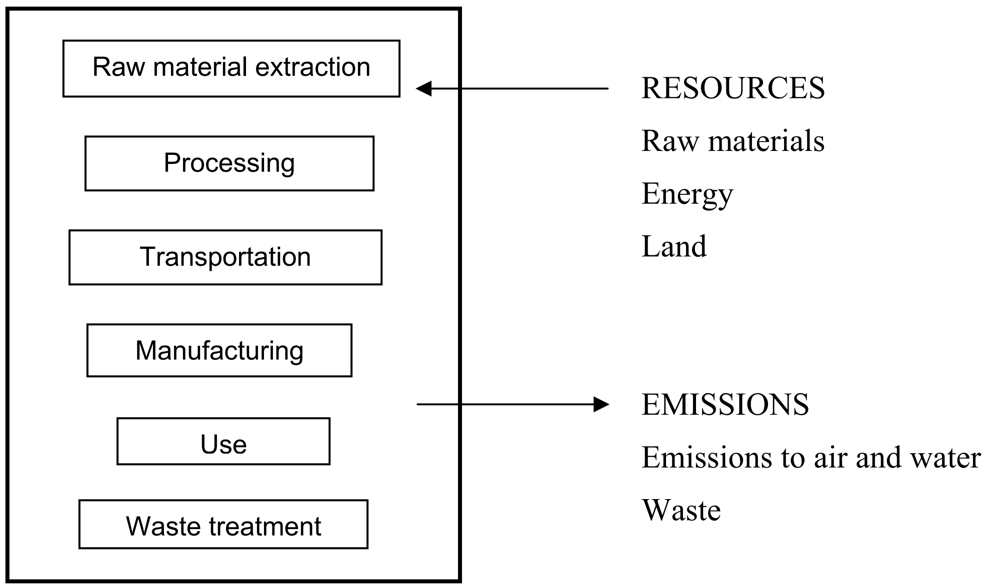


Figure 1.1 The LCA model representing a typical life cycle

The LCA methodology has been developed within a general framework established by SETAC[1] and further harmonised within an international standardisation process within ISO[2] 14000 (CEN, 1997). The ISO framework is shown in figure 1.2.

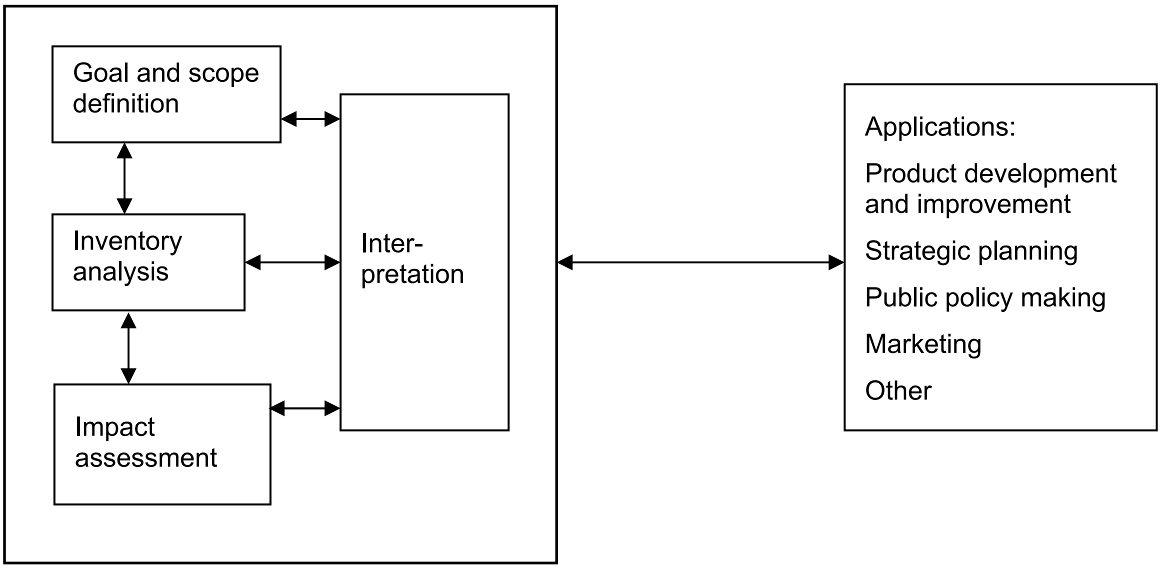


Figure 1.2 Phases of an LCA (CEN, 1997)

The procedure for performing an LCA consists of four phases (Figure 1.2). In the first phase, the *goal and scope definition*, the aim and the range of the study is defined. Important decisions are made concerning definition of functional unit (i.e. reference unit), choice of allocation methods and system boundaries. In the *inventory analysis*, information about the system is gathered and relevant inputs and outputs are identified and quantified. In the *impact assessment,* the data and information from the inventory analysis are linked with specific environmental parameters so that the significance of these potential impacts can be assessed. In the final *interpretation phase,* the findings of the inventory analysis and the impact assessment are combined and interpreted to meet the previously defined goals of the study.

We would like to convey our thanks to Torbjörn Lovang and Per Axelsson at Lovang-gruppen in Östergötland and Lars Törner at Odling i Balans in Vallåkra, for all their help and assistance in the work with the inventory analysis of this study.

[1] SETAC is short for the Society of Environmental Toxicology and Chemistry and this organisation is one of the driving forces in the standardisation of LCA methodology.

[2] ISO is short for International Organisation of Standardisation

2 Goal and scope definition

2.1 Goal and purpose of the study

The goal of this study is to perform an environmental system analysis of three scenarios of future pig farming systems in Sweden using LCA methodology. The scenarios are put together by Stern *et al* (2004).

The purpose of the study is to gain increased knowledge about the environmental impacts of different future farm production systems of pig meat and to illustrate environmental benefits and disadvantages that are integrated in the production systems. The study will also help to illustrate which conflicts of interests that are relevant when different aspects of sustainability are prioritised. The three future scenarios analysed focus upon:

A – animal welfare

B – environment

C – product quality at low price

2.2 Scope of the study

The analysis deals with all phases of the life cycle of pig meat as shown in figure 2.1 including production of materials and energy used. Transport steps are also taken into account.

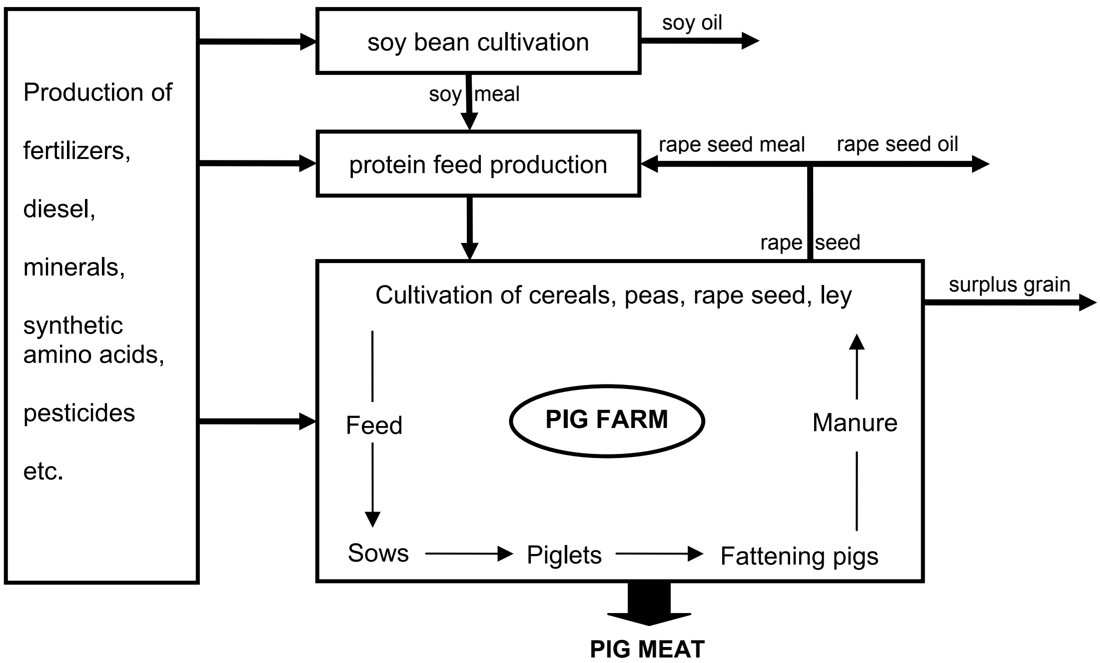


Figure 2.1 The figure shows a flow diagram for farm production of pig meat. Important co-products in the production are rape seed oil, soy oil and surplus grain produced in the farms´ crop rotation

2.2.1 Descriptions of the three scenarios

In **scenario A**, production on the future pig farm is focused on animal welfare. Sows and fattening pigs are integrated, farm houses are non-isolated and the animals have an ample supply of straw. From April to October, sows and piglets are held outside in huts and have access to large areas of grassland. The growth rate of the slaughter pigs is lower than in the other scenarios. Appendix 1A shows a diagram of the flows considered in scenario A.

Environmental care is the priority of the pig production in **scenario B**. Feed efficiency is high and the dominant part of the feed is cultivated at the farm site. Livestock density is lower than in scenario C. The farm buildings are equipped with ammonia collectors in the ventilation system and the manure is stored and spread with best technique available in order to reduce emissions. Catch crops are used in the cultivation and the crop rotation is strictly planned to minimise pesticide use. Mechanical regulation of weeds is used frequently. In appendix 1B, the flows considered in the scenario are shown.

Finally, in the last **scenario C**, the production is focused upon high quality products at low prices. Cereals for feed production are cultivated at the farm, otherwise all protein feed is imported to the farm. The growth rate is high and a low amount of straw is used. The handling of the manure follows the general law regulation. In appendix 1C, the flows in scenario C are shown.

2.2.2 Delimitations

Production of farm buildings and farm machinery is excluded in the study.

The production, use and emissions of medicines are not included due to lack of knowledge of the environmental impact from medicine residues in the ecosystems.

The production and use of pesticides are included in the inventory analysis but a toxic assessment of the fate of pesticide residues is not included in this study. In the project "*Hållbart växtskydd* (Sustainable Plant Production)" within Food 21 a pesticide risk index for scenario B and C will be presented (Cederberg *et al,* 2004, report in prep).

Production of synthetic amino acids used in pig production is not included due to lack of data. Production data for amino acids used in poultry production are available and these data are tested as a simplified kind of sensitivity analysis (see section 5.5). Production of the enzyme phytase is excluded due to lack of data. This enzyme is used to improve the utilisation of phosphorous in the feed components making it possible to reduce the need for mineral feed complement. This might lead to a discrepancy in the comparison of the scenarios which is discussed in section 5.

Disinfectants, washing detergents and minor stable equipment are not taken into account.

2.3 Functional units

The functional unit (FU) in the study is *"one kg of bone- and fat free meat"*. This functional unit was selected to measure the final function at the consumer, i.e. the eatable parts from meat production. When data on meat production and consumption are presented in statistics it is mostly as carcass weight. The amount of meat finally consumed will however differ since the consumer does not eat the bones of the chop and most often not the fat; this is the basis for the choice of the FU in the study.

Emissions of ammonia and nitrate are the source of local as well as regional environmental impact. The concentrations of the emissions are therefore of interest and consequently the impacts of these emissions are also referred to the functional unit *"one hectare of arable land"*. Pesticide use is also assessed per hectare of arable land.

2.4 Allocations

As shown in figure 2.1 the important co-products in the production of pig meat in the three future scenarios are surplus grain from the farms´ crop rotation, soy oil and rapeseed oil (see also appendix 1a – 1c).

Allocation is avoided when handling the production of surplus grain on the farms. The data are collected and handled separately for each crop, and overall measures in the crop rotation (for example application of glyphosate) are divided between all the crops. Resource use and emissions from the surplus grain in the feed production are excluded from the total feed production of the farm.

In scenario A and B, rapeseed is grown on the farm. This rapeseed is sold from the farm to a crusher. The equivalent quantity of protein meal from this yield is returned back to the pig farm in the protein feed after the extraction. In this process, rapeseed oil is a co-product and the allocation between oil and meal is based on the economic value of the two products.

Soy meal is used as an ingredient in the protein feed in all scenarios and soy oil is here a co-product. Similar to the allocation of oil and meal from rapeseed, economic allocation is used for dividing the environmental burden of the two products.

The production of protein feed differs between the scenarios and it is reasonable to presume that the choice of allocation when handling the co-products from soy meal and rape seed meal production might have an impact on the results. Therefore, a sensitivity analysis is performed to investigate the outcome of *i*) no allocation at all (soy meal and rapeseed meal carry the whole environmental burden and *ii*) mass allocation (the environmental burden of soy meal and rapeseed meal is divided according to the mass of the products). The result of the sensitivity analysis is presented in section 5.

2.5 Chosen impact categories

The environmental impact categories considered in this study are:

- Resources – energy, material, land use
- Toxicity – the use of pesticides is included, pesticide risk indicators for the three scenarios are presented in a coming study.
- Ecological effects
    - Climate change
    - Acidification
    - Eutropihication
    - Photo-oxidant formation

Water use is not considered since water is not seen as a limited resource under Swedish conditions. Soil fertility and biodiversity are not quantified but discussed from a quality perspctive in the category land use. The toxic effects of PAH, NOx etc – important emissions from transports - are not aggregated in an index here since it is assumed that the toxic effects of pesticides are more important in environmental system analysis of agricultural products.

2.6 Data quality

The scenarios are projections of future pig production in 10 – 20 years. The production data of the pigs are based on discussions with experts in the area and today there are a number of farmers that reach this production results. The future yields in the plant production is based on historical yield trends, results from field trials for different crop rotations and discussions with the extension service in the province of Östergötland where the model farms in the future scenarios are situated.

The resource use and emissions from fertiliser production are presumed to be the same as contemporary production. This is also the case for production of diesel and electricity. Due to the coming European directives of emissions for NOx emissions from agricultural farm machinery, the emissions of NOx is assumed to be lower in future production.

3 Inventory analysis

3.1 General description of the systems

The different scenarios for future pig farming systems were constructed (Stern *et al*, 2004). The scenarios were optimised according to three different strategies:

A – animal welfare

B – environment

C – product quality at low price

In all scenarios, the production is integrated with sows and slaughter pigs at the same farm.

Scenario A: focus on animal welfare

Sows and piglets are kept outdoors on pasture with huts during the summer period (six months). Slaughter pigs are kept indoors on straw, in a veranda system with access to a paddock. The space allowance per slaughter pig is 2.5 m^2. Groups are kept intact throughout the rearing period, to avoid fighting and re-ranking.

Strategic feeding with diets that are diluted with forages to give longer eating times and occupation for the pigs are used. Slaughter is based on age, thus the whole batch is slaughtered at the same time. The feed consists of cereals produced at the farm site. The dominant protein feed originates from rapeseed meal and peas grown at the farm. Some soy meal is used as supplement, as are synthetic amino acids.

Scenario B: focus on environment

Both sows with piglets and slaughter pigs are kept indoors. The buildings are closed, in order to control the nitrogen emissions through air and manure. The ventilation air is filtered and ammonia is retained. Slatted floors and covered manure storage keep nutrient losses and smell low.

Synthetic amino acids and enzymes are used to increase the feed efficiency. Phase feeding is practiced to reduce nitrogen losses. Phytase is used to enhance the uptake of phosphorous in the feed ingredients, thus decreasing the need for minerals. Special pathogen free (SPF) pigs are used. Pigs of different sex are raised to different slaughter weights and males are kept intact for higher feed efficiency. The pigs are slaughtered in batches.

The feed is based on grain produced at the farm site and the dominating protein part is rapeseed meal and peas, also grown at the farm. The concentrate is completed with smaller amounts of soy meal and synthetic amino acids. This facilitates low nitrogen content in the feed.

In the crop production in this scenario, the overall goal is to reduce the use of fertilisers and pesticides as well as emissions of nitrogen.

Scenario C: focus on product quality at low price

In this scenario, the whole production chain from animal to retailer is integrated. Production is indoors with specialized or external integration. The buildings allow a well-controlled environment, regarding ventilation, temperature, feed distribution etc. Feed ingredients are controlled for nutritional and hygienic value. SPF pigs are used. Health is controlled and preventive medical treatment is used. It is possible that several different breeding goals will be used depending on the product, such as bacon pigs, heavy pigs etc.

Slaughter based on weight (160 kg) in groups in slaughterhouses with high standards to assure product quality. Cereals produced at the farm site are complemented with imported soy meal and synthetic amino acids. The handling of manure follows current law regulation.

3.2 Animal production

There are 330 sows per farm in the three scenarios. Data on the animas are summarised in table 3.1.

Table 3.1 Data on the animal production in the three scenarios

	Scenario A	Scenario B	Scenario C
Number of sows	330	330	330
Produced slaughter pig per sow*yr	20	25	25
Replacement, %	35	45	45
Mortality, %	1	1	1
Number of slaughter pigs produced per yr	6 534	8 168	8 168
Live-weight at slaughter, kg per pig	117	105	160
Carcass weight, kg per pig	85.4	76.6	117
Live-weight gain, gram per day	988	988	988

3.2.1 Meat production

The functional unit is *one kg bone-and fat free meat*. This functional unit was selected to measure the final function at the consumer, i.e. the eatable part from meat production. The meat percentage out of the carcass weight was 59 % in A, 59 % in B and 58 % in C. In table 3.2, the production of bone-and fat free meat is presented.

Table 3.2 Production of bone free meat in the three scenarios

	Scenario A	Scenario B	Scenario C
Carcass weight slaughter pigs, kg	558 004	625 631	955 598
Carcass weight sows, kg	13 860	17 820	17 820*
Total production of bone free meat, kg	337 400	379 636	564 761

* meat percent is 59 % for the sows

3.2.2 Feed consumption

The total feed consumption in the three scenarios is presented in table 3.3 and in appendix 2, table 1, the composition of feed rations is shown. It should be observed that the sows´ consumption of feed is included per produced slaughter pig.

