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Life Cycle Assessment of Milk Production - A Comparison of Conventional and Organic Farming

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PREFACE

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A Comparison of Conventional and Organic Farming

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Life Cycle Assessment of Milk Production

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SUMMARY

Life Cycle Assessment (LCA) is a method for assessing the environmental burdens of a product, process or activity through their whole life cycle. The purpose of this study was to identify and quantify the flows of energy and materials in a conventional and an organic milk production system. Important items were to identify the hotspots in the systems studied and to suggest improvements.

The functional unit (FU) was 1 000 kg ECM milk leaving the farm gate. The systems analysed included all phases in the life cycle of fertilisers, feed products, seed, diesel, pesticides and other chemicals. Transport steps were also taken into account. Buildings, machinery and medicines were not included. Allocation between milk and meat (based on casual relationship of fodder intake and output products) was 85 % / 15 %. For ingredients in concentrate feeds, price allocation was used.

Chosen impact categories were: 1) Use of resources: energy, material and land. 2) Human health: pesticide use. 3) Ecological effects: global warming, acidification, eutrophication, photo-oxidant formation and ozone depletion.

Data were collected from two dairy farms in western Sweden with equivalent technology and processes. Data on concentrate feed production were provided from the feed industry in southern Sweden at a high technological level.

The use of energy was 15 % lower in the organic production. This was explained by the feeding strategy, i.e. organic milk production uses less imported concentrate feeds and more roughage based on non-fertilised clover/grass.

The total use of fossil fuel was greater in the conventional production. However, the diesel use was relatively higher in the organic system due to higher reliance on home-produced fodder while the use of natural gas (due to N-fertilisers) was considerably greater in the conventional system.

The use of phosphorus, which is an important resource for agricultural production, was 57 % lower in the organic production.

Land use was significantly higher in the organic system. This was partly due to higher yields in the conventional system, but also due to the choice of concentrate feed. The concentrate feeds in conventional production are co-products from oil/starch/sugar crops, leading to an efficient use of arable land, compared to crops generating only one product.

Pesticide use is significantly higher in conventional production. In some of the crops providing raw materials for the concentrate feed production, hazardous pesticides are used. The minimal use of pesticides in organic milk production is due to restrictions limiting the use of conventionally produced fodder (maximum 5 %).

Milk production generates three important greenhouse gases: CO₂, methane (CH₄) and nitrous oxide (N₂O). However, emissions of CO₂ are of minor importance. The emissions of CH₄ are higher from organic production due to a greater consumption of roughage fodder. On the other hand, N₂O losses are higher in conventional production due to larger N-flows. Due to the uncertainty of the calculations of emissions of CH₄ and N₂O, the difference between the systems were not large enough to be able to promote one production system rather than the other one from a global-warming perspective.

The total potential acidification of milk production is almost exclusively dependent on the ammonia emissions which were higher in the conventional system in this study. These emissions are also a significant contributor to the potential eutrophication of milk. Nitrate losses are yet another contributor. Although nitrate leaching was lower per hectare arable land in the organic system studied, the nitrate loss per kg fodder and consequently the nitrate loss per FU were higher in the organic production.

Identified hotspots in conventional milk production are: use of phosphorus, pesticide use, global warming (especially N_2O but also methane) and losses of nitrogen pollutants resulting in acidification and eutrophication.

Identified hotspots in organic milk production are: global warming (especially methane), land use (merely considering the quantitative area occupancy) and losses of nitrogen pollutants resulting in acidification and eutrophication. To a minor extent, it could be argued that pesticide use is a hotspot here as well, since in the production of the permitted use of 5 % conventionally produced feed, hazardous pesticides may have been used.

Suggested improvements in conventional production are: changes in concentrate feed, improving the nutrient flows on the farm to reduce nutrient surplus and demands for less use of toxic pesticides in imported concentrate feeds. An increased use of domestic/regionally produced rape-seed meal instead of feed ingredients imported from other continents would lower both energy use and pesticide use. If the self-supporting capacity of fodder was increased on the conventional farm in the study, the P-flow would be more efficient. Since grain is purchased from a neighbouring farm, manure could easily be exported there, a measure improving P-cycling and probably also reducing ammonia emissions. Through its purchase of feed components, the feed industry could promote the development of integrated soybean cropping in which toxic pesticides could be replaced by biological substances.

Suggested improvements in organic production are: differentiation in limits of purchased feed and an increase in the self-supporting capacity on the farm. The life cycles of concentrate feeds and their environmental burden should be considered when the limit is established for how much conventionally used fodder can be permitted in organic production. One way is to use a differentiation and to allow a higher limit of feeds with less environmental burden, of which rape-seed meal is a good example. A greater use of concentrate feed in organic milk production (providing this feed has a relatively low environmental burden) could also favour emissions of methane since these are connected to feed composition and quality. The studied farm should try to increase its self-supporting capacity of fodder. One way is to reduce the replacement rate so that fewer heifers have to be fed. Cultivating crops which can produce a great deal of fodder on small areas is another way. Fodder beets are such a crop. This measure could contribute to lower nitrate loss per FU, since the imported crops to the farm studied are responsible for a considerable part of the nitrate loss in relation to their yield.

The overall conclusion of the study is that feeding strategy and methods of fodder cultivation have strong influence on the key environmental impacts of milk production; pesticide use, emissions of nitrate and nitrous oxide from agricultural soils as well as emissions of ammonia and methane from ruminants. When designing future milk production systems, environmental aspects should seriously be taken into account.

SAMMANFATTNING

Bakgrund

I denna rapport redogörs för en livscykelanalys (LCA) av svensk gårdsproduktion av mjölk där konventionell och ekologisk produktion jämförs. LCA är en metod för analys av potentiell miljöpåverkan av produkter, tjänster eller processer. Genom att följa produkten från vaggan till graven kartläggs resursförbrukning samt emissioner till luft, vatten och mark för de olika delarna av livscykeln.

Forskningsprojektets övergripande målsättning var att identifiera och kvantifiera flödena av energi och material i svensk mjölkproduktion och värdera miljöpåverkan av dessa flöden. Genom LCA-metodiken kan de mest miljöpåverkande delarna, så kallade "hotspots", pekas ut och förslag till förbättringar ges. Ett annat syfte med projektet var att samla in data om kraftfoderproduktion och flödena av komponenter i kraftfoder samt att beräkna markanvändningen i mjölkproduktion. Resultaten kan också användas för vidare miljöanalyser av livsmedel.

Utgångspunkten för en LCA är den funktionella enheten, dvs den studerade produktens eller de jämförda produkternas funktion. Den funktionella enhet som valts var 1 000 kg ECM mjölk som säljs från gården. Det analyserade systemet omfattade alla faser i livscykeln av gödsel, foder, utsäde, diesel, pesticider, övriga lantbrukskemikalier (t ex ensileringsmedel). Även transportsteg beaktades. Byggnader, maskiner, mediciner och mindre förmödenheter som diskmedel ingick ej i analysen. Vad som inkluderats i systemet framgår ur flödesdiagram i figur 2.2. Fördelning av resursanvändning och emissioner mellan mjölk och biprodukten kött var 85 % för mjölk och 15 % för kött. Denna fördelning var baserad på relationen mellan inflöde av foder och utflöde i produkter. I kraftfoderproduktionen används nästan uteslutande biprodukter från olje/stärkelse/ socker-grödor och här togs hänsyn till produkternas marknadsvärde för att fördela resurs-användning och emissioner mellan produkterna.

Följande miljöeffektkategorier har beaktats: 1) Resursanvändning i form av energi, material och mark. 2) Mänsklig hälsa i form av pesticidanvändning. 3) Ekologiska effekter i form av växthuseffekt, försurning, eutrofiering, foto-oxidant bildning samt ozonnedbrytande ämnen.

Gårdsspecifika data hämtades från två av Hushållningssällskapetets gårdar i Västsverige där produktionsdata av god kvalitet fanns tillgänglig. Denna metod för datainsamling valdes eftersom det finns en stor brist på grunddata för energi-och markanvändning på gårdsnivå i olika produktionsformer. Båda de studerade gårdarna har kall lösdrift med fullfodersystem och flytgödselhantering. Data för kraftfoderproduktion hämtades från HBKL:s foderfabrik i Falkenberg och råvarutillförsel gäller förhållande under 1996/97.

Resultat

Energi

Energianvändningen var ca 15 % lägre i det ekologiska systemet. Skillnaden kunde nästan uteslutande förklaras i utfodringsstrategi, i detta system används mindre importerat kraftfoder och mera grovfoder vilket baseras på icke-handelsgödselad klöver/gräsvall. Liknande differenser i energianvändning har identifierats i studier av mjölkproduktion i Danmark. De komponenter i kraftfoderblandningarna som orsakar högst energikostnad är råvaror från andra kontinenter (brasilianskt sojamjöl, argentinskt solrosmjöl och palmkärnexpeller från Malaysia), där de långa båttransporterna utgör en betydande andel av energikostnaden. Även betfäber, som utgör en väsentlig del av nötkraftfoder, är energikrävande; i detta fall är det torkningen som orsakar stor energianvändning.

Material

På grund av en betydligt större hemmaodling av foder var dieselförbrukning och därmed den totala förbrukningen av råolja större i det ekologiska systemet. Förbrukningen av naturgas för kvävegödselproduktion ledde dock till att den totala användningen av fossil bränsle var större per funktionell enhet i det konventionella systemet vilket totalt resulterade i högre CO₂-utsläpp. Det förbrukades mer av den ändliga resursen fosfor per funktionell enhet i det konventionella systemet trots att den studerade gården inte tillförde någon handelsgödsel fosfor. Detta beror på att foder inköptes från odlingar där handelsgödsel fosfor tillförts.

Mark

Markanvändningen var väsentligt högre i det studerade ekologiska systemet. I detta system användes 3 464 m² mark för foderproduktion per funktionell enhet medan motsvarande ytanvändning var 1 925 m² i det konventionella systemet. Förutom att skördenivån var lägre för de ekologiska grödorna vilket förbrukade större arealer, ledde också kraftfodervalet till olika arealbehov. På den ekologiska gården i studien användes ansevärliga mängder arter i foderstaten vilka krävde betydande arealer att odla fram. Användningen av biprodukter i kraftfoderproduktionen i konventionell mjölkproduktion innebär ett effektiv markutnyttjande eftersom man får ut flera produkter på ett hektar, t ex olja + mjöl från rapsodling och socker + betfäber + melass från sockerbetsodling. I beräkningarna av markanvändning har hänsyn tagits till alla produkter som produceras per ytenhet.

Pesticider

Användningen av pesticider var, som väntat, väsentligt högre i det konventionella systemet, i foderproduktionen användes motsvarande ca 75 gram aktiv substans per funktionell enhet. I odling av majs (Frankrike) och sojabönor (Brasilien) som är råvaruleverantör av majs glutenmjöl och sojamjöl till kraftfoderindustrin, används pesticider som är förbjudna i svenskt lantbruk på grund av deras toxicitet och lätttröglighet i marken. Drygt 5 gram aktiv substans per funktionell enhet användes i det ekologiska systemet vilket motsvarade pesticidanvändningen i det konventionellt producerade foder (maximum 5 %) som är tillåtet att använda enligt KRAV:s regler.

Växthuseffekt

Produktionen ger upphov till tre viktiga växthusgaser; koldioxid, metan (CH₄) och lustgas (N₂O). Endast en mindre del av mjölkproduktions potentiella påverkan på växthuseffekten kan förklaras av CO₂-utsläpp. Metanutsläpp från djurens ämnesomsättning representerade mer än hälften av den totala potentiella växthuseffekten från mjölkproduktion och är särskilt betydelsefullt i det ekologiska systemet eftersom den mer grovfoderbaserade foderstaten i detta system också resulterar i större metanutsläpp från djuren. Även N₂O -utsläpp är betydelsefulla för mjölkproduktionens potentiella växthuseffekt, i motsats till metan är det dock den konventionella produktionen som ger upphov till större utsläpp. Förluster av N₂O-N är proportionella till tillfört kväve, och i konventionell produktion är kväveflödet större eftersom både stallgödsel och handelsgödsel tillförs. Dessutom sker utsläpp av lustgaskväve vid handelsgödselproduktion. I studien tenderar det konventionella systemet att ha något högre utsläpp av växthusgaser per funktionell enhet än det ekologiska systemet. Skillnaden är dock liten och kunskapen om emissionernas storlek av CH₄ och N₂O är ännu begränsad, varför det inte med säkerhet går att uttala sig om en fördel/nackdel för någon av produktionsformerna.

Försurning

Utsläpp av försurande ämnen i mjölkens livscykel är svaveldioxider, kväveoxider och ammoniak. SO₂ och NO_x beror på användningen av fossila bränsle, framförallt diesel och båttransporter. Den totala potentiella påverkan på försurning från mjölkproduktion beror nästan

uteslutande på NH_3 -utsläpp, i synnerhet från stallgödselhanteringen. Det konventionella systemet i studien visar ett något högre totalt utsläpp av försurande ämnen.

