Acta Universitatis Agriculturae Sueciae

Agraria 333

Ammonia Release and Nitrogen Balances on South Swedish Dairy Farms 1997–1999

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Doctoral thesis
Swedish University of Agricultural Sciences
Alnarp 2002

Acta Universitatis Agriculturae Sueciae
Agraria 333

ISSN 1401-6249
ISBN 91-576-6176-6

Abstract

Swensson, C. 2002. *AMMONIA RELEASE AND NITROGEN BALANCES ON SOUTH SWEDISH DAIRY FARMS 1997 – 1999*. Doctor's dissertation.
ISSN 1401-6249, ISBN 91-576-6176-6

The thesis summarises and discusses studies concerning factors influencing ammonia release in cow houses and factors influencing nitrogen surplus and nitrogen efficiency on dairy farms.

The first investigation was carried out at the Animal Experimental Station at Alnarp. The aims were to investigate if a lower content of crude protein in the diet for high-yielding dairy cows will decrease the ammonia release from manure. The ammonia release was significantly decreased for cows fed with lower protein levels compared with high protein diets.

The effects of manure-handling system, type of cow houses and feeding of dairy cows on ammonia release were studied in a field investigation. Results demonstrated a higher release of ammonia in free stall barns with liquid manure handling systems compared with tie stall barns with solid manure handling systems. There was a higher ammonia release from cow diets with a higher content of crude protein.

A theoretical calculation of the nitrogen efficiency and nitrogen surplus at cow level and farm level was carried out. The assumptions for the calculations were for a farm located in central Skåne (south Sweden) with 50 dairy cows and 50 hectares of arable land. The nitrogen efficiency at farm level was 28% on an average. Nitrogen surplus per hectare varied between 135 – 145 kg when the intensity was 8600 kg milk/ha.

Nitrogen balances from conventional dairy farms situated in southern Sweden were investigated using the farm gate method. Neither nitrogen surplus per hectare nor nitrogen efficiency showed significant effects of the manure-handling system. The results showed that nitrogen efficiency was significantly improved by including sugar beet in the crop rotation and was negatively correlated with milk yield per hectare and nitrogen fertiliser per hectare.

Analysis of dairy farms with balances from three consecutive years 1997, 1998 and 1999 showed that these dairy farms decreased their nitrogen surplus by 25 kg N/ha between 1997 and 1998. This decrease was not repeated in the following year. Input of N from artificial fertiliser decreased significantly from the first year.

Keywords: farm gate balances, environment, ammonia emission, milk production, manure handling system, cow houses, crude protein.

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In memory of Per Sandgren

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Explanations

Ammonia release	Release of ammonia from fresh manure to the interior atmosphere in the building
Ammonia emission	Emission of ammonia from the building to the outdoor atmosphere by the ventilated air
AAT	Amino acids absorbed in the intestine
PBV	Protein balance in rumen
CP	Crude protein
N	Nitrogen
NPN	Non protein nitrogen
TAN	The sum of ammonium-N and ammonia-N in manure (Andersson, 1995). TAN = ammoniacal N (Sommer & Hutchings, 2001).
Farm Gate balance	The farm gate method treats the farm as a black box. On the input side are purchased feed, fertiliser, biological N-fixation and N-deposition. On the output side are livestock and crop products. The difference between the input and output flows is the nutrient surplus/deficit (Cederberg, 2002).
STANK	Manure – nutrition in circulation (Stallgödsel – näring i kretslopp – in Swedish) (Swedish Board of Agriculture, 1999). A computer tool developed by Swedish Board of Agriculture, which among other things,calculates farm gate balances and nitrogen losses on farm level.
MINAS	Dutch Nutrient Accounting System, Mineralenboekhouding in dutch (Breembrok et al., 1996)
ALFAM	Ammonia loss from field applied manure. Calculation of ammonia losses by using a multiple regression model (www.alfam.dk -2000-03-23)
Nitrogen efficiency	Ratio between N in animal products and crop products and N input.
LU	Livestock Unit

Appendix

Papers I - V

This thesis is based on the following papers, which will be referred to in text by their Roman numerals.

I. Frank, B. & Swensson, C. 2002. Relationship between Content of Crude Protein in Rations for Dairy Cows and Milk Yield, Concentration of Urea in Milk and Ammonia Emissions. Accepted for publication in the Journal of Dairy Science.

II. Swensson, C. & Gustafsson, G. 2002. Characterisation of influence of manure handling system and feeding on the level of ammonia release using a simple method in cow houses. Acta Agriculturae Scandinavica, Section A, Animal Science 52: 49-56.

III. Swensson, C. & Lidström, E-M. 2002. What is a realistic target of nitrogen outflow from a dairy farm in southern Sweden? Manuscript.

IV. Swensson, C. 2002. Effect of manure handling system, N fertiliser use and area of sugar beet on nitrogen surpluses from dairy farms in southern Sweden. Will be accepted for publication in the Journal of Agricultural Science, Cambridge.

V. Swensson, C. 2002. Analyses of mineral balances between 1997 - 1999 from dairy farms in the south of Sweden. Submitted.

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Introduction

Decreasing milk prices and increasing input costs have forced dairy farmers to increase the efficiency of dairy production in west European countries. Several different ways have been used; increasing herd size, increasing milk yield per cow and year, and/or decreasing the cost per kg milk. At the same time, society has placed new demands on dairy production, both ethical issues and environmental issues. Examples of the former are banning electric cow trainers or the movement towards loose-housing in Sweden (Hultgren, 2001), and an example of the latter is the increased attention to environmental pollution from dairy farms. Hence, a dairy farmer in the 21th century has a great challenge to achieve the balance between efficient dairy production and ethical and environmentally friendly dairy production.

This thesis is focused on nutrient flows in dairy farms in south Sweden, especially nitrogen flows.

Assessing dairy farms

To achieve a successful dairy farm, judged not only by the dairy farmer and his family but also by society, there is a need of tools, that evaluate the ethical and environmental impacts of the dairy farm. Dairy farms have a long history of comparing production and productivity from the dairy herd, for example, with key figures such as kg milk butterfat per cow. The problem with these figures is that they fail to reflect the economic output of dairy production. During recent decades in Sweden, efforts have been made to compare the economic outcomes of dairy farms. This has been done in the campaign "25-öringen" or in RAM (Analyses of the result in milk production) (Påhlstorp *et al.*, 1997; Swensson *et al.*, 1997a; Swensson *et al.*, 1997b; Swensson, 1998).

From having focus on evaluation of production and the economy, the focus during recent years has changed to environmental and ethical issues.

Welfare issues

In Sweden, the new Animal Protection Act (APA, 1988), meant that more considerations should be taken to animal welfare when assessing existing systems and, especially, introduction of new production systems and methods. Still, there is a lot to do in Swedish dairy production to achieve a production that meets high ethical demands. Compared with other intensive regions of dairy production in Europe, most Swedish dairy cows are found in tie stall barns instead of free stall barns. On the other hand, Swedish dairy cows are legally required to be on pasture during the summer and they probably have fewer problems with mastitis and foot problems compared with dairy cows in the Netherlands or in Great Britain.

The APA is a platform that states the minimum or lowest limit of animal welfare. Both the Farmers Union (LRF) and dairy organisations have more specific options to improve animal welfare in the dairy herds. For example, it is forbidden to use hormones to create heat synchronisation in heifers (LRF, 2001, http://www.miljohusesyn.nu/ 2001-11-28).

Environmental issues

Society, and especially the "green movements", has initiated increased attention to environmental issues in agriculture in the western world during recent decades, both regarding crop production (Carson, 1963) and animal production. The intensification and specialisation in animal production means that more manure is produced on fewer farms. Hence, these farms have difficulties in absorbing all nutrients in manure. The amount of nitrates in ground water may be too high. Increased emissions of ammonia occur also on these farms, which has negative influences on both animals and human beings in the cow houses. Emissions of ammonia lead to an increased deposition of ammonia/ammonium. The deposition causes eutrophication in freshwater and marine ecosystems and may also contribute to acidification of soils if nitrified and leached (Kirchmann *et al.*, 1998). According to Kirchmann *et al.* (1998), ammonia emissions near very large animals may cause local toxic effects on surrounding vegetation. In Europe, numerous efforts have been made to decrease the negative environmental influence from the whole livestock sector, for example in The Netherlands, Denmark and Sweden (Kuipers *et al.*, 1999; Jakobsson, 1999). Also in the United States, a process has started to reduce the environmental impact caused by animal production and this process appears to be accelerating (Nelson, 1999; Meyer & Mullinax, 1999). Initially, focus has been directed at nitrogen and phosphorus. Chase (1999) reports that these nutrients are being overfed in relation to requirements in many herds in United States.

Aims of the thesis

The general aims of the thesis were to contribute to the understanding of the nitrogen flows on a dairy farm, how to handle them, and thereby reduce the negative environmental impact of dairy farms. The purpose of the studies was to find possibilities to improve the utilisation of nitrogen on dairy farms. The goals of the investigations have been to study the variation in utilisation of nutrients between different dairy farms and to find some of the weak links in the chain; feed – animal- house – storing of manure – spreading of manure – crops. Focus has been on the first two steps of the chain.

The goal was to test the following hypothesis. All hypotheses were not possible to clarify in details, due to limited resources and time, hence some of the questions remain for testing in new projects.

1. In comparison with other intensive dairy-producing regions in Europe, dairy farms in the south of Sweden have fewer surplus problems with nutrients.
2. The handling of manure is of great importance for the utilisation of nutrients.
3. Dairy farms with high-yielding cows utilise the nutrients better compared with dairy farms with normal milk yields.
4. A very important factor behind a good utilisation of nutrients is the human factor, i.e. the manager of the dairy farm.

The specific aims were;

- To test the hypothesis; A lower content of crude protein in the diet will decrease the ammonia release from cow manure and a well-balanced diet with feedstuffs of Swedish origin will not decrease the milk yield (Paper I).
- To compare ammonia emission from different types of cow houses and manure handling systems and to analyse the influence of crude protein in the dairy cow diets on ammonia emission. To evaluate a simple method to measure ammonia emission from cow houses with indirect estimation of the ventilation rate (Paper II).
- To calculate nitrogen efficiency and nitrogen surplus per hectare of a dairy farm situated in the south of Sweden. The detailed aims were to analyse five feeding strategies, typical for the region, and two milk yield levels, and the influence on nitrogen efficiency and nitrogen surplus per hectare (Paper III).
- To compare and analyse the influence of manure handling systems on nitrogen surplus per hectare and nitrogen efficiency. To test the hypothesis that liquid manure handling should give lower nitrogen surplus compared with solid manure handling (Paper IV).
- To analyse nitrogen balances from dairy herds during three consecutive years, 1997, 1998 and 1999, and analyse causes of changes between different years (Paper V).

Structure of the thesis

Cow level	Papers I and III
Cow house level	Paper II
Farm level	Papers III and IV
Regional level	Paper V
Human level	In thesis

Demarcations of the thesis

With the exception of ammonia, nitrogen treated in the thesis is not divided into nitrogen compounds as N_2, NO_3 or N_2O, or nitrification and denitrification. All dairy herds included in the thesis are situated in the south of Sweden.

SHORT SUMMARY OF INCLUDED PAPERS

Paper I

The investigation was carried out at the Animal Experimental Station at Alnarp, belonging to the Swedish University of Agricultural Sciences. The aims were to investigate if a lower content of crude protein in the diet for high-yielding dairy cows will decrease the ammonia release from manure and if a well-balanced diet with feedstuffs of only Swedish origin would maintain milk production. Five treatments were used in the experiment, two different protein supplements made of ingredients of Swedish origin were each fed at two protein levels, 17% compared with 13 – 13.5%. As a control, a commercial protein mix, based to a high degree on imported products, was fed at the higher protein level. The experimental design was a Latin square including twenty Holstein cows. The five experiment periods lasted for six weeks. Diets with high protein content gave a higher content of urea in the milk. Diets with lower protein content gave the same level of casein and whey protein. The ammonia release (measured by a special capsule over trays of collected manure and urine) was significantly decreased for cows fed the lower protein levels compared with the high protein diets. Treatments with low protein levels had significantly lower milk yield, kg ECM, but the net profit, milk income minus feed costs were nearly the same in all treatments. Hence, a well-balanced diet of Swedish origin can compete with diets based on imported feedstuffs and the ammonia release can be decreased without affecting net profit. The nitrogen efficiency in the low protein diets was approximately 45% and in the higher protein diets it was 34 %.

Paper II

The effects of manure handling system, type of cow houses and feeding of dairy cows on ammonia release were studied in a field investigation. Altogether 34 dairy farms in the south of Sweden were visited twice during winter. The level of ammonia release was analysed by calculating a ratio between ammonia concentration and the temperature difference between outside and indoor temperature or the ratio between ammonia concentration and the differences between outdoor and indoor carbon dioxide concentrations. These ratios gave characteristic levels of ammonia release in relation to animal density independently of the actual ventilation rate. The accuracy of the ratios is dependent on the difference between the temperature inside the cow house and the outside temperature. Therefore, measurements at wintertime are preferable.
Results demonstrated a higher release of ammonia in free stall barns with liquid manure handling systems compared with tie stall barns with solid manure handling systems. There was a higher ammonia release from cow diets with a higher content of crude protein in the cow diet.

Paper III

A theoretical calculation of the nitrogen efficiency and nitrogen surplus at cow level and farm level was carried out. The assumptions for the calculations were for a farm located in the middle of Skåne with 50 dairy cows and 50 hectares of arable land. Five typical diets were used, one based mostly on commercial feed, two diets were grain based + purchased concentrate, two diets were based on alternative feedstuffs, super-pressed beet pulp and distiller's grain. Two levels of milk yield were analysed, 8600 kg/year and 11000 kg/year. All other inputs and outputs were the same, for example crop yields. The amount of purchased mineral fertiliser was based on the assumption that all manure from animal production was utilised in the crop production. The losses of nitrogen from cow house and storing were calculated according to the Swedish extension tool STANK. Losses during spreading of manure were calculated in two ways; according to STANK or according to the simulation model ALFAM. The results from the two calculations were nearly similar. The following results were obtained. The nitrogen efficiency at farm level varied between 27–30 %. Nitrogen surplus per hectare varied between 135–145 kg when the intensity was 8600 kg milk/ha. Lowest surpluses were achieved with the diets including super pressed beet pulp at both intensities.

Paper IV

Nitrogen balances from 283 conventional dairy farms situated in southern Sweden were investigated using the farm gate method. The material was obtained from Skånemejerier, which has a campaign named "Environmental bonus" and this campaign includes calculations of farm gate balances.
Nitrogen balances were determined for 1997 and 1998. Three nitrogen balances were calculated; for the whole farm, for crop production and for milk production. The aims of the investigation were to study if factors such as the manure handling system, the amount of nitrogen obtained from mineral fertiliser per hectare and the proportion of sugar beets have an influence on the nitrogen balance (Paper 4).
There was neither significant effect of manure handling system on the nitrogen surplus per hectare nor on nitrogen efficiency. The results showed that nitrogen efficiency was significantly improved by including sugar beet in the crop rotation and was negatively correlated with milk yield per hectare and nitrogen fertiliser per hectare. The nitrogen surplus per hectare was positively correlated with milk yield per hectare and nitrogen fertiliser per hectare.

Paper V

Altogether 138 farm gate balances from three consecutive years 1997, 1998 and 1999 were analysed. The farm gate balances were selected from dairy farms which did not export or import manure, did not have any major animal production except milk production and the crop production was of minor importance. The dairy farms decreased the nitrogen surplus by 25 kg N/ha between 1997 and 1998. This decrease was not repeated in the following year. Input of nitrogen from artificial fertiliser decreased significantly from the first year. Comparing dairy farms with no output of crop products with dairy farms with output of crop products shows that dairy farms that did not sell crop products had on average, approximately 20 kg higher nitrogen surplus per hectare and 8% less nitrogen efficiency. Both groups delivered about 6600 – 6800 kg milk per hectare.

Background

Historical background

Since the second world war (WW II), agriculture has changed rapidly. Modern agriculture has increased outputs from both crop products and animal products. At the same time the structural development has rapidly increased the size of the farms. The change in Swedish dairy production is summarised by Hultgren (2001). The leaching of nitrogen from Swedish agriculture in a historical perspective is simulated by Hoffmann *et al.* (2000) in the simulation model SOIL/SOILN. The outcome from the model highlights the following findings;

- Leaching of N from agriculture was nearly the same in 1860 as today. Agriculture 100 – 150 years ago could not utilise all nutrients due to crop diseases, pests and poor management.
- The leaching increased by approximately 100% post-WWII – from 1950 to 1980. This is explained by a higher input of N from manure and mineral fertiliser.
- Still, the net load to the sea is higher due to lower retention by wetlands today compared with the middle of the 19th century. 100 years ago the drainage of rivers, lakes and wetlands started, which destroyed the retention capacity of nitrogen.

From the study it is possible to draw several conclusions (Hoffmann *et al.*, 2000);

1. It is important to have wetlands as a nitrogen sink before nitrogen transported by streams, reaches the sea.
2. The higher input of nitrogen after WWII has, in combination with the first factor, been negative to the environmental situation in the coastal regions.

The situation today

Environmental goals in Sweden

In Sweden, the government has decided upon 15 environmental objectives. The overruling goal for the environmental policy is to leave to the next generation a society where major environmental problems have been solved. Several of the environmental objectives have interim targets and action strategies for environmental quality objectives (Swedish government, 2000). Many of the objectives concern agriculture directly or indirectly. At least two of them are directly connected with the manure problem in agriculture. These objectives are: "Natural acidification only" and "Zero Eutrophication".

Natural acidification only

Only natural acidification means, for instance, that "the deposition of substances that lead to acidification, should, in the long run, not exceed the critical load in land and water areas" and "measures to prevent anthropogenic soil acidification preserve natural production capacity, archeological objects and biological diversity".

Interim targets for “natural acidification only” are stated below.

By year 2010;

- A maximum of 5 % of all lakes and 15% of the total length of running water in the country will be affected by anthropogenic acidification
- The trend towards increased acidification of forest land will have been reversed in areas that have been acidified by human activities , and a recovery will be under way
- Atmospheric emission of sulphur dioxide will be reduced by 60 000 tonnes
- Atmospheric emission of nitrogen oxides will be reduced by 148 000 tonnes

Zero eutrophication

Zero eutrophication means that “nutrient levels in soil and water must not have adverse effects on health, biological diversity or the possibility to use land and water resources”. Interim targets for this objective are specified below

1. “By 2009, an action programme in accordance with the Water Framework Directive will specify how to achieve a good ecological status in lakes and streams, as well as costal waters”.
2. “By 2010, waterborne anhtropogenic emissions in Sweden of phosphorus compounds into lakes, streams and coastal waters will have diminished continuously from 1995 levels”.
3. “By 2010, waterborne anthropogenic nitrogen emissions in Sweden into marine areas to the south of Åland sea will be reduced by 30% compared with 1995 levels, i.e. to 38 500 tonnes”.
4. “By 2010, ammonia emissions in Sweden will be reduced by at least 15% compared with 1995 levels, to 51 700 tonnes”.
5. “By 2010, emissions in Sweden of nitrogen oxides into the atmosphere will be reduced to 148 000 tonnes”.

Many of these objectives are directly connected with agriculture, for example, numbers 3 and 4. One way to achieve the target of number 3 could be to establish wetlands and the objective of number 4 could be achieved by improved handling of manure in all steps.

In table 1, the leaching from Swedish agriculture is summarised. The leaching from agriculture is made by using the simulation model SOIL-N (Hoffmann *et al.*, 2000). According to these calculations, the leaching from the root zone in arable land in 1995 was 24 kg N /ha with a variation of 15 – 40 kg N. The leaching from extensive grass is estimated to vary between 1 to 7 kg N/ha and this is assumed to be the background leaching from land not affected by man (Swedish Board of Agriculture, 1999c).