Table 3.3 Feed consumption, kg per slaughter pig

	Scenario A	Scenario B	Scenario C
Sow feed, dry period	63	56	56
Sow feed, weaning period	63	56	56
Slaughter pig, phase 1	86	70	93
Slaughter pig, phase 2	196	140	284
Total	*408*	*322*	*489*

3.2.3 Manure production and nutrient balances in the stable

The manure production and the nutrient composition of the manure were calculated through balances of input of nutrients in the feed and output of nutrients in the produced pigs. All manure is handled as slurry and the dry matter content of the slurry is 8.8 % (Steineck *et al*, 1999). In scenario A, the sows and piglets are outside grazing during six months of the summer period and the manure produced during this time is applied directly in the field. This share of the total manure production corresponds to around 15 %, the total manure in A is 6 000 tonnes/year but only 5 000 tonnes need to be stored and spread. Data on manure production are shown in table 3.4.

Table 3.4 Data on manure production.

	Scenario A	Scenario B	Scenario C
Slurry production, kg wet weight per slaughter pig [1]	919	800	1 225
Total manure production, tonnes/yr	5 007 (6 005)	6 535	10 000

[1]Manure from sows is included and calculated per slaughter pig

In Appendix 2, a balance of the nutrient flows in the stable is calculated. Feed efficiency is an interesting indicator and is defined as the ratio between nutrients uptake in the animal and nutrients in the feed intake. In table 3.5, this indicator is shown as well as the nutrient content in the manure before any losses.

Table 3.5 Nutrients production in manure (gross) and feed efficiency.

	A			B			C		
	N	P	K	N	P	K	N	P	K
Nutrients in manure, kg/slaughter pig	5.6	1.95	2.7	4.05	0.92	1.72	6.9	2.4	2.8
Feed efficiency	0.37	0.22	0.1	0.41	0.36	0.12	0.39	0.25	0.12

The use of the enzyme phytase increases the phosphorus efficiency in scenario B significantly. The pig production in all scenarios have a rather high feed efficiency of nitrogen (especially B and C) and this is a consequence of a high piglet production per sow and relatively low feed consumption per kg of growth for the slaughter pigs. The lowest N-efficiency is found in A (welfare) where the piglet production per sow is lower than in the other scenarios and the feed consumption is 5 % higher.

The amount of N in the manure is of significance to the losses of ammonia and nitrous oxide. Total-N in manure (before any losses to atmosphere) was 108 g N/functional unit (FU) in scenario A and 87 and 100 gram N/FU in scenario B and C, respectively.

3.2.4 Emissions of ammonia

Emissions of ammonia take place in animal housing, during manure storage and for scenario A, during the grazing period for the sows and piglets. The ammonia losses in the stables are calculated to be 14 % of the excreted nitrogen (STANK 4.2, Jordbruksverket 2003). In scenario B, the ventilation system has a filter to catch discharged ammonia and it is estimated that approximately 75 % of the ammonia emission in the stable can be caught in the filter and washed out as ammonium-sulphate and led into the slurry store. Thus, ammonia emission in B was calculated to be 5 % of excreted N.

There is no official emission factor for ammonia losses from grazing pigs in Sweden. The ammonia losses from grazing cattle are estimated to be 8 % of excreted N according to EMEP/CORINAIR (McInnes, 1996). It is reasonable to assume that ammonia losses are higher for grazing pigs since the N content in pig manure is higher than in cattle manure. Losses of ammonia from the grazing sows and piglets in scenario A was estimated to be 15 % of N excreted and approximately 15 % of the total manure production in A was produced during the grazing period.

In all three scenarios, the slurry is stored in a well-covered tank. The ammonia losses are low from this storage system, 1 % of total nitrogen in the manure is estimated to be lost during the storing period (STANK 4.2, Jordbruksverket 2003). The losses of ammonia from housing, manure storing and grazing are summarised in table 3.6.

Table 3.6 Yearly emissions of ammonia from manure in stables, grazing period and during storage

Losses of ammonia-N	Scenario A	Scenario B	Scenario C
Housing, kg NH_3-N per pig[1]	0.67	0.22	0.97
Grazing, kg NH_3-N per pig[1]	0.13		
Storage, kg NH_3-N per pig[1]	0.04	0.04	0.06
Total emission for the whole farm, kg NH_3-N	5 495	2 090	8 405

[1] Per slaughter pig including also sows and piglets.

3.2.5 Emissions of nitrous oxide

The manure is transported daily to the slurry tank, thus no losses of nitrous oxide in the stable are calculated. IPCC (1997, 2000) gives emission factors for losses of nitrous oxide during storing corresponding to 0.001 kg N_2O-N/kg N in slurry (after deduction for N emitted as ammonia). For manure deposited directly on soils by livestock the emission factor is 0.02 kg N_2O-N/kg N excreted (after ammonia losses are reduced). This factor was used when estimating the nitrous oxide emissions during the grazing period in scenario A. The losses of nitrous oxide from manure storing and grazing are summarised in table 3.7.

For estimations of indirect N_2O emissions due to deposit of ammonium, IPCC gives the EF of 0.01 kg N_2O-N/kg NH_4-N deposited. So far, there is very little data behind this emission factor and due to the great uncertainty, IPCC recommends this factor to be used rather than county-specific data (IPCC 2000). The potential indirect emissions of N_2O caused by emissions of ammonia in housing, manure storage and grazing are also shown in table 3.7

Table 3.7 Yearly emissions of nitrous oxide from manure in storing and grazing period

Losses of nitrous oxide	Scenario A	Scenario B	Scenario C
Manure storage, kg N_2O-N per pig[1]	0.0041	0.0041	0.00594
Grazing, kg N_2O-N per pig[1]	0.014		
Total direct emission for the whole farm, kg N_2O-N	120	34	48
Total indirect emission for the whole farm, kg N_2O-N	55	21	84

[1] Per slaughter pig including share of sow (and piglet)

3.2.6 Emissions of methane

The discharges of methane due to enteric fermentation are 1.5 kg CH_4/pig according to IPCC (1997). Due to differences in the intensity as well as choice of slaughter weight, the total life time of the slaughter pigs are 22.6 weeks/pig in A, 16.6 weeks/pig in B and 23.7 weeks/pig in C. In table 3.8, the total yearly methane emissions from the sows and slaughter pigs are shown.

The emission of methane from manure storage is calculated according to IPCC (1997):

Emission of CH_4 = VS * Bo * 0.67 kg/m^3 * MCF

VS stands for volatile solids excreted from animals. VS are 87 % of the dry matter in the manure (Dustan 2002). The average dry matter of the slurry in the three scenarios is estimated to 8.8 % which has been recorded as an average for slurry on Swedish pig farms (Steineck et al 1999). Total manure production is according to table 3.4.

Bo is the methane generation potential, IPCC (1997) suggests 0.45 CH_4/kg VS for swine; this factor was also suggested by Naturvårdsverket (2002).

MCF is the methane conversion factor. For slurry in cold climates, IPCC (1997) suggested MCF to be 10 %. In the revised guidelines (IPCC 2000) MCF for slurry in cold climate was significantly increased, up to 39 %. Dustan (2002) argues that, based on Danish long-term measurement and calculations, the MCF of cattle and swine slurry should be around 10 %. Naturvårdsverket (2002) uses MCF = 10 % for slurry and this emission factor is used also in this study. In Scenario A, approximately 15 % of the manure is dropped during the grazing period. MCF is 1 % for manure dropped in pasture according to IPCC (2000). The total methane emissions from the manure handling is shown in table 3.8.

Table 3.8 Total yearly emissions of methane from animals and manure

	Scenario A	Scenario B	Scenario C
Enteric fermentation, kg CH_4/year	4 709	4 416	6 131
Manure management, kg CH_4/year	11 950	15 082	23 083
Total, kg CH_4/year	16 659	19 498	29 214

3.2.7 Direct energy use

The use of electricity in the stable was calculated as 650 kWh/sow*yr and 15 kWh/slaughter pig (LBT 1982). This figures include heating, ventilation etc. Due to the sows grazing outdoors and less heating of the stables in A, the electricity use for the housing was approximately 25 % lower in this scenario. In B (environment), techniques for energy saving was used, such as low energy lamps and heat exchanger. Calculations of such measures show that it is possible to lower the electricity use by approximately 25 % in contemporary pig production (Kjeang, A pers comm., 2004) which was done in B. In C, the electricity use per slaughter pig was calculated as 18,5 kWh due to the longer life time.

It was estimated that in the drying processes of cereals and peas, the electricity use was 70 kWh/ha (Törner, L. pers comm 2003). The use of oil for heating and drying is described in 3.3.7.

All the farms have their own feed production unit were the grain and peas are ground and mixed with the protein feed that is delivered from the feed industry. The electricity for the preparation of the pig feed was estimated at 30 kWh/tonne and this is based on data from the feed industry (Tietz F, pers comm 2003). The electricity use is summarised in table 3.9.

Table 3.9 Yearly use of electricity (kWh) in the three scenarios

	Scenario A	Scenario B	Scenario C
Housing, sows	159 060	160 875	214 500
Housing, slaughter pigs	74 487	110 268	151 108
Drying of cereals/peas	28 630	30 240	38 080
Feed preparation (grinding, mixing)	60 240	62 340	99 990
Total, kWh	322 417	363 723	503 678

The total use of diesel in the crops (including diesel for feeding the sows during the grazing period) is described in 3.3

3.3 Crop production

The feed consumption of the pigs is the base for the choice of crops and the crop rotation on the farms. The total use of feed in the three scenarios is summarised in table 3.10.

Table 3.10 Total feed consumption in the three scenarios

Substance	Scenario A	Scenario B	Scenario C
Oats, tonnes	295.2	310.2	351.2
Wheat/Barley/Triticale, tonnes	1417.6	1460.9	2981.9
Wheat bran, tonnes	305.2	313.4	70.8
Peas, tonnes	294.5	307.2	0
Rape seed meal, tonnes	118.6	127.9	0
Soy meal, tonnes	28.1	28.6	451.6
Synthetic amino acids, tonnes	5.79	5.88	7.87
Mono-calciumphosphate, tonnes	21.7	0	47.3
Straw, tonnes	128	123	0

3.3.1 Crop rotations

With the pigs´ feed consumption as a starting point, crop rotations were constructed for each scenario. The goal was to produce as much as possible of the pigs´ feed requirement at the farm. This creates a problem for scenario C, where soymeal is the only protein feed ingredient and soybeans are not cultivated in northern Europe with successful results.

In scenario A (animal welfare), the crop rotation is seven years and the farm has 470 ha (7 year * 67 ha). Table 3.11 shows crop sequences and yield.

Table 3.11 Crop rotation and production in scenario A

Year, crop	Yield, kg/ha	Production, tonnes	Use
1) Winter rape	3 050	204	Meal:feed, Oil:food industry
2) Winter wheat	7 000	469	Feed
3a) Barley, 20 ha	5 800	116	Feed
b) Grass, 49 ha	-	-	Grazing for sows
4) Oats	5 500	368	Feed, surplus 73 tonnes sold
5) Peas	3 900	261	Feed
6) Winter wheat	7 000	469	Feed
7) Barley	5 800	388	Feed

In the A crop rotation, cereals and rapeseed meal are produced in sufficient amount for the pigs. The rapeseed is sold from the farm to the oil crusher in Karlshamn (Swedens largest crusher) and approximately 58 % of the rape seed (=the meal part) is returned back to the farm as a protein feed ingredient. There is a small surplus of oats that is sold from the farm while a small deficit of peas (33 tonnes) is bought from a neighbouring farm (see also appendix 1a).

Also in scenario B (environment), the crop rotation is seven years but it does not include grassland as in A since all the pigs are kept indoors in this scenario. The farm has 490 ha (7 years*70 ha). Table 3.12 shows crop sequences and yield.

Table 3.12 Crop rotation and production in scenario B

Year, crop	Yield, kg/ha	Production, tonnes	Use
1) Winter rape	3 100	217	Meal:feed, Oil:food industry
2) Winter wheat	7 000	490	Feed 173 tonnes, surplus 317 tonnes sold
3) Barley+catch crop	5 600	392	Feed
4) Peas	3 900	273	Feed
5) Winter wheat+catch crop	7 000	490	Feed
6) Oat	5 500	385	Feed 310 tonnes, surplus 75 tonnes sold
7) Barley	5 800	406	Feed

Cereals and rape seed meal is produced in sufficient amount in this crop rotation. As is the case for scenario A, rape seed is sold to the crusher in Karlshamn and 58 % of the mass is imported back to the farm as protein meal. Oat is produced in a small surplus that is sold. Winter wheat is produced in quite a big surplus but in view of the large amounts of the co-product wheat bran used in the feed ration in this scenario, this surplus production is reasonable. There is a small deficit of peas (34 tonnes) that is bought from a neighbouring farm (see also appendix 1b).

Finally the crop rotation in scenario C (product quality and price) is shown in table 3.13. This differs from A and B since peas and rapeseed meal are not used as protein feed in the feed ration in C. The farm in scenario C has 600 ha and the crop rotation is five year (5 years*120 ha).

Table 3.13 Crop rotation and production in scenario C

Year, crop	Yield, kg/ha	Production, ton	Use
1) Oats	5 500	660	Feed 351 tonnes, surplus 309 tonnes sold
2) Winter wheat	6 700	804	Feed
3) Barley	5 500	660	Feed
4) Winter wheat	6 000	720	Feed
5) Triticale	6 000	720	Feed

Cereals are produced in sufficient amount in this scenario and there is rather a big surplus of oats (309 tonnes) that is sold from the farm. It is also possible that some break crop like rapeseed could be grown or fallow could be used instead of oats in this crop rotation (see also appendix 1c).

3.3.2 Yields

The future crop yields in the three scenarios were estimated with the help of yield trends based on statistical surveys, discussion with the extension service in the province of Östergötland (see figure 3.1) and with data from field trials examining the importance of crop sequence for the yield level.

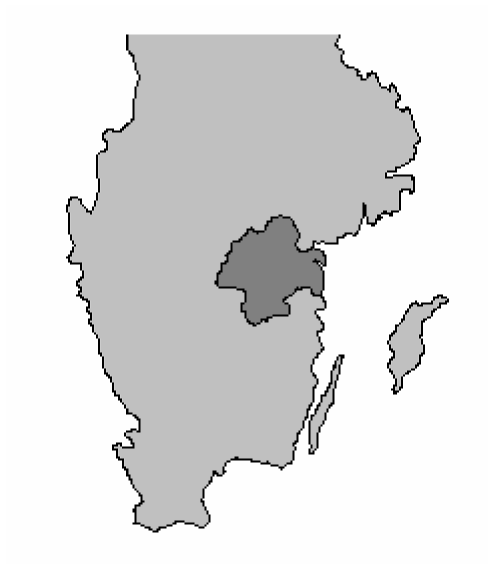


Figure 3.1 The province of Östergötland is situated in the east of south-central Sweden

In table 3.14 results are shown from field trials with different break crops in mono-cultural cereal cultivation. As can be seen, the introduction of peas or rape seed, increases the winter wheat yield with at least 1 000 kg/ha in comparison to having wheat as precursor to itself. Also oats is a good precursor to wheat, increasing the yield by 700 kg/ha.

Table 3.14 Increased yield, kg/ha, with different precursor crop in a mono-cultural grain cultivation

Precursor	Winter wheat	Spring wheat	Barley	Oats
Winter wheat	4 200			
Spring wheat	+ 100	3 800	+ 100	+ 150
Barley	+ 300	+ 300	3 700	+ 200
Oats	+ 700	+ 400	+ 200	3 500
Winter rape	+ 1 100	+ 500	+ 400	+ 300
Peas	+ 1 100	+ 700	+ 550	+ 400
Potatoes	-	-	+ 1 000	+ 800

Source: Olofsson & Wallgren, 1984.

The standard yield[3] of wheat in the province of Östergötland was 6 300 kg/ha in 2002 (SCB 2003) with a variation of 5 160 – 6 782 kg/ha in different yield survey district. A follow-up of the true yields shows that the yields have levelled out during the past ten years. In figure 3.2, the trend of true winter wheat yields is shown in three-years moving average (Statistikdatabasen, SCB, 2004).

[3] The standard yield is an estimate of the yield that can be expected if the weather and other conditions that influence the crop are normal.

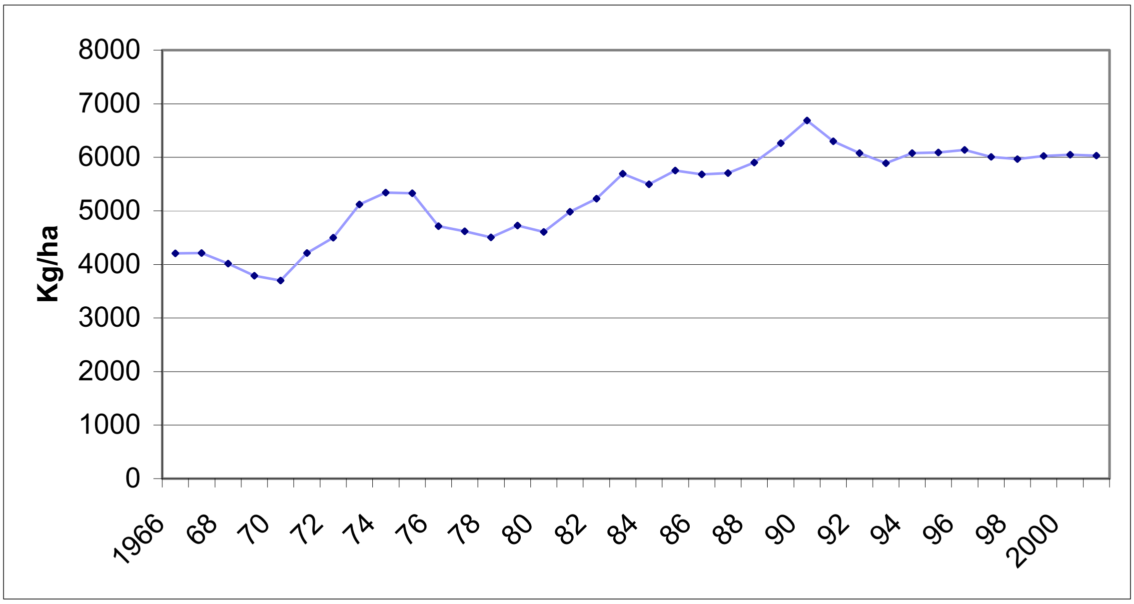


Figure 3.2 Winter wheat yields in Östergötland, three-years moving average

The extension service group in Östergötland, the Lovang-group, has extensive data on the yield development on farms in the area. The average yield of winter wheat during the last ten years on this group of farms is approximately 6 700 kg/ha (Lovang, T pers comm. 2003). This is a higher yield level than the official statistics gives but the farms in the Lovang group are to a high degree situated on the most productive arable land in the province of Östergötland.