Eutrofiering

Utsläpp av syreförtärande ämnen från produktionen är kväveoxider och ammoniak till luft samt nitrat och fosfat till vatten; NO_3 och NH_3 stod här för nästan det totala potentiella bidraget till övergödning. Det ekologiska systemet uppvisade här en något högre potentiell påverkan. Trots att kväveläckaget var lägre per hektar åker på den studerade ekologiska gården, var nitratförlusterna per kg foder foderspannmål och arter relativt högre p g a den lägre skördenivån jämfört med den konventionella gårdens foderspannmål. Värt att notera är ammoniakutsläppen stora betydelse också för denna miljöeffektkategori.

Marknära ozon

Det ekologiska systemet uppvisar större utsläpp av föreningar som bidrar till bildning av foto-oxidanter, marknära ozon. Trots att användningen av fossila bränsle totalt var lägre i detta system, var dock användningen av diesel större per funktionell enhet och här ger förbränning upphov till emissioner av kolväten och koloxid.

Hotspots i konventionell produktion bedöms vara: användning av material (fosfor), pesticidanvändning, växthuseffekt (speciellt lustgasutsläpp men även metan) samt utsläpp av kväveföroreningar vilka kan orsaka förurning och övergödning. Fosfor är en ändlig resurs vilken nästan uteslutande används i jordbruk (handelsgödsel och fodermineraler) och för att främja en långsiktig produktion av mat måste denna resurs användas på ett hållbart sätt.

Eftersom den konventionella gården i studien har betydande inköp av importerat foder, har denna produktion indirekt medfört att några mycket toxiska kemikalier använts på andra platser i världen. Även om den kvantitativa markanvändning för den konventionella produktionen befanns vara väsentligt lägre, kan importen av framförallt sojamjöl leda till negativa miljöeffekter p g a markanvändningen i andra delar av världen. Den omfattande odlingen av den yteffektiva proteingrödan sojaböna i Brasilien kan lätt leda till markerosion och odlingen har expanderat genom uppodling av naturliga savanner ("cerrados") där biodiversiteten är hög. Utsläppen av lustgas som har en stor potentiell påverkan på växthuseffekten (310 kg CO_2 -ekvivalenter) är 35 - 45 % större i det konventionella systemet p g a större kväveflöden.

Hotspots i ekologisk produktion bedöms vara: växthuseffekt (speciellt metan), markanvändning samt utsläpp av kväveföroreningar som kan orsaka förurning och övergödning.

Utsläppen av metan har beräknats till drygt 12 % högre per ko i det ekologiska systemet eftersom foderstaten är betydligt mera grovfoderbaserad. Eftersom metan har en stor potentiell påverkan på växthuseffekten (21 kg CO_2 -ekvivalenter), får denna gas mycket högt genomslag, nära 2/3 av den ekologiska mjölkproduktionens totala potentiella bidrag till växthuseffekten utgörs av metan. Den betydligt större markanvändningen i ekologisk produktion kan ses som en hotspot, att observera är dock att markanvändningens kvalitativa aspekter ej har beaktats. Ett viktigt miljömål för svenskt lantbruk är det öppna landskapet med hög biodiversitet och i dagens läge är det snarare bristen på betande idisslare än för stor markanvändning som är ett problem.

Förslag till förbättringar

Konventionell produktion: förändringar i kraftfoder, förbättra näringsflödena på gården för att minska näringsöverskottet, garantier på importerat kraftfoder för minskad användning av toxiska pesticider.

En ökad användning av inhemskt/regionalt producerat värmebehandlat rapsmjöl istället för foderråvaror importerade från andra kontinenter skulle minska både energi- och pesticid-användning. En ökad användning av HP-massa istället för torkade betfiberprodukter är ett bra miljöval för mjölgårdar i Sydsverige.

Om självförsörjningsgraden av foder skulle bli högre på den konventionella gården i studien skulle fosforflödet bli mera effektivt. Eftersom spannmål köps in från en granngård, kan växtnäring i stallgödsel återföras dit, en åtgärd som skulle förbättra fosforcirkulationen och minska fosforuttag, samt sannolikt också reducera ammoniakutsläppen. När råvaror köps in för kraftfoderproduktion, bör garantier krävas för hur odling och produktion har skett. Sådana åtgärder skulle kunna befrämja utvecklingen av integrerad sojabönsodling i Brasilien och leda till en minskad användning av toxiska pesticider.

Ekologisk produktion: differentiering av gränsen för tillåten mängd konventionellt producerat foder och en ökad självförsörjningsgrad av foder.

Olika kraftfoderkomponenters livscykel och deras miljöbelastning bör beaktas när gränser fastställs för hur mycket konventionellt producerat foder som tillåts i ekologisk produktion. Genom en differentiering kan större användning tillåtas av foder med förhållandevis låg miljöbelastning, värmebehandlat rapsmjöl är ett sådant exempel. En större användning av kraftfoder i ekologisk mjölkproduktion (förutsatt att detta foder har relativt låg miljöbelastning) kan också minska utsläppen av metan eftersom dessa är beroende av fodersammansättning. Den ekologiska gården i studien bör försöka att öka sin självförsörjningsgrad av foder. Ett sätt är att minska rekryteringsandelen så att färre kvigor behöver utfodras. Odling av fodergrödor som ger mycket foder på liten yta är ett annat sätt, fodersockerbetor är en sådan gröda. En sådan åtgärd sannolikt leda till lägre nitratförluster per funktionell enhet, eftersom nuvarande inköpta fodergrödor till gården (ekologiskt korn och ärter) har högt nitratläckage per kg produkt.

En viktig sammanfattning av detta arbete är att utfodringsstrategi och odlingsmetoder av fodergrödor har ett stort och avgörande inflytande på viktiga miljöparametrar i mjölkproduktion: användning av pesticider, användning av den ändliga resursen fosfor, emissioner av nitrat och lustgas från åkermark liksom ammoniak och metan från de idisslande djuren. När framtida produktionssystem för mjölk utvecklas, måste dessa miljöparametrar noggrant övervägas.

1 LCA methodology

Life Cycle Assessment (LCA) is a method for analysing and assessing the environmental aspects and the potential impact of a material, product or service throughout its life cycle. When studying the products life-cycle (i. e. from cradle-to-grave) from raw material acquisition through production, use and disposal, a flow model of a technical system is used. In Figure 1.1, the LCA model and LCA procedure are illustrated according to Baumann (1998).

Figure 1.1 The LCA model and LCA procedure according to Baumann (1998). The broken arrows indicates that iterations may be necessary.

This study on milk production is based on the guidelines from "Nordic Guidelines on Life-Cycle Assessment". This manual is the result of a Nordic research financed by the Nordic Council (Lindfors *et al*, 1995).

An LCA includes four phases, the relation between the different phases is illustrated in Figure 1.1, the LCA procedure.

- Goal and scope definition
- Inventory Analysis
- Impact assessment
- Interpretation and Improvement Assessment

Goal and scope definition

The first phase of an LCA is the base for the analysis where the goal of the study is outlined as well as the width and depth of study (the scope). The system boundaries of the LCA should be clearly defined. Flow diagrams can be used to show the different subsystems, processes and material flows that are part of the system model.

The functional unit measures the performance of the system studied and provides a reference to which the input and output data are normalised. In comparative LCAs, comparisons can only be made on the basis of equivalent functions.

Inventory analysis

In the inventory phase, all the inputs to the system such as energy and raw materials, as well as emissions from the system are identified and quantified. This part of the study results in an inventory scheme. The more specific the data are, the more trustworthy the analysis will be. However, due to time and financial means, some average and standard data must be used in the inventory phase. In section 2.4.6, the base for the data quality in this study is described.

The data were systematised and assessed through the software package "LCA Inventory Tool" (LCAiT) which has been developed by Chalmers Industriteknik, Göteborg.

Impact assessment

In the impact assessment, the potential environmental impacts from the studied products or systems are evaluated. Impact assessment is divided into three sub phases:

Classification, where material and energy input and outputs are classified into impact categories. Example of important impact categories are; use of resources (energy, material, land, water), ecological effects such as global warming, acidification etc.

Characterisation, where the contributions to each impact category are assessed by quantitative or qualitative methods. In the characterisation the different flows are multiplied by an equivalent, for example acidification can be weighed into SO₂-equivalents, global warming potential in CO₂-equivalents. After using the weighting factors each category can be summarised. Classification and characterisation are based on accepted scientific results and are often used as the terminal point of the analysis.

Valuation, is the last sub phase where the impact of each impact category is addressed and related to each other, and the total impact is assessed. The purpose is to achieve one index for the products/systems' total environmental impact. The valuation part will always contain element of subjectivity since it can not be based on merely scientific methods but also on subjective valuations.

Different valuations methods are further described in Nordic Guidelines. There are no satisfactory method for evaluating an LCA of the complex systems that agricultural production are. In this analysis, impact assessment consists of classification and characterisation.

Interpretation and improvement assessment

In the interpretation phase of an LCA, the results of the inventory analysis and the impact assessment are critically analysed and interpreted in line with the outlined goal and scope of the study. The interpretation should generate in an improvement assessment, i.e. an identification of opportunities to improve the environmental performance of the studied products, systems or processes.

2 Goal and scope definition

2.1 Purpose

The purpose of this study is to identify and quantify the flows of energy and materials in a conventional and an organic system of Swedish milk production on the farm level and to evaluate the environmental impacts of the flows. The research project aims to penetrate the following items:

- to identify which parameters have the largest environmental impact (‘‘hot spots’’) in the studied systems and suggest to improvements in the systems.
- to test the hypothesis that systems for milk production with a relatively large input of resources in the context of fodder and fertilisers have a greater environmental impact than systems with high self-supporting capacity of fodder and plant nutrients.
- to collect data on production of concentrate feed
- to quantify the area occupancy for milk production

The research project was initiated by SIK, the Swedish Institute for Food and Biotechnology and financed by the Swedish Farmer Foundation for Agricultural Research.

2.2 Functional unit

In order to compare two alternative systems, all emissions and resources were related to a certain quantity of the investigated product. The functional unit is the major function performed by the systems. This unit was defined in the following manner:

1 000 kg ECM milk leaving the farm gate

ECM stands for energy corrected milk (4 %) and is the correction factor used by the dairy industry in Sweden.

2.3 Studied objects

Data were collected from two dairy farms in the west of Sweden, Rossared and Tingvall (see Figure 2.1). Both farms are run by an Agriculture Society and follow a current commercial production scheme.

Rossared has 134 cows and 135 replacement heifers and follows a conventional milk production system. On the Tingvall farm, there are 52 cows and 51 replacement heifers and the farm has been delivering organic milk since 1992.

The farms were chosen to represent the studied products for the following reasons:

- they are run by an Agriculture Society which means that their production data have high quality. For example, all fodder is weighed and there are records for the tractor hours in the crop production
- both farms are specialised milk producers, there are no other products except the co-product meat from the farms.
- the farms have the same feeding system, all components are mixed in a mixer wagon.
- the farms have identical stables, a loose housing system that provides good animal welfare.

Fig. 2.1 The locations of the studied farms

2.4 Scope definition

2.4.1 Description of systems in study

Conventional milk production

Current milk production in Sweden is characterised by an intense production and the dairy cows are among the highest yielding in Europe. In 1996, the number of dairy cows was 466 265 (SCB, 1997). In 1996/97, the average production was 8 200 kg ECM per cow for animals connected with the breeder organisations' milk recording program. Totally 371 948 dairy cows joined this program. Their production is on the average 1 000 kg higher than cows outside the milk recording program. (Carlander C. priv comm 1997). During the 1990s, the intensity in feeding has increased a long with a rising milk yield.

Organic milk production

In 1997, 352 farms with a total of 11 259 dairy cows produced organic milk according to the eco-labelling system KRAV which is the sole environmental marking system for organic milk in Sweden (Asplund, M. priv comm. 1998). Characteristics for this form of milk production are:

Fodder	Limits on input of purchased conventionally-produced feed. Maximum input is 5 % (10 % before November 1997). On a yearly basis, 50 % of the fodder must be produced on the farm itself. Animal feed ingredients are not allowed. During the grazing period, grass must be at least half of the fodder intake (as dry matter). Calves shall be given non-processed milk for the first 10 weeks.
Crops	No synthetic minerals or pesticides are allowed.
Medicines	If medicines are used, the waiting time before delivering milk must be double compared to conventional production.
Animal welfare	The animals natural behaviour shall be promoted, e.g. during the grazing period most of the days shall be spent outdoors. Cows shall be able to give birth in a private loose box.

2.4.2 System boundaries

This analysis deals with all phases of the life cycle of milk as shown in fig. 2.2, including the production of materials and energy used. Transport steps are also taken into account.