Table 1. *Nitrogen leaching from Swedish sources and the contribution to the sea, tonnes nitrogen (Modified from Swedish Board of Agriculture, 1999c)*

Year	1985	1995
Total leaching	135 000	112 000
Total leaching from root zone,	75 000	56 000
Background leaching	10 000	10 000
Leaching from deposition	4 000	4 000
Anthropogenic leaching,	61 000	42 000
Retention, tonnes	27 000	17 000
Anthropogenic contribution to the sea	34 000	25000

Ammonia

Atmospheric ammonia contributes to natural acidification and is an important factor for zero eutrophication. The emission of ammonia from agriculture was approximately 49 500 tonnes in 1999 (Statistics Sweden, 2001). This is a decrease of 10% since 1995. The decrease is explained by a decrease in number of animals and changes in manure storage and manure spreading-methods.

The government has the objective that ammonia emissions should be decreased by 15% compared with the level in 1995 (Swedish government, 2000), the target is 51 700 tonnes. This means that the contribution from agriculture should decrease to 46 500 tonnes (Table 2).

Table 2. *Total ammonia emission and emission from agriculture, tonnes of ammonia (Swedish Board of Agriculture, 1999c; Statistics Sweden , 2001)*

Year	1995	1997	1999	2010
Total emission	60 800	58 800	55 000[1]	51 700[2]
From agriculture	55 200	52 800	49 500	46 350[3]
Emission from agriculture % of total emission	91	90	90	90

[1] 5 % decrease from 1997 to 1999 according to Statistics Sweden (2001).
[2] Swedish government, 2000
[3] Calculated, 90% of total ammonia emission.

One of the objectives in Papers 2 and 4 is to compare the effects of different manure handling systems on ammonia emission and nitrogen balances.

Material and methods

Paper I - Cow level

Experimental design

This experiment was carried out at the Mellangård experimental station, Alnarp. Five different diets, named A, B, C, D and E, were compared in a Latin square test including twenty Swedish Holstein cows in 2^{nd} or higher lactation. They were kept in tie-stalls and milked twice daily. The barn at the experimental farm was equipped with mobile feed carriers for individual feeding of all feedstuffs. Roughages were fed twice a day and concentrate mixtures four times daily. Feed refusals were weighed every morning. As described earlier, 5 different diets were tested.Diets A, B and D had high protein levels i.e. 17% crude protein (CP-) in total dry matter (DM), and diets C and E had a low protein level (13.1-13.5% CP).

The following feedstuffs were utilised, roughages consisted of hay, grass silage and super-pressed beet pulp silage. Two types of concentrates were given according to milk yield. The base mixture consisted of grain and the other type included different protein supplements. In diet A, a commercial protein supplement was used. Diets B and C used a protein concentrate mixed of peas, rape seed meal, heat-treated, rape seed expeller, heat treated, dried brewer's grain and dried beet pulp fibre. Diets D and E included also linseed cake. Hence, diets B,C,D and E were based on feedstuffs of Swedish origin.

The roughage was the base in the feeding and the concentrates were given according to milk yield. To alter the protein content in the diets, the amount of concentrates and roughages, mostly beet pulp, were changed.

Animals and management

As mentioned earlier, five different treatments were tested. The design of the experiment is given in Table 3. Each period extended over 6 weeks; the first 2 weeks were pre-experimental to get the cow adapted to the new feeding regimen. Total daily amounts of faeces and urine were collected together from individual cows in blocks 1 and 3, during 4 days in the last week of each period.

Table 3. *Block design. A, B, C, D, E refer to different diets (from Paper I)*

Block			1*					2		
Period 1	A	B	C	D	E	A	C	B	D	E
Period 2	B	C	D	E	A	C	E	D	A	B
Period 3	C	D	E	A	B	B	D	A	E	C
Period 4	D	E	A	B	C	E	A	C	B	D
Period 5	E	A	B	C	D	D	B	E	C	A
Block			**3***					**4**		
Period 1	A	C	E	D	B	C	B	E	D	A
Period 2	E	A	C	B	D	A	C	B	E	D
Period 3	D	B	A	C	E	D	A	C	B	E
Period 4	B	E	D	A	C	E	D	A	C	B
Period 5	C	D	B	E	A	B	E	D	A	C

*Manure was collected

Registrations and analyses

Feeds. Samples of silages were collected every day and frozen for later analysis of pooled two-week samples. Samples of concentrate ingredients and blends were taken on each mixing occasion. Samples were pooled for four weeks. Chemical analyses were made on pooled samples and nutrition values were calculated according to standard methods (Spörndly, 1995).

Milk. Individual milk recording with milk sampling was done two days weekly. Pooled milk samples were analysed every week at a commercial dairy laboratory. The contents of true protein, fat, lactose, urea and somatic cell count (SCC) in milk were analysed by the infrared technical instrument Foss Combi (Foss Electric AS, Denmark).

Live weight. The cows were weighed at the beginning of the trial and at the end of each period. The body condition was scored at the beginning of the trial and after the whole trial was finished.

Manure. During four consecutive days in the last week of each period, plastic bins were placed in the manure channel behind each cow in blocks 1 and 3 for total collection of individual faeces and urine for 24 hours at a time. The collected amount was thoroughly mixed and a sample was frozen for chemical analyses. During these days, the cows were separated by empty tie-stalls in order to avoid a mixture of manures.

Frozen samples of manure were analysed at a commercial agricultural laboratory. The dry matter was analysed together with the contents of total N and NH_4-N. Total N (nitrogen) and NH_4-N were estimated in wet material to avoid losses of ammonia.

About 1/3 of the fresh manure was put in a plastic bin and the ammonia release was estimated using a ventilated chamber, constructed at the department. This analytical technique to determine ammonia release from faeces and urine has been described by Andersson (1994). Ammonia concentrations in the chamber air were measured with reagent tubes (Kitagawa). The ventilation rate through the chamber was determined by measuring the pressure difference over an orifice plate. In order to eliminate errors caused by variations in ventilation rate, all determinations were made at a ventilation rate of 100 m^3/m^2h and at a room temperature close to 16°C (Frank et al., 2002).

Paper II - Cow house level

Estimation of Ammonia - emission background

Production of ammonia is created by two different processes, organic nitrogen from excreta can be broken down or hydrolysis of urea can occur, the main source of urea is from urine. The latter process is catalysed by the enzyme urease (eq. 1). The urease enzyme comes from microbes in faeces. The process starts immediately after urine is deposited on a floor, for instance in a cow house (Elzinger & Swiestra, 1993). Less than 1% of total ammonia emission from slurry originates from excreta according to Hartung (1992). The reaction is highly dependent on temperature and the reaction becomes slower when the temperature is below 5 10 ° C.

$$CO(NH_2)_2 + 3\,H_2O \rightarrow 2NH_4^+ + HCO_3^- + OH^- \rightarrow 2NH_3 + CO_2 + 2H_2O \quad (1)$$

Emission of ammonia can be described by this simplified formula (after Monteny, 1996).

$E = k*A*dC$

where:

E = emission of ammonia (kg/s)
A = area of emitting surface (m^2)
k = mass transfer coefficient (m/ s)
dC = difference in ammonia concentration at the emitting surface and in the air (kg/ m^3)

Factors affecting ammonia release

With focus on dairy cows, the following factors are of importance. Nitrogen content in manure and urine is the source of ammonia and is, of course, of great importance. In an ideal solution, the content of TAN, total ammoniacal nitrogen, has an almost linear relationship to ammonia release (Svensson & Ferm, 1993). The manure surface area is of importance, however. It is not clear whether the relationship is linear or not. The amounts of manure and urine, and the period the manure and urine are exposed to air in the barn have influence on the release of ammonia. In pig houses, it has been shown that the ammonia concentration increases when the manure is stored more than 24 hours. Hence, transport of manure out from the barn 1 – 2 times per 24 hours is enough (Gustafsson, 1992). A higher frequency of transporting manure out from the barn will not decrease the release of ammonia. Higher manure temperature increases the ammonia release, maximum at 35°C. Higher pH increases the release of ammonia, with a maximum at pH 9. The moisture content of the manure also has an influence on release of ammonia. A high C/N-ratio decreases ammonia release due to the fact that microbes will utilise nitrogen in mineralisation or in transformation of nitrogen to organic compounds (Gustafsson, 1992). Also air movements in the building, air velocity above the manure surface and air flow rate through the building will influence on release of ammonia (Andersson, 1995; Jeppsson, 2000a). All the factors can, of course, be changed in one or another way, but some factors are determined when the building is constructed, for example, the type of manure handling system and the possibility to change the manure temperature or the separation of solid manure and urine. Andersson (1995) claims that the most effective measures of reducing release of ammonia, with focus on livestock buildings, are to

- decrease the area of manure surface
- decrease air velocity
- decrease manure temperature
- separate urine from faeces as quickly as possible

The type of floor in cubicle houses for dairy herds has a significant effect on ammonia emissions. An investigation, carried out in The Netherlands, showed a significant effect of a solid floor with a gutter in the middle to collect the urine compared with a concrete slatted floor. The ammonia emission was reduced by 50% (Swiestra, Smits & Krodsma , 1995). Comparing different management practises to reduce the nitrogen surplus, kg/ha and ammonia emission of the whole farm, Kuipers *et al.* (1999) concluded that low-emission housing techniques are both expensive and have little effect compared with other management practises, for example, injection of slurry or covering slurry storages. On the other hand, a factor with quick response is the nitrogen content in manure (including urine) which is determined by the nitrogen content or content of crude protein (CP) in the feed ration. The relationship between ammonia volatilisation and nutrition and the formation of urea and ammonia is summarised by Monteny & Erisman (1998). The dairy cow's production of urea is the key factor in ammonia emission from manure and urine. Urea converts to ammonia from floor areas wetted with urine and from manure (Smits *et al.*, 1995).

A schematic overview of processes and factors involved in ammonia release from livestock houses is shown in Table 4.

Table 4. *Processes and factors involved in ammonia release from livestock houses (after Groot Koerkamp* et al., *1998)*

Processes	Nitrogen compounds and appearance	Contributory factors
Manure production ↓	Uric acid, urea, undigested protein	Animal
Degradation ↓	Ammonia/ammonium in manure	Process conditions (manure): Temperature, pH, water activity
Volatilization ↓	Ammonia in air	Process conditions and interaction local climate and process conditions
Ventilation ↓	Ammonia in animal houses	Local climate (air), temperature, relative humidity, air velocity
Emission	Ammonia in environment	Air cleaning

A simple method to estimate ammonia emission from in animal buildings – theory

Measurements of ammonia emissions from animal buildings or elsewhere are not an easy task. To be able to analyse losses of ammonia from cow houses it must be possible to measure, or at least quantify, the losses in an easy and cheap way. To be able to determine the emissions of ammonia in conventional ways it is necessary to measure both the ammonia concentration in the outgoing air and the ventilation rate. The ventilation rate in animal buildings varies considerably, depending on the heat balance of the buildings, which in turn depends on the outside temperature. All these interactions make it difficult to evaluate and compare measurements of concentrations and releases of ammonia in animal buildings, as they might have been performed under different climatic conditions. These types of measurements are laborious and need expensive equipment.

Increased ventilation rate may also increase the release of ammonia (Gustafsson, 1988; Andersson, 1995).

In paper 2 a simple method is used, which can characterise ammonia emissions from an animal building without actual measurement of the ventilation rate (Gustafsson *et al.,* 2000). The method is developed from the following assumptions;

- Release of sensible and total heat increase with the body weights of the animals. Hence, ventilation requirements in animal houses also increase with body weights of the animals (CIGR, 1992, 1999)
- Release of carbon dioxide in animal houses is in relation to the total heat release from the animals (CIGR, 1984). Gustafsson (1988) has shown that

the number and weight of the animals influence the release of ammonia, carbon dioxide and dust.

- Measurements of differences in indoor and outdoor temperatures and also indoor carbon dioxide concentrations may give information about the ventilation rate in relation to the total release of sensible heat in animal houses (Pedersen et al., 1998).
- Increased ventilation rate may have a diluting effect on concentrations for most air pollutants. Increased ventilation rate may also increase the release of ammonia (Gustafsson, 1988; Andersson, 1995).

Calculations from mass balances of sensible heat, carbon dioxide and ammonia show that it may be possible to characterise the emissions of ammonia in the ventilated air from an animal building by some simple relationships that are easy to measure in cow houses. The following equations illustrates this (Gustafsson *et al.*, 2000).

The emission of ammonia by the ventilation is described as:

$$E = q * (C_2 - C_1) \qquad (2)$$

where E is emission of ammonia in mg/animal and h, q is ventilation rate, m^3 per animal and h, C_2 and C_1 are concentrations of ammonia in indoor (or exhaust) air and outdoor (inlet) air, respectively, in mg/m^3.

If the release of ammonia per animal should be determined, then it is necessary to determine a measure of the ventilation rate per animal.

If the over-all heat transmission loss is considerably lower than the ventilation heat loss, then the necessary ventilation rate to remove sensible heat at a certain temperature difference may be approximated as:

$$q \sim \frac{P * 3600}{(T_2 - T_1) a * Cp} \qquad (3)$$

where P is release of sensible heat, W/animal, T_1 and T_2 are temperatures of outdoor and indoor air in °C, a is air density in kg/m^3, C_p is specific heat capacity of air in J/kg, K^{-1}.

Combining equations 2 and 3 will give an estimation of the emission of ammonia in relation to produced sensible heat as:

$$\frac{E}{P} = \frac{3600}{a * C_p} * \frac{(C_2 - C_1)}{(T_2 - T_1)} = const. * \frac{(C_2 - C_1)}{(T_2 - T_1)} \qquad (4)$$

The ratio between concentration and temperature differences will give a characteristic value of the level of ammonia emission per animal, independently of the ventilation rate, as:

$$TR = \frac{(C_2 - C_1)}{(T_2 - T_1)} \tag{5}$$

A similar approach can be made by using the indoor carbon dioxide concentration as an indicator of ventilation requirement;

$$CR = \frac{(C_2 - C_1)}{C_{CO_2,2} - C_{CO_2,1}} \tag{6}$$

The ratio between differences in concentrations of ammonia and carbon dioxide between exhaust (indoor) and outdoor air will therefore also give a characteristic value of the release of ammonia per animal independently of the level of ventilation rate.

The accuracy in the determinations of the ratios *TR* and *CR* will depend on accuracies in the measurements of differences in concentrations and temperatures.

The maximum errors in measurements have been estimated to:

$/T_2 - T_1/ = 2°C$	Simple handheld instrument
$/C_{CO_2,2} - C_{CO_2,1}/ = 200$ ppm	Detector tubes
$/C_{NH_3,2} - C_{NH_3,1}/ = 2$ ppm	Detector tubes

The temperature difference between indoor and outdoor air will also have a large influence on the error in determination of *TR* and *CR*. Calculated maximum errors in determinations of *TR* and *CR* at different differences in temperatures in an insulated animal building are illustrated in Figs. 2 & 3. The figure clearly shows the influence of temperature difference on the accuracy in determinations of *TR* and *CR*.

The error will increase at decreasing temperature differences.The difference in concentration of ammonia will also decrease at reduced temperature difference (increased ventilation rate), which will also enlarge the error of *TR* and *CR*.

Outdoor climatic conditions will therefore influence the precision in determination. Measurements during winter conditions, when the differences in temperature and concentrations of carbon dioxide and pollutants are high, will improve the precision.

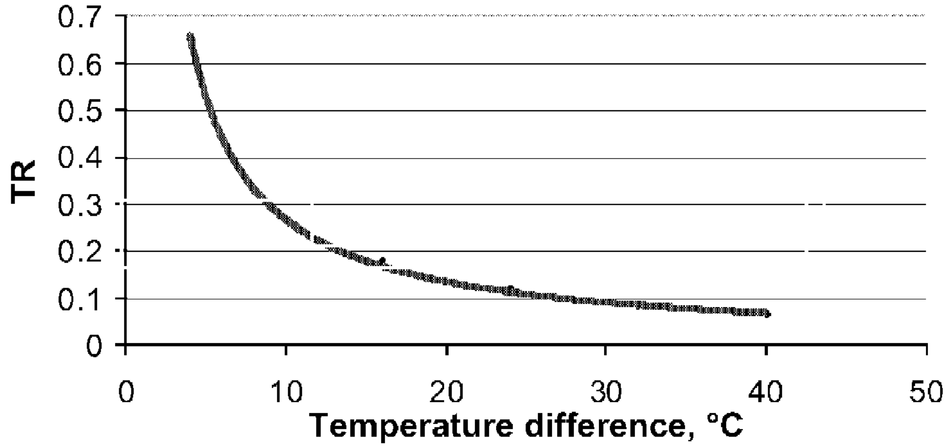


Fig 1. Maximum errors in determinations of TR as a function of temperature difference in animal houses (from Paper II).

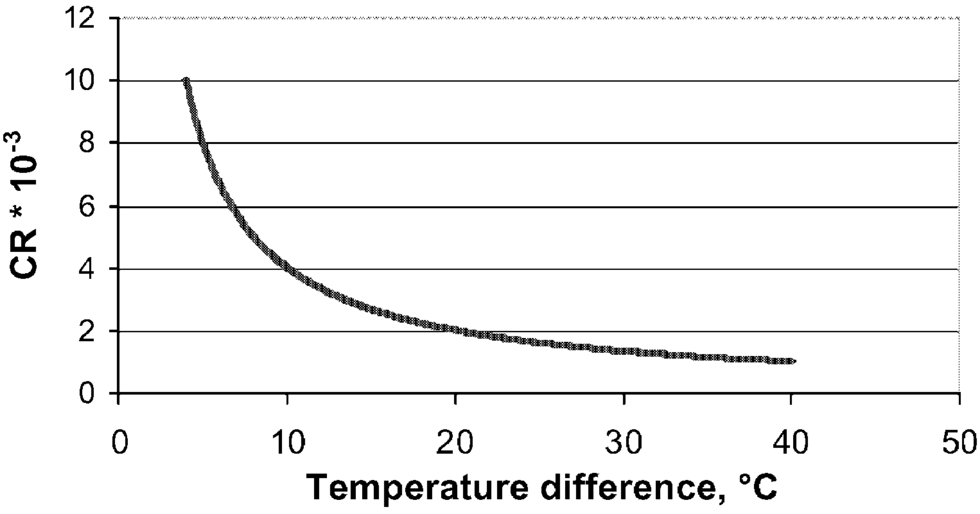


Fig 2. Maximum errors in determinations of CR as a function of temperature differences in animal houses (from Paper II).

Material in Paper II

Thirty-four dairy farms in the south of Sweden were visited twice during the winter. A short description of the different dairy farms is given in Table 5.

Table 5. *Investigated houses for dairy cows, with different ventilation and manure handling systems and number of dairy cows*

Type of herd	Number of herds	Number of dairy cows		Number of cow houses with mechanical ventilation	Number of cow houses with natural ventilation
		Mean	Standard deviation		
Tie stall barns with solid manure	16	45	15	15	1
Tie stall barns with liquid manure	8	43	14	7	1
Free stall barns with liquid manure	6	113	45	3	3
Free stall barn with solid manure	4	84	65	-	4

No barn had ventilation through the manure channel.

The ammonia release is calculated using the TR and CR described earlier. Levels of ammonia, carbon dioxide and temperature in the barns and in outside air were recorded with detector tubes (Kitagawa) and electronic thermometers in the exhaust air in mechanically ventilated cow houses or in the middle of the buildings in naturally ventilated cow houses at 1.5 m height above floor level. The concentration of ammonia and carbon dioxide of air leaving through exhaust fans gives a weighted sample of the concentrations in the entire building. Outside temperatures were measured at a place not exposed to solar radiation. Two measurements were made within two months during the winter. Data relating to the buildings, the manure and feeding systems were collected during the visits.

At the first visit, the farmers were interviewed about their feeding strategy and the daily feed ration of the cows. If the farmer was uncertain about the daily feed ration, a weight check was made of the different feedstuffs and if the farmer did not have any information about the analyses of roughage, a mixed sample was taken and sent for analysis. The content of crude protein, amino acids absorbed in the intestine (AAT), protein balance in the rumen (PBV), MJ in total feed ration were recorded. Information on the fat, protein and urea contents of the milk was collected from the regular milk analyses made by Skånemejerier.

Papers III, IV and V - Farm level

Before a description is given of material and methods applied in papers 3, 4 and 5, an introduction to element balances will be presented.