With this information as background, the average wheat yield in the province of Östergötland in ten years from now is estimated to be 7 000 kg/ha on fertile soils with good break crops as precursors and 6 700 and 6 000 kg/ha with oats and barley/wheat respectively as a precursor crop.

The standard yield for spring barley in the province of Östergötland was 4 669 kg/ha in 2002 (SCB 2003) with a variation of 3 409 – 5 309 kg/ha between different yield survey districts. Figure 3.2 shows the yield trend for barley, also for this crop, the yields have levelled out during the past ten years (Statistikdatabasen, SCB, 2004).

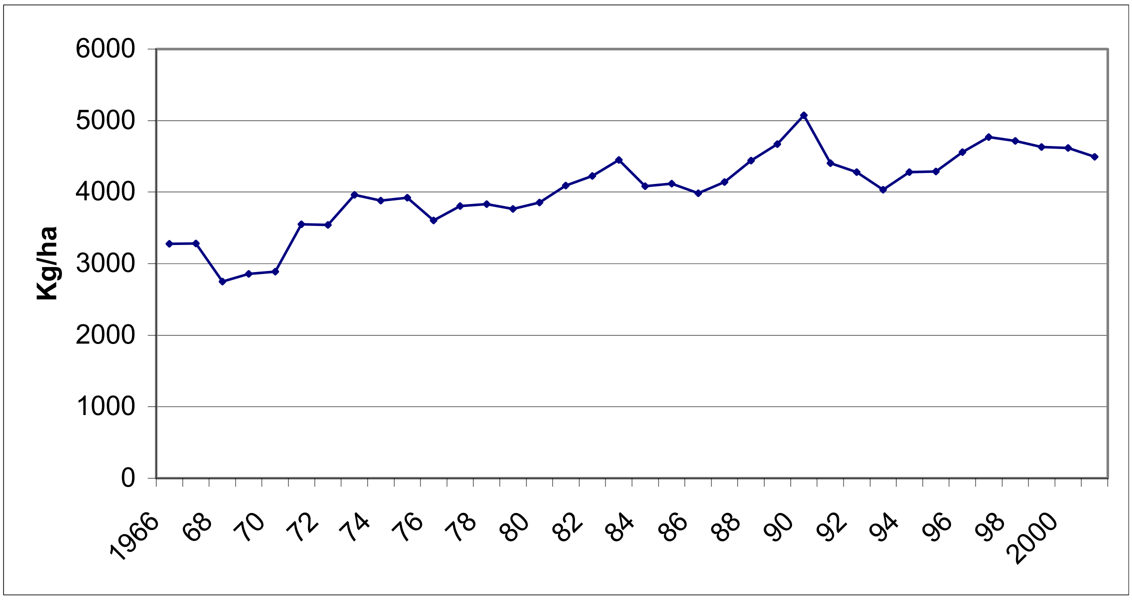


Figure 3.3 Barley yields in Östergötland, three-years moving average

The extension service of the Lovang-group reports an average yield of barley for the last ten years of 5 450 kg/ha (Lovang, T. pers comm., 2003). This is higher than the standard yield for the province and most likely a consequence of a higher share of highly productive soils in the Lovang group. Based on this information, the average yield of barley in ten years on fertile soils in the province of Östergötland is estimated to vary between 5 500 – 5 800 kg/ha.

The standard yield for oats in Östergötland was 3 924 kg/ha in 2002 (SCB 2003) with a variation of 3 152 – 4 964 kg/ha between different yield survey districts. The yield trend for oats is shown in figure 3.3 (Statistikdatabasen, SCB, 2004).

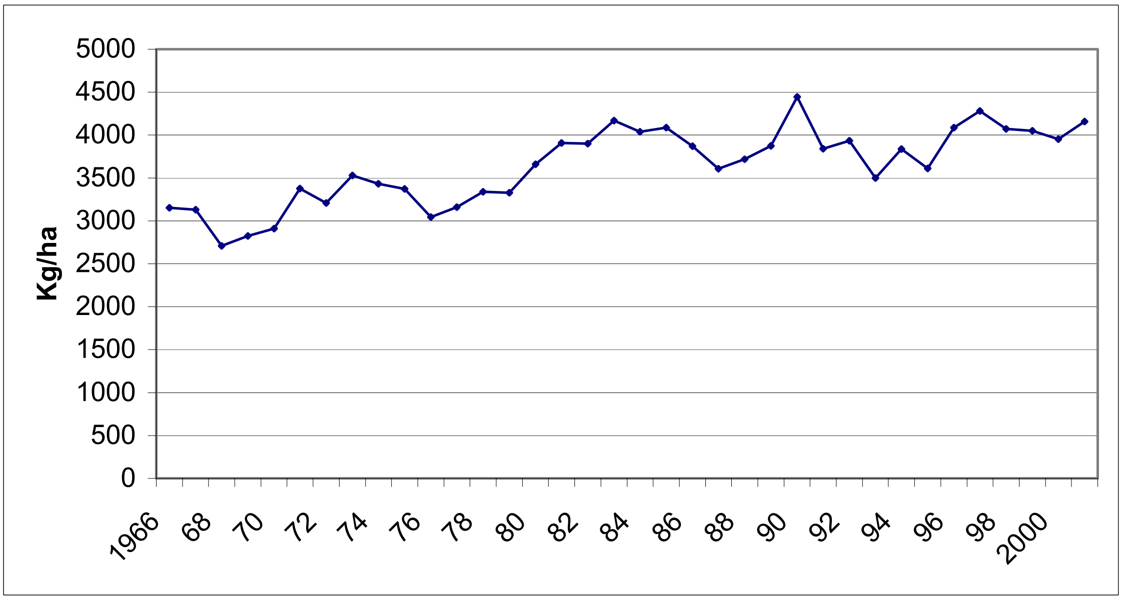


Figure 3.4 Yield of oats in Östergötland, three-years moving average

The variation in yields between different years seems to be larger for oat than barley. The average of oat yield during the last ten years is 5 250 kg/ha on farms in the Lovang-group.

The future average yield in ten years time for oats on fertile soils in the province of Östergötland is estimated at 5 500 kg/ha.

During the last five year the average yield in the province of Östergötland was 3 150 kg/ha for peas and 2 850 kg/ha for winter rapeseed. In consultation with the extension service of the Lovang group, the future average yield in ten years time is estimated to fully 3 000 kg/ha for winter rapeseed and 3 900 kg/ha for peas on fertile soils.

3.3.3 Manure and fertiliser use

The need of N-fertilisers was calculated in accordance of the guidelines of the National Board of Agriculture (Jordbruksverket 2003). The recommended fertiliser rate is based on economic optimal nitrogen fertilisation and is to be adjusted to expected yield, increased N-mineralisation due to regular manure use and pre-crop. A winter wheat crop used for human consumption (protein-content > 12 % desired) with the expected yield of 7 000 kg/ha has an economic fertiliser rate of 155 kg N/ha. When the wheat is grown for fodder, the economic fertiliser rate should be deducted by 15 kg N/ha (no extra payment for high protein). The recommended fertiliser rate is lowered by 10 kg N/ha*yr per tonne dry-matter manure that is annually given (increased N-mineralisation). When the preceding crop is cereals, no nitrogen comes from this crop. When winter wheat is grown after winter rape or peas, the value of the nitrogen effect from these precursors is 30 kg N/ha.

In scenario A (animal welfare), approximately 15 % of the yearly manure production is spread by the sows and piglets during there grazing period. The grassland where the pigs are grazing is rotating in the crop rotation so this manure is evenly spread (not concentrated to fields close to the farm centre). Approximately 25 % of the manure is spread in August before sowing winter rape and the rest (60 %) is spread during April and May. The N-content in the slurry is calculated from the stable balance and losses in stables and store. Table 3.15 shows the use of manure-N and fertiliser-N.

Table 3.15 Use of manure and N-fertilisers in the crop rotation in scenario A

Crop	Slurry, tonnes/ha	N, plant-available, slurry, kg N/ha	N from fertilisers, kg N/ha	Plant-available N, total kg N/ha
1:Winter rape	Autumn:22	63		Autumn: 63
	Spring:15	38	Spring: 75	Spring: 113
2:Winter wheat			110	110
3a:Barley, 20 ha	Spring: 30	75	30	105
3b:Leys, 47 ha	Grazing		0	
4:Oats			80	80
5:Peas			0	0
6:Winter wheat	Spring: 30	75	40	115
7:Barley			100	100

The average yearly use of mineral nitrogen fertilisers in scenario A is 59 kg N/ha.

In scenario B (environment) great concern is taken to use the manure as efficiently as possible and to avoid fertiliser rates above economic optimum. The total production of slurry was 6 530 tonnes of which 21 % was used in August before sowing the winter rape and 79 % in April and May. The N-content in the slurry (calculated from the nutrient balance in the animal housing and reduced for losses) was 5 kg N/ton which of 3.4 kg NH_4-N/ton (plant-available N). The effect of the plant-available N was presumed to be 80 % in winter rape and 70 % in cereal crops. The use of manure and N-fertilizers is shown in table 3.16.

Table 3.16 Use of manure and N-fertilisers in the crop rotation scenario B

Crop	Slurry, tonnes/ha	N, plant-available, slurry, kg N/ha	N from fertilisers, kg N/ha	Plant-available N, total kg N/ha
1:Winter rape	Autumn:20	54		Autumn: 54
	Spring:15	41	Spring: 74	Spring: 115
2:Winter wheat[1]			115	115
3:Barley	Spring: 29	69	30	99
4:Peas			0	0
5:Winter wheat	Spring: 29	69	40	109
6:Oats			90	90
7:Barley			100	100

[1] winter wheat year two is fertilised as cereals for human consumption since 75 % of this crop is sold as bread wheat

The average yearly use of mineral nitrogen fertilisers on the farm in scenario B is 64 kg N/ha.

Due to the use of phytase, the phosphorous content of the manure is considerably lower in B than in scenario A and C. To maintain the P-saldo at the farm level, a small amount of P fertilisers is used in crop rotation B. On average, 1 300 kg phosphorous is used yearly in the crop rotation and the quantity is evenly distributed in the crop rotation.

In scenario C (price-product quality) the fertiliser rates are slightly higher that in B. Today, there is a tendency that the fertiliser rates in practice are higher than the officially recommended fertiliser rates based on economic optimum (Jonasson, 2004). The reason for this can be the farmer wanting to be on the safe side and/or not knowing the actual nutrient content of the manure.

One third of the manure production in C is spread in September, before sowing winter wheat and two thirds are spread in April and May. The N-content in slurry (calculated from the stable balance in appendix 2 and corrected for losses) is 4.8 kg N/ton of which 3,2 kg NH_4-N/ton. Table 3.17 shows the use of manure and N-fertilizers in scenario C.

Table 3.17 Use of manure and N-fertilisers in the crop rotation in scenario C

Crop	Slurry, tonnes/ha	N, plant-available, slurry, kg N/ha	N from fertilisers, kg N/ha	Plant-available N, total kg N/ha
1: Oats	Spring:28	62	40	102
2:Winter wheat	Spring:28	62	70	132
3:Barley			90	90
4:Winter wheat	Autumn:28	27	110	137
5:Triticale			100	100

The yearly average use of fertiliser-N in the crop rotation in scenario C is 82 kg N/ha. The higher N fertilising in scenario C compared to B and A is partly due to the absence of peas in the crop rotation and partly due to a less efficient use of the manure (e.g. slurry to winter wheat in autumn).

Data for resource use and emissions from fertiliser production is according to Davis & Haglund (1999), important parameters are shown in table 3.18.

Table 3.18 Energy use and emissions of CO_2 and N_2O in fertiliser production

	per kg nitrogen	per kg phosphorous
Energy use (MJ/kg)	41.8	30.6
Emission		
CO2, g/kg	2 950	3 080
N2O, g/kg	14.6	0.287

Fertiliser transports are shown in Appendix 3.

3.3.4 Energy use

The use of diesel for different field operations where calculated according to data in table 3.19.

Table 3.19 Data for calculating diesel consumption

Operation	Diesel l/ha and occasion
Five-furrow plough	19.3
Disc-harrow, 5 m	12.2
Harrow, 9 m	8.6
Drilling machine	5.6
Fertiliser, disk broad-caster	1.1
Crop sprayer	0.6
Weeding harrow	2.5
Combine harvester, transport at harvest	28.8
Manure spreading	0.4 l/tonne manure

Source: www.lr.dk/agrimach

The diesel consumption on the farms in the three scenarios was calculated from the base data shown in table 3.19. An addition of 10 % extra diesel were made in all scenarios to cover the over-all diesel use at the farm for maintenance, snow-clearance and other smaller work.

The total diesel use for the cultivation of the crops in scenario A is 39 640 l/ha (table 3.20) and an extra 10 % of this is added for various maintenance work. During the sows´grazing period a diesel use of 340 l/year for shifting the animals between different grazing areas and 525 l/year is derived for transporting feed and water. Approximately 400 tonnes of straw is used for feeding and bedding. Baling of straw is done by a contractor and is estimated to consume 1 l diesel/ton straw. The total diesel use on the farm is thus 44 869 l diesel corresponding to in average 96 l diesel/ha.

Table 3.20 Diesel use in scenario A

Crop	Diesel, l/ha	Comments
1:Winter rapeseed	114	Manure twice
2:Winter wheat	70	No ploughing
3a:Barley, 20 ha	109	Manure
3b: Ley	3*	
4: Oats	97	Two disc-harrowing
5:Peas	85	
6:Winter wheat	82	No ploughing, manure
7:Barley	97	Disc-harrowing before barley

* mowing grass, feeding/mowing sows separately calculated

In scenario B, the total diesel use in crop production is 45 920 l (table 3.21). When adding 10 % for maintenance work and 300 l diesel for baling straw, the total diesel use is 50 812 l on farm B which corresponds to 104 l/ha.

Table 3.21 Diesel use in scenario B

Crop	Diesel, l/ha	Comments
1:Winter rapeseed	113	Manure twice
2:Winter wheat	71	No ploughing before wheat
3: Barley	122	Manure, three disc-harrowing before barley
4: Peas	85	
5:Winter wheat	82	No ploughing before wheat, manure
6:Oats	73	
7:Barley	110	Three disc-harrowing before barley

Finally, in scenario C, the total diesel use in crop production is 49 560 l (table 3.22). Adding 10 % for various maintenance and 190 l for baling straw give a total consumption of 54 700 l diesel (91 l/ha). In scenario C, mechanical cultivation is minimised and Glyphosate is used 2 years out of five in the crop rotation. This measure leads to a lower diesel use than in B and A.

Table 3.22 Diesel use in scenario C

Crop	Diesel, l/ha	Comments
1:Oat	84	Manure
2:Winter wheat	85	Manure
3: Barley	73	
4: Winter wheat	97	Manure
5: Triticale	74	

Data for emissions from diesel use in tractors and harvest machines (table 3.23) is based on Lindgren et al (2002) but the NO_X – emissions are reduced due to coming directives on agricultural engines in the EU (Hansson et al, 2003).

Table 3.23 Emissions from diesel combustion tractors

Emission	Gram/MJ diesel
CO	0.095
CO_2	74.6
HC	0.025
NO_X	0.8
SO_2	0.019

The cereals, peas and rapeseed are dried at the farm. The electricity use in the drying plant on the farm is 70 kWh/ha (see 3.2.7). Light oil is used for heating the air in the drying plant. The organisation Odling i Balans (Törner, L pers medd) gives a consumption of oil corresponding to 0.17 l oil/kg of water. The average water content in harvest in Östergötland was estimated in consensus with the extension service (Lovang, T. 2003). Table 3.24 shows the estimated water content at harvest and after drying.

Table 3.24 Estimated water content at harvest and after drying

Crop	Water content, harvest %	Water content, after drying, %
Wheat	20	14
Barley	18	14
Oat	18	14
Rapeseed	10.8	9
Peas	20	14

The average yearly use of oil for drying the crops was 22 981 l in A, 26 390 l in B and 36 360 l in C.

3.3.5 Pesticide use

In scenario B (environment) and partly also A (animal welfare), it was of high priority to minimise the pesticide use. In this report, toxicity is only discussed as use of pesticides but in the Food 21-project "Sustainable Plant Production" there will also be a risk assessment of the pesticide used in the three scenarios (Cederberg *et al,* 2004 report in prep).

The use of pesticides in the different crop rotations was estimated from economic optimal use but in scenario B (environment), the goal was to minimise pesticide application as far as possible without reducing the yield levels. Therefore, mechanical alternatives are utilised in B (and partly also in A) to regulate weeds. Table 3.25 shows the average yearly use of pesticides in scenario B. In winter wheat the frequency of fungicide application is 0.5 meaning that on average one fungicide application is used every other year. In this crop, the frequency for insecticides is 0.25 meaning that on average one year out of four, insecticides are used in the wheat crop. The weeds are regulated mechanically (row-hoeing or harrowing) in rape seed, peas and sometimes in a spring cereal crop. These mechanical weed regulations are known to give efficient weed control and with little or no negative impact on the yield. There is also an aim at keeping the use of Glyphosate at a low level in scenario B and A. Two autumns in the crop rotation, couch grass (*E.repens*) is regulated with repeatedly disc-harrowings. On average, Glyphosate is used one year out of seven in the crop rotation in A and B. The total diesel use in this scenario B and A is hereby higher than in C.