Fig 2.2 The figure shows a flow diagram for milk production and flows considered in this study. The organic system does not use any co-products from the sugar industry and has only a minor input of concentrate feeds. Furthermore this system has no input of synthetic fertilisers and pesticides. The conventional system does not use peas as a feed.

The time period is the milk production during one year. The milk yield and fodder consumption on the farms follow the milk recording year 1996/97 which lasts from September 1st until August 31st. The data on the farms' production of fodder crops are from 1996 which is a logical consequence; the fodder cultivated and harvested during summer and autumn 1996 will be consumed during the stable period 96/97. The origin of the ingredients in the concentrate feed reflects the international market where the Swedish feed industry purchased their commodities during the milk recording year 1996/97.

2.4.3 Delimitations

One of the objects of this study is to compare two similar products. Since the stables and farm buildings are principally the same in the two compared systems, buildings are excluded from this analysis.

Capital goods in the form of agricultural machinery were shown to have a considerable impact on the overall energy consumption (approximately 15 %) in agricultural production by Weidema *et al* (1995). Many machines, e.g. harvesters, are used during limited time of the year. However, the machinery is not included in this analysis due to uncertainty and lack of data on machinery used in crop production outside Sweden.

The use of medicines is not included in the analysis. Meeusen-van Onna & Leneman (1996) have shown that medicines are of little environmental importance in Dutch milk production: the impact is smaller than 1 %. Furthermore, using data from only one year and from two farms is too little material to be representative of the use of medicine in different milk production systems. Washing detergents, minor stable equipment such as disinfectants, salt for cows etc are not taken into account.

2.4.4 Co-product allocations

In production processes that generate more than one product (i. e. outputs with a positive economic value as opposed to waste), the environmental effects of the process and the upstream processes have to be allocated between the products. The farms in this study were chosen because they are specialised dairy producers and the only outputs are milk and meat, an inevitable co-product in milk production. This simplifies the calculations, the fertilisers and diesel used on the farms are solely allocated to the fodder production and no other farm products than milk and meat are responsible for these inputs.

Since milk production delivers the co-product meat, environmental impact of beef cattle production can be avoided. By expanding the system boundary to also include meat production from beef cattle, this allocation could have been avoided. This has not been possible due to time and financial means and the allocation is therefore based on the causal relationship between feeding and the output products. The average yearly production of one dairy cow is approximately 8 000 kg milk + one calf + 0.4 slaughter cow. The replacement percent in Sweden is as high as 40 %. This means that principally all the cow calves are kept for replacement since the heifers are 29 months old on average when they give birth to their first calf and start to produce milk.

The input in the dairy cows' feed rations are composed to cover three parts: 1) maintenance 2) pregnancy 3) milk production. Figure 2.3 shows that 50 % of the feeding for pregnancy (i.e. the cow calf) is allocated to milk production and 60 % of the maintenance (40 % of the cow will be meat so this is allocated to meat). Hundred % of the feeding for the cow's milk production is allocated to milk. By making this calculation according to Swedish fodder tables,

approximately 85 % of the yearly fodder intake is due to milk production and 15 % to meat production (Spörndly, 1993).

Figure 2.3 Average yearly products from one dairy cow

In a Dutch LCA for milk and milk powder (Blonk and van Zeijts, 1997) the milk/meat allocation was 83 % / 17 %.

The allocation in this study is 85 % milk and 15 % meat which is a ‘‘biological allocation’’, based on the causal relationship between the fodder input and outputs of milk and meat.

Most of the raw materials in the concentrate feeds are co-products, for example rape seed meal is a co-product in the vegetable oil production and maize gluten meal in maize starch production. Allocation is based on the economic value of these products. When the co-products have a very small value, less than 5 %, they are regarded as waste and only the direct product processes and transports are allocated to the fodder product.

When calculating the area needed to produce milk, mass allocation is used. With this calculation, all the products from one crop are considered, for example, the crop sugar beet yields three products: sugar, beet pulp and molasses.

2.4.5 Chosen impact categories

In the classification, the inputs and outputs of the systems are assigned to different impact categories which are based on the expected type of impacts on the environment. The environmental impact categories considered in this LCA study are:

- Resources - energy and material
- Resources - land use
- Human health - pesticide use
- Ecological effects
 - global warming
 - acidification
 - eutrophication
 - photo-oxidant formation
 - depletion of stratospheric ozone

In practice, the most readily available information is that of materials and energy flow in the life cycle. However, when performing LCA of agricultural production, there are several more parameters that are of great importance to assess. An extensive use of pesticides in agriculture implies to both human health aspects as well as ecological aspects, for example in decreased biodiversity. The occupancy of land for crop production decreases the area available for natural habitats and can also alter the habitats. Depending on cultivation methods, the farming systems have a long term impact on soil quality. It is also debatable whether animal welfare should be included in an LCA. All in all, performing a complete LCA of agricultural products is a very complicated task and still under development.

Human exposure to toxic substances causes health problems and the use of pesticides in agricultural production can give exposure through air, water, soil and especially through the food chain. Other effects of pesticide use are ecotoxicological impacts in aquatic and terrestrial systems. Indirectly, discharges of pesticides can also contribute to decreased biodiversity. Most of the methods for toxicity assessment need more elaboration and this is further discussed in the Concerted Action Report on Harmonisation of Environmental Life Cycle Assessment (Audsley *et al* 1997). In this analysis of milk production, the quantitative use of pesticides per 1 000 kg milk is calculated and, according to the Nordic Guidelines of Life-Cycle Assessment (Lindfors *et al* 1995), a "red-flag" classification is used. This is a method to explicitly point out hazardous compounds by putting a red flag beside the relevant chemicals. Examples of reasons for red-flagging are:

- chemicals that are banned in some countries
- chemicals that are expected to be banned
- chemicals that are regulated with respect to their use
- chemicals that have been classified as carcinogenic

The base for red-flagging in this study is chemicals which are prohibited in Swedish agriculture according to *Bekämpningsmedel 1997* (Pesticides 1997).

Omitted impact categories in this analysis are water use, human health - non-toxicological impacts and working environment, soil quality, eco-toxicological impacts, habitat alterations and impacts on biological diversity.

2.4.6 Data quality

The usefulness of an LCA depends to a great extent on the quality of input data. Transparency in reporting data and calculations is essential. According to Nordic Guidelines on Life-Cycle Assessment, the following items can be used as a check-list for data quality assessment.

Acquisition method

All data from the farms studied are measured data and only asserted to milk production with the exception of electricity consumption which has been divided between milk production and other activities on the farms through estimations. Data from the feed industry in Sweden and Norway are calculated data based on measurements. Data on fertiliser and pesticide production follow the European average for crops outside Sweden while specific Swedish fertiliser production data are used for the conventional farm's fertilising. Data on cultivation of crops outside Sweden for the concentrate feed production are based on qualified estimates by agricultural experts and statistics.

Independence of data supplier

There are differences in the degrees of independence of the data suppliers. The farms in this study and the Swedish feed industry are enterprises with interest in the study and they have given verified information. Nutrient emissions in Sweden were calculated with verified information from public authorities. Cultivation data for crops outside Sweden are mostly given by growers' associations.

Representative samples

The data collection method of this study was to choose a small number of enterprises (two farms) with high quality data based on continuous measurements. The fodder consumption per 1 000 kg ECM has been compared to similar producers and is within a reasonable range. The feeding system used by both farms (mixer wagon and a whole mixed fodder) can give 5 - 10 % higher consumption than a system where each cow is fed individually. Also the loose housing

system where the cow can move around and exercise outdoors in a exercise yard all year around, can contribute to a higher fodder consumption than in a tie-up cow-house.

Data age and geographical correlation

All data are from recent time, being a maximum of two years old. Due to an increasing interest in the production background of the imported commodities to the Swedish feed industry, the aim was that of obtaining specific data on each important oil/starch crop where the co-products are imported for production of concentrate feeds.

Techological correlations

The farms studied were chosen because of their equivalence in technology and processes.

3 Inputs in agriculture

Primary food production is a basic production using direct renewable energies such as sun, water and wind. The modern agricultural production is, however, largely dependent on non-renewable energy and imported resources. Direct energies (i.e. energy carriers) are essentially used for their energy properties and thereby assessed on the basis of their energy content. In contrast, indirect energies (such as fertilisers, feed, pesticides and machines) are assessed on the basis of the energy required for their use according to the production inventory. Audsley *et al* (1997) define different types of energy as follows:

Process energy is the energy input required and consumed by the considered process to operate within the process phase, excluding production and delivery energy (example: diesel consumption in a tractor).

Inherent energy (feedstock energy) is the extracted energy which remains in the product after its production and delivery to its site of use (example: natural gas in the production of N-fertilisers).

Production and delivery energy is the energy input into the process which extract, process, refine and deliver energy and material inputs to a process.

Total process energy is the sum of process energy and of production and delivery energy of both the energy and material input to the process.

Total inherent energy is the sum of inherent energy and of production and delivery energy

Total energy is the sum of total process energy and total inherent energy

3.1 Energy carriers and related emissions

3.1.1 Energy data

The most frequently used energy carriers and their inherent energy content in this study are listed in table 3.1

Table 3.1 Energy content in energy carriers (Audsley *et al* 1997)

Energy carrier	Inherent energy content, MJ kg ⁻¹
Diesel ¹	42.8
Hard Coal	27.1
Natural gas	46.1
Oil	42.7
Electricity	1 MJ MJ ⁻¹

1) 1 l diesel = 0.84 kg diesel = 35.95 MJ

The production and delivery energy for diesel is approximately 10 % of the inherent energy.

The total energy for the production of 1.0 MJ diesel is 1.07 MJ crude oil which corresponds to 25.1 g crude oil and 0.03 MJ natural gas corresponding to 0.58 g natural gas (LCAiT)

The energy use is presented as use of primary energy and use of resources (see section 10).

The consumption of primary resources for electricity depends on the origin of the input electricity. In the database of LCAiT, the mix of electricity sources per MJ Swedish electricity is: hydropower 0.47 MJel, nuclear power 0.560 MJel corresponding to 0.0032 g natural uranium¹, and the minor primary resources for Swedish electricity production²: coal 0.013 MJel, oil 0.021 MJel, natural gas 0.0031 MJel, peat 0.0015 MJel, renewable fuel 0.015 MJel.

¹ 1.0 g natural uranium corresponds to 504 MJ heat. Assumed efficiency: 0.35

² The efficiency for electricity production is assumed to be 0.33.

3.1.2 Emissions

Some important emissions factors for the main energy carriers in this analysis are shown in Table 3.2.

Table 3.2 Emissions at final use; g per MJ fuel (LCAiT database)

Energy carrier	CO ₂	CO	HC	Particles	NO _x	SO ₂
Diesel	74.60	0.300	0.200	0.100	1.300	0.140
Diesel, boat	74.60	0.140	0.00996	0.110	0.740	1.280
Natural gas	55.2	0.001	0.000015	0.0130	0.150	0.002
Oil	75.808	0.0129	0.00956	0.003	0.150	0.380

In the total emissions from combustion, emissions at extraction are also included. For example, extraction emissions for diesel are 10.4 g CO₂ per MJ, 0.044 g NO_x per MJ, 0.021 g SO₂ per MJ.

Emissions factors for diesel used in tractors and harvest machines vary from different sources; a summary is shown in Table 3.3. The reference Audsley refers to is an EU concerted action project for harmonisation of LCA for agriculture. The Swedish data come from the Swedish EPA "Air 90 - programme of action against air pollution". The emissions from final use of diesel according to LCAiT are recalculated in the table.

Table 3.3 Example of combustion emissions, g per kg fuel, from the use of diesel in tractors and harvest machines

	HC	CO	NO _x	part	SO ₂	CO ₂
Audsley ¹		29.1	57.1		4.15	3040
53 KW turbo tractor, >1980 ²	5	16.8	67.2	4.6	4.2	3045
53 kW tractor >1980 ²	6.7	16.8	63	7.1	4.2	3234
40 kW tractor ²	10.5	21	63	7.1	4.2	3360
Harvest machines ²	8.4	21	63	7.1	4.2	3234
Diesel, LCA-it ³	8.56	12.84	55.6	4.3	5.99	3193

1) Audsley et al 1997

2) Kartläggning av förorenande utsläpp från traktorer, arbetsmaskiner mm. Identification of polluting emissions from tractors etc. Swedish EPA (SNV 1990)

3) Emissions used in all diesel combustion in this study (LCA it)

When comparing the emissions from diesel combustion from the different sources, it becomes clear that some of the emissions figures for tractors are higher but they can also be lower than ordinary diesel use. However, the Swedish emission factors of diesel in tractors are now being investigated and it appears that the extent of emissions is not only dependent on the amount of fuel combusted but also on the type of work the tractor is performing. The emissions of NO_x, CO etc appear to be higher per MJ fuel during heavy work (for example ploughing) than light tractor work (such as pesticide application) (Hansson, P-A. priv.comm. 1998).