Element balances as a concept

Budgets to assess the flows of minerals, nutrients or other elements in agriculture have been used for many years. Element balances as a concept were introduced over 100 years ago in research to analyse the nutrient flows in arable land (Legg & Meisinger, 1982). Later they have been widely used both in fields or at farm level, regional level or national level to analyse element flows (Parris, 1998; Sveinsson *et al.*, 1998). For decades they have been a useful tool for scientists, farmers, advisors or policymakers, in the planning and control of nutrients (Oenema & Heinen, 1999). Elements that have been calculated are often nutrients like N, P and K (Sandgren *et al.*, 1999). Budgets can also be used to calculate heavy metals like cadmium or energy flows at farm level (Gustafson *et al.*, 2001). The most common element in budgets is N, due to the contamination of ground and surface water and to the pollution of the atmosphere (Watson & Atkinson, 1999).

The purpose of the budgets determines at which level the budget is calculated. If the purpose is to determine the impact of pollution from a certain sector, *i.e.* agriculture, this can be calculated on national or regional level. In research, budgets are often used for a special crop or animal production, hence, a minor part of the agricultural system. If the purpose is to help the farmer in management of the farm it is better to use a farm gate balance (Breembroek *et al.*, 1996).

The overall basic concept for an N-budget is simply a conservation of mass (Legg & Meisinger, 1982; Meisinger & Randall, 1991);

N in - N out = N stored within, or lost from the agroecosystems.

N stored within or lost from the system has been defined in different names; for example:

- N-surplus (Halberg *et al.*, 1995)
- Long-term potentially leachable-N (Meisenger & Randall, 1991)
- Positive or negative balances (Fagerberg *et al.*, 1996)

Farm gate balances

Many authors have pointed out that there is a need of standardisation of element balances (Breembroek *et al.*, 1996; Sveinsson *et al.*, 1998). One standardisation is to define the boundaries of the balance to a specific farm, hence, a farm gate balance. A farm gate balance is usually calculated per calendar year.

Different types of farm gate balances used in N-balances

Watson & Atkinson (1999) distinguish between the following three types of farm gate balances (Table 6);

- EIO budget, Economic Input:Output budget,accounts for purchased products bought and sales of N over the farmgate
- BIO budget, Biological Input:Output budget, includes estimates of biological nitrogen fixation and attempts to partition losses into leaching and gaseous forms
- TRIO budget, Transfer:Recycle:Input:Output budget, which also accounts for key soil processes

EIO- budget

This type of budget is based on farm management information. It is a simple approach, assuming the existence of steady-state on the whole farm. Calculated surpluses are assumed to be lost from the system.

BIO budget

In comparison with EIO budgets, the BIO budgets include inputs from symbiotic and non-symbiotic deposition. Surpluses are lost from the system and portioned in gaseous losses and leaching losses. Symbiotic N_2fixation is predicted from the content of clover in the swards.

TRIO budget

It includes all information from the BIO budget but also major internal soil N fluxes, i.e. mineralisation and immobilization. This means that it is possible that soil N declines or increases, hence, there is no steady state.

Table 6. *N pathways included in the three different budgeting approaches (after Watson & Atkinson, 1999)*

Pathways of N (inputs and outputs)	Budgeting approach EIO	BIO	TRIO
Purchased inputs [a]	X	X	X
Atmospheric deposition [b]		X	X
N_2-fixation [b]		X	X
Animal intake (grazing, silage, purchased feeds) [a]		X	X
Excretal returns (grazing and manure)[b]		X	X
Gaseous losses (grazing and housing)[b]		X	X
Mineralisation/contribution to soil organic matter [b]			X
Livestock outputs [a]	X	X	X
Other saleable outputs (e.g. surplus silage) [a]	X	X	X

[a] Based on primary data

[b] Calculated using relationships from literature

A comparison of nitrogen balances used in The Netherlands and Sweden

Farm gate balances, especially N and P-balances, have been calculated, at least in The Netherlands and Sweden, on a regular basis by national authorities. In Table 7 the different approaches are summarised.

Table 7. *A comparison of farm gate balances used in The Netherlands and Sweden (Breembroek et al., 1996; The Swedish Board of Agriculture, 1999a; Påhlstorp.2001. pers.comm.)*

Pathways of N-inputs	Budgeting approach: The Netherlands "MINAS" [1, 2]	Sweden "STANK" [3]	Sweden "Skånemejerier"
Atmospheric deposition		X	X
N_2-fixation		X	X
Inorganic fertilisers	X	X	X
By-products	X	X	X
Purchased feed	X	X	X
Natural pasture		X	X
Seed			X
Organic fertiliser from other farms (e.g. manure, compost)	X	X	X
Animals bought	X	X	X
Bedding material		X	
Pathways of N - outputs			
Animal products (Milk, meat ..)	X	X	X
Fodder to other farms	X	X	X
Arable land products, vegetables	X	X	X
Organic fertilisers to other farms (e.g. manure, compost)	X	X	X
Animals sold	X	X	X
NH_3 loss from housing (correction factor for livestock farms with > 2 LU / ha)	X	*	
Natural pasture			X

[1] Oenema *et al.*, 1998, [2] Neeteson, 2000, [3] Swedish Board of Agriculture, 1999a,

* Possible to calculate from STANK

Following the typology of Waton & Atkinson (1999) MINAS, must be considered as an EIO-model. The big difference between the Swedish nitrogen balances and MINAS is the absence of figures of nitrogen fixation and nitrogen deposition in MINAS, which makes it difficult to compare farm gate balances from Sweden and The Netherlands. For individual farms, this may make a great difference, especially in the case of farms with a lot of leys. The two Swedish balances can be considered as BIO – models.

Errors and uncertainties in determination of farm gate balances

How accurate are the farm gate balances? Oenema & Heinen (1999) state that the total variance of a nutrient budget is less than the sum of the variances of the individual inputs and outputs. This is explained by the fact that "the total variance is equal to the sum of the variance of the various flows plus twice the covariance of all possible two-way combinations of these flows. But the covariance is often negative due to the fact that it is a negative correlation between the various outputs". Table 8 summarises errors in % for a farm gate balance.

Table 8. *Approximate values for the relative errors of phosphorus and nitrogen budgets of farms in The Netherlands (after Oenema & Heinen, 1999)*

Input	Error, %	Output	Error %
Fertilizers	1-3	Milk	2-8
Manure	10-20	Meat	2-10
Plant material	5-20	Manure	10-20
Atmospheric deposition	10-30	Crops	5-10
Concentrates	5-10	Leaching	50-200
Forages	5-10	Runoff	50-200
Total	5-15	Volatilisation	50-200
		Total	10-20

Oenema (2001) claims that uncertainties increase in the order farm gate balance, soil surface budget and soil system budget. The latter had large uncertainties for internal nutrient flows, leaching losses and gaseous emissions.

Farm gate balances utilised in Papers III, IV and V

Papers 4 and 5 utilise farm gate balances (BIO-models, see Table 7) collected by Skånemejerier. In 1997 Skånemejerier started a campaign, "environmental bonus", for extra environmental commitment (Skånemejerier, 2001). Dairy farmers joining the campaign receive extra money for milk produced in accordance with specific criteria. The campaign was carried out on two levels. The most important measures in level one was to make an environmental inspection operated by the Federation of Swedish Farmers and to join the environmental training carried out by Skånemejerier. Level 2 comprised farm gate balances, including both animal balance and crop balance, and ceasing the use of pesticides on grass intended for dairy cows. Hence, farm gate balances have been calculated each year since 1997. The campaign was voluntary the first three years. From year 2000, dairy farmers marketing their milk through Skånemejerier, must join the first level of the campaign (Table 9).

Table 9. *Number of dairy farms joining the environmental bonus campaign, level 2 (Karlsson,2002, pers.comm.)*

Year	1997	1998	1999
Dairy farmers joining the environmental bonus campaign	461	610	705

As mentioned above, during the first three years the calculations included also an animal balance and a crop balance (Figs. 4, 5, and 6). The calculations were made by software developed by Skånemejerier using Microsoft Access®. Since year 2000, the software STANK was used. This software was developed by the Swedish Board of Agriculture (1999). The differences between the two softwares are that STANK does not calculate an animal balance or crop balance and the deposition of nitrogen from the atmosphere is more adapted to different regions in the software developed by Skånemejerier.

Input and output values from the dairy farmers to the balances were collected using protocols. The dairy farmers could fill in the protocols by themselves or the farmers were interviewed about input values and output values, for example how much mineral fertiliser was bought per year or how much concentrate was fed to the animals per year; doubtful data were double-checked with the farmer to exclude incorrect data from the analysis. Advisors from Skånesemin (the regional society for artificial insemination) collected the balance figures. The balances were calculated on the calendar year. All data were collected, processed and stored in a database, Microsoft Access®. The results from the balances were sent to the farmers during the following spring.

Amounts of purchased mineral fertilizer and purchased feed were recorded in the accounts as well as data on sold milk, sold live animals or slaughtered animals, and sold vegetable products. The nitrogen fixation from leys was calculated according to the method used in STANK (Swedish Board of Agriculture, 1999a), and the result depends on a subjective evaluation of the content of clover in the leys. This estimated figure may affect the result for farms that grow a lot of leys (Högh-Jensen *et al.*, 1998). Atmospheric nitrogen deposition was estimated to be 12 kg – 15 kg /ha according to estimates made by the regional agricultural society. The nitrogen deposition from the atmosphere is also an uncertain figure but is of minor importance for the whole inflow of nitrogen.

The whole farm's balance was defined as the difference between inputs to the farms and recovery in agricultural products. The nitrogen surplus per hectare was defined as the difference between input and output of nitrogen divided by the size of the farm in hectares. The farm size was defined as land on which manure could be spread; this includes all arable land on the farm but not natural pasture. The nitrogen efficiency was defined as the ratio between nitrogen output and nitrogen input (van der Hoek, 1998).

All farms shipping milk to Skånemejerier were defined as dairy farms. Dairy farms that exported or imported manure were excluded from the statistical analyses due to the uncertain analytical values of nitrogen in manure (Oenema *et al.*, 1998; Steineck *et al.*, 1999). Also dairy farms with a large outflow of nitrogen from other types of animal production such as pig production, were excluded from the analysis. The definition of a dairy farm is not the same in EU and Sweden. A Swedish definition of a dairy farm is; "dairy farm has at least 67% of the farm's total labour force occupied in milk production" (Statistics Sweden, 1997). The EU definition of a dairy farm is based on the dairy production's share of the total gross margin, hence, being an economic definition (EU,1985). It was not possible to use the EU-definition or the Swedish definition in a strict context due to lack of information on the economic outcome or the labour time at the dairy farms.

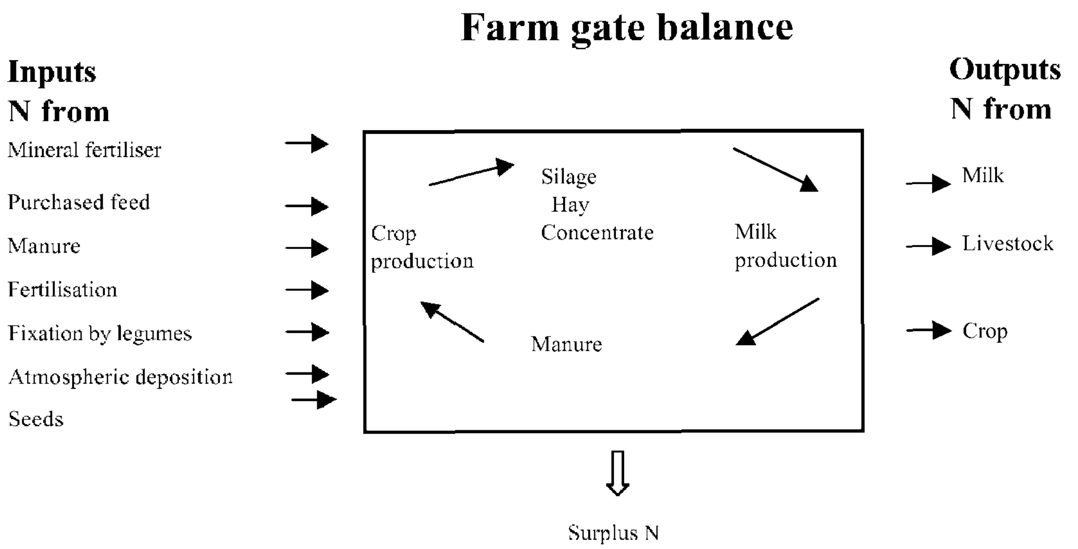


Fig 3. Farm gate balance. Surplus of N was defined as ammonia volatilisation + leaching + denitrification + change in mineral N and organic N in soil (from Paper IV).

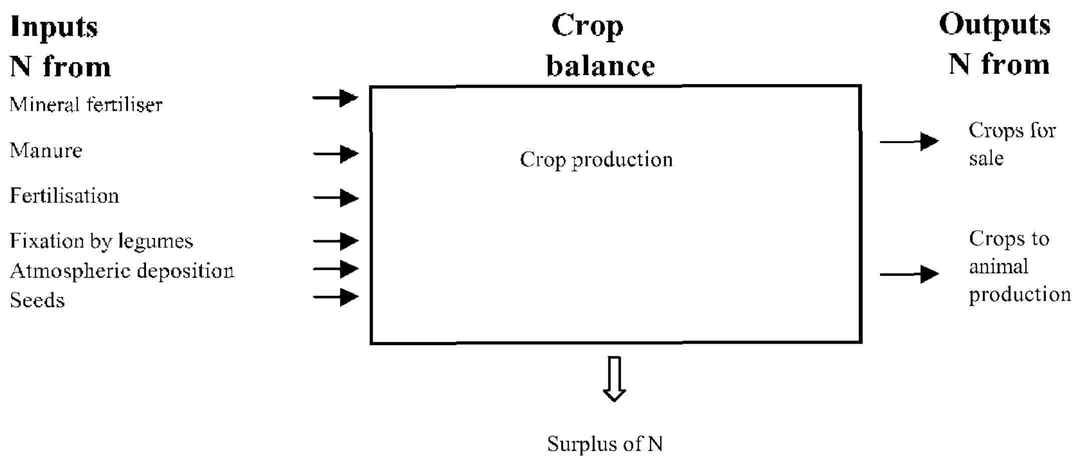


Fig. 4. Crop balance. Surplus of N was defined as ammonia volatilisation + leaching + denitrification + change in mineral N and organic N in soil (from Paper IV).

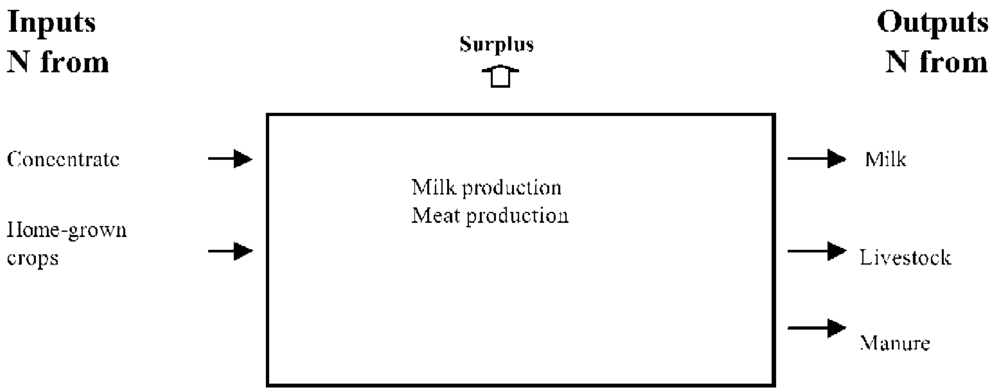


Fig. 5. Barn balance. Surplus of N was defined as ammonia volatilisation + leaching + denitrification + change in mineral N and organic N in soil (from Paper IV).

Paper III is a desk study in which calculations were made of nitrogen efficiency and nitrogen surplus on dairy farms in south Sweden. The outcome from five feeding strategies calculated in the software Bioptek was calculated (Larsson, 2001). The six feeding strategies were as follows;

1. Grass silage, barley and purchased concentrate
2. Grass silage, purchased concentrate
3. Grass/clover silage, barley and purchased concentrate
4. Grass/clover silage, super-pressed beet pulp, barley and purchased concentrate
5. Grass/clover silage, distiller's waste, barley and purchased concentrate

All feeding strategies were utilised on the intensity of 8 600 kg milk /ha. Strategies 3 and 4 were also utilised on the intensity 11 000 kg milk /ha. Crop yields are according to Agriwise (ref). Rate of nitrogen fertiliser is according to recommendations from the Swedish Board of Agriculture (2001) The losses of nitrogen from cow house and storing were according to the Swedish extension tool STANK (Swedish Board of Agriculture, 1999a). Losses during spreading of manure were calculated in two ways, according to STANK or according to the simulation model ALFAM. To calculate the value of TAN to be used in ALFAM, information from paper I was utilised. The outcomes from the calculation were compared with nitrogen balances calculated according STANK and also with results from the experimental farm at de Marke, The Netherlands (van Keulen *et al.*, 2000).

Methodological considerations

The thesis includes different types of investigations (Table 10), both research in an experimental herd (Paper I), modelling of a dairy farm(Paper III) and field investigations (Papers II, IV and V).

The investigation presented in Paper I is based on the experimental herd at Alnarp "Mellangård". The advantage of an investigation in an experimental herd is obvious, the dairy cows are in the same herd of the same origin, the management is the same during the whole experiment, hence, the influence of the environmental factor is low. On the other hand, generalisation of conclusions from one dairy herd to all dairy cows in Sweden, or in the world, may be a doubtful approach. The cow house at Mellangård includes a tie stall barn for intensive feeding experiments and a free stall barn, the number of dairy cows is around 170, with an average milk yield of 9 700 kg milk per cow and year, and the feed includes both super-pressed beet pulp and alfalfa. It is not a typical Swedish dairy farm, the average herd size in Sweden is slightly above 40 cows and the milk yield per cow and year approximately 8 600 kg milk (Statistics Sweden, 2000; Swedish Dairy Association, 2001). However, in Skåne, the average herd size is higher and the milk yield nearly 9 000 kg milk per cow and year (Swedish Dairy Association, 2001). Still, working with an experimental herd is the traditional way of research in dairy production. The investigation presented in Paper I could hardly have been done in normal dairy herds due to the demands of exact feeding and collection of manure for analysis of nitrogen compounds.

On the other hand, Paper II consists of an investigation carried out in normal dairy herds. The overall purpose of this investigation was to use a simple method to characterise ammonia emissions in dairy cow houses and to relate this to type of building, type of manure handling and feeding of the dairy cows. The simple method is not reliable if small differences occur in outside – inside temperatures, and during the wintertime part of the investigation was carried out 1999/2000, the weather was unfortunately mild. Still, the aim was to utilise the method and analyse the relationships mentioned above. This was done in dairy herds, that already had a lot of known background data, and the simple method could be evaluated satisfactorily. It is an advantage that the same persons make all the registrations, which probably decreases the human factor.

In the results presented in Papers IV and V, information was utilised from farm gate balances of dairy farms collected by Skånemejerier. As in many other investigations, this is research utilising information collected by other people for other purposes. Still, there is an opportunity to learn a lot from many dairy farms. The problems with a field investigation are to be able to exclude false information from reliable facts. One problem regarding research data among these investigations is the definition of a dairy farm. The investigation presented in Paper IV uses all data from dairy farms shipping milk to Skånemejerier, except dairy farms exporting manure. In Paper V, dairy farms with large crop and/or pig production were excluded.