Table 3.25 Average yearly use of pesticide applications in scenario B

Crop	Seed disinfection	Herbicides	Fungicides	Insecticides
1:Winter rape	-	Mechanical	-	1
2:Winter wheat	1	1	0.5	0.25
3: Barley	0.6	Mechanical 0.5 Chemical 0.5	0.2	0.2
4: Peas	-	Mechanical 0.8 Chemical 0.2	-	0.2
5:Winter wheat	1	1	0.5	0.25
6:Oats	-	1	0.2	0.2
7:Barley	0.5	1	0.2	0.2

The individual trade products and doses for scenario A and B are presented in appendix 4, they represent products normally used in today´s agriculture (Axelsson, P, pers comm., 2003).

In scenario C, where focus is on price and product quality, pesticide use is higher (see table 3.26). Crouch grass (*E repens*) is regulated by Glyphosate and no extra disc-harrowing is done in the autumn. It is calculated that Roundup is used two years out of five in the C crop rotation.

Table 3.26 Average yearly use of pesticide applications in scenario C

Crop	Seed disinfection	Herbicides	Fungicides	Insecticides
1:Oats	-	1	0.2	0.2
2:Winter wheat	1	1	0.75	0.25
3: Barley	0.6	1	0.2	0.2
4: Winter wheat	1	2*	1	0.25
5: Triticale	1	1	0.5	0.5

* herbicide application, autumn as well as spring

The use of fungicides are higher in crop rotation in scenario C than in B and A, which is an effect of the precursors in C that increase the risk of root and stem base diseases and leaf-spot fungis. The higher proportion of winter grown cereal crops in C in comparison with B and A increases the risk of autumn growing weeds (e.g. *Apera spica-venti*) and this increases the use of herbicides in wheat. No mechanical regulation of weed is used in this scenario C. The individual trade products and doses for scenario C are presented in appendix 4. In table 3.27, the average yearly use of pesticides is shown for the three scenarios.

Table 3.27 Average yearly use of pesticides in the three scenarios

	Scenario A		Scenario B		Scenario C	
	Kg active substance	Gram Active substance/ha	Kg active substance	Gram Active substance/ha	Kg active substance	Gram Active substance/ha
Herbicides, weed	100	213	107.7	220	262.8	438
Herbicides, Glyphosate	84.4	185	88.2	180	302.4	504
Fungicides	31.2	66	35	71	108.8	181
Insecticides	37.1	79	39.5	80	4.6	7.6
Total	*252.7*	*543*	*270.4*	*551*	*678.6*	*1131*

Data on energy use in pesticide production are according to Green (1987).

3.3.6 Seed

Data for cultivation of the seed is similar to the data for the cultivation on the pig farm. The cereals and peas grown for seed production are transported by tractor (distance 30 km) to a seed central in Östergötland, where it is controlled and, when required, disinfected. 100 % of the winter wheat/triticale, and 50 - 60 % of the barley are disinfected. The seed is then packed and delivered to the pig farms (distance 50 km from seed central to pig farm). Table 3.28 shows the amount of seed used on the pig farms in the three scenarios. The total energy consumption of handling the seed (including transportation) from arable farm to pig farm was estimated at 288 MJ/tonne (Ringstad L, pers comm. 2004).

Table 3.28 Consumption of seed in the three scenarios

Seed	Scenario A	Scenario B	Scenario C
Wheat/Triticale, kg	26 800	19 000	72 000
Barley / Oats, kg	26 100	35 300	33 000
Peas, kg	16 750	17 500	-
Total, kg	*69 650*	*71 800*	*105 000*

3.3.7 Emissions of N and P

The nitrate leaching is calculated with an empirical model used in the computer program STANK (Aronsson & Torstensson, 2002). In this model, a number of factors are considered that are relevant for the size of the leaching. Important factors are soil type, average yearly precipitation, total manure application in the crop rotation (average manure rate as tonne dry matter/ha), crop, time for cultivation/soil preparation in the autumn, time for manure application and possible over-optimal N-fertiliser rate. The N-leaching, (as kg NO_3-N/ha) in a single field is calculated as:

(Base-leaching * Crop factor * Soil preparation factor) + factor of manure application + factor for over-optimal N-fertilising

The province of Östergötland is characterised by a dry climate and yearly precipitation is 516 mm. The base leaching on clay soil is 18.5 kg N/ha in scenario A and B and 18.7 in scenario C (higher yearly manure application in C due to higher livestock density). By applying the factors that are presented in the model (see appendix 5), the nitrate leaching in the three crop rotations was calculated (see table 3.29 - 3.31).

Emission factors for ammonia from spreading manure was according to Karlsson & Rodhe (2002), se appendix 5. It was estimated that 1 % of nitrogen in the N-fertilisers (ammonia-nitrate) were emitted as ammonium-N (Bång, M pers comm. 2003)

Direct emissions of nitrous oxide from soil when adding fertiliser N, manure or growing leguminous were estimated with emission factors from IPCC (2000) as was indirect emissions (see appendix 5).

Table 3.29 Emissions of nitrate-N, ammonia-N from manure and nitrous oxide (direct emissions) in the crop production in scenario A

Crop	Kg NO_3-N/ha	Kg NH_3-N/ha	Kg N_2O-N/ha
1:Winter rape	42	8.3	3.3
2:Winter wheat	11[1] / 18		1.4
3a:Barley, 20 ha	24	7.6	2.3
3b: Ley	52		0
4: Oats	17		1
5:Peas	24		1.6
6:Winter wheat	24	7.6	2.4
7:Barley	19		1.3

1) lower leaching from the part of the field where there is established grassland for the sows next year (no cultivation in autumn after wheat harvest).

The total nitrate leaching in scenario A is 12 160 kg NO_3-N, corresponding to an average of 26 kg N/ha*yr. The total loss of ammonia from the spreading of manure and fertilisers is 1 490 kg NH_3-N. The total direct nitrous oxide losses (shown in table 3.29) are 778 kg N_2O-N and the indirect losses are 319 kg N_2O-N

Table 3.30 Emissions of nitrate-N, ammonia-N from manure and nitrous oxide (direct emissions) in the crop production in scenario B

Crop	Kg NO_3-N/ha	Kg NH_3-N/ha	Kg N_2O-N/ha
1:Winter rape	35	7.5	3
2:Winter wheat	19		1.4
3: Barley+catch crop	18	4.9	2.1
4: Peas	24		1.6
5:Winter wheat+catch crop	20	6.9	2.2
6:Oats	19		1.1
7:Barley	19		1.3

The total nitrate leaching in scenario B is 10 675 kg NO_3-N, corresponding to in average 22 kg N/ha*yr. The total loss of ammonia from the spreading of manure and fertilisers is 1 666 kg NH_3-N. The total direct nitrous oxide losses (shown in table 3.30) are 897 kg N_2O-N and the indirect losses are 280 kg N_2O-N.

Table 3.31 Emissions of nitrate-N, ammonia-N from manure and nitrous oxide (direct emissions) in the crop production in scenario C

Crop	Kg NO_3-N/ha	Kg NH_3-N/ha	Kg N_2O-N/ha
1:Oats	24	13.3	2
2:Winter wheat	22	6.2	2.5
3: Barley	19		1.1
4: Winter wheat	42	16	2.8
5: Triticale	17		1.3

The total nitrate leaching in scenario C is 14 840 kg NO_3-N, corresponding to on average 25 kg N/ha*yr. The total loss of ammonia from the spreading of manure and fertilisers is 4 760 kg NH_3-N. The total direct nitrous oxide losses (shown in table 3.26) are 1 160 kg N_2O-N and the indirect losses are 420 kg N_2O-N.

The loss of phosphorous from Swedish arable land varies but a reasonable average is 0.3 kg P/ha and year (Kyllmar *et al* 1995).

3.3.8 Nutrient balances

A nutrient balance was put together for each scenario farm using a farm gate balance calculation (van Erdt & Fong, 1998). The pig farm in scenario A (table 3.32) has a N-surplus of 60 kg N/ha and a P-surplus of 10 kg P/ha, which is solely due to the imported feed (in which P-minerals are added).

Table 3.32 Farm-gate balance in scenario A.

	Kg N/ha	Kg P/ha	Kg K/ha
Input			
Mineral fertilisers	59	-	-
Imported feed, seed	38	21	13
N-fixation	18		
N-deposition	5		
Total input	*121*	*21*	*13*
Output			
Animal products	43	7.7	4
Vegetable products	18	3.1	4
Total output	*61*	*11*	*8*
Surplus/deficit	***60***	***10***	***5***

In scenario B (table 3.33), the farm´s N-surplus is lower, 50 kg N/ha and this is very much an effect of an efficient handling of the manure leading to a lower need of mineral fertilisers. In this scenario, the pig farm has no surplus of phosphorous which is a consequence of the addition of phytase in the concentrate feed which erases the need for mineral feed.

Table 3.33 Farm-gate balance in scenario B

	Kg N/ha	Kg P/ha	Kg K/ha
Input			
Mineral fertilisers	64	3	-
Imported feed, seed	39	11	13
N-fixation	18		
N-deposition	5		
Total input	*126*	*14*	*13*
Output			
Animal products	47	8.3	4
Vegetable products	29	5.1	7
Total output	*76*	*13.4*	*11*
Surplus/deficit	***50***	***0***	***2***

Finally, in scenario C (figure 3.34), the farm´s surplus of nitrogen and phosphorous is considerably higher than in B. Substantially more protein feed is imported in this scenario which means a larger input of nitrogen through the feed purchase. Also, a higher fertiliser rate translates into a greater input of fertilisers on the farm. The complement of minerals in the concentrate feed is the main reason for the surplus of phosphorous.

Table 3.34 Farm-gate balance in scenario C

	Kg N/ha	Kg P/ha	Kg K/ha
Input			
Mineral fertilisers	82	-	-
Imported feed, seed	61	26	17
N-fixation	-		
N-deposition	5		
Total input	*148*	*26*	*17*
Output			
Animal products	58	10.2	5
Vegetable products	8	1.7	2
Total output	*66*	*12*	*7*
Surplus/deficit	***82***	***14***	***10***

3.4 Concentrate feed production

As described in the flow chart in figure 2.1 and appendix 1a - 1c, protein feed is imported from the feed industry to the pig farms. Soy meal is a feed ingredient in all three scenarios and is the main protein source in scenario C. Rape seed meal is used in scenario A and B, and this feed ingredient is calculated as the meal part from the two farms´ rapeseed cultivation. Synthetic amino acids are used in equivalent amounts in all three scenarios. Monocalciumphosphate is used in scenario A and C, while the enzyme phytase is added in the concentrate feed in scenario B. All these feed ingredients are mixed and treated at the feed industry in the province of Östergötland (Norrköping). The energy consumption in the feed industry for handling pig concentrate feed is calculated as 13.7 kWh/tonne feed (Tietz, F. pers comm. 2003). Transports of concentrate feed are summarised in appendix 3.

Peas are an important protein feed ingredient in scenario B and C. There is a small deficit of peas in the farms´ crop rotation and this is imported from a neighbouring farm and ground at the pig farms feed facilities. Wheat bran, a co-product from mills, are used in all three scenarios (especially A and B) and transported directly from the mill to the pig farms and mixed into the feed at the farms.

Data on these feed ingredients are discussed in the following sections.

3.4.1 Soy meal

The soy meal is imported from Brazil and the dominant part comes from the state Mato Grosso. In this region there is a fast expansion of soybean production and new arable land is taken into production by reclamation of the savannas “Cerrados”. Data on soy bean cultivation and extraction are collected from a life cycle inventory of milk farms in western Sweden (Cederberg, 2004 report in preparation). The yield level of soybeans in Brazil is today approximately 2 500 kg/ha and in the future scenarios it is assumed that the yield level will be 3 000 kg/ha.

Data on fertiliser, diesel etc are collected from calculations for soybean cultivations from the website of AgBrazil[4] were information is given on the conditions for cultivation in this part of Brazil. These data have been compared with data collected from Embrapa in earlier studies (Cederberg, 1998). Cultivation data are shown in table 3.35.

The soybean is a leguminous and only minor amounts or no nitrogen fertilisers at all are applied. The symbiotic nitrogen fixation varies between 60 – 168 kg N/ha, in optimal irrigated conditions up to 244 kg N/ha and in average 132 kg N/ha (FAO 1994)

Table 3.35 Use of diesel, fertilisers and lime in soybean cropping in the Cerrados

	kg/ha	litre/ha
Seed	50	
Fertiliser, N	8	
Fertiliser, P	31	
Fertiliser, K	57	
Lime	50	
Diesel		65

The use of pesticides in soybean cultivation is extensive. Depending whether the soybean is cultivated in a conventional soil tilling system or in a no-till system, different strategies for weed application are used. The herbicide application according to table 3.36 is an average of conventional and no-till cropping (www.agbrazil.com). Insecticides are normally applied at least twice per soybean crop and toxic products like monocrotofos and endosulfan are used (Cederberg, 1998). The doses presented in table 3.36 have been checked against recommendations from Embrapa (2002)[5]

Table 3.36 Estimated average pesticide use in soybean cropping.

	active substance	dose, g/ha
Herbicides	Glyphosate	540
	2,4-D	250
	Cletodim	36
	Lactofen	48
	Oxasulfuron	22
	Trifuraline	380
	Imazaquin	70
Insecticides	Monocrotofos	160
	Profenofos	75
Fungicides	Difenoconazole	50

[4] www.agbrazil.com

[5] www.cnpso.embrapa.br

Data on leaching of nitrogen and phosphorous have not been possible to collect. To calculate the leaching of nitrate, a field balance was established. A yield of 3 000 kg/ha soybeans require 230 kg N/ha and 192 kg N/ha is removed in the soybean harvest (FAO 1994). According to Castro & Logan (1991) soybean cultivation does not increase organic matter in the soil and the difference of 36 kg N/ha is assumed to leach. Soil erosion in soybeans can be significant; Klink (1995) reports on soil losses in the order of tonnes per hectare. Due to much higher losses of soil in Brazil it is assumed that phosphorous losses are ten times higher than in Sweden, corresponding to 3 kg P/ha*yr.

The emission of nitrous oxide is calculated to be 1.25 % of applied N in fertilisers and symbiotic N-fixation (IPCC 1997). Losses of N and P are summarised in table 3.37

Table 3.37 Estimated emissions of nitrogen and phosphorous in soybean cultivation

Emission	kg/ha
Nitrate, NO_3-N	36
Nitrous oxide, N_2O-N	1.7
Phosphorous, P	3

When the soybean is extracted, the exchange is 80 % meal and 17 % oil. Price allocation is due to average world market prices during October 2001 – September 2002. The basis for the allocations is given in table 3.38.

Table 3.38 Mass and price relations of soy meal and oil

Products	Mass ratio*, %	World market price**, $/tonne	Price ratio, %
Meal	80	190	68
Oil	17	412	32

* Mass according to Boulder (1985)
** Price according to Oil World (2003)

Data on extraction of soybeans were presented by Cederberg (1998) and they are based on modern extraction industry with new technique. The dominant energy source for this industry in Brazil is wood for steam production and hydropower (Cederberg, 1998).

Today, approximately 75 % of the imported soy meal in Sweden come from the Cerrado region in Mato Grosso and 25 % from the coastal region in south Brazil (Kämpe, 2003 pers comm.). This was presumed to be the same in the future scenarios. All transports accounted for are presented in appendix 3.

3.4.2 Rape seed meal

The rape seed is cultivated on the pig farms in scenario A and B and the rape seed is transported to be pressed and crushed at Karlshamn´s Crushing & Feed. Data on the extraction processes are given by Cederberg (1998). The basis for the allocation is given in table 3.39.

Table 3.39 Mass and price relations of rape seed meal and oil

Products	Mass ratio*, %	World market price**, $/tonne	Price ratio, %
Meal	58	129	30
Oil	40	452	70

* Mass according to Boulder (1985)
** Price according to Oil World (2003)

The rape seed meal is transported from the crusher at Karlshamn to the feed industry in Norrköping where it is mixed in the concentrate feed before delivered to the farms in scenario A and B. Data on transports according to appendix 3.

3.4.3 Peas

The deficit of peas is approximately 33 tonnes on farm A and B. The peas are imported from neighbouring farm (distance 10 km) and ground in the farms´ feed facilities. All data on resource use and emission from the imported peas´ cultivation are the same as the pea cultivation on the two farms.

3.4.4 Wheat bran

Wheat bran is a co-product from the mill industry and a large mill is situated in the province of Östergötland (Mjölby). The wheat was cultivated according to the quality label "Svenskt Sigill"[6] and ground at Mjölby. Data for this cultivation were collected in the project "LCA of seven food items" (LRF 2002). The wheat was a mixture of spring and winter wheat cultivated at relative high yields. Data from the mill in Mjölby are according to table 3.40 and collected from Stadig et al (2001).

Table 3.40 Inventory data from the mill in Mjölby

	Consumption/Emission
Electricity, GJ_{el}/ton wheat	3.985
Oil (EO1), MJ/ton wheat	302.6
Water, m^3/ton wheat	0.71
Waste, kg/ton wheat	39

When the wheat is ground, 72 % of the mass is wheat-flour and there are two feed co-products: wheat-bran and wheat feed-flour. The allocation is according to Stadig et al (2001).