3.1.3 Transports

The concentrate feeds are passed along different transport routes before ending up at the farms. The energy requirements for transport from the LCAiT database is shown in Table 3.4.

Table 3.4 Energy consumption in transports

Mode of conveyance	MJ per kg km
Boat, ocean-going	0.0002
Boat, coastal traffic	0.00047
Road, long distance	0.001
Tractor ¹	0.0027

1) Data for tractor has been calculated by author assuming a load of 10 tonnes, average speed of 20 km h⁻¹ and a diesel consumption of 15 l h⁻¹

3.2 Fertilisers

3.2.1 Nitrogen

Fertiliser production, especially the production of nitrogen, is energy demanding. Practically the entire modern N-fertiliser production is dominated by the Haber-Bosch ammonia synthesis. Ammonia is produced from water, air and energy, and the energy source is usually natural gas, thus providing hydrogen as well as energy. Today, the steam reforming of natural gas or other light hydrocarbons is the dominating production process for ammonia synthesis in Europe (EFMA 1995).

Ammonia is converted into different N-fertilisers such as ammonium nitrate, urea, mono/diammonium phosphate. Patyk (1996) presents data stating that calcium ammonium nitrate (CAN) and urea are the most frequently used fertilisers in Germany. In Table 3.4, the total energy use for production of these N-fertilisers is shown.

Table 3.5 Energy use in production of chemical N-fertilisers (MJ kg N⁻¹)

N-fertiliser	inherent energy	total process energy	total energy
ammonium nitrate 27.5 % N	30.5	15.1	45.6
ammonium nitrate 34.5 % B	30.5	13.8	44.3
Urea	30.5	32.5	63

Source: Audsley *et al* 1997

As an average for the N-fertiliser used in crops cultivated outside Sweden, 45.6 MJ kg N⁻¹ in the form of natural gas are used. The emission of CO₂ is calculated on the whole amount of natural gas used in the process, both as feedstock and as energy source.

There is a large variation of energy consumption in different fertiliser industries and ammonia is an international trade product being hard to follow to its basic production site in every separate analysis. Hydro Agri Europe gives data on their ammonia production varying from 36 - 60 MJ kg N⁻¹ (Bertilsson, G. priv. comm.). The N-fertiliser used by the conventional farm in this analysis originates to a great extent from Hydro fertiliser industry in Landskrona, southern Sweden. In most cases, this industry purchases ammonia from producers with low energy requirements. When the ammonia is refined into ammonium nitrate in the factory in Landskrona, there is a delivery of surplus energy to the municipal heating system in the city, resulting in a net gain of fossil fuel corresponding to 5.3 MJ kg N⁻¹. The total energy use for ammonium nitrate from Landskrona Sweden used in the conventional system is estimated as 33.3 MJ kg N⁻¹.

Average data on process emissions in production of chemical N-fertilisers are given in Table 3.6.

Table 3.6 Process emissions from production of N-fertilisers (kg kg N⁻¹)

emission	to air	to water
N ₂ O	0.016	
NH ₃	0.013	
NO ₃ ⁻		0.00022
NO _x	0.013	
Total-N		0.06

Source: Bockmann *et al* 1990

3.2.2 Phosphorus

Weidema *et al* (1995) summarise different data on production of P-fertilisers. These production data on P-fertilisers include mining of the phosphate rock, conversion of the tri-calcium phosphate in the rock into phosphoric acid and the final production of super phosphates. Total energy requirement of this process is calculated as 26.3 MJ kg P⁻¹ by Weidema *et al* (1995) and the energy source is assumed to be mainly fuel oil.

Table 3.7 Process emissions from production of triple superphosphate (g kg P⁻¹), energy production emissions excluded.

Air emissions	g/kg P	Water emissions	g/kg P
Fluorides	0.46	As	0.01
P ₂ O ₅	0.45	Cd	0.01
NO _x as NO ₂	5.43	Cu	0.05
Particulates	2.32	Cr	0.05
SO _x as SO ₂	11.45	Hg	0.0095
		Ni	0.04
		Zn	0.06
		Fluorides	167
		P ₂ O ₅	103
		Pb ^{2&4+}	0.043
		Gypsum	7500

Source: Audsley *et al* 1997

3.2.3 Potassium

The energy consumption of the K-fertiliser production (including mining) is given by Bockmann *et al* (1990) and calculated to 5.0 MJ kg K⁻¹. The energy sources are assumed to be 87 % fuel oil and 13 % diesel. According to Audsley *et al* (1997), the emissions associated with K-fertiliser production, excluding energy emissions, are not known.

3.2.4 Lime

Varying estimates of the energy requirement for the mining and milling of limestone are presented in different studies according to Weidema *et al* (1995). This source assumes a primary energy requirement as 0.8 MJ diesel per kg CaCO₃.

3.3 Pesticides

There is information about energy requirements for the production of only a few pesticides from Green (1987), and these are listed by Audsley *et al* (1997). Emissions from pesticide production can be regarded as negligible.

Table 3.8 Total process energy for some pesticides used in conventional system

	MJ kg ⁻¹	Main energy carrier
Glyphosate	454	electricity
Bentazon	434	electricity

No energy data are available for the active substances tribenuronmethyl, propikonazol and pirimicarb applied in conventional winter wheat. The energy requirements for these pesticides are assumed to be as for glyphosate.

The energy requirements for pesticides applied in oil/starch crops that provide raw material for concentrate feed are not considered. This is because there is an uncertainty concerning the average use of pesticides; also, energy data is only available for a limited number of pesticides. But above all, the energy cost of pesticides in these crops is negligible when compared with the energy requirements for cultivation, transport and processing of the ingredients in the feed concentrates.

3.4 Other chemicals

Other chemicals of importance in this analysis are silage agents used in both systems and NaOH used in the conventional system for preserving grain.

3.4.1 Silage agents

Myric acid comes from Perstorps AB, a large plastic producer in Sweden. In the production of polyalcohols, natrium formate is a co-product. Natrium formate is reacted with H₂SO₄ forming myric acid and Na₂SO₄. The direct energy consumption is 0.1 kWh electricity per kg myric acid and it takes one tonne of sulphuric acid to produce one tonne of myric acid (85 %) (Ausfeldt, K. priv.comm. 1997). Sulphuric acid comes from Kemira, Helsingborg and is produced from elementary Sulphur. Energy requirements for producing this acid are estimated as 1 MJ per kg H₂SO₄, process emissions 0.002 SO₂, 0.003 SO₃, 0.0005 NO_x per kg H₂SO₄ (Buwal 1996). Myric acid is used in the organic system.

The silage agent Promyr is used in the conventional system. Seventy percent is a mixture of propic acid and myric acid and 30 % is ammonia. Due to lack of data, the whole acid part is accounted for using data for myric acid. Energy data for ammonia is according to Buwal (1996).

3.4.2 Lye (NaOH)

Instead of drying the grain, the conventional farm uses natrium hydroxide (99 %) for preparing the grain after harvest. Energy requirements for NaOH is according to Buwal (1996). Process emissions are not considered.

3.5 Seeds

If the method of seed production is similar to crop production, as for grains, the difference in production of seed and crop are assumed to be small. Seeds in wheat, barley and grain have been net calculated in this study and increased by 10 % to compensate for higher cultivation costs in seed production.

3.5.1 Seed production of grass and clover

The seed production of clover and grass varies significantly from the cultivation of silage and hay. Data on production for seeds for leys and grassland are based on cost estimates on cultivation of red clover and timothy from the seed company Svalöf Weibull AB (Nilsson, L. priv comm. 1997).

Table 3.9 Data on clover and grass seed production (south of Sweden)

	Red clover	Timothy
Yield, kg ha ⁻¹	385	550
N-fertiliser, kg kg seed ⁻¹	0	0.18
P-fertiliser kg kg seed ⁻¹	0.0390	0.0273
K-fertiliser kg kg seed ⁻¹	0.0779	0.0545
Pesticides, kg kg seed ⁻¹	0.0051 kg Bentazon 0.0013 kg MCPA 0.0013 kg Diquat	0.001 MCPA 0,0000545 kg fenvalerat
Field operations	Sowing, fertiliser spreading, pesticide application = 3.12 h ha ⁻¹ Assumed diesel 8 l hour ⁻¹ Harvester 1.7 h ha ⁻¹ . Assumed diesel 14 l/hour. Total diesel use: 0.127 l diesel kg seed ⁻¹	Sowing, fertiliser spreading, pesticide application = 2.87 h ha ⁻¹ Diesel use 8 l hour ⁻¹ Harvester 1.5 h ha ⁻¹ . Assumed diesel 14 l hour ⁻¹ . Total diesel use: 0.08 l diesel kg seed ⁻¹
Drying, cleaning and packaging	No data	
Transport	No data	

The conventional system uses a combination of 20 % clover and 80 % grass in the leys.
The organic system uses a combination of 30 % clover and 70 % grass.

4 Concentrate feeds

The milk production in Sweden is based on high yielding cows. However, their consumption of grain and concentrate feeds is large in comparison with some similar European countries (Sahlberg, 1994). The most frequently used raw materials in concentrate feed for cattle (dairy and beef) are soymeal, different types of rape seed meal and beet pulp from the sugar industry (Foderstatistik 1997). The trade of concentrate feed commodities is extensive, not only on a regional basis, but to a great extent also between continents. In Figure 4.1 (page 23), the present flows of commonly occurring feed ingredients are shown.

4.1 Data from Swedish feed industry

Both the studied systems have an input of concentrate feeds to their production; however, the conventional system has a substantially higher input per cow. The farm representing the conventional system uses the products *Elit* and *Protein-mix* which come from the HBKL's feed industry in Falkenberg. The conventional farm also has a substantial input of co-products from the sugar industry in southern Sweden in the form of super pressed pulp (*HP-massa*) and dried molassed beet pulp (*Betfor®*). The organic system, represented by the farm Tingvall, purchases the feed product *Protein-mix* from the Odal feed industry in Lidköping and the rape seed meal product *ExPro®* from Karlshamns AB. The situation of these industries is shown in Figure 4.2.

Figure 4.2 The situation of the feed industries in Falkenberg and Lidköping. In Karlshamn rape seed meal is produced. Köpingsbro and Örtofta are two sugar industries.

The product *Elit* is the most frequently used feed for dairy cows in Sweden and it is a complement to hay, silage and grain in the dairy cow's feed ration. Data on the standard composition of this product were provided by the central organisation of the co-operative feed industry, and is shown in table 4.1 (Cederberg, L.-G. priv comm 1997). The exact recipe for the product *Elit* used in the conventional system in this study is confidential but follows the standard composition presented below. Both farms also use the concentrate feed *Protein-mix* which is found in different formulations in the Swedish feed industry. This is a mixture of soymeal, rape-seed meal and maize gluten meal in fairly equal parts.

Fig 4.1 Material flows in the production of concentrate feeds

Table 4.1 Standard ingredients in the concentrate feed Elit for dairy cows

	>20%	>15%	>10%	<10%	>5%	<5%
Dried beet pulp	x					
Soymeal		x				
Maize gluten meal			x			
Expro®, sunflower meal				x		
Rape seed cake, palmkernel expeller					x	
Rape seed, potato protein						x

The HBKL feed industry in Falkenberg manufactures 200 000 tons fodder yearly, 40 % were feed for cows in 1995. This feed factory has recently been certified according to EMAS and ISO 9002. Depending on product and recipe, 60 - 80 % of the raw materials for the feed production are imported and transported by boat. After the feed components have been mixed, the feed is expander treated and pelleted. The expander treatment means a heating of the feed which, together with the pelleting process, demands energy in the form of steam. Data from HBKL are according to Dressler R. *et al* 1997.

Table 4.2 Energy consumption and energy carriers in the production of Elit

	MJ ton ⁻¹	Energy carrier
Discharging cargo	7.2	electricity
Handling of raw materials	7.2	"
Grinding, mixing	46.8	"
Expander treatment, pelleting	313.2	40 % el., 60 % gas
Total	374.4	

The product Protein-mix is not expander treated and the energy consumption is thereby lower; 259.2 MJ ton⁻¹. The energy data from the HBKL feed industry for the production of the concentrate feed Protein-mix are also used for the organic system.

4.2 Data on production of concentrate feeds components

In this section data on cultivation, processing and transports of the different ingredients in the concentrate feed are reported. Energy requirements for seed production and pesticides in these crops are not included in the analysis; they represent a very small part of the total energy consumption.