Table 10. *Type of research in the thesis*

Type of research	Number of dairy herds	In
Dairy herd, experimental station "Mellangård"	1	Paper I
Dairy herds, field investigation	30	Paper II
Dairy herd, modelling	1	Paper III
Dairy farms, "meta analysis"	283 & 138	Papers IV & V

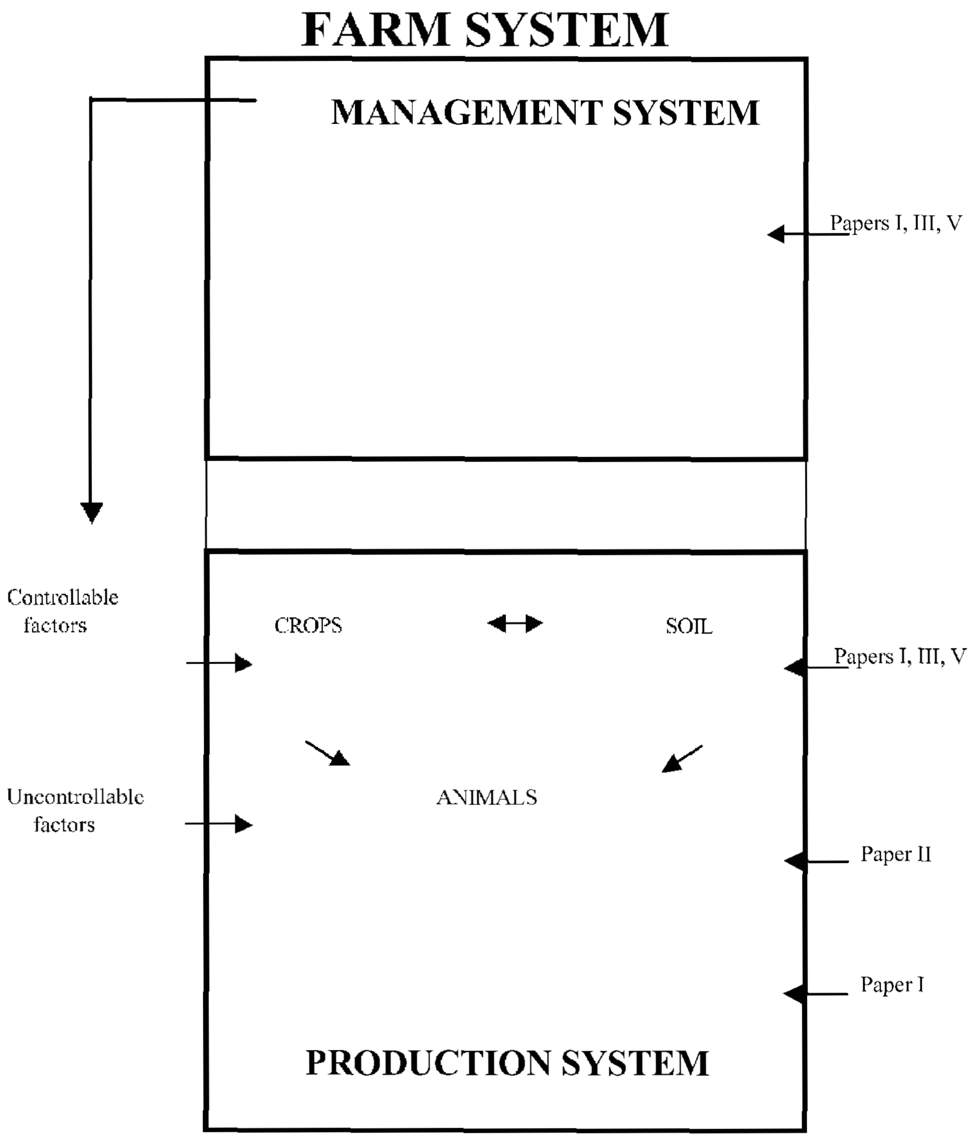


Fig. 6. Overview of the thesis (Modified from Keating & McCown, 2001).

Statistical analyses

The statistical analyses were mainly carried out using the SAS statistical package (SAS, 1985; 1986). Before analysis of variance was carried out, normal distribution among data was tested using proc Univariate. According to Montgomery (2001), the following criteria must be fulfilled if a variance analysis is to be used: Data should be normally distributed, the variance should be equal, and the data should be independent. Analysis of variance was used in Papers I, II, IV and V. In these papers, log-transformation was used to fulfil the criteria of normal distribution for some parameters, *i.e.* somatic cells in milk. In other cases, when the parameters were not normally distributed, a non-parametric test, Wilcoxon-Mann Whitney test, was utilised.

Results and discussion

Cow level

Results from the experimental herd

Nitrogen efficiency was calculated for the dairy cows in the experiment by calculating nitrogen from milk protein in percent of total consumed nitrogen, without consideration to changes in body weight or score. Extremely high efficiencies around 42% were observed with low protein diets. The efficiency was also rather high, around 34%, with the high level diets. However, the efficiency referred only to a part of the lactation. According to van Vuuren and Meijs (1987), a maximumof 45% of ingested N can be transferred into milk and body yield. Aarts et al. (1992) are of the opinion that the nitrogen efficiency in practice will be 15 – 25 %. An investigation among 33 Danish dairy herds showed a nitrogen efficiency of 26% during the winter period and 23 % during the summer period (Nielsen & Kristensen, 2001) In our Swedish experimental herd the nitrogen efficiency has been around 25 – 32 %, when feeding according to standard recommendations (~ 19 % CP).

The analyses of different milk constituents showed that the content of urea was significantly higher (P <0.0001) in treatments with high crude protein level in the diet.

Analysis of different protein components in morning milk showed significantly higher NPN at high levels of protein in the diets. The content of casein was not influenced, while the commercial concentrate showed a tendency to give lower values of whey protein compared with the Swedish mixtures.

Daily amounts of fresh manure or manure DM percent did not differ significantly between diets. There were significant differences in both total-N and ammonium-N in wet manure depending on the content of crude protein in the diet. Especially, diet D showed high levels of nitrogen in manure. Diet D, like diet E (low protein level), had linseed cake in the concentrate. The protein level had little influence on organically bound N.

Comparing the production of manure and nitrogen in manure on a yearly basis, excluding the pasture period, clearly demonstrates a lower production of nitrogen with a lower protein content in feed, diets C and E (Fig. 7). The low protein diets C and E gave significantly lower ammonia release compared with the high protein diets (p<0.0001).

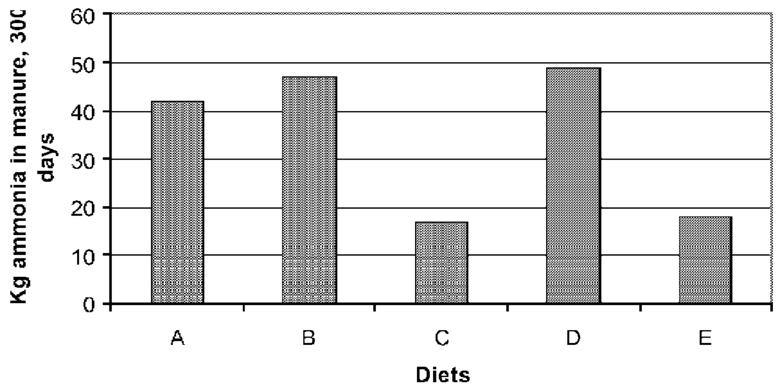


Fig. 7. Calculated production of ammonia during indoor period, per cow and 300 days (Modified from Paper I).

The reduction of protein in the diets of dairy cows is known to decrease nitrogen excretion substantially, especially urinary nitrogen (Bussink & Oenema, 1998). Urine nitrogen mainly consists of urea, which is rapidly converted to ammonia by urease and ammonia can easily volatilize (Tamminga, 1992; Kulling *et al.*, 2001). Smits *et al.* (1995) compared, amongst other things, the effect of two levels of protein, 15 and 20 %, on ammonia release. They found a 63% higher ammonia release in the diet with 20% crude protein compared with the diet with 15% CP. Also Paul *et al.* (1998) found an increased ammonia release when the content of crude protein was increased. The same trend was found in heifers fed with diets with different levels of % crude protein (James *et al.*, 1999). Using a dynamic model of N metabolism, Kebreab *et al.* (2002) found that ammonia release decreases by 20% when decreasing CP % from 20 to 16%. An earlier experiment conducted at Mellangård than described in Paper I, found a 66 % decrease of ammonia release when lowering the content of CP in cow diets from 19 % to 14 % (Frank *et al.*, 2002). This is in agreement with our own findings illustrated in Fig. 8. In summary, the relationship between % crude protein in the diet of dairy cows and ammonia release is clear.

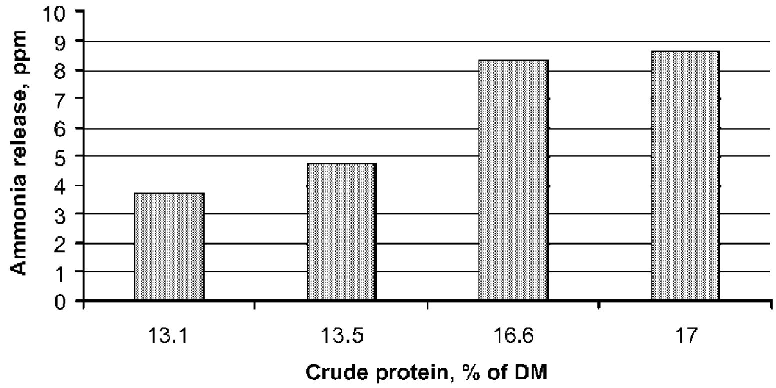


Fig. 8. Ammonia release from fresh manure related to % CP in DM (Modified from Paper I) .

The nitrogen content in urine is most important regarding ammonia release. According to Kebreab *et al.* (2001) there is a linear relationship between nitrogen in urine and ammonia release. There is also a relationship between milk urea and nitrogen in the urine. Both Castillo *et al.* (2000) and Kebreab *et al.* (2001) found an exponential function predicting nitrogen in urine from nitrogen intake with an exponential function;

$N_{urine} = 0.0052*(N_{intake})^{1.7}$ (Kebreab *et al.*, 2001)
$N_{urine} = 30.4*(e^{0.0036Nintake})$ (Castillo *et al.*, 2000)

Kohn *et al.* (2002) calculated nitrogen in urine (g N/day) from MUN – milk urea nitrogen. MUN corresponds to milk urea as; 28/60 * milk urea.

$N_{urine} = 0,026*BW * MUN$ (Kohn *et al.*, 2002)

From the three equations, the following values of nitrogen in urine were obtained from values in Paper I (Table 11).

Table 11. *Comparison of three equations calculating urinary N, g N/day. Input values from Paper I*

Diet	Castillo *et al.* (2000)	Kebreab *et al.* (2001)	Kohn *et al.* (2002)
A	222	239	232
B	214	231	231
C	137	149	161
D	222	238	256
E	134	145	165

Comparing these results with a dynamic model of N metabolism developed by Kebreab *et al.* (2002) gave the following results (Table 12).

Table 12. *Output of nitrogen in milk, urine and faeces, using the nitrogen dynamic model developed by Kebreab et al. (2002). Input of nitrogen fromPaper I*

Diets	A	B	C	D	E
Inflow of N	552	542	418	552	412
Outflow					
N in milk	176	174	146	176	145
N in urine	210	203	130	210	127
N in faeces	145	144	125	145	124
N efficiency, %	32	32	35	32	35

The simulation model could not predict the output of N from milk in the low protein diets C and E. This might be explained by an underestimation of the microbial production of the dairy cows in these alternatives. The diets had a higher ration of super-pressed beet pulp which has a high content of easily fermented carbohydrates. Another explanation could be that the dynamic model is developed and evaluated from research data from England, where the milk yield, kg milk per cow, is at least 2 000 kg below the average level of the dairy cows of Mellangård.

However, there are still numerous questions to be answered, for example, what is the ideal ration of crude protein to dairy cows and what happens with the high-yielding cow? An answer to the first question is proposed by Castillo *et al.* (2000) and Kebreab *et al.* (2001). They simply state that to diminish the problem with nitrogen pollution from dairy cows the nitrogen intake should not exceed 400 g N per day for average-yielding cows or a level of 14.7% CP in diet. They propose that the content of crude protein per kg dry matter in total diet should be 15%. In Great Britain, this should decrease the annual nitrogen excretion by 21% and 66% in the urine (the comparison is made with 20% crude protein in the diets) (Castillo *et al.*, 2000; Kebreab *et al.*, 2001). This recommendation was based on a literature review (Castillo *et al.*, 2000) and on an investigation of five nitrogen balance trials with Holstein-Friesian dairy cows in early or mid–lacation. N-intake ranged from 289 – 628 g N per day (1806 – 3925 g CP per day) (Kebreab *et al.*, 2001). Tamminga & Verstegen (1996) propose a minimum of 24 gram nitrogen per kg of DM (15.4 % CP) if the rumen should function well.

On the input side in nutrient balances of dairy farms the input of nitrogen in purchased feed is on the same level or just below intensive dairy regions in western Europe – adjusting for kg milk per hectare (Paper IV ; Aarts *et al.*, 1992). The content of crude protein and the intake of dry matter will determine the level of the input of nitrogen to dairy cows. During recent decades, the crude protein level in the diets has been increasing (Gustafsson, 2000, 2001). There are several explanations of this; firstly the increased level of milk production has resulted in a demand for more crude protein and protein of higher quality for the dairy cows. A higher content of crude protein in the rations gives a higher milk yield but the efficiency decreases (Fig. 9) (Tamminga, 1992; NRC, 2001).

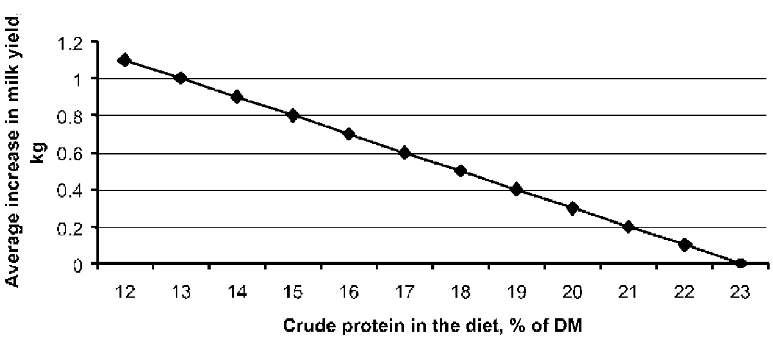


Fig. 9. Marginal response according to NRC (2001).

Secondly, the microbes in the rumen can support a milk production of 25 – 30 kg per day, a higher daily yield means that the cow has to be supported with amino acids protected from, or with a slow, breakdown in the rumen. This also leads to a higher content of crude protein in the diets. A third explanation could be that it is difficult to provide the energy to dairy cows yielding 50–60 kg milk per day – with carbohydrates. This leads to a breakdown of protein to energy or glucose, but also to a "spill" of nitrogen.

Another explanation is the introduction of the AAT/PBV-system in Sweden. The AAT/PBV-system of feed evaluation of cows was introduced in the beginning of the nineties both in Denmark and Sweden. The system was developed as a Scandinavian cooperative project. However, the practical use differs among the Scandinavian countries (Madsen, 1985; Madsen *et al.*, 1995). The system has basically the same principles as the Dutch system, the French system and has many similarities with protein evaluation in United States (Tamminga & Verstegen, 1996; NRC, 2001). One of the aims of the system was to decrease the content of crude protein in the diets to dairy cows (Magnusson *et al.*, 1990). One of the criteria of the AAT/PBV-system is the great importance of feeds with low-degradable protein to high-yielding cows. The majority of Swedish dairy cow diets are based on silage with high-degradable protein and this has to be matched with low-degradable protein. This type of protein feed is mostly imported. Unfortunately, the feed industry in Sweden based the first concentrates adapted to the AAT/PBV-system on imported corn-gluten meal. Corn-gluten meal is low in lysine content and, therefore, the dairy cows did not milk as expected. The solution to the problem recommended by the advisory service was to give more concentrate to the dairy cows and to raise the level of AAT per kg milk. Then there was enough lysine to support the cows' needs. But this meant also that the content of crude protein was raised. Another problem was that soon after the AAT/PBV-system was introduced in Sweden the tolls on protein feeds disappeared. The economic motives to decrease the content of crude protein were no longer present. Making diets for dairy cows using the AAT/PBV system means fulfilling the criteria of energy and AAT required by the cows. The goal is not to optimise the content of crude protein. This means that, quite frequently, some diets have too much crude protein per kg dry matter; levels above 20% CP have been reported from Swedish diets (Lidström, 2001, pers. comm.). In spite of the fact that the introduction of AAT/PBV system of feed evaluation was expected to decrease ammonia emission, the introduction of the AAT/PBV-system has not decreased the emission (Magnusson *et al.*, 1990; Swedish Board of Agriculture,1991,1994). The AAT/PBV-system itself is not to blame, it is the use of the AAT/PBV-system that has failed. It is a contradiction between theory and practice.

Today, many advisors in Sweden use a computer software, "Individram", to compile diets to dairy cows. This software has many advantages, but one disadvantage is that the crude protein content in diets can impossibly be optimised.

In recent years another feed evaluation system has been introduced to dairy cows, the LFU-system. It is developed by the Swedish Farmers´ Supply and Crop Marketing Cooperative.

According to recommendations compiled by this cooperative (2001), a high-yielding dairy cow should have, by average, a content of 17. 4 % CP in the diet, including lactation and dry period (Table 13).

Table 13. *Intake of DM and CP of a dairy cow with a milk yield of 10 950 kg per year according to recommendations compiled by the Swedish Farmers' Supply and Crop Marketing Cooperative (2001)*

	Kg milk/day	Days in lactation	Kg milk in the period	Intake of DM Kg/day	Total intake, DM kg	CP %	Total intake of CP, kg
Period 1	50	45	2250	27.2	1224	19	233
Period 2	40	105	4200	22.9	2405	18	433
Period 3	30	150	4500	18.6	2790	17	474
Dry period	0	60		9.5	618	13.6	84
Sum		365	10950		7036	17.4	1224

Gustafsson (2000, 2001) discusses the consequences of decreasing the content of crude protein in feed rations of dairy cattle in Sweden. One of the conclusions is that a decrease of 1 – 2% of the content of crude protein in the feed rations enables considerable reductions in emission of ammonia to the atmosphere. In practical feeding, this means a decrease from 18 - 19% to 17 – 16% CP of the ration's dry matter in early lactation.

In summary, the increasing input of protein to the dairy cows has been nearly synchronized with the new awareness of nitrogen surplus or ammonia emissions on dairy farms.

Cow House Level

Results from the field investigation

Ammonia

The results from the field investigation showed that the hygienic threshold limit for ammonia concentration in barn air, 10 ppm, in Sweden was exceeded in one case. The hygienic threshold limit for carbon dioxide, 3 000 ppm, was not exceeded in any case (Table 14).

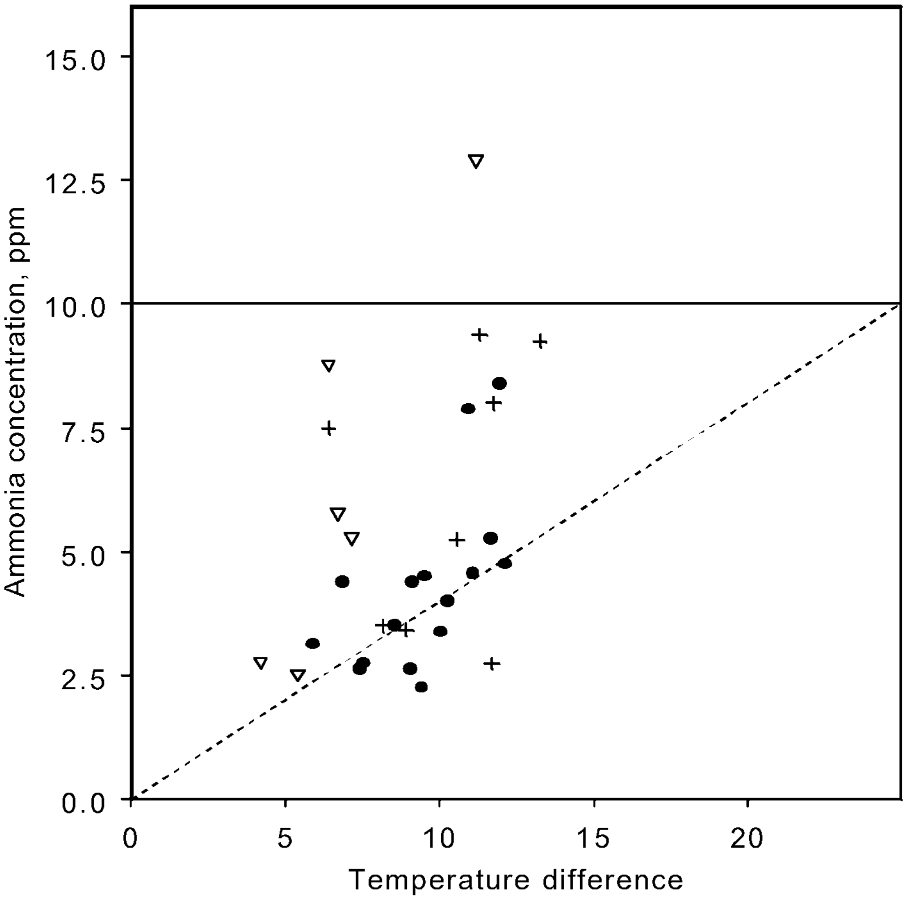
Table 14. *Concentrations of ammonia and carbon dioxide in cow houses (from Paper II)*

Type of herd	No	Ammonia, ppm			Carbon dioxide, ppm		
		Mean value	Min.	Max.	Mean value	Min.	Max.
Tie stall barn with solid manure (TS)	16	4.3	2.3	8.4	1645	1125	2425
Tie stall barn with liquid manure (TL)	8	6.1	2.8	9.4	1670	1050	2375
Free stall barn with liquid manure (FL)	6	7.4	5.1	12.9	1423	1088	2225

Groot Koerkamp *et al.* (1998) investigated concentrations and emissions of ammonia in different livestock buildings in England, The Netherlands, Denmark and Germany. The investigations were carried out in livestock houses for cattle, poultry and pigs. The highest ammonia concentration in cattle houses was found in Germany (22.7 ppm), with mean values in different countries varying between 0.9 ppm to 7.1 ppm. The lowest values were found in England. Another investigation of ammonia concentrations in livestock buildings in Germany found a mean value of 6.4 ppm in cow houses. The ammonia concentrations were measured hourly and a mean value from 24 hours was calculated (Seedorf & Hartung, 1999).