Table 3.41 Mass and price relation of wheat-flour and its feed co-products

Products	Mass ratio, %	Price ratio, %
Wheat-flour	72	91
Wheat-bran	17	4
Wheat feed-flour	11	5

[6] www.svensktsigill.com

3.4.5 Minerals

The added minerals in the concentrate feed are monocalciumphosphate (scenario A and C). Data for extraction and grinding of lime/dolomite and data for production of commercial rock phosphate (32 % P_2O_5) are collected from Davis & Haglund (1999). The energy consumption for mineral fabrication is 1.08 MJ_{el} and 1.08 MJ_{gas} per kg minerals (Cederberg, 1998).

3.4.6 Others

Data on amino acids and phytase production are excluded due to data gap. Minor feed ingredients, such as salt and vitamins are also excluded.

4 Results and impact assessment

4.1 Use of resources

Table 4.1 shows the total use of resource per FU (functional unit = one kg of bone- and fat free meat).

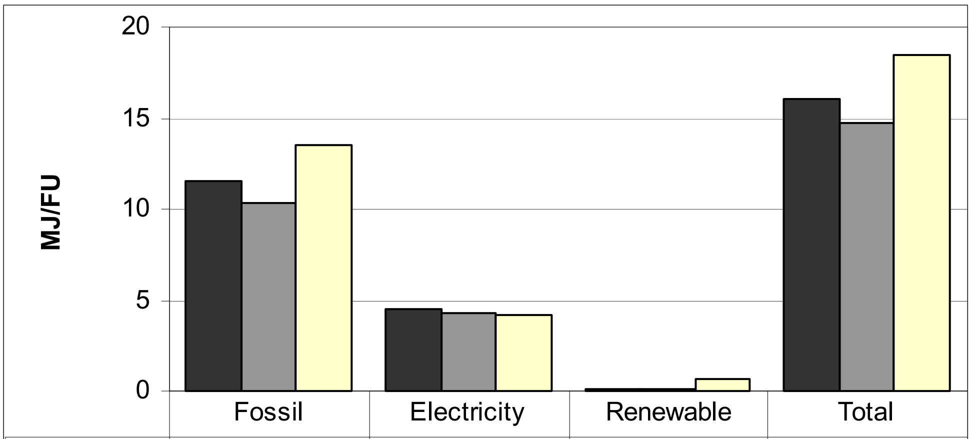
Table 4.1 Use of resources in the three scenarios

	Scenario A, g/FU	Scenario B, g/FU	Scenario C, g/FU
Abiotic (energy)			
Coal	47	37.3	62.1
Lignite	16	10.6	27
Crude oil	236	222	276
Natural gas	64	52.9	79
Uranium	0.0176	0.0167	0.0160
Abiotic (non-energy)			
Phosphorous	17	5.3	29
Potassium	3.2	2.9	14

The use of fossil fuels is highest in scenario C (low price-product quality). In C, approximately one third of the oil is consumed by the production and transports of the imported feed to the farm where soy meal is the dominating ingredient, 52 % of the oil is used directly on the farm. In scenario A (animal welfare) and B (environment), almost 75 % of the total oil is consumed at the farms and 16 % is consumed by the imported feed. This a consequence of the high level of self sufficiency of feed in A and B since the majority of protein feed is cultivated at the farm in these two scenarios. Natural gas is mainly used in fertiliser production and the use of natural gas in scenario B is approximately one third lower than in scenario C. This is very much an effect of the efficient use of the manure in scenario B (which saves N-fertilisers) and the use of peas (not N-fertilised) in the protein feed. Approximately 90 % of the phosphorous used in scenario A and 70 % in C is due to mineral feed. The low P-use in B is an effect of the addition of phytase in the concentrate feed. Apart from mineral feed, the high consumption of phosphorous in C can be explained by the large use of soy meal from soy beans which were P-fertilised.

4.2 Energy

The energy use is presented as secondary energy (see figure 4.1). Scenarios A and B have lower energy requirements than C which is mainly due to the difference in feeding strategy. The use of rapeseed meal and peas grown at the farm site is a feed alternative that saves fossil fuel in comparison with the use of soy meal in scenario C. The production in scenario B (environment) has a lower energy requirement than in A (animal welfare) and this is mainly a consequence of greater feed efficiency in B and lower use of N fertilisers compared to A. The use of electricity per FU is rather similar between the three scenarios. The use of renewable energy in C is due to wood chip combustion in the extraction process of the soybean.



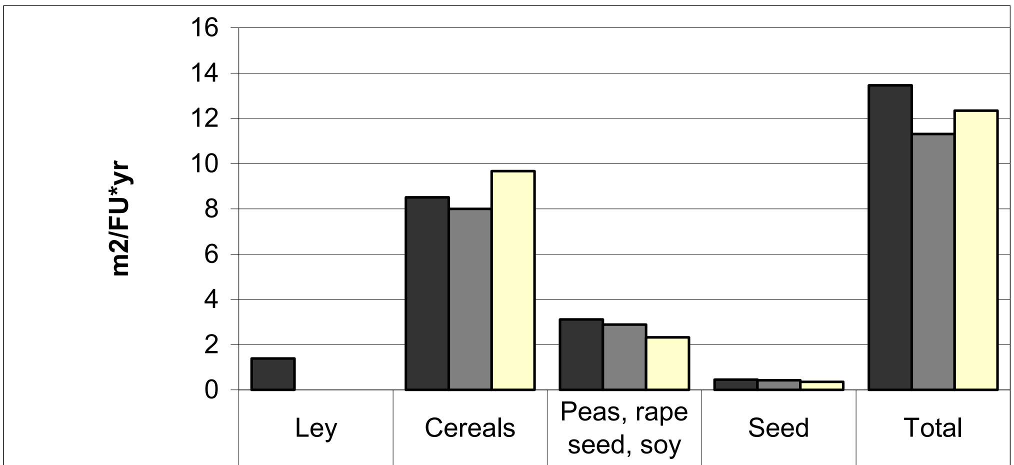
	Fossil	Electricity	Renewable	Total
scenario A	11,51	4,51	0,07	16,09
scenario B	10,38	4,25	0,06	14,70
scenario C	13,56	4,20	0,66	18,43

Figure 4.1 Energy use in the three scenarios

4.3 Land use

The total yearly land use for the production of one kg of bone free meat varies between 11.3 – 13.5 m^2. Scenario A (animal welfare) requires the largest area due to the grassland area needed for the sows´ grazing period (figure 4.2).

Cultivation of grains is the dominating land use in all scenarios but especially in scenario C (low price-product quality) where the protein feed is exclusively imported soy meal. Consequently, the use of arable land at farm C is mono-cultural grain cultivation. The higher yields of grains in B (environment) are an effect of a more diversified crop rotation, leading to a lower land requirement for grain per produced kg meat in this scenario.

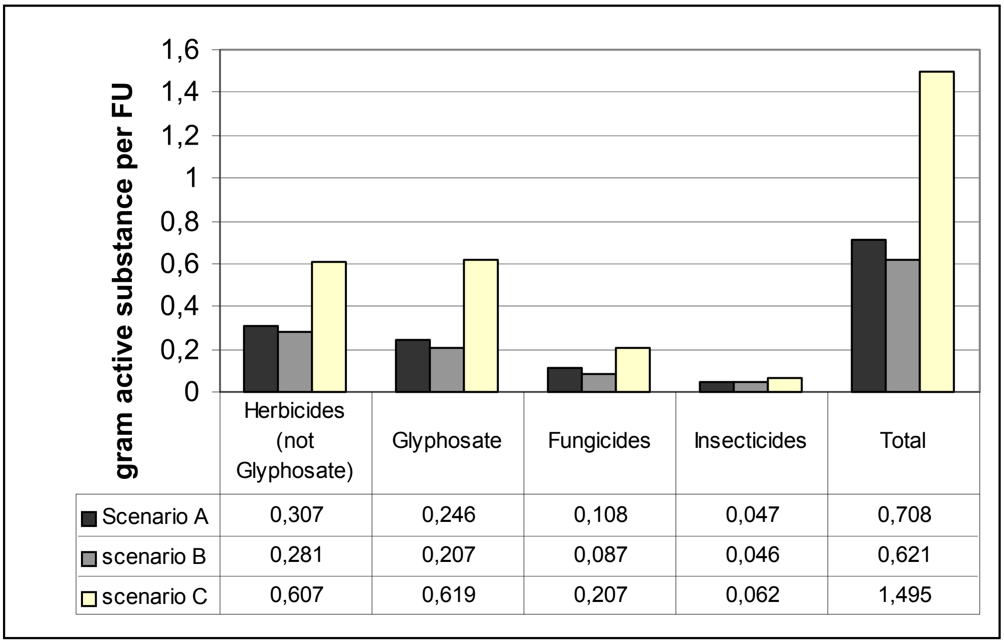


	Ley	Cereals	Peas, rape seed, soy	Seed	Total
scenario A	1,39	8,51	3,11	0,45	13,46
scenario B	0	8,00	2,88	0,43	11,31
scenario C	0	9,67	2,32	0,35	12,34

Figure 4.2 Land use for the production of one kg of bone free meat

4.4 Use of pesticides

The total use of pesticides in the life cycle of pig meat is shown in figure 4.3.



	Herbicides (not Glyphosate)	Glyphosate	Fungicides	Insecticides	Total
Scenario A	0,307	0,246	0,108	0,047	0,708
scenario B	0,281	0,207	0,087	0,046	0,621
scenario C	0,607	0,619	0,207	0,062	1,495

Figure 4.3 Use of pesticides in the three scenarios

Pesticide use is a coarse indicator for a toxic assessment of pesticides. Risk assessment of pesticide use in feed production is analysed and discussed more closely in Food 21-project "Sustainable Plant Protection" (Cederberg *et al*, report in prep). However, the conscious strategy in scenario B (environment) to reduce pesticide use by measures such as diversified crop rotation (due to altered protein feeding in comparison with C), the practice of mechanical weed regulation in some crops and disc-harrowing in some autumns results in a significantly lower pesticide use than in scenario C. The total herbicide use in the life cycle of pig meat in scenario B is approximately only 40 % of the use in scenario C. The risks to environment and health are likely to be lowered due to this pesticide reduction.

In table 4.2, the average yearly pesticide use on the pigs farms are shown.

Table 4.2 Average yearly use of pesticides on the pig farms in the three scenarios

	Farm A gram act.subst/ha	Farm B gram act. subst/ha	Farm C gram act subst/ha
Herbicides (not Glyphosate)	213	220	420
Glyphosate	185	180	504
Fungicides	66	71	181
Insectides	79	80	8
Total pesticide use	*543*	*551*	*1 113*

In the crop rotation on pig farm C (low price-product quality), the strategy is to keep production costs low and applications of Glyphosate to regulate *E. repens* are chosen instead of mechanical alternatives like disc-harrowing in autumn. This strategy has been used during the last ten years in Swedish agriculture since the cost of diesel relative to the cost of Glyphosate has steadily increased over this period (Jordbruksverket 1999).

4.5 Climate change

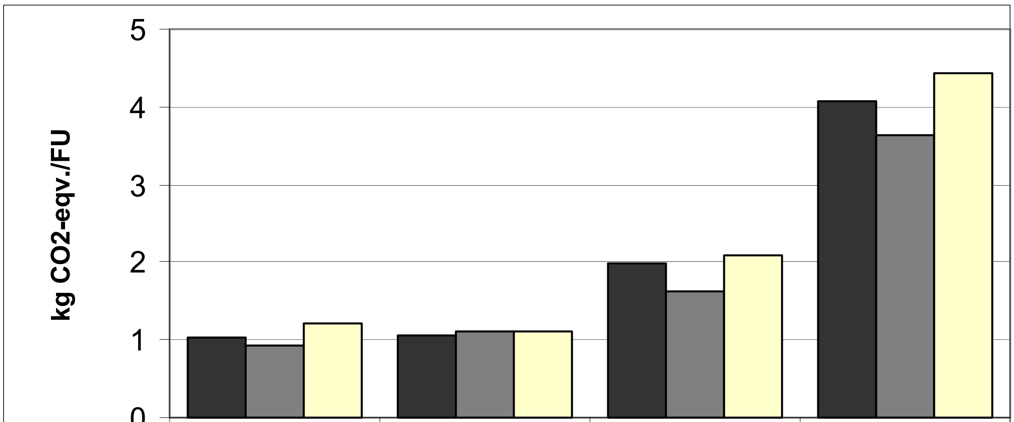
The emissions of greenhouse gases are carbondioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). In table 4.3, the corresponding weighting factors are shown.

Table 4.3 Used weighting factors for greenhouse gases

Emission	Weighting factor, GWP (100 years)
CO_2	1
CH_4	21
N_2O	310

Source: IPCC, 1997

The total emissions of greenhouse gases vary between 3.6 – 4.4 kg CO_2-equvialents/FU (see figure 4.4). Scenario B (environment) has the lowest total emissions. The potential contribution to climate change originates by approximately 50 % from nitrous oxide and 25 % from carbon oxide and methane respectively.



	CO2	CH4	N2O	Total
scenario A	1,02	1,07	1,99	4,08
scenario B	0,92	1,10	1,61	3,63
scenario C	1,22	1,12	2,09	4,43

Figure 4.4 Emissions of greenhouse gases in the life cycle of pig meat

The lower total emission of greenhouse gases in scenario B is an effect of the overall high nitrogen efficiency in this scenario. Reduced ammonia emissions, efficient manure application and relatively low N-fertiliser application leads to lower discharges of nitrous oxide per FU in this scenario. Also CO_2-emissions are smaller in B compared to scenario C, which is an effect of the lower fossil energy use in scenario B (see figure 4.1).

4.6 Eutrophication

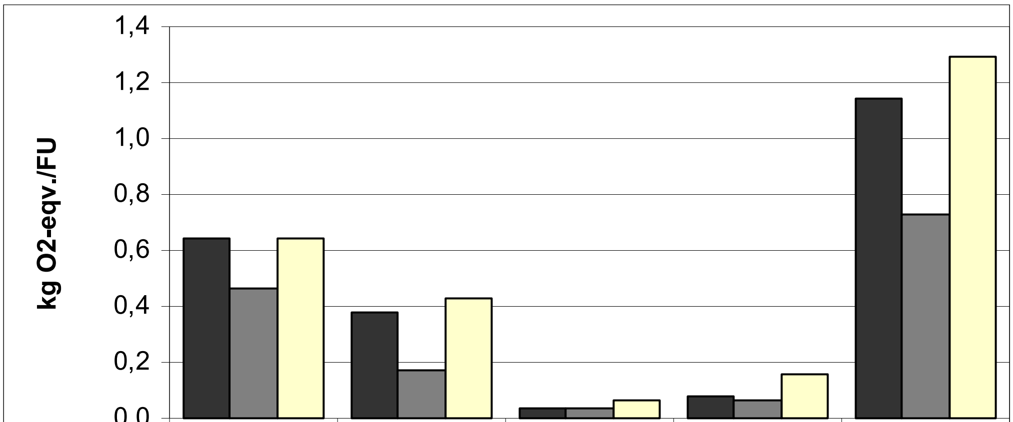
Weighting factors for eutrophication (maximum scenario, both N and P) are shown in table 4.4.

Table 4.4 Weighting factors for eutrophication (maximum scenario)

Substance	Maximum g O_2-eqv./g
NO_X to air	6
NH_3 to air	16
NO_3 to water	4.4
PO_4^{3-} to water	46
COD	1

Source: Lindfors et al, 1995

The potential maximal eutrophication in the three scenarios is shown in figure 4.5.



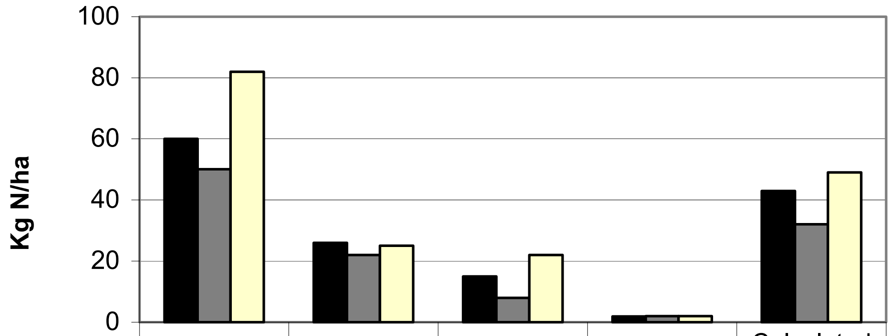
	NO3	NH3	NOx	P	Total
scenario A	0,64	0,38	0,04	0,08	1,14
scenario B	0,47	0,17	0,03	0,06	0,73
scenario C	0,65	0,43	0,06	0,16	1,29

Figure 4.5 The maximal potential contribution to eutrophication

Leaching of nitrate from the arable land is the dominating discharge of nutrifying substance in all scenarios. Scenario B (environment) has the lowest discharge of nitrate/FU and this is mainly a consequence of the higher feed efficiency in B compared with A (less feed/FU) and the higher grain yields in B compared to C (lower nitrate emission/kg grain). The reduced ammonia discharges in B compared to the other scenarios are mainly an effect of the ammonia filter in the ventilation of the stables.

The losses of nitrate, ammonia and nitrous oxide at the pig farms were calculated per hectare and the sum of calculated losses of reactive nitrogen can be compared to the total nitrogen surplus calculated according to the farm-gate method (see table 3.32 – 3.34). The impacts of emitted nitrate and ammonia are of regional as well as local character. High nitrate leaching per hectare of arable land means a greater risk of contaminating the ground water in the area and nutrifying the coastal water if it is a sensitive area. A large share of emitted ammonia from agriculture is deposited close to the source and concentrated ammonia discharges can cause damage on the vegetation in a local area. In Figure 4.6, the calculated N-losses and N-surplus per hectare of arable land at the farms (according to the farm-gate balances) in the scenarios are shown.

Approximately 60 – 65 % of the N-surplus was found as N-losses in the calculations in scenario B and C, while approximately 70 % was found in A. One explanation for this discrepancy is that the models for calculating nitrate and ammonia emissions do not include factors for N-discharges from outdoor grazing pigs. The emission calculations in scenario A are therefore less correct.