4.2.1 Rape seed and rape seed meal (ExPro®)

One consequence of the implementation of the EU's agricultural policy in Sweden is that the profitability in growing rape seed has deteriorated; in 1996, the rape seed acreage had decreased to 65 400 ha, corresponding to only 2.5 % of the utilised Swedish arable land. Rape-seed meal and rape seeds are important ingredients in the concentrate feed and, due to the decrease in domestic cultivation, about half of the rapeseed used in the oil-and feed industry is imported, mainly from Germany and Denmark. Most of the rape-seed meal in the Swedish concentrate feed originates from the edible oil industry Karlshamn Sweden AB, whose division Karlshamns Crushing & Feed has a yearly capacity of processing 250 000 ton rape seed. Similar to the edible oil industry Denofa in Norway (see 4.2.2), Karlshamn's has a heat treatment of the extracted meal resulting in a feed with a higher value for cows than standard rape seed meal.

This product is called ExPro®. The allocation for oil and meal from rape seed is shown in Table 4.3

Table 4.3 Allocation of rape seed oil and meal

Products	Mass allocation ¹ %	Market price ² US dollar/ton	Price allocation %
Rape seed oil	40	540	67
Rape meal	58	176	33 (chosen allocation)

1) Mass allocation according to Boulder, R. 1985.

2) Price according to lowest asking prices for Nearest Forward Shipment, 1996/97, *Oil World* no 36, vol 40 (1997)

Cultivation of rape seed

Data on cultivation of rape seed are summarised in Table 4.4 (page 26). Swedish data come from Sonesson, (1990) and Mattsson, B. (1998) and German data are adapted from various material from UFOP (Union zur Förderung von Oel-und Proteinpflanzen). The Swedish condition refers to a mixture of winter and spring rape seed while the German condition refers only to winter rape seed, mainly grown in northern Germany. As seen in Table 4.4, the German rape seed cultivation is more intense both in fertiliser and pesticide use, but also in a higher yield.

Transports of rape seed and meal

During 1996/97 approximately half of the rape seed meal processed in Sweden originated from domestic grown rape seed (Herland, P.J. priv. comm. 1997). Half of this amount is estimated to come from southern Sweden and is transported to the crusher in Karlshamn by lorry, while half originates from central Sweden and is transported by boat. The imported rape seed comes mainly from northern Germany, some comes from Denmark, and is delivered by boat. Smaller amounts of rape seed are used directly in the concentrate feed products; this is transported directly to the HBKL feed industry in Falkenberg and purchased from local farmers.

Table 4.5 Transports of rape seed and rape meal

	Transport system	Distance, km
Rape seed		
- farm to feed industry, Falkenberg	tractor	30
- farm to dealer (Sweden)	tractor	20
- dealer to Karlshamn (½ Sweden)	lorry	150
- dealer to Karlshamn (½ Sweden)	coastal ship	350
- farm to dealer (Germany)	tractor	20
- dealer to harbour	lorry	100
- harbour, N Germ to Karlshamn	coastal ship	400
Meal and Expro®		
- Karlshamn to feed industry, Falkenberg	lorry	221
- Karlshamn to Tingvall (org farm)	lorry	440

Pressing and extraction of rape seed

The rape seed is pressed and extracted at Karlshamn's Crushing & Feed. In the process, the seed is cleaned and conditioned before passing flaking rolls and a screw press where approximately 2/3 of the seed oil is expelled. The press cake is extracted using technical hexane as solvent and after the extraction the meal is treated by live steam in a desolventiser to remove the solvent. The hexane is re-used and the discharge at Karlshamn's is 0.04 % hexane corresponding to totally 100 tons per year. Although hexane is internal recycled, an inflow of 0.4 kg hexane per ton rape seed is balanced to compensate for the losses.

Table 4.4 Summary of inventory on cultivation data in rape seed and soybeans.

	Rape seed, Sweden ¹	Rape seed, Germany ²	Soybeans, Brazil ³
Yield, kg ha ⁻¹	2 470	3 150	2 200
Ferti- lisers kg ha ⁻¹	N : 160 P : 14 K : 28	N : 200 P ₂ O ₅ : 70 K ₂ O : 160	NPK 0 - 20 - 20 200 kg ha ⁻¹ (as P ₂ O ₅ and K ₂ O)
Pesti- cides, active subst	Metazaklor 500 g / ha Esfenvalerat 10 g / ha	Fungicides 0.8 l / ha ^d Insecticides 1.5 - 2 l / ha Herbicides 0.26-0.3 l / ha (n.b. as chemicals not active substances)	Glyfosat 540 g / ha 2,4-D 750 g / ha Monocrotofos 112 g / ha Endosulfan 66 g / ha Diflubensuron 5.6 g / ha
Field opera- tions	100 l diesel per ha ^a	No data, Swedish data used	Conventional system 62 l diesel per ha. Minimum tillage system 48 l per ha. 60 l diesel/ha used as an average
Drying	Drying from 18 to 7 % means reducing 330 kg water ^b . 0.126 kg oil per kg H ₂ O = 41.6 kg oil per ha. 0.03 MJ el. per kg rape seed = 84.7 MJ per ha	According to Swedish data: 420 kg water from 18 to 7 % 0.126 kg oil per kg H ₂ O = 52.9 l oil per ha. 0.03 MJ el. per kg rape seed = 107 MJ per ha	Reusser (1994) estimates drying soybeans from 17 to 11 % as 72 kg H ₂ O per ton soybeans. ^c Reusser estimates energy for this as 0.474 MJ per kg of which 88 % is heating and 12 % is el. Fuel in Brazil: non-fossil wood.
N-leach- ing ^e	42 kg N per ha	46 kg N per ha	40 kg N per ha
P-losses ^f	0.3 kg P per ha	1.1 kg P per ha	1.1 kg P per ha

- 1) Data from Mattsson 1998. 2) German data adapted from various materials from Ufop (Union zur Förderung von Oel-und Proteinpflanzen) 3) Data from Embrapa 1997
- a) Diesel consumption according to "Odling i Balans" (Swedish organisation working for development of an integrated farming system with low environmental impact). Measured under current conditions on farms with good farming practices (Törner, 1997)
- b) Data for drying according to Sonesson 1990
- c) Data for drying according to Reusser 1994
- d) Standard use of chemicals in German rape seed cultivation (Jonsson, H. 1996).
- e) Swedish leaching according to Johnsson & Hoffman (1996), rape seed in southern Sweden. German leaching assumed to be 10 % higher than Swedish. No measurements of N-losses in Brazilian soybean cropping are made. The figure is an assumption by author and is equal to N-leaching for organic peas in Sweden.
- f) Swedish P-losses are average data for Swedish arable land according to Kyllmar *et al* (1995). European data is according to Audsley *et al* (1997). No data was available for Brazilian soybean, European data from Audsley *et al* also used here.

Hexane production is assumed to be comparable to naphta production (Ceuterick, D. & Spririnckx, C. 1997) and energy data for naphta is from Audslesy *et al* 1997. 0.2 kg hexane per ton rape seed is estimated as an emission to air in the process. Some of the hexane losses will end up in the oil and/or fodder part, and some are reclaimed in the process and used for energy production, therefore, the emissions are calculated lower than the actual losses (Broberg, J. priv. comm. 1997).

The solvent-free meal may either be dried directly until it reaches 11 % moisture content, or before drying, it is heat treated in the ExPro plant. The ExPro® process makes the protein more valuable by reducing its degradability in the rumen, producing a "bypass protein". The ExPro® process is unique for Karlshamn's and is patented.

In Table 4.6, the energy consumption and emissions at Karlshamn Crushing are summarised. The energy carriers are gasol and electricity. The size of the respective sources of energy is confidential, only total energy consumption was provided. The total energy consumption includes pressing, extraction and heat treatment in the ExPro process. The different processes are hard to separate, surplus heat from the early steps are used in later stages, so the total energy consumption of standard rape meal will be the same as for the ExPro® product. Data from Karlshamn's Sweden AB according to Herland, P.J. *et al* priv comm (1997).

Table 4.6 Energy and emissions at Karlshamn's Crushing & Feed

		Per ton rape seed
Energy (total)		918 MJ
Emissions	CO ₂	51 kg
	NO _x	33 gram
	SO ₂	6 gram
	COD	63 gram
	N	2 gram (waste water to sewage plant)
	Hexane	0.4 kg (0.2 kg to air)
	Solid waste	0.2 kg
Water consumption		0.4 m3

4.2.2 Soybeans and soymeal

Due to the discussion on gene-modified cultivars in agriculture, the Swedish dairy industry has prohibited their supplying farms to use feed from gene-modified plants. The soymeal used in the concentrate feeds is therefore imported from Brazil that has so far guaranteed that no GMO seeds are used in the cultivation process. During 1997, approximately 15 % of the soybean seed in the US, the world's largest producer of soy beans and meals, was gene-modified for resistance of glyfosat (Roundup) and the US can not guarantee buyers demanding GMO-free soymeal. This has led to the cessation of soymeal import from the US.

Contrary to the other ingredients in the concentrate feed, soymeal is the major product from the cultivation and the oil can be regarded as the smaller co-product. As seen in Table 4.7, regardless of method of allocation (mass or price), the protein meal will bear a dominating share of the impacts of cultivation, processing and transport of the bean.

Table 4.7 Allocation of soy bean oil and soymeal

Products	Mass ¹ allocation, %	Market price, ² US dollar/ton	Price allocation, %
Soybean oil,	17	515	31
Soy meal	80	292	69 (chosen allocation)

1) Mass allocation according to Boulder, R. 1985.

2) Price according to lowest asking prices for Nearest Forward Shipment, Oct/Aug 96/97. *Oil World* no 23, vol 40

There are two different soymeal products in the Swedish concentrate feed. Ordinary soymeal, which is the standard trading product and crushed in the Brazilian oil extraction industry. Soypass, which is soybeans extracted and soymeal heat-treated in the edible oil industry Denofa in Fredriksstad, Norway. This heat-treatment increases the value and utilisation of the proteins in the rumen of the cows and is similar to the previously described ExPro-process.

Cultivation of soybeans

Soybeans are cultivated on approximately 10.740 million hectares in Brazil and the crop has increased rapidly during the 70s and 80s. The most important areas for soybeans are in the southern and south east states (Rio Grande do Sul, Parana, Mato Grasso do Sul) but the cultivation has recently expanded in the western part, mainly through clearing of land, especially "cerrados" (steppes similar to savanns).

Table 4.8 Soybeans, areas and yields in Brazil, 1960 - 1986 and 1996

Year	Area (1000 ha)	Yield (kg ha ⁻¹)
1960	171	1 200
1965	432	1 212
1970	1 319	1 144
1975	5 823	1 699
1980	8 774	1 727
1985	9 600	1 792
1996	10 740	2 200

Data 1960-1985 according to Amstel *et al* 1987. Data 1996 according to Embrapa 1997¹

The cultivation of soybeans is highly mechanised. Since the crop is leguminous, no N-fertilisers are applied. In the newly cultivated land, "cerrados", extensive liming is essential. Because of a severe problem with soil erosion, cultivation methods with reduced tilling have been developed, reducing the consumption of diesel but increasing the use of herbicides (Amstel *et al* 1987).

The use of insecticides is high and about two applications are performed every season. The most frequently used insecticides are monocrotofos, endosulfan and pyrethroids, of which the first two groups are organophosphorous/chlorine compounds and very toxic. However, biological methods for regulating insects have been developed and taken into practice during the 1980s (Moscardi, F. 1993). In the last season, about 10 % of the soybean area was treated with biological products against the important soybean pest the velvet-bean caterpillar (Galerani, P.R. priv comm 1997). The trend for insecticide use is now reducing hazard pesticides like monocrotofos and endosulfan and replacing them with biological products (*Bacillus thuringensis* and a virus *Baculovirus anticarsia*) together with substances like diflubensuron.

The data on cultivation are summarised in table 4.4 (page 26). The data were obtained from Embrapa Soja (Galerani, P. R. priv comm 1997).

¹ Embrapa is the Brazilian Agricultural Research Corporation

Transports of soybeans and soymeal

Depending on whether the soybeans are to be extracted in Brazil or exported to the edible oil industry Denofa in Fredriksstad, Norway, the soya follow different transport routes. Estimated distances in Brazil were provided by Embrapa.

Table 4.9 Transports of soybeans and soymeal

	Transport system	Distance, km	Calculated distance, km
Soybeans			
farm to crusher	lorry	30-50	50
farm to harbour	lorry	200-1000	600
harbour, Bra to F-stad, Norway	boat	10 700	10 700
Soymeal and soypass			
crusher to harbour, Brazil	truck	200-1000	600
harbour, Bra to Brakke, Germ	boat	10 200	10 200
harbour, Brakke to F-berg, Swe	boat	700	700
Denofa, Norway to F-berg, Swe	truck	461	461

According to Embrapa, 85 % of the transports in Brazil are done by lorries. All transports in Brazil will therefore be accounted for as lorries in this study. The ocean going vessels transporting soymeal to Europe carry 30 - 50 000 tons and reloads in Brakke (Bremen) or go directly to Fredriksstad, Norway. The final boat transport from Bremen to the HBKL feed industry in Falkenberg is done by boats loading 1000 tons. The transport of soypass from Denofa in Norway to the feed industry in Falkenberg is by lorry.