TR and CR

Mean values and standard deviations of TR and CR are shown in Table 15. When comparing tie stall barns and free stall barns, free stall barns have higher values of both TR and CR. Within tie stall barns, manure handling systems with liquid manure have higher values of both TR and CR. The ranking of TR and CR was TS< TL <FL, in order of increasing magnitude. Relative ratio is TR and CR compared to TR and CR at the hygienic limits. TR at the hygienic limit is calculated with the assumption that the temperature difference at minimium ventilation is 25°C, for example an outdoor temperature of – 10°C and indoor temperature of + 15°C. This assumption means that TR is 0.4. CR is independent of temperature difference and is 0.0038. Figures 10 and 11 show the ammonia concentrations at different temperature and carbon dioxide differences. The hygienic threshold limits of TR and CR are plotted in the figures. It can be seen that all dairy farms with free stall barn are above the hygienic limits and nearly all dairy farms with tie stall barns with liquid manure are below the limits. This is more pronounced in the TR figure. However, in wintertime, with greater temperature differences than registered in this study, the ventilation rate will be held at minimum level, which may lead to problems with ammonia levels in the barn above the hygienic limit. Hence, just measuring the ammonia concentration in a barn without considering ventilation flow or the temperature difference does not reveal very much about the hygienic conditions under other conditions.



Tie stall barn with solid manure

Tie stall barn with liquid manure

Free stall barn with liquid manure

Hygienic threshold limit

Hygienic threshold limit according to TR

Fig. 10. Ammonia concentration in relation to temperature difference in different types of cow houses. Each dot is the mean of two measurements from one dairy farm.

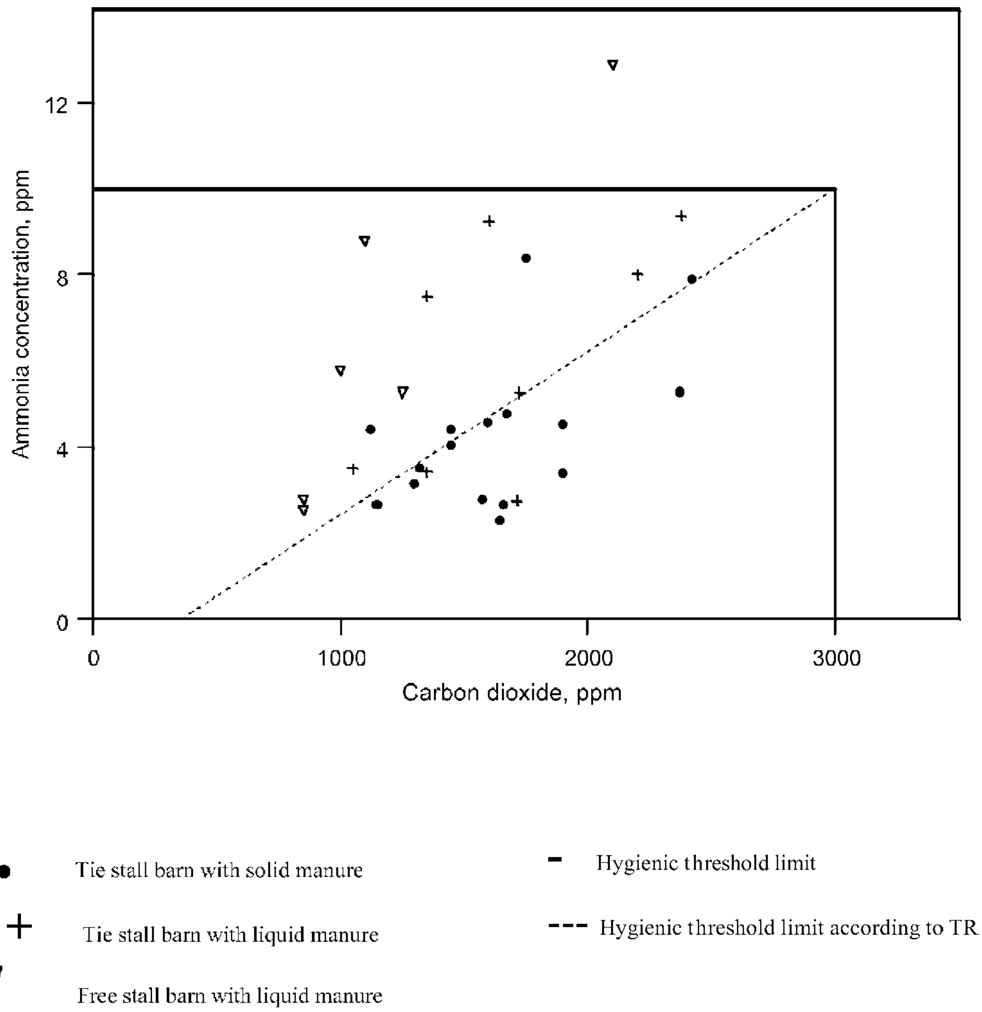


Fig. 11. Ammonia concentration in relation to carbon dioxide difference in dairy farms. Each dot is the mean of two measurements from one dairy farm

Some of the differences of TR and CR between the different types of cow houses in this investigation can be explained by environmental variables. The exposed area of manure is larger in free stall barns, which means a higher opportunity to ammonia release. All tie stall barns with solid manure used straw as bedding material. Tie stall barns with liquid manure and free stall barns used saw dust, shavings or chopped straw in less amounts compared with tie stall barns with solid manure. All except two tie stall barns with solid manure separated urine and excreta. These farms had a manure handling system with greater opportunities to make better use of the urine. Urine is, as mentioned earlier, the key factor in ammonia release in the barn.

Table 15. *A comparison of TR- and CR-ratios for NH_3 from investigated dairy farms. Mean values from two measurements*

Type of farm	Tie stall barn with solid manure			Tie stall barn with liquid manure			Free stall barn with liquid manure		
	n = 16			n = 8			n= 6		
	Mean	S.D[1]	C.V[2]	Mean	S.D	C.V	Mean	S.D	C.V
TR	0.45	0.14	0.31	0.64	0.35	0.55	0.95	0.26	0.28
TR, relative ratio	1.12	0.35	0.31	1.60	0.87	0.55	2.36	0.65	0.28
CR * 10^3	3.4	1.13	0.33	4.8	1.9	0.39	7.18	1.1	0.16
CR, relative ratio	0.90	0.30	0.33	1.25	0.49	0.39	1.89	0.29	0.16

[1] Standard deviation [2] Coefficient of variation

Comparing these results with pig or chicken production, it can be concluded that the overall ammonia concentration from cow houses is lower (Wachenfelt & Gustafsson, 2001; Wachenfelt, 2001). The correlation coefficient between TR and CR was 0.87. An investigation in pig houses carried out by Wachenfelt & Gustafsson (2001) had a correlation coefficient of 0.76 between TR and CR.

As mentioned above (page 37), there is a relationship between the content of CP in the diet, urea in urine and urea in the milk. Hence, one could suspect that a high level of urea in the milk should contribute to higher CR and TR, at least in barns with conditions of high ammonia release, for example, tie stall barns with liquid manure. This is illustrated in Fig. 12.

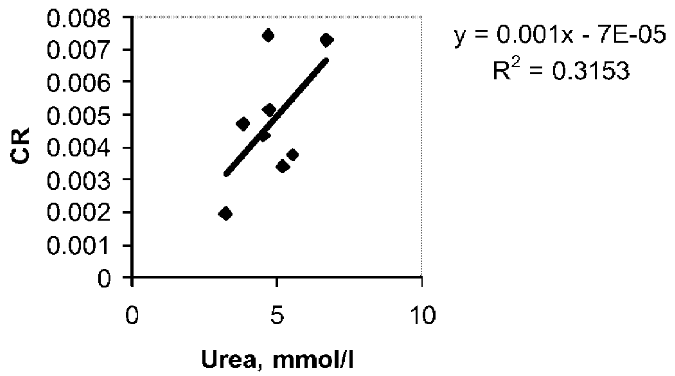


Fig. 12. The influence of urea in the milk tank on the CR in tie stall barns with liquid manure (from Paper II).

To investigate the influence of different parameters in the diet a regression analysis (backward selection) was carried out (SAS, 1986) to find the best regression equation with significant factors influencing TR and CR. Analysing barns with liquid manure, the model with highest rate of explanation of TR and CR included the following factors with significant influence;

TR	CP/ME**	with R^2 40%
CR	CP/ME*** PBV***	with R^2 60%

* $p<0.05$ ** $p<0.01$; *** $p<0.001$; R^2 rate of explanation

The findings in Paper II indicate that ammonia emission from the house is highly dependent on the type of house and manure handling. Tie stall barns have less ammonia emission compared with free stall barns and solid manure handling systems have less ammonia emission than liquid manure handling. This difference is probably due to the smaller fouled area per cow and/or the amount of bedding material (Monteny, 1996). The dominating trend in construction of cow houses in Sweden today is to build free stall barns (Hultgren, 2001), often with liquid manure handling systems (Schönbeck, 2002, pers. comm.). Free stall barns are recommended for several reasons, *i.e.* animal welfare and labour efficiency. The liquid manure handling system is recommended by the Swedish Board of Agriculture due to fewer losses during storage and spreading of manure compared with other systems (Swedish Board of Agriculture, 1997; 1999b). Free stall barn systems must be optimised both from animal welfare aspects and from the aspects of ammonia emission. Especially in The Netherlands, research has been focused on solveing the latter problem. Monteny (1996) reported that in cubicle houses for dairy cows with slatted floor and scrapers, flushing with water reduced ammonia emissions by approximately 20%. Using sloped concrete floor with a central urine gutter reduced ammonia emission by 48% (Swiestra , Smits & Krodsma, 1995).

The general opinion is that nitrogen losses are higher from liquid manure compared with solid manure (Karlsson, 1996). However, there are several reports that question this conclusion, or at least give a more complicated picture.

Kulling *et al.* (2001) investigated both different types of dairy manure storage and the influence of dietary crude protein content on emission of ammonia, nitrous oxide and methane. They investigated four types of dairy manure storage systems, *i.e.*, deep litter manure (10 15 kg straw per cow and day), farmyard manure (1 – 2,5 kg straw per cow and day), ordinary slurry and urine-rich slurry. The manure was stored for 7 weeks. Ammonia emissions were reduced due to the content of crude protein in all manure types except deep litter manure. Deep litter manure had the lowest emission of ammonia. In a laboratory experiment, Dewes (1999) compared liquid manure from cattle with two types of solid cattle manure, one based on a straw content of 2.5 kg straw per livestock unit and day and solid manure based on a straw content of 15 kg per livestock unit and day. The conclusion was "that the storage of solid manure may be associated with lower ammonia emission compared with the storage of liquid manure". This was explained by the fact that the maximum heat of the manure, due to self-heating, was reached earlier in solid manure with a high straw content. When the maximum heat was reached, then NH^{+}_{4} was rebound by NHC-heterotrophic metabolism and this was dependent on the content of C (straw). Dewes (1999) concluded that in practise the opinion is that ammonia emissions are higher from solid manure but considered that a comparison in practise is not made on the same assumptions; solid manure is often stored in open heaps with a convex surface and a large ammonia-emitting area compared with liquid manure stored in a tank with a plane surface. Petersen *et al.*(1998) compared solid cattle and pig manure stored during 9 – 14 weeks under spring, summer and autumn conditions and found higher ammonia emission in pig manure than in cattle manure. They explained this as a difference in dry matter content, 15 – 18 % in cattle manure compared to 24% in pig manure. Hence, the temperature was never raised in the cattle manure and the composting process did not start (Sommer, 1999). This is in accordance with a Swedish investigation where cattle manure did not compost in contrast to pig manure (Forshell, 1993). Sommer & Dahl (1999) found, in a Danish investigation, small nitrogen losses in composted deep manure litter from cattle.

In summary; the trend towards free stall buildings, which is positive in animal welfare aspects and labour aspects, puts a great challenge on solving the problem with ammonia release in free stall barns.

Farm level

Altogether 283 dairy farms without manure export had farm gate balances from both 1997 and 1998. Of these, 270 farms had information on the manure system. In Table 16 nitrogen surplus, nitrogen efficiency and nitrogen surplus per tonne of milk in 1997 and 1998 are shown. The average values for nitrogen efficiency or nitrogen surplus per hectare in 1997 and 1998 were used in the calculations.

Table 16. *Nitrogen surplus, nitrogen efficiency and nitrogen per tonne of milk, 1997 and 1998*

	Nitrogen surplus per hectare		Nitrogen efficiency		Nitrogen per tonne of milk	
	Mean	S.D	Mean	S.D	Mean	S.D
1997	163	61	29	11	28	9
1998	146	56	32	11	28	13

Influence of mineral fertiliser, milk yield per hectare and sugar beets

As expected, nitrogen from mineral fertiliser significantly influenced on both nitrogen surplus per hectare and nitrogen efficiency. The same effects were found for milk yield per hectare except when dairy farms below 5 000 kg milk per hectare were excluded (Table 17). Probably this is explained by the great variation in nitrogen surplus among dairy farms. Nitrogen surplus per tonne of milk was significantly influenced by milk yield per hectare, mineral nitrogen per hectare and the proportion of sugar beet on the whole farm when dairy farms with a milk yield below 5 000 kg /ha were excluded.

The main crops at the dairy farms were grass and grain. Sugar beet was the third crop on approximately one-third of the dairy farms (Table 18). The dairy farms growing sugar beet were generally larger, had less area of grass and more area of grain and also had a higher annual milk yield per cow; on the other hand, they had a lower milk yield per hectare (- 1590 kg /ha, Table 18). The reason for the lower nitrogen surplus per hectare and the better nitrogen efficiency for dairy farms growing sugar beet was probably the difference in farm size and the output of nitrogen in crops. The more varied production on the dairy farms growing sugar beet was reflected in the higher output of nitrogen in their crops. On farm level, the nitrogen surplus per hectare will decrease and nitrogen efficiency will be improved when the output of nitrogen from crops increases (Granstedt, 2000). The higher input of nitrogen to these farms is probably explained by the higher nitrogen rate to sugar beet and grain compared with grass. Grassland in Sweden is often a combination of grass and clover and, therefore, the nitrogen rate to grassland does not exceed 100 kg nitrogen/ha (Table 19). Dairy farms growing sugar beet had a better nitrogen efficiency, which is shown by the significant positive correlation coefficient as well as the analysis of variance (Table 18).

Table 17. Significant factors influencing N efficiency and N surplus as identified by analysis of variance, together with correlation coefficient (from Paper IV)

	All dairy farms	Dairy farms with a milk yield per hectare below 5 000 kg /ha excluded		
	n = 270	n = 160		
	N efficiency	N efficiency	N surplus per hectare	N surplus per tonne milk
Manure handling system	ns	ns	ns	ns
Milk yield per hectare	***	ns	***	***
Mineral N per hectare	*	**	***	***
Proportion of farm as sugar beet	***	***	ns	*
Correlation coefficients				
Milk yield (kg/ha)	-0.35	-0.04	0.45	-0.30
	***	ns	***	***
Mineral nitrogen (kg/ha)	-0.03	-0.14	0.48	0.33
	ns	ns	***	***
Proportion of farm as sugar beet	0.49	0.37	0.02	0.13
	***	***	ns	ns

ns = not significant * $P<0.05$. ** $P<0.01$. *** $P<0.001$

Table 18. *Farm characteristics, input of N, N surplus per hectare and N efficiency for farms with and without sugar beet. Average values from 1997 and 1998 except milk yield per cow and herd size (from Paper IV)*

	Dairy farms without sugar beet n = 177		Dairy farms growing sugar beet n = 93		
	Median	Range	Median	Range	*P* for sugar beet
Farm size [3] (ha)	50	15-486	75	22 – 1245	0.02
Area of grass [3] (ha)	31	5- 194	28	2 - 152	0.1093
Area of grain [3] (ha)	16	0.2 - 334	35	5 - 739	<0.0001
Area of sugar beet (ha)	0	-	8	2 - 324	-
Herd size [3] 1997	38.9	10-139	42.5	13-329	0.1798
Milk yield in 1997 [1] (kg /cow and year)	8683	5440-11234	8949	5784-11328	0.0255
Milk yield [3] (kg /ha)	6441	2285-25647	4850	1167-13291	<0.0001
Mineral [1] fertiliser (kg N /ha)	88	1.18-174	108	25-185	<0.0001
N fixation [3] (kg N /ha)	23	3-79	19	3-55	0.0014
Purchased concentrate [3] (kg N /ha)	76	9-326	55	5-191	0.0004
N output in milk and livestock [3] (kg N /ha)	37	0.4 - 127	23	0 - 62	<0.0001
N output in crops [3] (kg N /ha)	12	0 - 78	42	3 - 108	<0.0001
N surplus [3] (kg N /ha)	160	58-328	143	53-311	0.0036
N efficiency [2] (%)	27	10-63	38	19-62	<0.0001

[1] analysed by T-test (SAS 1985)
[2] analysed by T-test after transformed to log 10 (SAS 1985)
[3] analysed by the non-parametric Wilcoxon test (SAS 1985)

Table 19. *Recommended rates for N fertiliser in Southern Sweden (Modified from The Swedish Board of Agriculture, 2001) (from Paper IV)*

Crop	Wheat	Barley Oats	Grassland, 2 harvests	Grassland, 3 harvests	Grassland with 50 % clover, 2 harvests	Sugar beet
Expected yield (t/ha)	7	6	7	8	7	45
kg N/ha	150	105	145	205	85	120

Milk yield per cow and year and nitrogen surplus and nitrogen efficiency

Information on the milk yield per cow and year was available from 1997. In Table 20 the result from the correlation analysis shows a positive significant correlation between nitrogen surplus per cow and milk yield per cow and year and a negative significant correlation between nitrogen surplus per tonne milk and milk yield per cow and year.