	N-surplus	NO3-N	NH3-N	N2O-N	Calculated N losses
scenario A	60	26	15	1,9	43
scenario B	50	22	8	2,0	32
scenario C	82	25	22	2,0	49

Figure 4.6 N-surplus and calculated N-losses at the three pig farms

The higher ammonia emission and total nitrogen surplus per hectare in scenario C is partly an effect of a higher production of meat per hectare of arable land at the pig farm (higher livestock density) in comparison with the farms in scenario A and C. Farm C cultivates the grains for their pigs´ feed but imports all the protein feed as soy meal. Farm A and B are self sufficient of grains and cultivate the dominating part of the protein feed as peas and rapeseed. The manure as well as the emissions from the manure is thus distributed on a larger area than in scenario C. The focus on high nitrogen efficiency and low emissions in scenario B is successful; the ammonia emissions in particular are successfully maintained low in this scenario.

4.7 Acidification

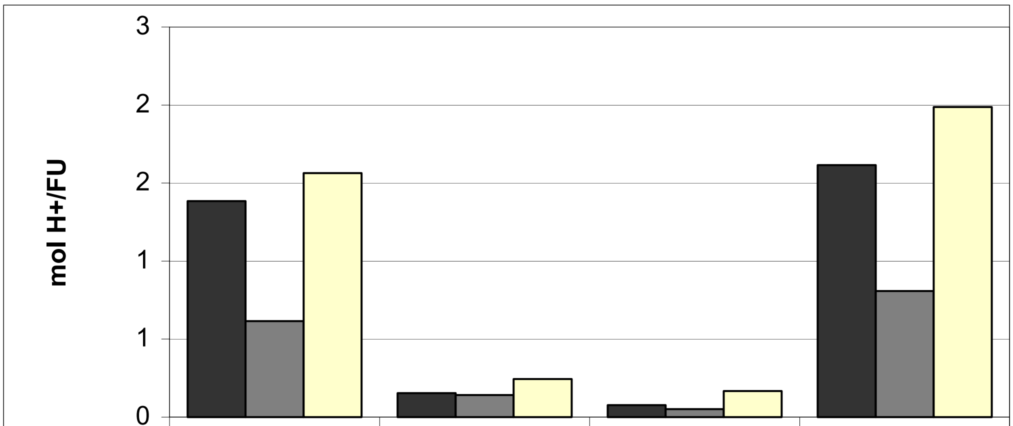
Weighting factors for acidification (maximum scenario) are shown in table 4.5.

Table 4.5 Weighting factors for acidification (maximum scenario)

Substance to air	mol H^+/g
SO_2	0.031
NO_X	0.022
NH_3	0.059

Source: Lindfors et al, 1995

Ammonia is the dominating acidifying substance emitted from livestock production. The use of modern technique filtering the ventilation air in the stables as well as an efficient technique for manure spreading, leads to significantly lower acidification potential for scenario B (see figure 4.7).



	NH3	NOx	SO2	Total
scenario A	1,39	0,15	0,07	1,61
scenario B	0,62	0,14	0,05	0,81
scenario C	1,57	0,25	0,17	1,99

Figure 4.7 The maximal potential contribution to acidification.

The higher use of fossil fuel in scenario C is mainly due to the imported protein feed and this leads to higher emissions of NO_X and SO_2 in comparison with scenarios B and A. The total emissions of acidifying substances are more than halved in scenario B in comparison with C.

4.8 Photo-oxidant formation

There are difficulties in assessing the impact category photo-oxidant formation. Factors that influence the possibility of ozone formation are where the emissions take place, background concentrations of NO_X etc. However, independent of characterisation factors and method, the potential for photo-oxidant formation in the life-cycle of pig meat varies in accordance to the energy use (see figure 4.1). The differences are very small for the systems so it is not possible to make a clear cut conclusion in favour of one alternative when it comes to photo-oxidant formation.

5 Discussion

5.1 Central issues

Overall, there are some important conditions that differ not only for each of the three scenarios, but also in their relation to today´s production. These conditions are: feed consumption, choice of protein feed and the utilisation of advanced technical/biological know-how.

5.1.1 Feed consumption

Feed consumption per unit of production is a central indicator when assessing the environmental impact of animal production. Generally, a high feed consumption leads to a higher use of energy and land per kg meat/milk. Since more crops are needed to provide a high feed consumption, higher pesticide use per unit of animal product can also be a consequence. A high feed efficiency usually leads to a lower amount of nutrients in the manure per produced unit. Low content of nitrogen in the manure is one measure for reducing the emission of ammonia and nitrous oxide in the whole production chain. In table 5.1, some indicators on feed consumption from different environmental system analyses of pig production are presented.

Table 5.1 Feed consumption and share of grains in pigs´ration of feed, data from different studies

	scenario A	scenario B	scenario C	present conventional[1]	present organic[2]
kg feed/slaughter pig[3]	408	322	489	353	408
kg feed/kg bone-free meat (FU)	7.9	6.9	7.1	7.24	8
share of grains[4] in the ration of feed	0.8	0.8	0.85	0.85	0.68

[1] Conventional pig production, south west Sweden, good production results (Cederberg & Darelius, 2001)

[2] Organic pig production, central Sweden, good production results (Cederberg & Nilsson, 2004)

[3] Also including the share of the sow

[4] Also including wheat bran, by-product from milling industry

In scenario A (animal welfare), the feed consumption/FU is approximately 14 % higher than in scenario B (environment) and it is higher than present conventional production with good results. This is an effect of lower piglet production per sow and the 5 % higher feed intake in scenario A due to the animals movement and staying outdoors. Feed consumption per kg meat in present organic production is about 10 % higher than in present conventional production, a consequence of the organic pigs´ exercise and constant movement in this outdoor production form. Higher feed consumption seems to be a consequence that is hard to avoid in production forms with a high degree of animal welfare.

The share of grains (and by-products from milling industry) in the ration of feed is another interesting indicator. When comparing this indicator in the three scenarios, present conventional production and present organic production, the latter deviates from the others. One important reason for this is the lack of synthetic amino acids in organic feed and this leads to a need for a higher share of protein sources in the total ration of feed. The possibility of designing the protein composition in the feed is limited in organic pig production due to the absence of synthetic amino acid. A higher nitrogen amount in the excrements per produced unit is one consequence of this (table 5.2).

Table 5.2 Indicators for nitrogen in manure in different pig production

	scenario B	scenario C	present conventional[1]	present organic[2]
Gram N_{manure} per kg bone.free meat (FU)	93	100	115	160

[1] Conventional pig production, south west Sweden, good production results (Cederberg & Darelius, 2001)

[2] Organic pig production, central Sweden, good production results (Cederberg & Nilsson, 2004)

The relatively low N in manure per FU (due to the high feed efficiency) in scenario B (environment) is the first step in a row of measures for keeping the emissions of ammonia and nitrous oxide low in this scenario.

5.1.2 Protein feed

The choice of protein source in pig production has a decisive impact on how the crop rotations can be designed. In scenario C (price-product quality), a traditional ration of feed in Sweden (and northern Europe) for pigs was put together, based on domestically grown grains and imported soy meal as the main protein source. In scenario A (animal welfare) and B (environment), the lion´s share of the protein feed was grown at the pig farms as peas and rape seed and only minor amounts of soy meal was imported (se table 5.3). As an average, it is estimated that within the EU today, there is a self-sufficiency of protein of approximately 25 % (ISTA, 2002; Biärsjö, J pers comm., 2004)

Table 5.3 Share of protein feed locally produced in the three scenarios

	scenario A	scenario B	scenario C
Share of protein feed locally cultivated (% of mass basis)	92	92	0

The more diversified crop rotation in A and B due to the cultivation of peas and rape seed leads to higher yields of grains, but most significantly, to a much lower need and use for pesticides, at the farm site, as well as within the whole life cycle of pig meat. The large amount of locally grown protein feed crops also contributes to the lower energy use in scenarios A and B compared to scenario C. The yearly land use for the cultivation of protein feed is somewhat higher for scenario B (environment) compared with C (price-product quality). This is, however, counteracted by a lower land use for grains in scenario B due to higher yields which is an effect of a more diversified crop rotation. The overall result is that the yearly land use for the production of one kg pig meat is lowest in scenario B (environment) and this is basically a result of the locally produced protein feed that is the foundation for a more productive crop rotation.

5.1.3 Technical/biological improvement

In a prospective study, it is always difficult to make forecasts about changes and innovations in means of production. There are, however, technical and biological developments in pig production that have already been applied and some of these developments are considered in this study. A high growth rate and efficient use of feed are, as discussed earlier, important for the use of resources and the genetic progress in this area has been considered when estimating these future important production results. The production of piglets per sow and growth rate per slaughter pig is high in scenario B and C, but already today there are producers in Sweden that reach these results. Optimising the protein feed with synthetic amino acids is a well established technique in pig and poultry production today and addition of enzyme phytase in pig´s concentrate feed has an interesting potential. In scenario B (environment), the best known methods of handling manure are employed and the introduction of ammonia filter in the pig house ventilation system is important in lowering the ammonia emissions. As seen from the results, this measure seems to have significant importance on potential eutrophication as well as acidification.

5.2 Use of resources

The use of non-renewable energy resources was in all respects lowest in scenario B (environment). The strategy of feeding the pigs with locally produced protein feed was the major cause for this result. In table 5.4, the energy cost in the life cycle of the three major protein feed soy meal, rapeseed meal and peas used in the scenarios is shown. The low energy cost of rape seed meal is above all a consequence of the low use of synthetic fertiliser in the rapeseed cultivation in scenario A and B which is an effect of an efficient use of the liquid manure in this crop. The low energy cost of peas is due to fact that no synthetic N-fertilisers are needed in the cultivation. A major part of the energy cost of soy meal is due to the long transports. The dependence of the choice of allocation is further discussed in a sensitivity analysis in section 5.4.

Table 5.4 Energy cost for protein feeds in the scenarios

	MJ/kg feed	Comments
Peas	1.6	
Rapeseed meal	2.2	Economic allocation, see table 3.39
Soy meal	5.4	Economic allocation, see table 3.38

When comparing the energy cost for the protein feed (soy meal, rapeseed meal and peas) in the three scenarios, the energy use is 2.6 MJ/FU in scenario A, 2.4 MJ/FU in scenario B and 4.3 MJ/FU in scenario C. A large share of the difference in energy use between the three scenarios (see figure 4.1) is thus explained by the variation in protein feed (see table 3.10).

Another important indicator for energy use in feed production is the consumption of mineral fertilisers. In scenario B (environment), a larger part of nitrogen in the manure was plant-available in comparison with scenario C (price-product quality) due to a more optimal use of slurry in the crop rotation and ammonia filters in the ventilation system. Since grains produced at the farm site are used in all three scenarios and the grain crops make up more than 80 % (mass basis) of the pigs´ ration of feed, it is of interest to compare the N-fertiliser used in the grain cultivation in the three scenarios (table 5.5).

Table 5.5 Nitrogen fertiliser use in cereals cultivation in the three scenarios

	Scenario A	Scenario B	Scenario C
Average yield of cereals, tonnes/ha	6.3	6.2	5.9
Average N-fertilising cereals, kg N/ha	79	75	82
Average N-fertilising, kg N/tonne cereals	12.5	12.1	13.8

The average yield of grain is higher in scenario A (animal welfare) and scenario B (environment) than in C (price-product quality) due to a more diversified crop rotation. The more efficient use of manure results in 12 % lower use of N-fertilisers/tonne grain in scenario B compared to C. This results in a lower energy cost in the production of pig meat of approximately 0.35 MJ/FU in scenario B compared to C.

The resource phosphorous should also be focussed upon since food production is the main user of this mineral. Of the global phosphate production corresponding to approximately 40 million tonnes of P_2O_5, 80 % is used in mineral fertilisers and 5 % in animal feed (Steén, 1998). Due to the use of phytase in scenario B (environment), the need for this resource can be significantly lowered in comparison with scenario A and C where mono-calciumphosphate is added to the concentrate feed (see table 4.1). According to feeding expertise, there is large potential in lowering the P-content of pigs´ feed in the future by complementing the feed with enzymes. In scenario B (environment), the average P-content is 4.5 % of the feed (and 6.2 % in scenarios A and C). Developing the technique of adding enzymes is thus an important measure in reducing the use of the non-renewable apatite resource. The higher phosphorous use in scenario C (price-product quality) than in A (animal welfare) is due to the different protein sources. The soy meal in scenario C comes from soybeans fertilised with synthetic fertilisers, while in scenario A (as well as B), manure from the pigs is the main P source for the rapeseed meal and the peas. A high level of self-sufficiency of feed on livestock farms is an important pre-condition for a better nutrient cycling and a reduced need for virgin phosphorus.

5.3 Land use

Impact assessment of man-controlled use of the resource land is still not fully developed in the LCA methodology. The main reasons for this are (Lindeijer et al 2002):

- Land-use impacts seem very dependent on the regional and local situation, which is generally not known in LCA
- Land use is an environmental intervention that is far more complex than for example emissions of CO_2. Land use consists of many different elementary activities such as excavating, ploughing, draining etc. Describing the types of land use and studying the corresponding impacts on nature is therefore a very difficult task for developers of LCA methodology.
- Land use data are not included in traditional environmental data collection schemes since such data are not easily available.

Although not included in impact assessment, it is generally recognised that land use practices over the last few decades have been a main cause for the threatening of biodiversity all over the globe. Sala et al (2000) estimate that in the 21st century, land-use changes will have the largest impact on biodiversity of all possible interventions.

In the framework of principles for land use assessment developed so far, two types of land use are defined:

1) *Land occupation*: the use of land area for a certain man-controlled purpose, e.g. growing wheat on arable land

2) *Land transformation*: the change of a land area due to a man-controlled purpose, e.g. deforesting a rainforest in order to create grazing land.

Important impacts caused by land use are: increase of land competition, degradation of biodiversity, degradation of life-support functions (e.g. soil fertility) and degradation of cultural values (Lindeijer et al. 2002).

In this study, the yearly land use varies between 11.3 – 13.5 m^2 per kg of bone-free pig meat (FU). In all scenarios, the major land use type is Swedish arable land that has been in this occupation for a long period of time, more than 100 years. An example of negative occupation impact due to this land use is soil compacting, i. e whether the cultivation of the pigs´s feed cause a degradation of soil fertility due to the use of heavy machinery. Soil compacting is seen as the most serious threat to long term soil fertility in Swedish agriculture and today it is estimated that present cultivation systems and degree of mechanisation will lead to soil compaction that can reduce the harvest by one percent unit per 15 – 20 year (JBV 1999). The lack of grassland in the crop rotations in scenarios B and C (due to the pigs´ requirement of feed) increase the risk for soil compacting.

Soy meal is the main protein source in scenario C. Soybean cultivation is expanding very fast in Brazil and especially in the state Mato Grosso where the soybean area has increased from 1.5 million hectares in 1990 to 4.4 million ha in 2003 and where there is a great potential for increasing this area (Bickel & Dros, 2003). Today, the major part of imported soy meal come from Mato Grosso (Kämpe, G pers comm., 2003) and it is assumed that this will be the case also in the future scenarios. The increase of soybean cultivation is due to transforming cerrado (savannas) and forestland into agriculture land. According to Bickel & Dros (2003), the cerrado in Mato Grosso is recognised as a biome with a high number of endemic species, but the area protected until now is absolutely insufficient for preserving its biodiversity. The use of soy meal in scenario C (price-product quality) and to some extent in scenarios A and B thus has an impact on biodiversity in Brazil. The land use type for soy meal has not only an occupation impact (e.g. soil compaction, soil organic matter degradation) but also a transformation impact. Replacing the biome cerrado, very rich in species, with mono-cultural soybean cultivation, will most likely have a negative impact on biodiversity. To reduce the negative impacts of land transformation in soy meal production, it is essential that the Brazilian forest law (permitting legal foresting rates) is followed to a much greater extent than is the case today (Brickler & Dros, 2003).

5.4 Environmental impact

5.4.1 Use of pesticides

The most significant difference between the three scenarios is clearly shown in the impact category pesticide use (toxicity). By growing the protein feed (peas and rape seed) in interaction with the grain, a more diversified crop rotation is introduced in scenario B (environment) and A (animal welfare) and this makes it possible to halve the pesticide use per hectare at the pig farm. When it comes to the whole life cycle, scenario B requires only 40 % of the amount of pesticides in comparison with C (price-product quality) to produce one kg of pig meat.

Contemporary Swedish pig production is based on domestically produced grain and imported soy meal from Brazil as the main protein source. Scenario C can be seen as a prolonging in the future of this production system. These feed compositions create a dependency of pesticides in a twofold way. The large dominance of grains in crop rotations in many parts of Sweden today, has led to an increased use of herbicides and fungicides. Large-scale soybean production in Brazil is greatly dependent of chemicals for regulation of insects and weeds. Some of the chemicals used are very toxic. Pesticide application is often done with aircraft in soybean cultivation with an obvious risk of spreading active ingredients to a larger area than intended (Birkel & Dros, 2003). By using an alternative protein feeding strategy in scenarios A and B, the need for soy meal is reduced in scenarios B and A and thereby also the risks that are associated with the pesticides used in this crop (table 5.6). This issue will be discussed further in the project report "*Hållbart Växtskydd*" (Sustainable Plant Protection) (Cederberg et al, in prep, 2004).

Table 5.6 Pesticide use due to the soy meal production in life cycle of pig meat

	scenario A	scenario B	scenario C
Used pesticide from soy meal, gram active substance/FU	0.04	0.04	0.38

The use of diesel was approximately 13.9 l/tonne grain in scenario C and 14.8 l/tonne in B; this difference was due to the mechanical disc-harrowing to regulate couch grass *(E. repens*) in crop rotation B. The increased diesel use for mechanical regulation has an energy cost which makes pig meat production in scenario B approximately 0.17 MJ/FU higher than in scenario C. However, this relatively small energy cost for mechanical regulation does not effect the overall result which shows that pig production in scenario B has the lowest energy use (se table 4.1). Domestically produced protein feed and lower use of N-fertiliser in scenario B compared to scenario C are much more significant to the total use of energy than the option of mechanical regulation in scenario B.