Pressing and extraction of soybeans

Since soymeal as well as sunflower meal are parts of a large international feed market, it is not possible to follow these products to one unique extraction industry. Therefore data on standard energy consumption for crushers were obtained from Krupp Extraktionstechnik GmbH (Kappes N. priv. comm. 1997) which is a company that supplies the extraction industry with equipment and technology all over the world. These data represent a high technology level.

The energy consumption of a modern crusher for pressing and extracting soybeans is estimated as 280 kg steam per ton soybeans (10 bar pressure, 183-184°C). Steam of 11 bars saturated (i.e. 184°C) has an enthalpy of 2.78 MJ per ton. Boiler efficiency is assumed as 80 %; leading to an energy demand of 3.475 MJ/kg steam. The dominant energy source in the crushers in Brazil is wood (Galerani, P.R. priv comm 1997). According to Krupp Extraktionstechnik, the electricity consumption in a modern crusher is estimated as 46 kWh per ton soybeans. Hydropower is a dominant source of Brazilian electricity. Hexane is used as a solvent and the losses are approximately 0.02 - 0.06 % in a modern crusher; 0.02 % is assumed to be an average emission to air. 0.4 kg hexane per ton soybean is calculated to be an input (energy data of naptha).

The soymeal production in Denofa (Norway's single producer of oils and fats) has a similar heat treatment as the one in Karlshamns Crushing and Feed. Details of this process are confidential. Sugar, in the form of xylose is added to the soymeal in the toaster. The xylose is a by-product from the Spanish pulp-industry, with eucalyptus serving as raw material. Due to confidentiality, the amount of added xylose has not been made public and can not be accounted for. The final feed product, called soypass, has a substantially higher amino acid utilisation in the rumen than ordinary soymeal.

The energy consumption in the extraction industry Denofa in Fredriksstad, Norway, is 316 kg steam per ton soybeans (Evensen, K. priv comm 1997) including the heat treatment. 3.475 MJ/kg steam is calculated energy demand and the energy source is mainly fuel oil, minor amounts of surplus heat are delivered to the district heating. Electricity consumption is 40 - 45 kWh per ton soybeans and input of hexane is 0.4 kg per ton. Half of this is calculated as an emission to air.

4.2.3 Co-products from sugar industry

Co-products from the sugar industry are important ingredients in the feed rations for dairy cows. The conventional farm also uses super-pressed pulp (*HP-massa*) as substitute for silage and this is further discussed in chapter 5.

In the concentrate feeds, two different forms of beet pulp products can be found. One is dried beet pulp (90 % dry-matter, DM), which is a dominant ingredient in the product Elit. The other one is Betfor®, a dried pulp product (DM 90 %) to which molasses is added, both pulp and molasses are of Swedish origin. The beet pulp in Elit is a mixture of straight beet pulp, originating from Denmark and Poland, and Betfor®. Apart from being used in different cattle feeds, Betfor® is also a popular feed for horses.

The allocation of the products from the sugar beet crop according to price and mass are shown in table 4.10. Contrary to the oil crops previously presented, the fodder co-products in the sugar beet crop are fairly small compared with the main product sugar.

Table 4.10 Allocation of sugar and co-products

Products	Mass allocation ¹ , %	Market price SEK/kg	Price allocation, %
Sugar	66	2.3 ²	83
Beet pulp	22	0.92 ³	11(chosen allocation)
Molasses	12	1.00 ³	6

1) Mass allocation according to Danisco Sugar AB (Landquist. B. priv. comm. 1997)

2) This is the world market price in autumn 1997 and not an European market price which is much higher because of the sugar price arrangements in the European Union

3) Price in Swedish harbours autumn 1997 per kg dry matter

Cultivation of sugar beets

Data on sugar beet cultivation are summarised in table 4.11 (page 32). The cultivation only takes place in the south of Sweden and is highly mechanised. Data are given by Danisco Sugar AB and the Swedish cultivation data are used for all sugar beet co-products in the fodder including the beet pulp that is imported from neighbouring countries.

Extraction of sugar and co-products

After the beets have been disjointed in a cutter, the sugar is extracted from the beets with hot water. Gypsum is added and the beet pulp (which is about 5 % of the beet) is separated, containing over 90 % moisture content. The water content is reduced in pulp presses to a moisture content of about 75 - 80 %. The pulp products are finally dried to 90 % DM. The sugar solution from the extraction contains the water-soluble contents of the sugar beet and thus has to be purified before it is concentrated through evaporation and crystallization. The molasses are the residue of the sugar phase after the crystallization.

The process of extracting and refining the sugar is an energy demanding one, although the energy consumption per kg sugar has decreased by 35 % during the last 20 years in the Swedish

sugar industry (Danisco Sugar, 1995). In Table 4.12, the total energy use of the production process in the sugar industry is shown.

Table 4.12 Total energy consumption in the Swedish production of sugar and feed co-products

	MJ / ton sugar
Cultivation including machinery and transports	3 100
Sugar production	5 300
Drying of molassed beet pulp ¹	2 200
Transport of products, packaging	600

Source: Danisco Sugar 1995.

1) Refers to a situation when 70 % of the beet pulp is dried and 30 % is as processed as super pressed pulp.

The separate energy cost for drying and pelleting Betfor® (containing approximately 2/3 of pulp and 1/3 molasses) is 5.4 MJ per kg Betfor®. The energy sources in the Swedish sugar industry are approximately distributed as 60 % gas, 35 % oil and 5 % coal for drying and pelleting Betfor® (Landquist, B. priv comm 1997).

Drying pure beet pulp is estimated to have an energy cost of 6.4 MJ per kg. Since molasses is not added to this product, there will be more water to reduce (beet pulp has an initial dry matter content of 27 % and molasses has a dry matter content of 78 %). Energy sources for the imported Danish and Polish beet pulp is assumed to be; 50 % oil, 35 % coal, 15 % gas (Denmark) and 75 % coal, 16 % oil, 9 % gas (Poland). These assumptions are based on the countries' total energy supply according to the International Energy Association².

According to price allocation, the dried beet pulp products will carry 11 % of the energy consumption and emission in the cultivation. Of the process in the sugar industry, only the drying of the beet pulp is allocated to the feed part. Molasses from sugar beet (origin Poland) and molasses from South American sugar-cane production are included in smaller amounts in the concentrate feed product Elit. Only the transport costs are allocated to the molasses.

Transport of beet pulp and molasses

The different means of transports of the sugar co-products are summarised in Table 4.13. The dried beet pulp from Poland and Denmark is delivered on boats carrying 600 - 1 000 tons.

Table 4.13 Transports of sugar co-products

	Transport system	Distance, km
Beet pulp (in concentrate feed)		
Sugar factory, Polen to Falkenberg	boat	700
Sugar factory, Denmark to Falkenberg	boat	240
Sugar factory, Örtöfta to Fbg (Betfor®)	lorry	150
Beet pulp (as product)		
Sugar factory to conventional farm (Betfor®)	lorry	320
Molasses (in concentrate feed)		
Sugar factory, Polen to Falkenberg	boat	700
Sugar factory, South America to Falkenberg	boat	10 600

² Internet: www.iea.org

Table 4.11 Summary of inventory on cultivation data on sugar beets, maize and sunflower seeds

	Sugar beet, Sweden ¹	Maize, France ²	Sunflower seeds France ³	Sunflower seeds Argentina ⁴
Yield, kg ha ⁻¹	47 000	8 200	2 100 ^a	1 640
Ferti- lisers, kg ha ⁻¹	N: 113 P: 14, K: 28 (Manure is used on 50 % of acreage, corresponding to 17 NH ₄ -N, 20 P, 35 K. Only synthetic fertilisers are considered)	N : 180 P ₂ O ₅ : 80 K ₂ O : 80	N : 150 ^b P ₂ O ₅ : 50 K ₂ O : 300	No fertiliser use reported
Pesti- cides, active substance	Metamitron 1800 g/ha Fenmedifan 300 g/ha Etofusemat 300 g/ha Kloridazon 600 g/ha	Atrazin 1000 g/ha Alachlor 1900 g/ha Lambda- Cyhalotrin 12.5 g per ha	Trifuraline 1200 g/ha Flurochlorine 500 g/ha Fenpropimorf 300 g per ha	Trifuralin 960 g/ha Two applications of pyrethroid, presumed substance Deltametrin 20 g/ha
Field opera- tions	285 l diesel per ha N.b. 30 % is energy for transports of beets to sugar industry	112 l diesel per ha	100 -150 l diesel/ha (120 used in calculations)	No data, used the lower French data 100 l per ha
Drying	Not in sugar beets	Drying from 35 % to 15 % reduces 2 615 kg water. This process utilises 3,76 MJ/kg H ₂ O.	The average moisture content in the seeds are under 10%. No heat is normally needed, just some ventilation	Similar to French conditions
N- leaching^c	49 kg N per ha	30 kg N per ha	20 kg N per ha	20 kg N per ha
P-losses^d	0.3 kg P per ha	1.0 kg P per ha	1,0 kg P per ha	0.3 kg P per ha

1) Data from Danisco Sugar AB (Landquist, B. 1997) 2) Data from APMG (David, S. 1997) 3) Data according to Cetiom (1997) 4) Data from INTA (Schang, M. 1997). Yield according to FAO yearbook, 1996.

a) Yield in France according to Statistique des Oléagineux et Protéagineux 1996, (Proléa 1996).

b) Fertiliser recommendation when harvesting 3 500 kg/ha. Author reduces this amount by 25 % in inventory sheet since the actual harvest was significantly lower.

c) Swedish leaching according to Johnsson & Hoffman (1996). Leaching in French maize cultivation ranges between 20 - 40 kg N ha⁻¹ (David, S. 1997). According to oilseed growers association in France, the leaching from sunflower seeds is low. 20 kg N per ha is the author's assumption, the same amount is estimated for Argentina.

d) P-losses in Sweden according to Kyllmar et al (1995). European figures according to Audsley et al (1997). Due to low fertiliser input in Argentina, low P-losses are assumed.

4.2.4 Maize and maize gluten meal

The maize gluten meal used in the Swedish feed industry is only of European origin due to the demands for not using GMO-feed (GMO-maize is grown in the US). Maize gluten meal is a very protein rich fodder (> 60 % protein) which is a co-product from extraction of starch. It is delivered to the feed industry in Sweden from the Belgian starch industry; the maize is often of French origin. As seen in Table 4.14, the fodder products represent a fairly small part of the total products from the cultivar maize. The market price of native maize starch is approximately 2 500 SEK per ton (Berggren, H. priv comm 1998).

Table 4.14 Allocation of maize starch and co-fodder products

Products	Mass allocation, % ¹	Price ² US dollar/ton	Price allocation, %
Starch	63		78
Maize gluten feed	20	102	8
Maize gluten meal	5	528	10 (chosen allocation)
Germ meal	7	123	4

1) David, S. priv comm. AGPM 1997

2) Clabot, G. Amylum, Belgium, 1997.

Cultivation of maize

Approximately 1.8 million hectares grain maize are cultivated in France and about 20 % of this area is in monoculture. Otherwise maize is followed by one or two cereal grains or sunflower seed. Data on the French maize cultivation are summarised in table 4.11 (page 32) and were received from AGPM (l'Association Général des Producteurs de Mais) David, S. (1997).

Extraction of starch

The starch is extracted in hot water containing 0.1 - 0.2 % sulfur dioxide. Germ meal is thereafter removed by flotation and the next step is to separate the fibres from the starch and gluten protein.

The separated fibres are the major ingredient in maize gluten feed. Finally the starch and gluten are separated by their difference in density. The gluten products contain approximately 60 % protein and are concentrated and dried to form maize gluten meal (Corn Refiners Association, 1989). Data on energy consumption of the extraction of maize starch were obtained from Buwal (1996).

Figure 4.3 Energy consumption in starch extraction (maize)

Transport of maize and maize gluten meal

The maize gluten meal is delivered to Sweden from starch industries in Belgium (Amylon and Cerostar). The transport of grain maize from France to Belgium is assumed to be by lorry, average distance 700 km. The gluten meal is transported from Gent, Belgium, by boat to the feed industry in Falkenberg.

Table 4.15 Transports of maize and maize gluten meal

	Transport system	Distance, km
Maize: to starch factory	lorry	700
Gluten meal: Belgium to Sweden	boat	1 000

4.2.5 Sunflower seeds and sunflower meal

The sunflower meal in the concentrate feed originates from Argentina and France. Approximately half is imported from each country. Allocation of the products oil and meal from the sunflower seed is seen in Table 4.16.

Table 4.16 Allocation of sunflower oil and sunflower meal

Products	Mass allocation, % ¹	Market price, US dollar/ton ²	Price allocation, %
Sunseed oil	31	530	63
Sunseed expeller	68	139	37(chosen allocation)

1) Mass allocation according to Boulder, R. 1985.