Table 20. *Correlation analyses. Values from 1997*

	Milk yield per cow and year 1997	Herd size, 1997	Nitrogen surplus per cow, 1997	Nitrogen surplus per tonne milk 1997
Milk yield per cow and year 1997	----			
Herd size, 1997	0.03 ns	-----		
Nitrogen surplus per cow, 1997	0.49 ***	0.10 ns	----	
Nitrogen surplus per tonne of milk 1997	-0.21 ***	0.03 ns	0.57 ***	------

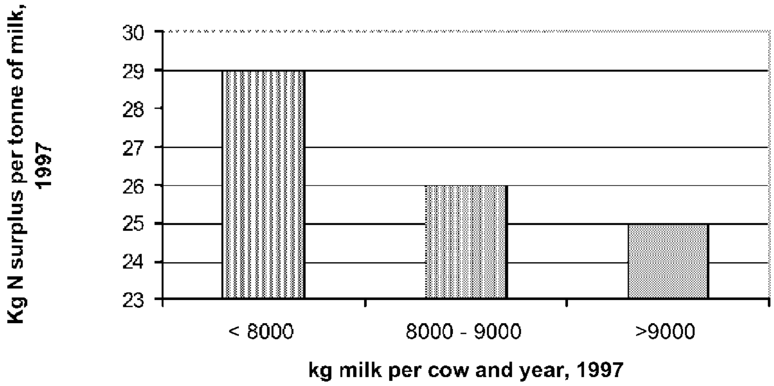


Fig. 13. Nitrogen surplus per tonne milk according to milk average herd level of milk yield per cow and year.

Influence of manure handling systems

A comparison of nitrogen efficiency or nitrogen surplus was made between dairy farms with solid manure handling system and liquid manure handling system. In this investigation, a few farms with deep straw bedding or a mixed manure system were excluded from the analysis. There was no significant effect of manure handling system on the nitrogen surplus per hectare or on nitrogen efficiency. It was concluded that farm size and herd size were bigger in farms with a liquid manure system compared with those based on solid manure ($p < 0.0001$). Dairy farms with a liquid manure handling system tended to have a lower input of N from mineral fertiliser than farms with a solid manure handling system (ns). This is in accordance with findings from Myrbeck (1999).

Recommendations from the Swedish Board of Agriculture (1997, 1999b) strongly focus on switching to liquid manure handling systems (Gustavson, 1998). These recommendations are based on the well established fact that ammonia emission during spreading of manure is higher from solid manure than from liquid manure, although some findings question this (Kulling *et al.*, 2001). It is more important that ammonia emission from spreading of manure is influenced by many factors. Temperature, wind speed, incorporation in the soil of manure are examples of this. Still, it is possible to model ammonia emissions from liquid manure, *i.e.* the ALFAM model (Sommer, Hutchings & Carton, 2001). However, according to Sommer & Hutchings (2001) ammonia emission from solid manure during spreading is impossible to predict due to lack of information and interrelationships between many factors. All together this means that it is a difficult task to optimise the spreading of manure to lower the ammonia emission. In theory liquid manure is probably right, in practise it is a problem to utilise the advantages with liquid manure.

There could be several explanations of this. First, farmers maybe not sufficiently consider the value of nutrients in manure, they have a lack of confidence in the value of nutrients in manure (Steineck *et al.*, 2000). Secondly, they have difficulties in utilising the nutrients in the right way. The farmers have to choose between many important things, which not always favours measures giving low ammonia emissions. For example, the advisors recommend that liquid manure should be spread after the first harvest of roughage to decrease the content of clostridia spores in silage, but at this time the temperature is high and increases ammonia emissions. Thirdly, another problem, at least in southern Sweden, is that many farmers let machine stations spread liquid manure and they have no time to wait for optimal weather conditions.

Nitrogen efficiency and nitrogen surplus at farm level

The desk study (Paper III) concluded that nitrogen surplus, N kg /ha, should approximately be around 140 kg nitrogen per hectare with the intensity of 8 600 kg milk per hectare. Nitrogen efficiency was about 25 30 % at the same intensity. So what is the situation in practice? In Paper IV the following regression equation was obtained, based on data from two years;

N surplus per hectare (kg/ha) = 77.6 + 0.0126 * milk production (kg/ha)

The intensity of 8 600 kg milk per hectare gives a nitrogen surplus of 186 kg N/ha, 40 45 kg above the result from the desk study.

Comparison of nitrogen balances from three years, 1997, 1997 and 1999

In Table 21 the results from farm gate balances over three consecutive years are summarised. These results are based on dairy farms selling both crop products and animal products such as milk and meat. It was a significant decrease of nitrogen surplus between the first year and second year, maybe best explained by a decrease in the rate of nitrogen from mineral fertiliser. On the other hand, the input of N from concentrate per hectare remained the same during the three years. In Table 22 the farm gate balances from 1998 was divided in farms with or without an output from crops together with an output from milk and meat. Hence, the first group is directly comparable to the desk study. The results from the field investigation compared with the desk study show a higher surplus in practice than in theory. But average values in the investigation are not particularly high, especially when considering the uncertainty in calculations (Table 8). The large variation between different dairy farms is more striking.

Table 21. *Farm size, milk production input of N, N efficiency and N surplus, 1997, 1998 and 1999, n = 138 (From Paper V)*

Factor	1997 Mean	SD*	1998 Mean	SD	1999 Mean	SD	*P* for year
Arable land, hectare	58 a	51	66 a	61	66 a	62	ns
Total milk delivery per year, kg	371347 a	254152	394027 a	268864	420021 a	290740	ns
Delivered milk yield, kg/ha	6917 a	2319	6622 a	2513	6865 a	2219	ns
N from mineral fertiliser, kg N/ha	101 a	39	88 b	35	91 b	33	0.0101
N from purchased feed, Kg N/ha	86 a	40	80 a	41	86 a	44	ns
N from fixation by leys (N/ha)	33 a	21	26 b	20	26 b	18	0.0020
N efficiency, %	24 a	8	27 b	8	29 b	8	0.0025
N surplus, kg N/ha	187 a	57	161 b	57	167 b	57	0.0002

SD = standard deviation, ns= non significant

a,b Values within a row without a common letter differ significantly

Table 22. *Farm size, milk production input of N, N efficiency and N, P and K surplus 1998. Dairy farms with output from milk and livestock – crops or without output from crops (from Paper V)*

Factor	Farms without output from crops	Farms with output from both livestock and crops	*P* for with/without
Number of farms	28	110	-
Arable land, hectare	56	68	ns
Total milk delivery per year, tonnes	374	399	ns
Delivered milk yield, kg milk /ha	6801	6576	ns
N from mineral fertiliser, N/ha	88	89	ns
N from purchased feed, N/ha	85	80	ns
N from fixation by leys, N/ha	30	24	ns
N surplus, N/ha	180	157	0.0783
N efficiency	21	29	0.0001
P surplus, P/ha	7	5	0.0151
K surplus, K/ha	32	26	0.0237

Ns=non significant p>0.1

In summary: describing nitrogen efficiency at dairy farm level is a difficult task depending on the definition of a farm. As discussed in Paper V, the definition of a dairy farm is not similar in Sweden and in EU. Another difficulty in comparing nitrogen efficiency between dairy farms is the influence of stocking rate. The simple statement is; "the higher the stocking rate the higher the surplus". As shown previously, it may be better to state that within a certain stocking rate there is great variation in both nitrogen surplus and nitrogen efficiency (Fig. 14). Hence, many dairy farms have an opportunity for improvements in this matter (Halberg, 1999;Kristensen & Börsting, 2001). Maybe the best advice is that dairy farms should not compare the nitrogen balances with nitrogen balances from other dairy farms, instead they should compare with themselves.

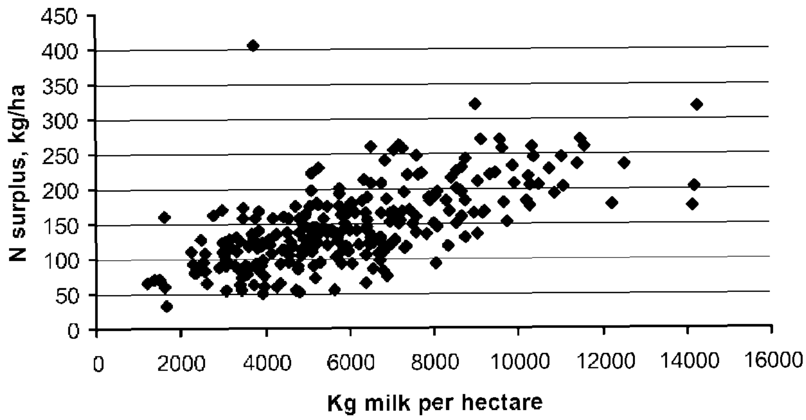


Fig. 14. Nitrogen surplus, kg N / ha in relation to kg milk per hectare. Year 1998.

Human level

A dairy farm, or any farm at all, is not a machine, it is a living system. As indicated in Fig. 6 (Methodological consideration), a farm can be described as a system with both technical and human components. Someone has said that a farmer makes at least 100 decisions per month, which have influence on the nitrogen flows on and off the farm. Therefore, it is important to highlight the human component of the farm. What are the goals and attitudes of the farmer?

van der Ploeg (1996) distinguishes between at least 5 farming styles in The Netherlands: economical farmers, intensive farmers, large farmers, cow men and machine men. These styles have different strategies and goals with their production. The answers to the environmental pressure in The Netherlands have made different responses according to farming styles. Between 1986/87 and 1990/91 the intensive farmers decreased the nitrogen surplus by approximately 60 kg per hectare compared with the cow men with a decrease of 180 kg nitrogen per hectare and machine men with a reduction of 250 kg nitrogen per hectare. The bottom line is; what is good farming practise? The answers must be that it differs between farmers.

A comparison of attitudes towards nature and the environment between agricultural students at Alnarp and Swedish citizens showed both similarities and differences (Swensson, 2002; Uddenberg, 1995). A majority of agricultural students, compared with ordinary Swedish citizens *i.e.*, the man in the the street, do not think "human beings and animals have the same value and have the same right to live". The majority of the students have been working within livestock production and it is almost an every-day decision to decide whether or not animals are going to live or die.

Also a majority of agricultural students compared with ordinary Swedish citizens consider that it is possible to divide animals and plants into harmful and useful categories. These concepts are included in the agricultural sector. Both groups agreed that environmental problems are a threat to the future of human beings. On the other hand, there was disagreement if "Nature's own balance is the best for human beings, animals and plants and therefore human beings should not disturb this balance", "Human beings have no right to destroy the possibilities of animals and plants to survive" and "The interference of human beings make nature more ugly". It is a challenge to farmers to cultivate without destroying nature.

Another survey was carried out among the dairy farmers joining Skånemejerier's environmental bonus campaign (Bernle, 2001).This study was based on two groups of farmers depending on the result from farm gate balance calculation; one group with a nitrogen surplus below 200 kg nitrogen per hectare and another group of dairy farmers above this limit. All the dairy farmers had been calculating a nutrient balance sheet during three years. The number of cows were between 20–80 dairy cows, milk yield above 5 000 kg sold milk/hectare. A telephone interview was made with the farmers. The interviews lasted between 60–120 minutes. Altogether 13 dairy farmers were interviewed.

Most of the farmers agreed with the negative environmental impact from agriculture, although some of them mentioned the industry sector as being a greater threat to the environment. Dairy farmers with a low nitrogen surplus did have lower inputs of nitrogen. These dairy farmers declared that they choose to decrease the input of nitrogen from purchased mineral fertiliser due to the possibility of negative environmental impact. The attitudes concerning the concept "Environmental bonus" were also different in the groups. Group "low" had a positive attitude towards this concept. Most of the farmers knew the content of crude protein in their silage, but none of them knew the content of crude protein in the total diets of the dairy cows. Hence, they had no idea of how the diets could influence ammonia release, as shown in Papers I and II.

Still, conclusions from this type of survey must be handled with great care. First, the studies are not made at the same time which means that attitudes can have changed. Secondly, especially the last survey is based only on a small number of interviews.

However, the results presented above indicate differences among dairy farmers towards environmental concern. It is not difficult to believe that a farmer with good knowledge of the nitrogen cycle in nature and with environmental concern does not exaggerate the rate of nitrogen fertiliser to the crops, thinks about the content of crude protein in the dairy cow diet, and spreads manure at the right time with great care. These types of farmers probably voluntarily join both the environmental bonus campaign and "grab the nutrients campaign". But how about the others?

One big problem on dairy farms is to balance the nitrogen from manure with nitrogen mineral fertiliser. The solution is not to skip manure or mineral fertiliser but to mix the use of these resources in the right way. This is in accordance with the conclusion of Körtschens (2000) that "highest yields are only attainable in an environmentally acceptable way in a combination of organic and mineral fertilisation". Still there are numerous of socio-psychological constraints among farmers and advisers to overcome before this can be used properly (Nowak *et al.*, 1998). To avoid the farmer's uncertainty about the manure's nitrogen content, it is better to use both manure and mineral fertiliser. A shortfall or surplus in nitrogen originating from manure is much less than if the farmer trusted only manure (Smith & Chambers, 1995). Hanegraaf (1998) considers that nitrogen surplus can be reduced substantially by better nitrogen management at farm level in The Netherlands. From England, Dampney, Lord & Chambers (2000) report that "a major difficulty that has been identified in campaigns to reduce nitrate pollution is convincing farmers that they are responsible in the most part for nitrate pollution problems and that the required changes in practise can be justified on economic or other grounds". Meyer (2000) states that the human component in managing manure is more important to study than new research on storage, collection, transportation and utilisation of manure.

Final Discussion

A higher milk yield per cow means, on average, a higher nitrogen surplus per cow. On the other hand, the nitrogen surplus per tonne of milk decreases (Fig. 13). If we focus only on the product milk this means that it is better to have a higher milk yield per cow with regard to nitrogen surplus. Still, it indicates that it is better, in general, to have high-yielding cows, assuming that the milk yield per hectare is not too high. The intensity of a dairy farm affects nitrogen surplus and nitrogen efficiency. The intensity can be expressed as kg milk per hectare or stocking rate. Korevaar (1992) reports from The Netherlands that nitrogen surplus per hectare increased from 297 kg N/ha to 442 kg/ha when kg milk/ha increased from 8667 kg N/ha to 20 510 kg N/ha. The intensive dairy farms had a higher input of nitrogen fertiliser and also had to buy more roughage and concentrate. Halberg et al. (1995) found also a correlation with the intensity, expressed as stocking rate, of the dairy farm and the nitrogen surplus. At least under Swedish conditions, it is better to use kg delivered milk per hectare than stocking rate as an indicator. An animal density with a cow milking 6000 kg milk per year compared with a cow milking 12 000 kg milk per year has a totally different nitrogen surplus per hectare. A better definition of animal density, at least in dairy production, is kg milk per hectare. Kg delivered milk is measured by the dairies every second day and Swedish dairy farms deliver very small amounts of milk to other buyers. Stocking rate, expressed as animal units per hectare, varies a lot more, and information on the number of the young animals is often lacking.

The results in Papers IV and V show that nitrogen surplus in Swedish dairy production is lower than in dairy production in Denmark and The Netherlands. This is probably best explained by lower animal density-kg milk per hectare and a lower inflow of purchased mineral fertiliser. Land in Sweden is cheap compared with other countries in western Europe and therefore dairy farms are generally larger. One of the reasons for cheaper land is the climate in Sweden, which influences both the average crop yields and the choice of crops. An average Swedish farmer cannot compete with colleagues in France, Germany, the Danish islands or The Netherlands on crop yields. This also means that the average ratio of nitrogen to crops is lower in Sweden than in these countries due to expected lower yields. Another striking difference between Sweden and the other countries is the lower deposition of atmospheric nitrogen in Sweden. This input of nitrogen may be up to 6 times higher in The Netherlands and Germany. In many ways, the lower use of fertilisers by conventional Swedish crop farmers make them more similar to organic farmers compared with conventional crop farming in western Europe. On the other hand, due to the high milk yield per cow and year in Sweden, Swedish dairy production has a similar or higher inflow of nitrogen from purchased feed than conventional dairy production in western Europe.

Comparison between conventional and organic dairy farming

Today, the Swedish government is encouraging a change from conventional agriculture to organic farming, sometimes called sustainable farming. Narrowing the discussion to dairy production and nitrogen flows at farm level, the most important changes are that nitrogen from mineral fertiliser is not allowed and the dairy herd should be self-supporting with at least 50% home-grown feeds. It is also stated in the rules that the dairy cows should have the possibility to go outside during the winter period on a hardstanding.

Comparison of the nitrogen surplus and nitrogen efficiency at organic dairy farms with conventional dairy farms has been done by, e.g., Halberg *et al.* (1995), Daalgard *et al.* (1998), Cederberg & Bergström (1999), Cederberg & Matsson (2000) and Myrbeck (1999). All these investigations have calculated farm gate balances according to the BIO model (see page 28) These authors, except Myrbeck (1999), claim that a change to organic dairy farming probably should decrease the nitrogen surplus and, at least in Denmark, would improve nitrogen efficiency. Myrbeck (1999) analysed balances from 1300 farms in Sweden, among them 608 dairy farms. The following conclusions were made from this study concerning dairy farms; there was a great variation between dairy farms, more intensive dairy farms had a higher nitrogen surplus, and there was a tendency for nitrogen efficiency to decrease. Organic dairy farms had a better nitrogen efficiency compared with conventional dairy farms. This material was not analysed statistically. However, there are some difficulties in making these comparisons. First, and naturally, animal densities are lower in organic dairy farming compared with conventional farming. Cederberg & Mattson (2000) use the Life Cycle Assessment (LCA) method to compare a conventional dairy farm with an organic dairy farm in

Sweden. They found a lower nitrogen surplus and a better nitrogen efficiency at the organic dairy farm. But the conventional dairy farm in this study had more than twice as much kg milk per hectare compared with the organic dairy farm. The LCA-method has advantages, but one disadvantage is that they have difficulties in considering the variation in the parameters. The standard deviation in our studies was 57 kg for nitrogen surplus per hectare (Table 20). This corresponds to Halberg *et al.* (1995), who had a standard deviation of 52 kg on 16 conventional dairy farms. Both Halberg *et al.* (1995) and Dalgaard *et al.* (1998) make comparisons at the same stocking rate and still found lower nitrogen surplus in organic dairy farming. However, kg milk per hectare is lower in organic dairy farming in the investigation made by Dalgaard *et al.* (1998). Secondly, it is difficult to estimate the nitrogen fixation by legumes. Organic farming is, of course, highly dependent on nitrogen fixation and, therefore, it is important to estimate this figure correctly. In Table 23, a comparison is made of conventional and organic dairy farming made in Denmark and Sweden. The investigations in Table 23 are not made in the same years, still they highlight some interesting facts; the input of N from purchased mineral fertiliser is probably higher in Denmark than in Sweden and the input of N from atmosphere is higher in Denmark. The comparison between conventional and organic dairy farming in Table 23 favours organic dairy farming, at least in the context of nitrogen surplus. However, there are several limitations in such a comparison. First, all comparisons should be made, as mentioned above, at the same milk yield per hectare, secondly the crop rotation and the crop production should be as equal as possible, at least the output of crop products should be equal. However, it is striking that the input of nitrogen in conventional dairy farming is not matched with an input of nitrogen fixation. Either conventional dairy farmers underestimate both nitrogen in manure and nitrogen fixation or the nitrogen fixation at organic dairy farms is underestimated. Still, it indicates that there is less circulating nitrogen on organic dairy farms than on conventional dairy farms. However, for economic reasons, organic dairy farmers are also trying to increase both crop yields and milk yields, which means more circulating nitrogen in the system. Probably, this places a higher demand on management skills among organic dairy farmers as they have difficulties in controlling crop diseases and they are more dependent on utilising nitrogen in manure. Inputs of nutrients in organic farming are mostly nitrogen from fixation by clover and legumes, which are difficult to steer to the crops (Torstensson *et al.*, 2000). According to Jarvis (2000), the leakage of N from mineral fertiliser and nitrogen by fixation are at the same level when the same amount of nitrogen is compared. Another problem is that one might suspect that ammonia emissions increase in organic dairy farming, at least, when high-yielding dairy cows are utilised. More legumes and clover are probably going to be utilised in the dairy cow diets in organic dairy farming, both in pasture, and indoor feeding, which leads to a higher content of CP in the dairy cows diets, which may increase ammonia emissions (see Papers I and II).