5.4.2 Emission of greenhouse gases

For present pig production (with good results), Cederberg & Darelius (2001) report of greenhouse gas (GHG) emissions of approximately 5.5 kg CO_2-equivalents when indirect N_2O-emissions are included. The farm investigated in that report, was situated in the south west of Sweden on sandy soils and had a higher livestock density than is the case for the scenario farms in this study. In the study of today´s production, manure from sows was handled as deep litter which leads to a higher potential for emissions of ammonia and nitrous oxide and probably also to a greater use of diesel. When comparing the results of the present production with the future scenarios, it is obvious that there are good potentials for improvement. The GHG emissions in scenario B are approximately 3.6 kg CO_2-equivalent per kg bone-free meat, i.e more than 30 % lower than in present production. Reduced emissions of CO_2 and N_2O due to lower use of fossil fuels and fertilisers, manure handled as slurry instead of deep litter and reduced emissions of reactive nitrogen (mainly ammonia) are the main explanations for this reduction potential. The GHG emissions in scenario C are approximately 15 % lower than today´s production and this can mostly be explained by a higher production result, a lower diesel use at the farm and all manure handled as slurry. The results imply that to obtain more radical GHG emission cuts (> 30 %) in the life cycle of pig meat, it might be necessary to use more radical changes such as changing the protein feed and lowering the N-fertiliser use. Emissions of methane from manure management represent approximately 20 % of the total GHG-emissions. In future, with increased biogas production from manure, there are good potentials for reducing this part of the GHG emissions.

5.4.3 Emission of nutrifying substances

Nitrate leaching from arable land is the most important emission of nutrifying substance in the life cycle of pig meat. The calculated leaching per hectare is relatively similar and varies between 22 – 26 kg N/ha in the three scenarios. The nitrate emissions per kg meat are lower in scenario B (environment) than in A and C. This is mainly due to a higher feeding efficiency in B and higher grain yields (lower nitrate emission per kg grain). The leaching could have been lower in scenario B but in this scenario a reduction of pesticide use was prioritised applying mechanical regulation of couch grass (*E. repens*). This measure increases the leaching in two years out of the seven years crop rotation in Scenario B. However, due to the use of catch crop and an efficient manure management in the crops in the B-scenario, the overall leaching on the farm is still lower than in the other scenarios. Measures towards leaching can not be assessed on an individual basis but must be seen integrated in the whole crop rotation.

The introduction of ammonia filter has a great impact on the overall emissions of NH_3. Since ammonia can be deposited close to the source, this technique can be very interesting in future when protecting sensitive eco-systems situated close to larger livestock units.

Farm-gate balances were put together to validate the calculations of N-losses (table 3.32-3.34). 60 % of the total N-surplus of the pig farm was found as losses in scenario B and C. The N-surplus not accounted are denitrification, N-storing in soil organic matter and under-estimated losses. In scenario A, 70 % of the N-surplus was found as N-losses. The share of total N-surplus found as N-losses is reasonably similar in the three scenarios and this indicates that the losses are justly accounted for in all three scenarios.

Leaching of phosphorous from arable land is investigated in a much lower degree than nitrate leaching in Sweden. The mechanisms behind P leaching are complex and there is not a clear connection between a high input of phosphorous and high field losses. The P-leaching was presumed to be same for all scenarios, 0.3 kg P/ha which is a Swedish average with large variations. However, due to use of phytase in the concentrate feed in scenario B, the P-content in the ration of feed can be held at a much lower level in this scenario. The positive result of this can be seen in the farm-gate balance where A and C have a yearly total P-surplus of 10 and 14 kg P/ha respectively while B has no P-surplus. When considering the risk for eutrophication in a long time perspective, the condition in scenario B is more desirable since there is a risk for P-saturation of the arable land in scenarios A and C.

5.5 Data gaps

Data on synthetic amino acids used in pig production are not available. Strid Eriksson (pers comm., 2004) refers to LCA-data for production of methionin, a synthetic amino acid used in poultry production. Per kg of methinoin, the energy use was 86 MJ, 3.6 kg CO_2-equivalents were emitted and the acidification potential was 41 g SO_2-equiv/kg. In pig production, lysine is the main synthetic amino acid, table 5.6 shows the use of this feed product per functional unit.

Table 5.7 Use of synthetic amino acids in the three scenarios

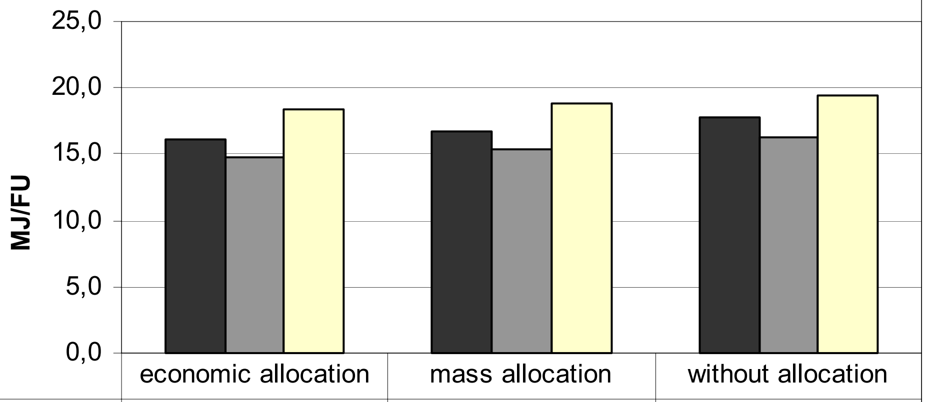
	Scenario A	Scenario B	Scenario C
kg synthetic amino acids per FU	0.017	0.015	0.014

Using the LCA-data for methionin production for the synthetic amino acids used in pig production increases the energy use in the life cycle with 1.46 MJ/FU in A, 1.29 MJ/FU in B and 1.20 MJ/FU in C. This increases the energy use for pig meat by approximately 7 – 9 % for all scenarios in the whole life cycle but it does not alter the relative position and conclusions of energy use between the three scenarios. Using the LCA-data for GHG-emissions from methionin production for the synthetic amino acids used in the scenarios increases the emissions by 0.05 – 0.06 kg CO_2-equivalents/FU and this is an increase of 0,5 – 1 % of the total GHG-emissions. The emissions of acidifying and nutrifying substance in synthetic amino acid production only have a marginal effect on the result for acidification and eutrophication.

No data were available on phytase production. The enzyme phytase is used in scenario B (environment) to reduce the need for phosphorous mineral feed. This data gap put the results for scenario B in a more favourable position than scenario A and C. It is, however, reasonable to assume that the environmental impact due to phytase production is similar to the impact of production of synthetic amino acid (see above) and thus mainly has an effect on energy use. Due to this data gap, energy use in scenario B is probably under-estimated.

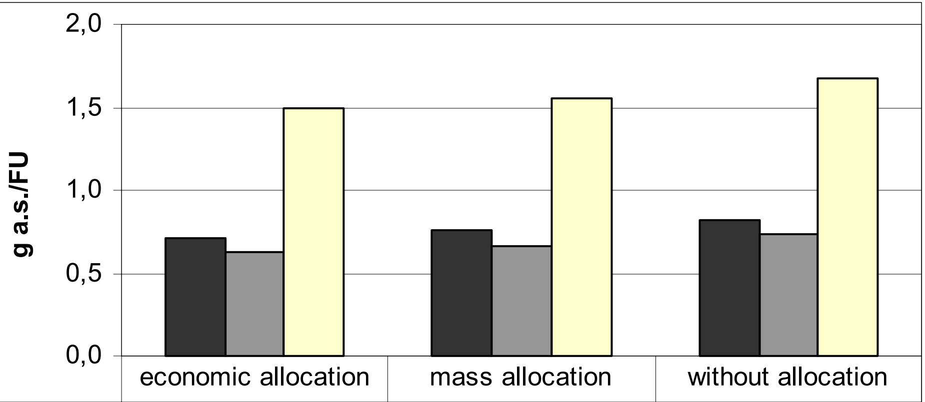
5.6 Sensitivity analysis

To investigate whether the choice of allocation method had an impact on the results, a sensitivity analysis was done comparing the three scenarios with *i)* the chosen method (economic allocation), *ii)* no allocation and *iii)* mass allocation. The results from the sensitivity analysis are presented for the impact categories where the differences from the base scenario (economic allocation) were most pronounced. As seen in figure 5.1 and 5.2, the relative positions of the three scenarios do not change with different allocation methods.



	economic allocation	mass allocation	without allocation
scenario A	16,1	16,8	17,8
scenario B	14,7	15,3	16,3
scenario C	18,4	18,8	19,4

Figure 5.1 Energy use in the life cycle of pig meat with different allocation methods



	economic allocation	mass allocation	without allocation
scenario A	0,71	0,75	0,82
scenario B	0,62	0,67	0,73
scenario C	1,49	1,56	1,67

Figure 5.2 Use of pesticides (active substance) in the life cycle of meat with different allocation methods

5.7 Improvement options

Improving pig meat production from an environmental perspective is very much a question of improving feed production. A short summary of the investigated improvement measures in this study is:

- Organising the feed production of pigs in the sense that protein feed crops are cultivated in integration with grain crops, creates the possibility for a diversified crop rotation which is an important basis for reducing the use of pesticides.

- Producing the protein feed locally/regionally reduces the use of fossil energy and emissions of CO_2, NOx and SO_2 in pig meat production.

- Land use transformation caused by reforestration into soybean cultivation is a threat to biodiversity in Brazil. Feed production systems should strive for labelling system that ensure that protected areas are saved in present soybean expansion in the tropics.

- New techniques for pig manure handling and careful planning of manure application in the crop rotation can significantly reduce emissions of reactive nitrogen.

- Efficient use of manure also saves synthetic fertilisers and thus non-renewable resources and energy.

- Feed additives, such as synthetic amino acids, reduce the need of protein feed and thus the land use impacts associated with growing this feed. Phytase reduce the need of the non-renewable resource phosphorous and reduce the risk of phosphorous accumulation in arable land.

Finally, a far-reaching integration of animals and fodder production, as was the conditions for scenario A and B, gives a solid basis for reducing the environmental burden of livestock production. This means, in practice, spreading animals over a larger area than is the case in present European pig production (Oomen *et al*, 1998). A mixed farming livestock farming system with proper balance between animals and fodder crops has good opportunities to minimise nutrient losses and resource use while still maintaining high yields and good product quality.

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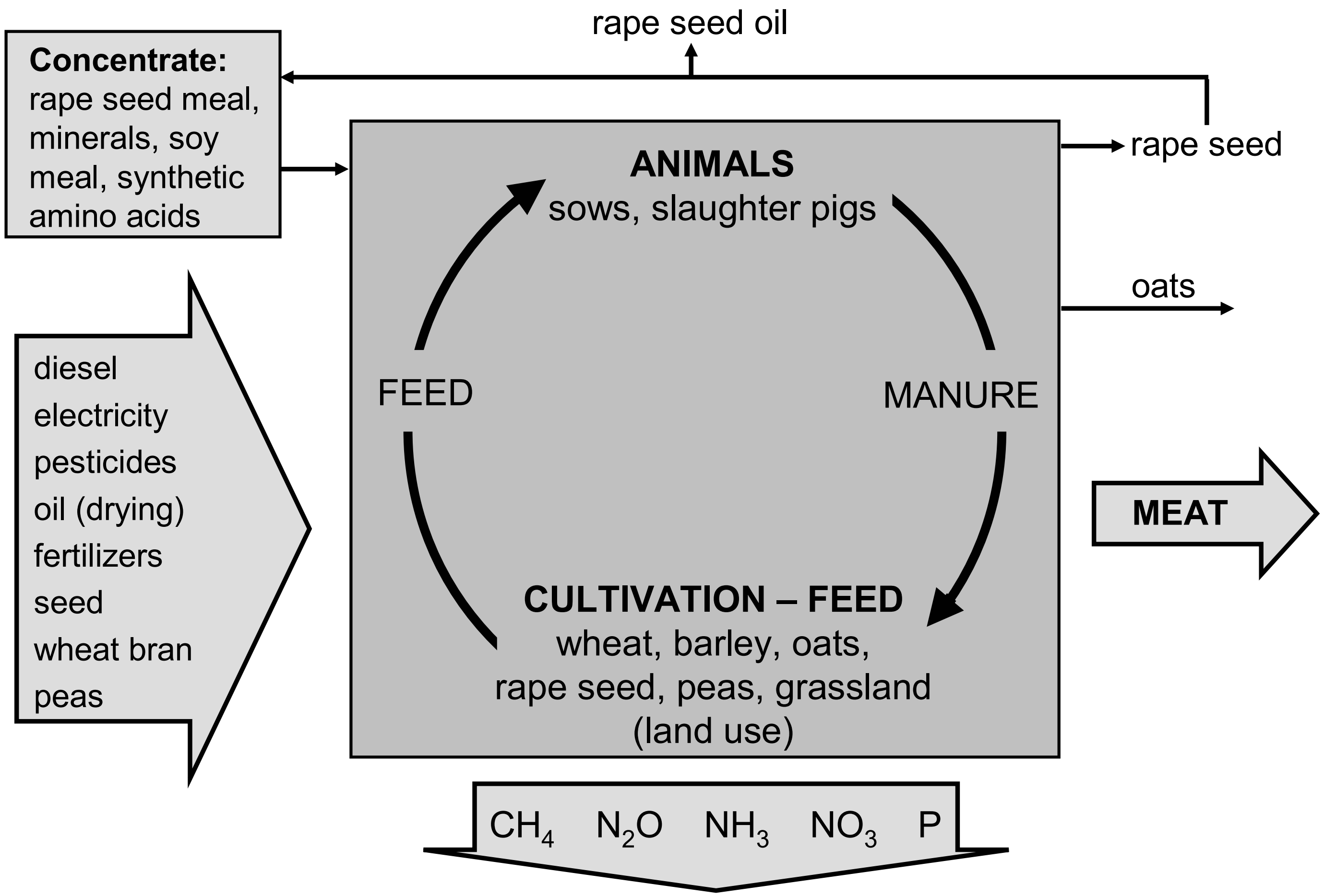
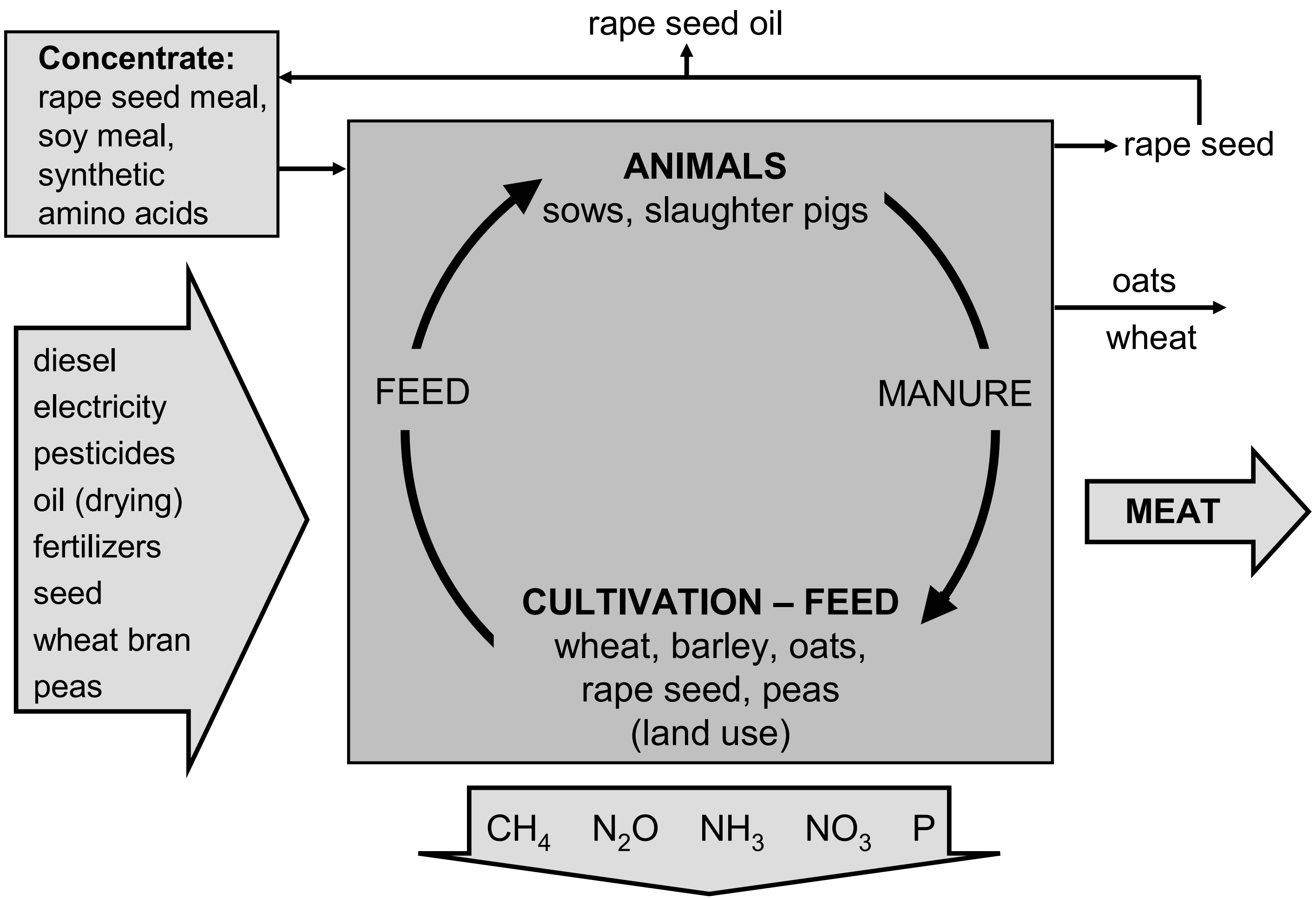
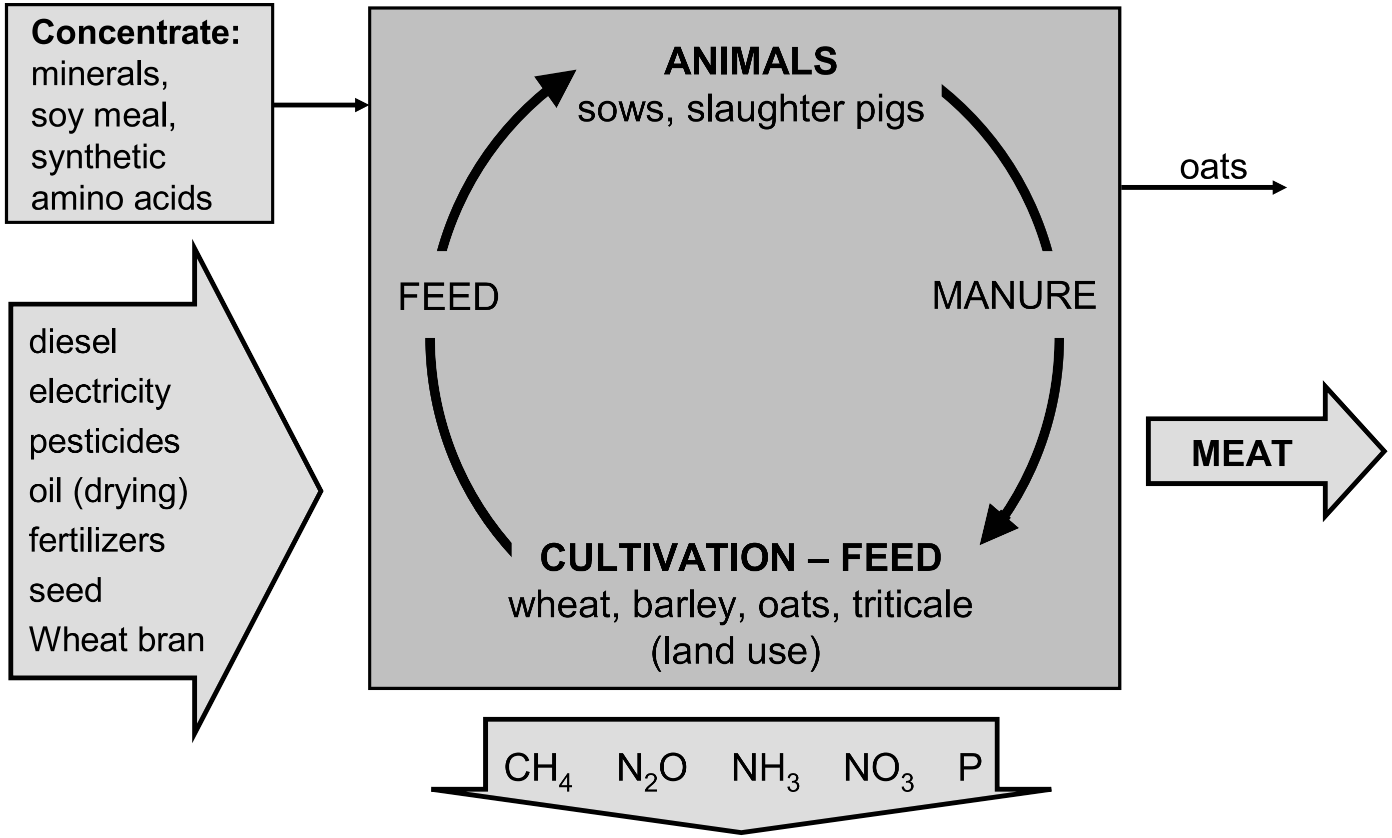
Appendix 1 A Flow diagram for meat production in scenario A – animal welfare