2) Price according to lowest asking prices for Nearest Forward Shipment, Oct/Aug 96/97. *Oil World* no 36, vol 40

Cultivation of sunflower seed

The cultivation pattern differs between the two countries. In France, the technique of growing is similar to the one of rape seed in northern Europe and quite high fertiliser rates are used. In Argentina the use of fertilisers is very low in an international perspective (FAO 1996), and it seems that through good crop rotation (pasture-maize-sunflower-wheat-pasture) a reasonably good yield can be obtained with very low or no-fertiliser input at all.

Data from Argentina were obtained from INTA (Schang, M. 1997 priv. comm.) and the French data are from CETIOM (1997) when nothing else is stated.

In the inventory sheet, the pesticides listed in table 4.11 were used. However, just as in the case of the Brazilian soybeans, there are some hazardous pesticides registered in the Argentine sunflower seed crop, not permitted to be used in Sweden and several other European countries. Examples of this are endosulfan, lindan, monocrotophos and paraquate. To what extent these pesticides are used in the cultivar sunflower is not known.

Pressing and extraction of sunflower

Pressing and extracting sunflower seeds follows the same pattern as soybeans and rape seed. Standard data for the energy consumption of the process were obtained from Krupp Extraktionstechnik (Kappes, N. priv comm. 1997). Estimated energy use in a smaller sunflower seed crusher industry is 300 kg steam/ton seeds and 40 kWh electricity/ton seeds. For the French crusher, a mix of European energy is assumed as the energy carrier, and oil is assumed to be the energy source in the Argentine crusher. 0.02 % hexane is estimated as emission to air. 0.4 kg hexane per ton seed is an energy input (naptha).

Transport of sunflower seeds and sunflower expeller

The dominant area for sunflower cultivation in France is in its south and southwestern regions. The extraction industry (Vamo-mills) is situated in Bordeaux, Sète and Rouen (Lot, L. priv comm 1997). It was assumed that the sunflower meal is shipped out from Bordeaux.

In Argentina, the sunflower meal is basically shipped out from Quequen, south of Buenos Aires provinces (Schang, M. priv.comm. 1997) and most of the sunflower crushing industry is in an area less than 250 km from that harbour. The intercontinental cargo ships load 30 - 50 000 ton and dock in Rotterdam. The final transport from Rotterdam to Falkenberg is by boats loading 1 000 tons.

Table 4.17 Transport of sunflower and sunflower meal

	Transport system	Distance, km
Sunflower seed		
France: farm to crusher, Bordeaux	lorry	200
Argentina: farm to crusher	lorry	300
Sunflower meal		
Bordeaux to Falkenberg	boat	2 180
Crusher to harbour, Argentine	lorry	200
Argentine to Rotterdam	boat	11 800
Rotterdam to Falkenberg	boat	900

4.2.6 Palm oil and palm kernel expeller

Palm kernel expeller is a co-product when producing palm oil and palm kernel oil. Malaysia and Indonesia are the largest producers of these products and an increased demand for these oils for cooking and technical purposes, for example in cosmetics, has expanded the plantation of palm oil, mainly in Malaysia. The harvest; fresh fruit bunches (FFBs) corresponding to approximately 18 ton per ha, are extracted in a palm oil mill, and the first product of this process is crude palm oil (CPO). The co-product, the palm kernel which contains 46 % oil, is then extracted, most often with mechanical extraction using high-pressure screw pressing. The final products of this extraction are crude palm kernel oil (CPKO) and the feed products palm kernel expeller or cake. A Life Cycle Assessment for palm oil production has been carried out by Hirsinger, Schick & Stalmans (1995) "*A Life Cycle Inventory for the Production of Oleochemical Raw Materials*". Data on oil palm cultivation and processing is obtained from this article.

In Figure 4.4, the flows in the palm and palm kernel oil production are shown. In the total production, there are other co-products, which do not become oil or fodder. These are for example fibres, used as fuel in the process, and shells used as shell material in road construction. When recalculating the mass flows in Figure 4.4 into one hectare of palm oil, the products that will be commercially sold are 3 909 kg CPO, 532 kg CPKO and 629 kg palm kernel expeller. Table 4.18 shows allocations for these products according to mass and price.

Table 4.18 Allocation of CPO, CPKO and kernel expeller

Products	Mass allocation %	WM-price ¹ US-dollar/ton	Price allocation, %
CPO	77	545	83.
CPKO	10	687	14
Kernel expeller	13	103	3

1) Price according to lowest asking prices for Nearest Forward Shipment, April 1997. *Oil World* no 23, vol 40.

Figure 4.4 Simplified flow diagram in the CPO and CPKO production

It is obvious that when using price allocation for this production, the feed part will take a very little proportion of the whole production and will therefore not be included in the analysis. Only transport are allocated to the palm kernel expeller.

Transport of palm kernel expeller

The expells are transported from Malaysia to Rotterdam where the feed is reloaded. The average distance between the mills in Malaysia and harbour is estimated as 150 km.

Table 4.19 Transport of palm kernel expeller

	Transport system	Distance, km
Palm oil mill to harbour	lorry	150
Malaysia to Rotterdam	boat	15 500
Rotterdam to Falkenberg	boat	900

4.2.7 Potato protein

In the starch production of potatoes, fibres and fruit water are co-products. In the Swedish potato starch industry, the waste product fruit water is used as fertiliser thus recycling a large part of the plant nutrients that the potato harvest has removed. In Europe, many potato starch factories produce the feed potato-protein *Protamyl* from the fruit water. One reason for not using the fruit water as a fertiliser is the lack of acreage due to high animal density; especially in Belgium and the Netherlands. Another reason is that the starch industries on the continent are very large compared to the Swedish industry, thus producing vast amounts of fruit water in a small area, leading to long transport distances had the fruit water been used directly as a fertiliser (Berggren, H. priv. comm 1998).

AVEBE (the Netherlands' starch co-operative) is the largest producer of starch in Europe and has LCA data for native starch but not for the energy consumption of the by-product Protamyl. The production process of Protamyl can briefly be described as heat coagulation of protein, de-watering of the protein flocs by centrifuges and finally drying of the protein cake (Zeeuw, W. priv. comm. 1997).

The de-watering and drying of the potato protein in fruit water must be presumed to be a quite energy consuming process and reasonably similar to the pressing and drying of beet pulp. Since there are no available data for the processing of the potato protein feed Protamyl, the same energy consumption as for processing beet pulp is assumed, 6.4 MJ per kg product with oil and gas comprising equal part of energy sources. Protamyl is transported from Belgium to the Swedish feed industry by lorry, estimated transport distance is 1 100 km.

4.2.8 Fats

Vegetable fatty acids are minor by-products from the edible oil industries, not carrying any of the emissions in cultivation and processing. Karlshamns Crushing & Feed has data on the energy consumption and emission directly connected to fodder fats (Broberg, J. priv. comm 1997).

Table 4.20 Data from production of fodder fats at Karlshamn Crushing & Feed

	per ton fats
Energy consumption, MJ	36
CO ₂ -emission, kg	1
NO _x -emission, g	0.7
SO ₂ -emission, g	0.13

Fodder fats are included in smaller amount in the products Elit and Protein-mix. The feed industry import some of these fats from Denmark. In this analysis, data on fodder fats are only Swedish.

4.3 Other feed ingredients

Minerals

The most important ingredients in minerals fodder are lime, phosphoric acid (as P₂O₅), magnesium oxide and dicalciumphosphate. Depending on the Ca/P-ratio and addition of Magnesia, the recipe of mineral feeds varies. In this study, a mixture of 65 % lime and 35 % P₂O₅ was calculated. Source for production of these components is according to data for production of P-fertiliser and lime (Wiedema *et al* 1995).

In the mineral feed production, pure phosphoric acid and calcium sources are reacted in a granulator under precise conditions. After the granulation the product is screened and cooled. The energy consumption at the mineral producer Kemira for this production is 1 080 MJ electricity per ton and 1 080 MJ gas per ton minerals (Steén, I. priv comm. 1998).

Lactamat (calf feed)

In the conventional milk producing system, the calves are fed with a milk substitute during the first ten weeks. In the organic milk production this is not allowed; the calves are fed with their mother's milk or in some stocks by a surrogat cattle mother.

The largest calf feed product on the Swedish market is *Lactamat*, which contains approximately 70 % whey, 15 % lard, 9 % soyprotein, 5 % lactos and a minor addition of vitamins (Ulvne, P. priv comm 1997)

Whey is considered to be a waste product by the cheese dairies. Only drying and transportation of this ingredient are allocated to the *Lactamat* product. The whey comes from different cheese makers in Sweden and is processed in the Lactamat production industry in Kimstad, Östergötland. Due to various pre-treatment of the whey, 43 % of it has an energy cost of 17.9 MJ kg⁻¹ (90 % DM, energy source gas) and 57 % of the whey has an energy cost of approximately 6.85 MJ kg⁻¹ (60 % DM).

Soya protein is imported from the German or Danish oil industry and transported by lorry. The same data as for the soybean meal in section 4.2.2 are used for this product. Lard is regarded as waste products from the slaughter industry and only the transport of 250 km from Extraco, Stidsvig is allocated to the Lactamat product. Lactos is transported from a nearby dairy, and only the transportation cost is included. Small amounts of vitamins come from a nearby industry and this is a minor input and therefore excluded in the analysis.

The energy consumption in the Lactamat production is 0.12115 m³ fuel oil per ton and 600 kWh electricity per ton. Approximately 200 kg BOD₇ per ton is emitted in wastewater for further treatment. Data for Lactamat production are according to Petterson, R. *et al* (1997).

Calf concentrate feed

The calves in the conventional system are fed with a "starter concentrate", a feed specially designed for calves. It contains approximately 50 % grain and 50 % of protein feed, the mixture quite similar to the one in the product Elit. The energy for producing this feed is 237.6 MJ ton⁻¹ at the HBKL feed industry. The included components are calculated using data on conventional wheat cultivation (Table 5.5), reduced in harvest by 10 % since there are barley and oats in this feed (lower yield than winter wheat) and with data on the feed product Elit.

5 Material and energy flows in the conventional system

5.1 Description of the farm studied

The Rossared farm is situated 35 km south of Göteborg. It straddles a stretch of land in between a flat coastal country to the west, where arable farming is most common, and the more woody inland area to the east, where grassland and pasture are more frequently found. After a fire in 1991, the stables were reconstructed for a loose housing system in 1992.

According to the milk recording statistics, the milk production in 1996/97 was 8 263 kg milk per cow with 3,7 % fat and 3,4 % protein. 7 813 kg ECM milk per cow left the farm gate; one cow produced 7.813 functional units (FU) from September 1st 1996 until August 30th 1997.

The acreage of the farm is 141.2 hectares and the stock is 134 cows and 135 heifers. The replacement rate is 40 % and the heifers calve at an average of 29 months of age; principally all cow calves are kept for replacing old cows. The bull calves are sold at the age of ten weeks.

The whole acreage is used for producing fodder. Winter wheat and straw are purchased from a neighbouring farm. Some of the area was used as set-aside land in 1996. This was because of co-operation with another of the agriculture society's farms. Part of the society's total set-aside area was decided to be at the Rossared farm; otherwise this single farm unit would not have been obliged to have set-aside area.

The leys last for four years and three harvests of silage are taken. On a smaller proportion of the grass acreage, hay is harvested in the first cut and grazing also is done on some of the land for roughage.

The soils of the farm have fine structure and can best be described as ranging from silty clay loams to clays. The organic matter content is 4 - 6%.

5.2 Animal production on the farm

The fodder is given with a 14 m³ mixer wagon. Twice a day, the cows are fed with a mixture of silage, straw, hay, super pressed pulp, grains and the concentrate feed Protein-mix. The low-milking cows (end of lactation) are given 60 % of the ration of the high milking cows. The stock has a free choice to eat and the amount of fodder is adjusted to avoid rejected fodder. The concentrate feed Elit is given in automatic feeding stations to the high yielding cows and the feed ration is steered by a transponder unit on each cow. Extra straw is given to low yielding cows, dry cows and older heifers.

5.2.1 Fodder consumption

The fodder consumption per cow during the milk recording year 1996/97 is shown in Table 5.1. The straw refers to straw mixed with the fodder and not bedding material. The data are based on the weighing of fodder which is continuously done on the farm. The consumption of grass during the summer period is calculated as follows: the cows graze from May 15th until September 1st during the daytime. The consumption is assumed to be 4 kg dry matter (DM) grass cow⁻¹ day⁻¹ during the first month, 2.5 kg DM cow⁻¹ day⁻¹ during June 16th until August 1st and 2 kg DM cow⁻¹ day⁻¹ during the last month. The amounts of pasture consumed are calculated from breeding organisations' estimates of dairy cows' daily grazing intake during the summer.