Table 23. *Comparison of nitrogen surplus and nitrogen efficiency in conventional and organic dairy farming in Denmark and Sweden, average values*

	Number of farms	Nitrogen surplus per hectare Kg N/ha	Nitrogen efficiency %	Stocking rate LU/ha	Kg milk per hectare	Input of N from fertiliser Kg N/ha	Input of N from atmosphere (deposition + fixation) Kg N/ha
Conventional[1]	16	217	16.4	1.5	Not known	161	50
Organic [1]	14	124	20.7	1.06	Not known	0	108
Conventional [2]	1	198	19 [4]	Not known	7415	86	25
Organic [2]	1	65	24 [4]	Not known	3297	0	56
Conventional[2]	14	167	33	0.94	7650	98	36
Organic [3]	12	85	25	0.58	6609	0	84.5
Organic [4]	41	54	29	0.74	2770	0	44 (only fixation)
Conventional [5]	138	161	27	Not known	6622	88	41

[1] Halberg *et al.* (1995), [2] Cederberg & Matsson, 2000, [3] Cederberg & Bergström, 1999; Cederberg, 2002
[4] Myrbeck (1999), median values, [5] Thesis, Table 21 and year 1998

Probably it is better to divide dairy farmers or all farmers according to their intensity, expressed as the attitudes towards striving to be high-producing in every aspect. Driving forces may be economical and/or a more laid–back attitude to farming. In the investigation presented in Papers IV and V, there are dairy farms with a very low input of purchased mineral fertiliser (Fig. 15) and the farmers had no interest in being organic due to the many regulations in organic farming (Påhlstorp, 2001, pers.comm.). Actually, there was a tendency that dairy farms with a low nitrogen surplus in 1997 increased the ratio of nitrogen from purchased mineral fertiliser between 1997 and 1998, and the opposite was noted for dairy farms with a high nitrogen surplus in 1997 (Swensson, 2000).

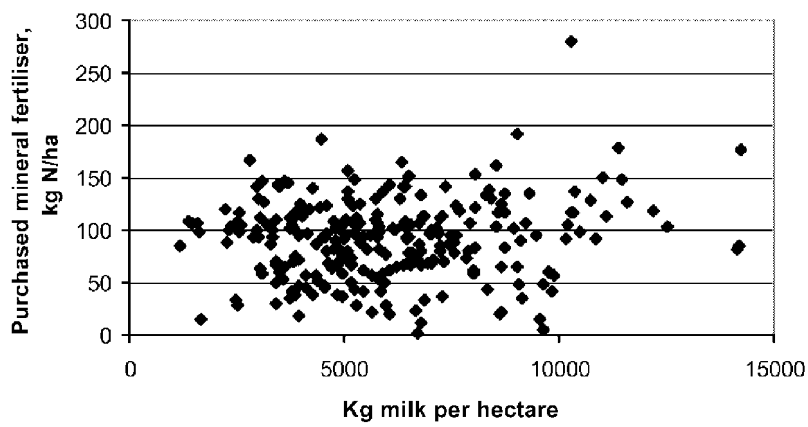


Figure 15. Nitrogen from purchased mineral fertiliser, kg N / ha in relation to kg milk per hectare. Year 1998.

The government's objective to decrease the ammonia emission by 15% compared with the level in 1995

In Table 24 trends in ammonia emission and nitrogen surplus in Sweden are summarised. As with many other things, there are conflicts between different goals inside and outside agriculture which make things complicated.

- As indicated in paper I, there is sometimes an economic advantage in increasing the level of CP in dairy cow diets due to the increased milk production per cow (Fig. 9).
- The trend towards free stall barns is motivated for reasons of animal welfare and probably reduces the labour time per cow but will also increase the ammonia release in the barn (Paper II and Table 15).
- The trend towards specialisation in both crop production and animal production makes it more complicated to utilise manure (Paper V). This may lead to higher ammonia emissions.

Table 24. *A short summary of trends in ammonia release/emission and nitrogen surplus and proposed measures to improve the situation*

	Trend in ammonia release/emission and nitrogen surplus from dairy farms in Sweden	Measures for improvement Farm level	Measures for improvement Extension level	Measures for improvement Research level
Dairy cow diets (Paper 1)	Increasing until now	Decrease the content of crude protein in dairy cow diets Change computer software for dairy cow diets	Focus from high yields in milk production to high net return in milk production	Develop the AAT/PBV-system More focus on high-yielding cows, improve dry matter intake
Cow houses (Paper 2)	Increasing due to more free stall barns	Use of more bedding material	Plan cow houses according to economic, animal welfare and environmental goals	Constructing of houses with a better separation of excreta and manure
Farm level – manure handling systems (Paper 4)	On the same level?	Analyse nutrients in manure Spreading of manure at right time	Education of employees at machinery stations	More research on solid manure handling systems
Farm level – (Paper 5)	Decreasing due lower ratio of nitrogen to crops	Decrease the ratio of nitrogen to crops	The ratio of nitrogen to different crops should more regionally specified	System analysis of dairy farms

The Swedish way to solve the problem with nitrogen surplus is to emphasise good farming techniques. In 2001 the campaign "Grab the nutrients" started. In the beginning this concerned only advisors working with farmers, who join the campaign voluntarily. Today, about 1400 or 25 % of the possible farmers who have joined the campaign (Olofsson, 2002, pers. comm.). This is an example of a very ambitious campaign designed to make the farmers aware of nitrogen surplus problem and then they will, hopefully, utilise nitrogen more efficiently, both in crop and in animal production. Actually, it is similar to the environmental bonus that was introduced in Skåne by Skånemejerier in 1997, in an attempt to restore the nutrient balance in conventional farming. There appears to be no problem to get farmers to join the campaign but comparing it with a similar Dutch campaign some lessons could be learned. The investigation in The Netherlands divides farmers into at least five types and they did not have the same strategy with regard to fulfilling the environmental pressure from society. As indicated in the paragraph "Human level", the intensive farmers did not decrease the nitrogen surplus as much as other types of farmers. Hence, it must be important both in education and extension, to learn and discuss farming as an activity with many different goals. In this respect, organic dairy farming, in most cases have an advantage, because the farmers probably have a broader understanding of the role of agriculture in the society a more holistic view (Lindholm, 2001).

Conclusions

Cow level

- It is possible to lower the content of crude protein in diets to dairy cows to 15–16% CP, if the diet has a good balance with easy digestible carbohydrates
- A high content of CP in dairy cow diets decreases the quality of protein in milk
- It is possible, at least in the south of Sweden, to use only feedstuffs produced in Sweden, without having lower milk yields
- There is a relationship between a dairy cow's intake of nitrogen, urea in its urine and urea in its milk. Hence, if two of the parameters are known it is possible to calculate the third.

Cow house level

- Ammonia emission from the house is dependent on the content of nitrogen in manure, which is chiefly dependent on the amount of urea in the urine.
- The occurrence of ammonia emissions from cow houses is also dependent on the type of manure handling system and the type of cow house. Ammonia emissions increases in the order tie stall barn with solid manure < tie stall barn with liquid manure < free stall barn with solid manure < free stall barn with liquid manure.
- It is possible to characterise the ammonia emissions from cow houses using a quick and simple method without actual measurement of the ventilation rate

Farm level

- Theoretical calculations of nitrogen balances of dairy farms in south Sweden with 8600 kg milk per hectare show that it should be possible to achieve a nitrogen surplus of about 140 kg N per hectare, or an N efficiency of approximately 28%.
- Still, there is a large variation in practice among dairy farms in N surplus per hectare or N efficiency
- The largest inflow of N to a dairy farm is N from mineral fertiliser. N from purchased feed contributes also with a large inflow of N, especially on intensive dairy farms.
- The N surplus and the N efficiency have improved between 1997 and 1998
- There is no effect of the manure handling system on N surplus
- Having sugar beet in the crop rotation improves N efficiency

Regional level

Comparing nitrogen balances in Sweden with nitrogen balances in countries with intensive dairy production, *i.e.* Denmark and The Netherlands, clearly shows that dairy production in Sweden has a minor problem with N-surplus compared with the average situation in these countries.

Areas for further research

Cow level

There is a lack of knowledge on nitrogen balances in high-yielding cows, above 10 000 kg milk per cow and year. Results from Paper I indicate a better nitrogen efficiency than reported in literature for dairy cows.

Cow house level

Ammonia emissions from storage and spreading from liquid manure handling systems are rather well understood. However, solid manure handling systems, including deep straw bedding, need further research due to the fact that solid manure handling systems are the most widely used systems in Sweden. It seems that the latter systems, at least in Sweden, have not been objectively evaluated. Sommer & Hutchings (2001) point out " To our knowledge, there is no information available concerning ammonia losses during handling and spreading of solid manure". However, research have actually been carried out, both in Sweden and other countries (Rodhe, 1998; Kullin et al., 2001; Rodhe, 2002, pers.comm.).

Investigations of the white spots of ammonia emission in milk production, i.e. ammonia emission from hard standings yards, have to be considered. An investigation carried out in Great Britain indicates substantial losses from these areas (Ellis *et al.*, 2001).

Farm level

When comparing manure handling systems, the consequences for soil compaction must be considered (Brundin & Rodhe, 1994).

One way to improve both organic and conventional farming is to breed crops, other than leguminous species, that can utilise biological fixation of nitrogen.

More sophisticated systems analyses are absolutely essential for ranking between different measures to reduce the negative environmental impact of dairy production.

An interesting way of solving the problem with ammonia emission from pasture and, at the same time, mixing the academic disciplines of teaching and of animal science is "to teach cattle to keep moving while urinating and defecating. It may seriously reduce leaching and gaseous losses" (Smaling *et al.*, 1999).

Practical recommendations

Cow level

- For a farmer, dairy farmer or not, the use of farm gate balances is a useful tool to understand the N flows on the farm, and most important, to learn the trends at farm level.
- Diets fed to dairy cows must be optimised for crude protein, not only AAT and PBV. At least the diets fed to dairy cows should not exceed 19% crude protein.
- The most commonly used software in Sweden for compiling dairy cow diets, Individram, should have a possibility to optimise the content of crude protein in the diets, or at least , have a fixed level of crude protein.

Cow house level

- Use a lot of straw or other bedding material in the cow houses. Both to decrease the release of ammonia and for reasons of animal welfare.
- When building a new cow house and having to choose a manure handling system – look at the whole chain when making the choice and consider animal welfare aspects. Do not only make economic calculations.

Farm level

- The decision support system STANK – an extension tool for crop production, has many advantages but also limitations. It should be able to consider the content of crude protein in the cattle diets. In addition as Gustafsson (2000, 2001) points out, the references should be described in greater detail.

- Recommended amounts of N from mineral fertiliser to different crops should be more farm-specific or even field-specific. General recommendations are not adequate and meaningless.
- Take care of, and use, the nitrogen in manure and consider the nitrogen content in manure when planning the need of nitrogen from mineral fertiliser – an old, but still important, advice.

Human level

- There is a need of more education in environmental topics in agriculture, both among students, farmers and advisors. Also a more holistic view on agriculture is preferable.

References

Aarts, H.F.M., Biewinga, E.E. & van Keulen. 1992. Dairy farming systems based on efficient nutrient management. *Netherlands journal of agriculture science 40*, 285 – 299.

Andersson, M. 1994. A climate chamber for measuring ammonia emission. *Proceedings XII World Congress on Agricultural Engineering*, Merelbeke. Belgium. 499 – 506.

Andersson, M. 1995. Ammonia volatilization from cow and pig manure. *Report 98. Department of Agricultural Biosystems and Technology. Swedish University of Agricultural Sciences*, Alnarp. 66 pp.

Animal Protection Act. 1988. *Svensk Författningssamling. SFS. 1998. 534.*

Agriwise.2002. http://www.agriwise.org/. Access 2002-03-08.

Bernle, F. 2001. Kvävestrategier på skånska mjölkgårdar. *Examensarbete i Lantmästarprogrammet. Dept. of Agricultural Biosystems and Technology, Swedish University of Agricultural Sciences.* Alnarp. (In Swedish with English summary). 50 pp.

Breembroek, J.A., Koole,B., Poppe,K.J. and Wossink, G.A.A. 1996. Environmental Farm Accounting: The Case of The Duthc Nutrients Accounting System. *Agricultural systems 51*, 29 40.

Brundin, S.G. & Rodhe, L. K. K. 1994. Comparisons of manure handling systems under Swedish conditions. *Journal of agricultural engineering 58,* 181 –190.

Bussink, D.W. & Oenema, O. 1998. Ammonia volatilisation from dairy farming systems in temperate areas: a review. *Nutrient cycling in agroecosystems 51,* 19 – 33.

Carson, R. 1963. *Tyst vår.* Tidens förlag. Stockholm.. (In Swedish). 410 pp.

Castillo, A.R., Kebreab, E. Beever, D.E. & France, J. 2000. A review of efficiency of nitrogen utilisation in lactating dairy cows and its relationship with environmental pollution. *Journal of animal and feed science 9,* 1 – 32.

Cederberg, C. & Bergström , S. 1999. *Näringsflöden och markanvändning i ekologisk och konventionell mjölkproduktion i Sydsverige.* Hushållningssällskapet Halland. (In Swedish).

Cederberg, C. & Matsson, B. 2000. Life cycle assessment of milk production - a comparison of conventional and organic farming. *Journal of cleaner production 8,* 49 -60.

Cederberg, C. 2002. *Life cycle assessment (LCA) of animal production.* Department of applied environmental Science, Göteborg University. Dissertation. 102 pp.

CIGR. 1984. *Report of working group on climatisation of animal houses.* Scottish Farm Building Investigation Unit. Aberdeen. 72 pp.

CIGR.1992. *2nd report of working group on climatisation of animal houses.* Center for climatisation of animal houses. State University of Ghent. Belgium. 147 pp.

CIGR. 1999. *CIGR handbook of agricultural engineering,* Vol II. ASAE, 41- 53..

Chase, L.E. 1999. *Animal management strategies – how will they change with environmenta lregulations* .CornellUniversity. http://www.ansci.cornell.edu/tmplobs/baaTQCDyb.pdf, Access 2002-03-18

Dalgaard, T., Halberg, N., Sillebak Kristensen, I. 1998. Can organic farming help to reduce N-losses? Experiences from Denmark. *Nutrient cycling in agroecosystems* 52, 277-287.

Dampney, P.M.R., Lord, E.I & Chambers, B.J. 2000. Development of improved advice for farmers and advisers. *Soil use and management 16,* 162 –166.

Dewes, T. 1999. Ammonia emissions during initial phase of microbial degradation of solid and liquid cattle manure. *Bioresource technology 70,* 245 – 248.

Ellis, S., Webb, J., Misselbrook,T & Chadwick, D. 2001. Emission of ammonia (NH3), nitrous oxide (N_2O) and methane (CH_4) from a dairy hardstanding in the UK. *Nutrient cycling in Agroecosystems 60,* 115 – 122.

Elzinger, A. & Swiestra, D. 1993. Ammonia emission measurements in a model system of a pig house. In *Nitrogen flow in pig production and environmental consequences* (eds. M.W.A. Verstegen, L.A. den Hartog, G.J.M. van Kempen, & J.H.M. Metz), 280-285. Wageningen, The Netherlands: Pudoc Scientific Publishers.

EU. 1985. Comission Decision of 5th June 1985 establishing a Community typology for agricultural holdings. *Official journal of the European communities No 220, vol. 28.*

Fagerberg, B., Salomon, E. & Jonsson, S. 1996. Comparisons between Conventional and Ecological Farming Systems at Öjebyn. Nutrient flows and balances. *Swedish journal of agricultural research 26,*169-180.
Frank, B., Gustafsson, G. & Persson, M. 2002. Feeding dairy cows for decreased ammonia emission. *Livestock production science*. In press.
Granstedt, A. 2000. Increasing the efficiency of plant nutrient recycling within the agricultural system as a way of reducing the load to the environment - experience from Sweden and Finland. *Agriculture, ecosystems and environment 80,* 165 - 185.
Groot Koerkamp, P.W.G., Metz, J.H.M., Uenk, G.H., Phillips,V.R., Holden, M.R., Sneath, R.W., Short, J.L. White, R.P., Hartung,J., Seedorf, J., Schröder,M., Linkert, K.H., Pedersen, S., Takai, H., Johnsen, J.O. & Wathes, C.M. 1998. Concentrations and emmissions of Ammonia in Livestock Buildings in Northern Europe. *Journal of agricultural engineering, 70,* 79 - 95.
Gustafsson, A.H. 2000. *Miljöeffektiv utfodring av protein till mjölkkor*. Svensk Mjölks Djurhälso- och utfodringskonferens, Växjö. (In Swedish).
Gustafsson, A.H. 2001. Högre kväveffektivitet i mjölkproduktionen genom ändrad utfodring vad är möjligt att uppnå? *Rapport nr 4999. Svensk Mjölk*. (In Swedish). 21 pp.
Gustafsson, G.1988. Air- and heat balances in animal houses. *Department of Farm Buildings, Report 59, Swedish University of Agricultural Sciences.* Lund.. (In Swedish with English summary). Dissertation. 385 pp.
Gustafsson, G. 1992. Ammoniak i djurstallar. *Fakta Teknik nr 12, SLU*.. (In Swedish). 4 pp
Gustafsson, G., von Wachenfelt, H. & Swensson, C. 2000. A simplified method for evaluation of ammonia release in animal production. *Paper number: 00-AP-023. AgEng,* Warwick
Gustafson, G.M., Salomon, E., Jonsson, S. & Steineck, S. 2001. Preliminary results from a study of fluxes of P, K and Zn in a conventional and ecological dairy farm system through feeds, animals and manure during one year. *Proceedings from Workshop "Element balances as a sustainability tool" in the conference Food 21 – Sustainable Food Production,* March 16 –17th , Uppsala.
Gustavsson, J. 1998. Swedish measures to reduce ammonia emissions. *Nutrient cycling in agroecosystems. 51,* 81 – 83.
Halberg, N. Steen Kristensen, E.S. & Sillebaeck Kristensen, I. S. 1995. Nitrogen turnover on organic and conventional mixed farms. *Journal of agricultural and environmental ethics 8,* 30 - 51.
Halberg, N. 1999. Indicators of resource use and environmental impact for use in a decision aid for Danish livestock farmers. *Agriculture, ecosystems and environment 76,* 17 – 30.
Hanegraaf, C.M. 1998. Environmental performance indicators for nitrogen. *Environmental pollution 102, S1,* 711 - 715.
Hanegraaf, M. 2001. Perspectives and limitations of nitrogen balances. *Proceedings from Workshop "Element balances as a sustainability tool" in the conference Food 21 – Sustainable Food Production,* March 16 –17th , Uppsala.
Hartung, J. 1992. Emission und Kontrolle von Gasen und Geruchsstoffen aus Ställen und Dunglagern. *Zentralbaltt fur Hygien, 192,* 389-418.
Hoffman, H., Johnsson, H., Gustafson, A. & Grimvall, A. 2000. Leaching of nitrogen i Swedish agriculture - a historical perspective. *Agriculture, ecosystems and environment 80,* 277 290
Hultgren, J. 2001. Observational and experimental studies of the influences of housing factors on the behaviour and health of dairy cows. *Acta Universitatis Agriculturae Sueciae, Veterinaria 104. Swedish University of Agricultural Sciences*. Dissertation. 136 pp.
Högh- Jensen, H., Loges, R., Jensen, E.S., Jörgensen, F.V. & Vinther, F.P. 1998. Emiprisk model til kvantificering af symbiotisk kvaelstoffiksering i baelgplanter. In. "Kvaelsofudvaskning og - balancer i konventionelle og ökolgiske produktionssystemer" (Eds. Kristensen, E.S & Olesen, J.E). *Föjörapport 2, Forskningscenter for Ökologisk Jordbrug.* 114 pp.
Jakobsson, C. 1999. Ammonia Emissions – Current Legislation Affecting the Agriculture Sector in Sweden. *Regulation of Animal Production in Europe. KTBL, Arbeitsp. 270,* 208-213.

James, T., Meyer, D., Esparza, E., Depeters, E.J. and Perez-Monti, H. 1999. Effects of Dietary Nitrogen Manipulation on Ammonia Volatilisation from Manure from Holstein Heifers. *Journal of dairy science 82,* 2430 – 2439.

Jarvis. SC. 2001. Improving nitrogen use efficiency from balance sheets: opportunities to reduce losses. *Proceedings from Workshop "Element balances as a sustainability tool" in the conference Food 21 – Sustainable Food Production,* March 16 –17th , Uppsala.