Appendix 1 B Flow diagram for meat production in scenario B – environment



Appendix 1 C Flow diagram for pig meat production in scenario C – product quality at low price



APPENDIX 2 A Composition of feed

Table 1 Composition of feed in the three scenarios

% of weight	Scenario A				Scenario B				Scenario C			
	Sow		***Slaughter pigs***		***Sow***		***Slaughter pigs***		***Sow***		***Slaughter pigs***	
	dry period	weaning	Phase 1	Phase 2	dry period	weaning	Phase 1	Phase 2	dry period	weaning	Phase 1	Phase 2
Oats	30	0	18,59	5,247	30	0	18,59	5,83	10,12	0	3,53	11,99
Wheat, barley, triticale	38,32	59,85	46,99	58,5	38,32	59,85	46,99	65	72,53	76,6	77,41	73,8
Straw meal	0		0	10	0		0	0	0	0	0	0
Peas	7,17	20	12	9	7,17	20	12	10	0	0	0	0
Rapeseed meal	11,51	8,06	4,51	0,99	11,51	8,06	4,51	1,1	0	0	0	0
Synt amino acids	0	0,11	0,58	0,162	0	0,11	0,58	0,18	0,01	0,02	0,59	0,14
Wheat bran	10	8,52	10	13,5	10	8,52	10	15	10	5,48	0	0
Soymeal	0		5	0	0		5	0	4	14,54	15	10,9
Others	3	3,46	2,33	2,601	3	3,46	2,33	2,89	3,34	3,36	3,47	3,17

APPENDIX 2 B Nutrient balance in stable

Table 2 Nutrient balance in stable for the three scenarios, all livestock

	Scenario A			Scenario B			Scenario C		
	Kg N	Kg P	Kg K	Kg N	Kg P	Kg K	Kg N	Kg P	Kg K
Input in the stable									
Grain	28 266	5 388	7 365	29 226	5 582	7 616	55 083	10 246	14 333
Wheat bran	6 717	3 359	3 053	6 895	3 447	3 134	1 558	779	708
Rapeseed meal	6 071	1 186	1 565	6 547	1 279	1 688	0	0	0
Peas	10 309	1 060	2 945	10 753	1 106	3 072	0	0	0
Soy meal	1 995	177	562	2 030	180	572	32 061	2 845	9 031
Synt amino acids	741	0	0	752	0	0	1 007	0	0
Minerals	0	4 774	0	0	0	0	0	10 406	0
Straw	2 814	402	4 021	2 072	296	2 960	1 330	190	1 900
Total input	***56 913***	***16346***	***19 511***	***58 275***	***11 890***	***19 042***	***91 039***	***24 466***	***25 972***
Output from the stable									
Pigs and sows	20 357	3 602	1 723	22 915	4 054	1 939	34 595	6 120	2 927
Total output	***20 357***	***3 602***	***1 723***	***22 915***	***4 054***	***1 939***	***34 595***	***6 120***	***2 927***
Feed efficiency*	***0,37***	***0,22***	***0,1***	***0,41***	***0,35***	***0,12***	***0,39***	***0,25***	***0,12***
In manure	36 556	12 744	17 788	35 360	7 836	17 043	56 444	19 378	23 045
Nutrients in manure, kg/slaughter pig**	***5,6***	***1,95***	***2,7***	***4,05***	***0,92***	***1,72***	***6,9***	***2,4***	***2,8***

* When calculating feed efficiency, straw is only included when it is applied as a feed component (A)

** Nutrient content before any losses in stables, stores etc.

Appendix 3 Transports

Table 1 The different transport data in the study

Product	Distance	share of product, %	Mode of transport	MJ/tkm	km
Soymeal	farm – crusher	100	Heavy truck MK1(highway, 26/40 tons, full+empty return, Euro 0)	0,405	25
	crusher – Parangua	20	Train, diesel MK3	0,230	500
	crusher – Parangua	5	Heavy truck (highway, 26/40 tons, 70%*, Euro 0)	0,590	500
	crusher – Santos	60	Train, diesel MK3	0,230	1800
	crusher – Santos	15	Heavy truck (highway, 26/40 tons, 70%*, Euro 0)	0,590	1800
	Santos/Parangua – Rotterdam	100	Freighter, large (>8000 dwt, 60%*)	0,202	10080
	Rotterdam – Norrköping	100	Freighter, small (<2000 dwt, 60%*)	0,396	1000
Rapeseed meal	farm – Mjölby	100	Tractor (10 tons, including empty return)	1,52	10
	Mjölby – Karlshamn	100	Heavy truck MK1(highway, 26/40 tons, 70%*, Euro 2)	0,610	270
	Karlshamn – Norrköping	100	Heavy truck MK1(highway, 26/40 tons, 70%*, Euro 2)	0,610	350
Minerals	lime, EU-continent – Helsingborg	100	Freighter, large (>8000 dwt, 60%*)	0,202	800
	P2O5, EU-contient – Helsingborg	100	Freighter, large (>8000 dwt, 60%*)	0,202	800
	minerals, Helsingborg – Norrköping	100	Heavy truck MK1(highway, 40/60 tons, 70%*, Euro 2)	0,540	405
Concentrate feed	Norrköping feed industry – farm	100	Medium truck MK1(rural, 14/24 tons, 50%*, Euro 2)	1,76	50
Wheat-bran	wheat farms – Mjölby mill	100	Medium truck MK1(rural, 14/24 tons, 50%*, Euro 2)	1,76	50
	Mjölby mill – pig fam	100	Medium truck MK1(rural, 14/24 tons, full+empty return, Euro 2)	0,761	30
Peas	arable farm – pig farm	100	Tractor (10 tons, including empty return)	1,52	10
Fertilisers	EU continent – Norrköping	50	Freighter, small (<2000 dwt, 60%*)	0,396	1010
	Köping – Norrköping	50	Heavy truck MK1 (highway, 26/40 tons, full+empty return, Euro 2)	0,405	110
	Norrköping – farm	100	Heavy truck MK1 (highway, 26/40 tons, full+empty return, Euro 2)	0,405	50
Seed	arable farm – seed central	100	Tractor (10 tons, including empty return)	1,52	30
	seed central – pig farm	100	Medium truck MK1 (rural, 14/24 tons, 50%*, Euro 2)	1,76	50

* loading factor of the vehicles

APPENDIX 4 Plant protection/pesticide use

Table 1a Herbicide used in scenario A

Crop	Active substances, dose per ha	Frequency*
Winter rape seed	Mechanical	1
Winter wheat	5 g tribenuron-metyl+90 g fluroxypyr	1
Barley	5 g tribenuron-metyl+480 g diklorprop	1
Oats	5 g tribenuron-metyl+480 g diklorprop	1
Peas	Mechanical	0,8
	522 g bentazon+420 g aklonifen	0,2
Winter wheat	5 g tribenuron-metyl+90 g fluroxypyr	1
Barley	5 g tribenuron-metyl+ 480 g diklorprop	1
Crop rotation (1 of 7)	1 260 g glyphosate	0,142

Table 1b Fungicides used in scenario A

Crop	Active substances, dose per ha	Frequency*
Winter wheat	75 g pyraklostrobin+188 g fenpropimorf+62 g propikonazol	0,5
Barley	188 g fenpropimorf+62 g propikonazol	0,2
Oats	281 g fenpropimorf+ 94 g propikonazol	0,2
Winter wheat	75 g pyraklostrobin+188 g fenpropimorf+62 g propikonazol	0,5
Barley	188 g fenpropimorf+62 g propikonazol	0,2

Table 1c Insecticides used in scenario A

Crop	Active substances, dose per ha	Frequency*
Winter rape seed	500 g fenitrotion	1
Winter wheat	7,5 g deltametrin	0,25
Barley	75 g pirimicarb	0,2
Oats	75 g pirimicarb	0,2
Peas	75 g pirimicarb	0,2
Winter wheat	7,5 g deltametrin	0,25
Barley	75 g pirimicarb	0,2

* Frequency: 1= application every year, 0.5 application every other year in average etc.

Table 2a Herbicides used in scenario B

Crop	Active substances, dose per ha	Frequency*
Winter rape seed	Mechanical	1
Winter wheat	5 g tribenuron-metyl+90 g fluroxypyr	1
Barley	Mechanical	0,5
	5 g tribenuron-metyl+375 g MCPA	0,5
Peas	Mechanical	0,8
	520 g bentazon+420 g aklonifen	0,2
Winter wheat	5 g tribenuron-metyl+90 g fluroxypyr	1
Oats	5 g tribenuron-metyl+480 g diklorprop	1
Barley	5 g tribenuron-metyl+480 g diklorprop	1
Crop rotation (1 of 7)	1 260 g glyphosate	0,142

Table 2b Fungicides used in scenario B

Crop	Active substances, dose per ha	Frequency*
Winter wheat	75 g pyraklostrobin+188 g fenpropimorf+62 g propikonazol	0,5
Barley	188 g fenpropimorf+62 g propikonazol	0,2
Winter wheat	75 g pyraklostrobin+188 g fenpropimorf+62 g propikonazol	0,5
Oats	281 g fenpropimorf+ 94 g propikonazol	0,2
Barley	188 g fenpropimorf+62 g propikonazol	0,2

Table 2c Insecticides used in scenario B

Crop	Active substances, dose per ha	Frequency*
Winter rape seed	500 g fenitrotion	1
Winter wheat	7,5 g deltametrin	0,25
Barley	75 g pirimicarb	0,2
Peas	75 g pirimicarb	0,2
Winter wheat	7,5 g deltametrin	0,25
Oats	75 g pirimicarb	0,2
Barley	75 g pirimicarb	0,2

* Frequency: 1= application every year, 0.5 application every other year in average etc.

Table 3a Herbicides used in scenario C

Crop	Active substances, dose per ha	Frequency*
Oats	5 g tribenuron-metyl+480 g diklorprop	1
Winter wheat	5 g tribenuron-metyl+90 g fluroxypyr	1
Barley	400 g MCPA+40 g klopyralid+80 g fluroxypyr	1
Winter wheat	750 g isoproturon+ 150 g diflufenikan	1
	5 g tribenuron-metyl	1
Triticale	5 g tribenuron-metyl+90 g fluroxypyr	1
Crop rotation (2 of 5 yr)	1 260 g glyphosate	0,4

Table 3b Fungicides used in scenario C

Crop	Active substances, dose per ha	Frequency*
Oats	281 g fenpropimorf+ 94 g propikonazol	0,2
Winter wheat	75 g pyraklostrobin+188 g fenpropimorf+62 g propikonazol	0,75
Barley	188 g fenpropimorf+62 g propikonazol	0,2
Winter wheat	125 g pyraklostrobin+188 g fenpropimorf+62 g propikonazol	1
Triticale	75 g pyraklostrobin+188 g fenpropimorf+62 g propikonazol	0,5

Table 3c Insecticides used in scenario C

Crop	Active substances, dose per ha	Frequency*
Oats	75 g pirimicarb	0,2
Winter wheat	7,5 g deltametrin	0,25
Barley	75 g pirimicarb	0,2
Winter wheat	7,5 g deltametrin	0,25
Triticale	7,5 g deltametrin	0,5

* Frequency: 1= application every year, 0.5 application every other year in average etc.

APPENDIX 5 Emission factors for nitrate, ammonia and nitrous oxide

Table 1a Base leaching in leaching model (data only for Götaland, south of Sweden)

	Sandy soil < 5 % clay			Loamy soil 5-15 % clay			Heavy soil (>25% clay)		
Precipitation, mm	<560	560-750	>750	<560	560-750	>750	<560	560-750	>750
Arable farm, kg N/ha	25	35	45	17,5	25	32,5	10	15	20
Livestock farm, increase of leaching as kg N per ton DM of yearly manure applic	1,5	2,25	3,25	1	1,75	2,25	0,5	1,25	1,75

Table 1b Crop factors used in the leaching model (only factors used in the calculations)

Crop	**Factor**
Grain	1
Winter rape	1,2
Grassland	1
Leguminous	1,3

Table 1c Soil preparation/cultivation factors used in the leaching model (only factors used in the calculations)

Time for soil preparation/cultivation	**Factor**	**Comments**
Early cultivation/preparation	1	Early = before September 15 th
Late cultivation/preparation	0,9	Late = after September 15 th
Catch crop, late cultivation	0,7	Catch crop until late autum
Establish of grass, no cultivation	0,5	
Grass ley, late cultivation	1,2	Grass cultivated after Sept 15 th

Table 1d Increased leaching due to manure application used in the leaching model (only factors used in the calcutations). Share (%) of ammonia-N in manure that is leached after application of manure.

Time of application	**Spring**	**Autumn**	
Crop	All	Winterwheat	Winter rape
Clay > 25 % clay	5%	25%	15%

Table 1e Over-optimal N-fertiliser rate, factors used in the leaching model (only factors used in the calculations). Share (%) of the N-rate above recommended fertiliser rate that is leached.

Over-optimal kg N/ha	**Clay > 25 %**
0 - 20	10%

Table 2 Emission factors for NH_3 when spreading manure, % of ammonium-N in manure

Time for application	Technique	Crop	EF	Scenario
Early autumn	Broadspread, immediately incorporated	Winter rape	5%	A, B
Autumn	Broadspread, incorporated 4 hous	Winter wheat	18%	C
Early spring	Bandspread, immediaterow-hoeing after	Winter rape	8%	A, B
Spring	Bandspread in crop	Wheat, barley	7%	A, B, C
	Broadspread, immediately incorporated	Barley	5%	B
	Broadspread, incorporated 4 hous	Barley	15%	C

Table 3a Emission factors for N_2O från manure management

System	kg N_2O-N/kg N excreted
Liquid/slurry	0,001
Pasture/grass	0,02

Table 3b Emission factors for N_2O as direct emission from agricultural soils

Nitrogen input	kg N_2O-N/kg N
Mineral fertilisers	0,0125
Manure	0,0125
N-fixation in crops	0,0125

Table 3c Emission factors for N_2O as indirect emissions from N used in agriculture

	kg N_2O-N/kg N deposited or leached
Deposit (NH_3)	0,01
Leached (NO_3)	0,025