Jeppson, K. H. 2000. Aerial environment in uninsulated livestock buildings.. *Acta Universitatis Agriculturae Sueciae.Agraria 245. Swedish University of Agricultural Sciences*. Dissertation. 128 pp.

Karlsson, S. 1996. Åtgärder för att minska ammoniakavgången i gödsel. *JTI rapport nr 228. JTI.* (In Swedish with English summary). 59 pp.

Keating, B.A. & McCown, R.L. 2001. Advances in farming systems analysis and intervention. *Agricultural systems 70, 2 –3,* 555 – 579.

Kebreab, E. France, J. Beever, D.E. & Castillo, A.R. 2001. Nitrogen pollution by dairy cows ad its mitigation by dieatary manipulation. *Nutrient cycling in agroecosystems 60,* 275 – 281.

Kebreab, E., France, J., Mills, J.A.N, Allison, R. & Dijkstra, J. 2002. A dynamic model of N metabolism in the lactating dairy cow and an assessment of impact of N excretion on the environment. *Journal of animal science 80,* 248 –259.

Kirchmann, H., Esala, M., Morken, J., Ferm, M., Bussink, W., Gustavsson, J. & Jakobsson, C. 1998. Ammonia emissions from agriculture. *Nutrient cycling in agroecosystems 51,* 1 3.

Kohn, R.A., Kalscheur,K.F & Russek-Cohn, E. 2002. Evaluation of models to estimate urinary nitrogen and expected milk urea nitrogen. *Journal of Dairy Science 85*, 227 233.

Korevaar, H. 1992. The nitrogen balance on intensive Dutch dairy farms: a review. *Livestock production science, 31, 1 - 2,* 17 - 27.

Kristensen, T. & Börsting, C.F. 2001. The effect of feeding and dairy production on N surplus at herd and farm level. *Book of abstracts no 7. 26 – 29 august, Budapest, Hungary, EAAP.*

Kuipers, A. & Mandersloot, F. 1999. Reducing nutrient losses on dairy farms in the Netherlands. *Livestock production science 61,* 139 -144.

Kulling, D.R., Menzi, H., Kröber, T.F., Neftel, A., Sutter, F., Lischer, P. & Kreuzer, M. 2001. Emissions of ammonia, nitrous oxide and methane from different types of dairy manure during storage as affected by dietary protein content. *Journal of agricultural science 137*, 235 - 250.

Körtschens, M. 2000. Carbon and nitrogen dynamics as well as nitrogen utilization in dependence on soil texture. *Kungl. Skogs- och Landbruksakademins Tidskrift 8.* 89-98.

Larsson, J. 2001. Manual foderstatsprogram Bioptek.xls. Stencil.(In Swedish). 13 pp.

Lindholm, S. 2001. Helhet och mångfald. *Acta Universitatis Agriculturae Sueciae.Agraria 272. Swedish University of Agricultural Sciences*. Dissertation. 110 pp.

Legg, J.O. & Meisinger, J.J. 1982. Soil nitrogen budgets. 1982. In: *Nitrogen in agricultural soils.* Ed. Stevenson, F.J. ASA,CSSA & SSSA. Madison, USA.

LRF.2001. http://www.miljohusesyn.nu/ 2001-11-28

Madsen, J. 1985. The basis for proposed Nordic protein evaluation system for ruminants. *Acta agriculturae scandinavica, 25,* suppl. 9.

Madsen, J., Hvelplund, T., Weisbjerg, M.R., Bertilsson, J., Olsson, I., Spörndly, R., Harstad, O.M., Volden,H., Tuori, M., Varvikko, T., Huhtanen, P. and Olafsson, B.L. 1995. The AAT/PBV protein evaluation system for ruminants. A revision. *Norwegian journal of agriculture, suppl. 19,*1 – 37.

Magnusson, A-T., Bertilsson, J., Everitt,B., Lindberg, J-E., Sanne, S. & Spörndly,R. 1990. Utvärdering av AAT/PBV-systemet för användning i mjölkproduktion. *Konsulentavdelningens rapporter Hudjur 68. Swedish University of Agricultural Sciences.* (In Swedish). 61 pp.

Meisenger, J.J. & Randall, G.W. 1991. Estimating nitrogen budgets for soil-crop systems. In: *Managing nitrogen for groundwater quality and farm profitability.* Eds: Follet, R.F., Keeney, D.R. & Cruse, R.M. Soil Society of America, Inc. Madison, USA.

Meyer, D. & Denise Mullinax, D. 1999. Livestock nutrient concerns:Regulatory and legislative overview. *Journal of dairy science. 82, Suppl. 2.,* 51-62.

Meyer, D. 2000. Dayring and the environment. *Journal of Dairy Science. 83*, 1419 - 1427.

Monteny, G.J. 1996. Technical possibilities to reduce ammonia emissions from animal husbandry. In: *Progress in nitrogen cycling studies* Eds Van Cleemput. 483 490. Kluwer academic publishers.

Monteny, G.J. & Erisman, J.W. 1998. Ammonia emission from dairy cow buildings: a review of measurements techniques , influencing factors and possibilities for reduction. *Netherlands Journal of Agricultural Sciences*, 46, 225 - 247.

Montgomery, D.C. 2001. *Design and analyses of Experiments. 5th Edi*tion, Wiley.

Myrbeck, Å. 1999. Nutrient flows and balances in different farming systems. *Meddelande från jordbearbetningsavdelningen 8. Dept. of Soil Sciences, Swedish University of Agricultural Sciences,* Uppsala. (In Swedish with English summary).84 pp.

Neeteson,J.J. 2000. Nitrogen and phosphorus mangement on Dutch dairy farms: legislation and strategies employed to meet the regulations. *Biology and fertility of soils 30* ,566 –572.

Nelson, J. 1999. Managing nutrients across regions of the United States. *Journal of dairy science, 82, suppl. 2,* 90-110.

Nielsen, N.M. & Kristensen, T. 2001. Nitrogen excretion and efficiency from dairy cows at herd level on practical dairy farms in Denmark. *DJF rapport nr 33, Husdyrbrug. Danmarks Jordbrugsforskning.*34 pp.

Nowak, P., Shepherd, R. & Madison, F. 1998. Farmers and Manure Management: A critical analysis. In *Animal Waste utilisation: Effective use of Manure as a soil resource.* Ed. Hatfield, J.L. & Stewart, B.A. Ann Arbour Press,Chelsea. ISBN 1-57504-068-9.

NRC, 2001. *Nutrient requirements of dairy cattle, 7th rev. ed.* National Academy Press. Washington, D.C.

Oenema, O. 2001. Improving nitrogen use efficiency from balance sheets: opportunities to reduce losses. *Proceedings from Workshop "Element balances as a sustainability tool" in the conference Food 21 – Sustainable Food Production,* March 16 –17th , Uppsala.

Oenema,O., Boers,P.C.M., van Eerdt;M.M., Fraters,B., van der Meer;H.G., Roest,C.W.J., Schröder,J.J. & Willems,W.J. 1998. Leaching of nitrate from agriculture to groundwater:the effect of policies and measures in the Netherlands. *Environmental pollution 102 (S1),* 471 – 448.

Oenema, O. & Heinen, M. 1999. Uncertainties in nutrient budgets due to biases and errors. In: *Nutrient disequilibria in agroecosystems.* Eds. Smalin, E. M.A, Oenema, O. & Fresco, L.O. Cab International. 336 pp.

Parris, K. 1998. Agricultural nutriemt balances as agri-environmental indicators:an OECD perspective. *Environmental pollution 102, S1,* 219 -225.

Paul, J.W., Dinn, N.E., Kannangara, T & Fisher, L.J. 1998. Protein content in dairy cattle diets affects ammonia losses and fertilzer nitrogen value. *Journal of environmental quality 27,* 528 – 534.

Pedersen, S., Takai, H., Johnsen, J.O., Phillips, V.R., Holden, M.R., Sneath, R.W., Short, J.L., White, R.P., Hartung, J., Seedorf, J., Schröder, M., Linkert, K.H., Metz, J.H.M., Groot Koerkamp, P.W.G., Uenk, G.H., & Wathes, C.M. 1998. A comparison of three balance methods for calculating ventilation flow rates in livestock buildings. *Journal of agricultural engineering research, vol. 20, no 1,* 25-37.

Petersen, S.O., Sommer, S.G., Aaes, O. & Søegaard, K., 1998. Ammonia losses from urine and dung of grazing cattle: Effects of N intake. *Atmospheric environment 32*, 295-300.

Påhlstorp, P-J., Sandgren, P., Swensson, C & Herlin, A. 1997. 25-öringen – rådgivning för ökad lönsamhet inom mjölkproduktionen. *Fakta husdjur nr 7*, SLU. (In Swedish). 4 pp.

Rodhe, L. 1998. Forskningsområde stallgödsel. *JTI Rapport nr 242*. JTI. (In Swedish with English summary). 42 pp.

Sandgren, P., Swensson, C. & Sällvik, K. 1999. Växtnäringsbalanser på mjölkgårdar i södra Sverige. *SSJ - Info 17.* Sydsvensk Jordbruksforskning. (In Swedish).

SAS®. 1985. User's guide: Statistics, version 5 Edition. Cary, NC: Sas Institute Inc.

SAS®. 1986. The SAS System for Windows, Release 6.12. Cary N.C., USA: SAS Institute Inc.

Seedorf, J. & Hartung, J. 1999. Survey of ammonia concentrations in livestock buildings. *Journal of agricultural science, 133,* 433 – 437.

Skånemejerier. 2002. www.skanemejerier.se Access 2002-04-08.

Smaling, E:, Oenema, O. & Fresco, L. Preface. In: *Nutrient disequilibria in agroecosystems.* Eds. Smalin, E. M.A, Oenema, O. & Fresco, L.O. Cab International. 336 pp.

Smith, K.A. & Chambers , B.J. 1995. Muck: From waste to resource. Utilisation: The impacts and implications. *The Agricultural engineer 50*, 33 38.
Smits, M.C.J., Valk, H., Elzing, A. & Keen, A. 1995. Effect of protein nutrition on ammonia emission from a cubicle house for dairy cattle. *Livestock production science 44*, 147 -156.
Spörndly, R. 1995. *Fodermedelstabell för idisslare.* Swedish University of Agricultural Sciences. (In Swedish). 96 pp.
Sommer, S.G. 1999. Lager. In: *Emission af ammoniak fra landbruget – status og kilder*. Eds. Andersen, J. M., Sommer,S.G., Hutchings,N.J., Friis Kristensen,V. & Damgaard Poulsen, H. (In Danish). 77 pp.
Sommer, S.G. & Dahl, P. 1999. Nutrient and carbon balance during the composting of deep litter. *Journal of agriculture engineering research 74,* 145 153.
Sommer, S.G. & Hutchings, N.J. & Carton, O.T. 2001. Ammonia losses from field applied manure. *DIAS report no 60.* Danish Institute of Agricultural Sciences. 112 pp.
Sommer, S.G. & Hutchings, N.J. 2001. Review Ammonia emission from field applied manure and its reduction – invited paper. *European journal of agronomy 15,* 1-15.
Statistics Sweden. 1997. Rapporter från lantbrukets företagsregister 1997. *Statistiska meddelanden, J 30 SM 9802.* (In Swedish with English summary).
Statistics Sweden. 2001. *Yearbook of agricultural statistics.* 327 pp. (In Swedish with English summary).
Steineck, S., Gustafson, G., Anderssson, A., Tersmeden, M. & Bergström, J. 1999. Stallgödseln innehåll av växtnäring och spårelement. Rapport 4974. Naturvårdsverket. (In Swedish).
Steineck, S., Gustafson, A., Richert Stintzing, A., Salomon, E., Myrbeck, Å. Albihn, A. & Sundberg, M. 2000. *Växtnäring i kretslopp*. SLU, Uppsala. (In Swedish). ISSN 1402-7445. 118 pp.
Sveinson, T., Halberg, N. & Kristensen, I.S. 1998. Problems Associated with Nutrient Accounting and Budgets in Mixed Farming. *Proceedings from International Workshop "Mixed Farming Systems in Europe".* Dronten, The Netherlands, 25 - 28th may.
Svensson, L. & Ferm, M. 1993. Mass transfer coefficient and equilibrium concentration as key factors in a new approach to estimate ammonia emission from livestock manure. *Journal of agricultural engineering research 56 (1),* 1 –11.
Swedish Board of Agriculture. 1991. Ammoniakförluster från jordbruket – förslag till åtgärdsprogram. *Rapport 11.*. (In Swedish). 102 pp
Swedish Board of Agriculture. 1994. Ammoniakförluster från jordbruket. (In Swedish). ISSN 1102-3007.
Swedish Board of Agriculture. 1997. Förslag till åtgärdsprogram för att reducera ammoniakavgången från jordbruket. *Rapport 16.*(In Swedish).
Swedish Board of Agriculture.1999a. STANK. Computer model. (In Swedish). 96 pp.
Swedish Board of Agriculture. 1999b. Ammoniak förluster till jordbruket – förslag till delmål och åtgärder. *SJV Rapport 23.* (In Swedish). 103 pp.
Swedish Board of Agriculture. 1999c. Sektorsmål och åtgärdsprogram för reduktion av växtnäringsförluster från jordbruket. *Rapport.* (In Swedish). 163 pp.
Swedish Board of Agriculture. 2001. Riktlinjer för gödsling och kalkning 2002. *Rapport 17.* (In Swedish). 66 pp.
Swedish Dairy Association. 2001.
http://www.kunskapsbonden.svenskmjolk.se/sarsreskokontroll.html. Access 2001-11-19.
Swedish Farmers Supply and Crop Marketing Cooperative. 2001. Värdering av foder. Almqvist & Wiksell, Uppsala. In Swedish.
Swedish government. 2000. Summary of. Gov. Bill 2000/01:130.
Swensson, C., Påhlstorp, P-J., Sederblad, B., Sandgren, P. & Herlin, A. 1997a. " The 25 öre concept" - Benchmarking in Swedish milk production using figures from the book accounting database. *Proceedings from First European Conference for Information Technology in Agriculture,* 15th - 17th june, Copenhagen
Swensson, C., Påhlstorp, P-J., Sederblad, B., Sandgren, P. & Herlin, A. 1997b. Factors associated with profitability of dairy farms in Sweden. *Book of abstracts 48th Annual Meeting of the EAAP,* Vienna 25 –28 august.

Swensson, C. 1998. Mixing the Result from Book-accounting and the Result from the Official Swedish Recording in a Computer to Make Dairy Farms More Profitable. *Proceedings from 7th International Conference on Computers in Agriculture* ,Orlando, Florida.
Swensson, C. 2000. Nitrogen balances as a tool to reshape conventional farming. EURSAFE 2000. *Preprints, EURSAFE, 2nd Congress of the European Society for Agricultural and Food Ethics*. 24 - 26 August, Copenhagen. 253 256.
Swensson, C. 2002. Kunskapssynen hos lantmästarstuderande. Under publicering. (In Swedish).
Swiestra, D., Smits, M.C.J. & Kroodsma, W. 1995. Ammonia emission from cubicle houses for cattle with slatted and solid floors. *Journal of agricultural engineering research 62*, 127 –132.
Tamminga, S. 1992. Nutrition Management of Dairy Cows as a Contribution to Pollution Control. *Journal of dairy science, 75*, 345 – 357.
Tamminga, S. & Verstegen, M.W.A. 1996. Implications of nutrition of animals on environmental pollution. In: *Recent developments in Ruminant nutrition 3* eds. Garnswothy, P.C. & Cole, D.J.A. Nottingham University Press. 370 pp.
Teenstra, E.D. 1997. To live and survive with MINAS. Scientific Report 168. Research institute for Animal Husbandry. University of Wageningen.
Torstensson, G., Gustafsson, A., Bergström, L. & Uhlén, B. 2000. Utredning av effekterna på kväveutlakning vid övergång till ekologisk odling. *Ekohydrologi nr 56*, avd för vattenvård, SLU.
Uddenberg, N.1995. *Det stora sammanhanget*. Nya Doxa, Nora. ISBN 91-88248-92-5. (In Swedish). ISBN 91-88248-92-5. 192 pp.
van Der Hoek, K.W. 1998. Nitrogen efficiency in global animal production. *Environmental pollution 102*, S1, 127 132.
van Keulen,H., Aarts, H.F.M., Habekotte', B., van der Meer & Spiertz, J.H.J. 2000. Soil – plant – animal relations in nutrient cycling: the case of dairy farming system ' De Marke'. *European Journal of Agronomy 13*, 245 –261.
van der Ploeg, J.D. 1996. Bottom-up pressures on intensive livestock systems. In: Livestock farming systems: research, development socio-economics and the land manager. *Proceedings of the third international symposium on livestock farming systems. EAAP publication no 79.*
van Vuuren, A.M. & Meijs,J.A.C. 1987. Effects of herbage composition and supplement feeding on the excretion of nitrogen in dung and urine by grazing dairy cows. Eds. van der Meer,H., Unwin,R., van Dijk,G. & Ennik, G. In: *Animal manure on grassland and fodder crops, fertiliser or waste?* Wageningen. Netherlands.
Wachenfelt, H. 2001. Hur ser det ut i verkligheten. *Konferens, Jordbrukets byggnads och miljöfrågor, 10 – 11 oktober* , SLU Alnarp. (In Swedish).
Wachenfelt, H. & Gustafsson, G. 2001. A simplified evaluation method for arial environment in pig houses. *Report 124. Dept. of Agricultural Biosystems and Technology, SLU* Alnarp.
Watson, C.A. & Atkinson, D. 1999. Using nitrogen budgets to indicate use efficiency and losses whole farm systems: a comparison of three metodological approaches. *Nutrient cycling in agroecosystems 53*, 259 –267.

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Karlson, U-K. Skånemejerier, Lunnarp, Sweden

Lidström, E-M. 2001. Skånesemin, Hörby, Sweden.

Olofsson, S. 2002. Swedish Board of Agriculture, Alnarp, Sweden.

Påhlstorp, P-J.2001. Skånesemin, Hörby, Sweden.

Rodhe, L. 2002. JTI, Uppsala, Sweden.

Schönbeck, PO. 2002. Länsstyrelsen Västra Götaland, Skara, Sweden.

Acknowledgements

I wish to thank everyone who helped me or contributed in any way to this thesis, especially;

Professor Krister Sällvik, my supervisor, for setting the time schedule, for all valuable guidance and support and for good cooperation in the renowned "fikagroup" at JBT.
Associate professor Birgit Frank, co-supervisor and co-author, for support and critical examination of the endless manuscripts I always gave her to review over most weekends.
Professor Gösta Gustafsson, co-author, always being helpful, for turning practice into theory, and critical examination of the statistical parameter R^2.
Eva- Marie Lidström, co-author, for turning theory into practice and for stimulating discussions.
Dr Jan-Eric Englund, Department of Biometry and Informatics, Alnarp, for statistical support and always giving quick and professional service. There are still some statistical rules left to break.
Kerstin Fredlund, Skånemejerier, for interesting discussions, help with, and permission to use, information from "Environmental Bonus".
Ulla-Kerstin Karlsson, Skånemejerier for practical help concerning "Environmental Bonus".
Per-Johan Påhlstorp, for interesting discussions and answering a lot of questions.
Martin Svensson and Tomas Johansson for all work concerning Paper II and Fia Bernle concerning "human level".
Head of Department, Eva von Wachenfelt for giving me time to finish the thesis.
Dr Anders Herlin (thanks for the loan of "Thank you for the music") and Cecilia Lindahl for replacing me in teaching.
Magnus Nilsson, Nils Bengtsson and colleagues for taking care of the heifers at Mellangård.
Nigel Rollison for providing suggestions on how to turn my efforts at English into a more readable version of his mother tongue.
The staff at Alnarp library, for help with literature

To all the colleagues I have been working with at the Swedish University of Agricultural Sciences (SLU), from north to south, no one mentioned, no one forgotten. I think the optimal solution to the organisational problems today afflicting SLU is one department with one coffee table (and someone else making the coffee).

SSJ – Sydsvensk Jordbruksforskning – is gratefully acknowledged for financial support.

To my children, Annika (next stop, Legoland), Olle (welcome on board, skate- or snow-), Emma (horses are cute, guys are ?) and Nicke (Linux is a challenge) for your love, support (although not financial) and all the good fun we have together.