Table 5.1 Fodder consumption per cow (1996/97)

	kg per cow	kg per FU
Silage (dry matter)	2267	290.2
Hay	17.9	2.3
Pasture (dry matter)	300	38.4
Straw	360	46.1
Super pressed pulp (27 % dry matter)	2380	304.6
Betfor®	49.5	6.3
Wheat (86 % dry matter)	1641	210
Protein-mix	771.9	98.8
Elit	759.5	97.2
Minerals	42.2	5.4
MgO	7.5	1

The wheat is treated with lye, water is added at the same time and it holds a dry matter content of 65 % when feeding. The farm has previously been feeding only Betfor®, but during 1996/97 this fodder was changed into super pressed pulp (*HP-massa*) instead. Moreover, 120 tons straw is used as bedding for cows and heifers.

Table 5.2 Fodder consumption per heifer (1996/97)

	kg per heifer
Silage (dry matter)	918
Hay	378
Pasture (dry matter)	375
Straw	18
Super pressed pulp (27 % dry matter)	34.4
Betfor®	13.3
Wheat (86 % dry matter)	285
Protein-mix	166.7
Kalv kraftt	40
Lactamat	8.3
Minerals	14

Kalv kraftt is a "starter" concentrate feed for calves that contains approximately 50 % grain and the rest is composed of the same ingredients as Elit. Lactamat is a milk replacement powder given to the calves during the first ten weeks.

Sixty-four heifers were grazing during 4 months. Their consumption was estimated to be 10 kg DM day⁻¹ during the first month, 7 kg DM day⁻¹ during June 16th until August 1st and 6 kg DM day⁻¹ during the last month (only 40 heifers were grazing the last month).

5.2.2 Diesel use in animal production

The total diesel consumption for the farm machinery was 18 900 l diesel in 1996. Hired contractors are performing the band spreading of manure, pesticide applications and bale catering of hay and straw. The diesel for these operations is included in Table 5.3 but excluded from the farm's total consumption. Of this volume, 11 630 l diesel were used in the cultivation of the fodder crops. The difference is the diesel used in tractors and loading machine in the daily work on the farm where mechanised feeding routines claim a considerable amount of diesel - for example, the loading machine is in use approximately 2.5 hours a day, loading fodder in the mixer wagon. The difference, 7 270 l diesel, corresponds to 54 l diesel per cow. Besides daily feeding routines, it also contains diesel for minor jobs such as maintenance of roads, snow clearing and errands for the farm's diesel car, etc.

5.2.3 Direct energy use

The farm's use of direct energy is in the form of electricity for milking equipment, cooler etc is 1 267 kWh per cow. Furthermore, 5 025 l fuel oil for heating of the milking parlour were used.

There are insufficient data on electricity consumption in Swedish milk production. In an advisory project for milk producers where the aim is to cut the production cost by 0.25 SEK per kg milk, data on electricity consumption is estimated. This material shows a range of electricity use from 600 - 2 200 kWh per dairy cow and year with a reasonable average around 1 100 kWh per cow (Sandgren, P. priv comm. 1998). In a Danish study for calculating the energy requirement for milk production, a standard for electricity use in cow stables of 673 kWh per cow and replacement animal is used (Dalgaard, T. *et al* 1998 in print). In comparison with these figures, the direct energy use seems to be somewhat high on the farm studied.

5.3 Emissions from animal production

5.3.1 Methane

Methane, an important greenhouse gas, is a by-product of microbial breakdown of carbohydrates (mainly cellulose) in the digestive tracts of herbivores. High methane losses are reported for ruminants that host large populations of bacteria and protozoans in their rumens (Crutzen *et al* 1986). Murphy (1992) has calculated, for Swedish conditions, that a high yielding dairy cow (> 7 200 kg milk) produces approximately 155 kg CH₄ year⁻¹ and a heifer has a yearly production of 67 kg CH₄.

5.3.2 Ammonia

Losses of ammonia-N occur in several phases during the production. NH₃-N is lost from the manure in the stables, during storage and spreading and when the cattle are grazing. Smaller losses can also occur during synthetic fertiliser application and from crop residues. In chapter 7, a plant nutrient balance for the farms is drawn up in which the nitrogen losses are quantified.

Ammonia losses during manure spreading (5 810 kg NH₃-N) are allocated to the plant production and are accounted for in the inventory sheet to the different fodder crops (se Table 7.9).

Remaining ammonia emissions according to section 7.4.1 are 2 773 kg NH₃-N corresponding to 20.7 kg NH₃-N cow⁻¹.

5.4 Fodder production on farm

Data on the cultivation of fodder crops at Rossared are summarised in Table 5.3. It should be pointed out that the yields of the roughage crops (silage, hay and whole crop silage) are not actual yields weighed in the field but the final fodder yield when it is weighed at the fodder table. There can be a large discrepancy between the biological harvest in field (the yield of grass/clover in field trials are often 8 - 10 tons DM ha⁻¹) and the actual amount of fodder fed per hectare of grassland. Due to hygienic restrictions, farmers are recommended not to cut the grass shorter than 15 cm. During grass harvesting and storing there can be substantial dry matter losses. Losses in the field during hay harvest can amount to 18 - 30 % of total dry matter. Depending on techniques, botanical composition of silage and weather conditions, losses can be 7 - 40 % of dry matter in silage during harvest and storage (Belotti, C. 1990).

Silage was harvested on an average of 79.5 ha and manure was applied with a band spreader to both 1st and 2nd cut. The fields are located near the farm and transport costs are low. After a short pre-dry in the field, the grass is packed into a ground silo. Approximately 35 respectively 25 l Promyr were used per hectare during the harvest of grass silage respectively whole crop silage. Promyr is a mixture of myric acid, propion acid and NH₃. Plastic is used to cover the silage corresponding to 3.9 kg per ha grass/clover and 3.3 kg per ha whole crop silage. Data for polyeten plastic with 75 % energy recovery are used for energy requirement (SOU 1991:77).

Table 5.3 Summary of data on cultivation of fodder on conventional farm

	Silage	Hay	Whole crop silage	Winter wheat	Pasture
Yield, kg ha ⁻¹	4 800 (dm)	5 700	5 740 (dm)	5 375	4 800 (dm)
Seed	400 kg total		190 kg ha ⁻¹	180 kg ha ⁻¹	
Fertilising	43 m ³ slurry ha ⁻¹ spring and summer. 204 kg N 34 ha ⁻¹ 116 kg N 34 ha ⁻¹	43 m ³ slurry ha ⁻¹ 204 kg N34 ha ⁻¹	30 m ³ slurry ha ⁻¹ late autumn 285 kg N 34 ha ⁻¹	26 m ³ slurry ha ⁻¹ before sowing. 385 kg N34 ha ⁻¹	71 kg N34 ha ⁻¹
Field operations Diesel, l ha ⁻¹	107	81	130	115	30
Pesticide use	324 g ha ⁻¹ glyphosate ¹	324 g ha ⁻¹ glyphosate	1 500 g ha ⁻¹ bentazon	7.5 g ha ⁻¹ tribenuron-metyl	
Fodder treatment	35 l Promyr ha ⁻¹	200 kWh El. ha ⁻¹	25 l Promyr ha ⁻¹	3 kg NaOH per ton	
Lime, kg ha ⁻¹	324		305	296	

1) Glyphosate (Roundup) was used on part of the grassland before ploughing.

The liquid manure from the livestock is used in all crops except pastures for grazing. The calculations of ammonia evaporation during spreading is more closely explained in section 7. The losses of $\text{N}_2\text{O-N}$ due to nitrogen turnover in the soils are calculated to 3.1 kg N ha^{-1} on the farm if emission factor 1.25 % is used and 1.6 kg N ha^{-1} when the factor is 0.625 %. Background to these estimated losses are explained closer in chapter 7. Leaching of phosphorus is estimated at $0.35 \text{ kg P ha}^{-1}$.

The diesel consumption in the cultivation of crops was measured and calculated fairly well. Diesel consumption for the ploughing of 15 ha leys and the ploughing and seedbed preparation of the set-aside area are not included since it will be charged to the following year's crops.

Instead of drying, the wheat was treated with lye (NaOH ; 99%) corresponding to 3 kg NaOH per ton wheat. For this fodder preparation 0.3 l diesel per ton wheat was used.

The yield of straw amounts to approximately 5 ton ha^{-1} , part of it is chopped before baling. A contractor performs the baling with a large Claas quadrant baler, and measured diesel consumption for baling and transports of the baler between fields is 1 l diesel per ton straw (Johnsson, B. priv. comm 1998). Gathering and transporting the quadrant bales to the stables are done by the farm's machinery. A total of 210 l diesel were used for this corresponding to 1.23 l diesel per ton straw. Principally all straw is collected from the wheat, all inputs in the wheat cultivation are allocated to the kernel and the straw accounts only for baling and transports.

Totally $32\,620 \text{ kg Dolomite lime}$ was use on the farm and was divided among the largest crops.

5.5 Fodder production on adjacent farm

5.5.1 Winter wheat

The production of grain on Rossared is far from sufficient and 86 % of the yearly wheat consumption is purchased from a neighbouring farm (7 km). Data for the cultivation of 1 hectare winter wheat in the region are shown in Table 5.5.

Table 5.5 Cultivation data on conventional winter wheat

Yield, kg ha^{-1}	6 000
Seed, kg ha^{-1}	190
Fertilisers, kg ha^{-1}	N: 150 P: 15 K: 15
Diesel consumption, l ha^{-1}	100
Fungicide use, gr ha^{-1}	75 propikonazol
Insecticide use, gr ha^{-1}	37.5 pirimicarb
Herbicide use, gr ha^{-1}	7.5 tribenuronmetyl
Nutrient losses, kg ha^{-1}	$\text{NO}_3\text{-N}$: 40 P: 0.3

The winter wheat standard yield for the yield survey district was $5\,952 \text{ kg ha}^{-1}$ in northern Halland in 1995 (SCB 1995). Data on fertiliser and pesticide use were estimated in co-operation with the agriculture society advisory service (Andersson, H. priv comm 1997). Herbicides are assumed to be used every year, fungicides three years out of five and insecticides one year out of three. Data for diesel consumption are obtained from the organisation "Odling i Balans" (Törner, L. priv. comm. 1997) and represent an average diesel use on a farm without manure spreading. Sources for nutrient losses are Johnsson and Hoffman (1996) and Kyllmar, K. *et al* (1995).

5.5.2 Super pressed pulp

As described in chapter 4, co-products from the sugar industry are important fodder ingredients in the Swedish milk production. Super pressed pulp is a product of beet pulp that is pressed and mixed with molasses. It has a dry matter content of 27 %; of which 22.5 %-units are pulp and 4.5 %-units are molasses. By adding molasses, the fodder product can be conserved as a silage on farms and it is principally used as a roughage, substituting grass or whole crop silage. During the past year there has been an increase in the use of this fodder instead of dried molassed beet pulp which demands considerable amounts of energy to process. This is especially the case for dairy farms in the south of Sweden where super pressed pulp today is a frequently used fodder. In Table 5.6 the allocations for sugar and super pressed pulp are shown.

Table 5.6 Allocation of sugar and super pressed pulp

	Mass allocation ¹	Market price SEK kg ⁻¹	Price allocation, %
Sugar	66	2.3 ²	83
Super pressed pulp	28	0.9 ³	14 (chosen allocation)
Molasses	6	1.00 ⁴	3

1) Mass allocation according to Danisco Sugar AB (Landquist, B. priv comm 1997)

2) This is the average world market price in autumn 1997 and not European market price, which is much higher because of sugar price arrangements in the European Union.

3) This sugar co-product is mainly produced in Sweden and Denmark. This is the average Swedish price in autumn 1997 and refers to the products' dry matter content.

4) Price in Swedish harbours in autumn 1997, as dry matter.

The energy use in sugar processing that can be allocated directly to pressing pulp is not available from the Swedish industry. A German source refers to electricity and damp consumption in the German sugar industry and gives energy data for pulp presses corresponding to 1 kWh per ton sugar beets. Using this source, the energy cost for processing super pressed pulp is 4.3 kWh per ton super pressed pulp.

The transport of super pressed pulp from the sugar industry in Köpingsbro (south east Sweden) to the Rossared farm is 320 km.

The energy and resources used by this fodder are 14 % of sugar beet cultivation (price allocation), 4.3 kWh per ton for pressing the pulp in the sugar factory and the transports to the farm. By using the world market price for sugar when allocating the sugar and fodder co-products it can be argued that the pressed pulp will take a rather large part of the cultivation. On the other hand, the energy cost at the sugar industry might be too low since only energy use in presses are included and not the handling of the pulp at the factory before transporting it to the farms.

6 Material and energy flows in the organic system

6.1 Description of the studied farm

The Tingvall farm is situated in the north of the county of Bohuslän in a rural area where milk production is the most dominant branch of agriculture. The farm has been growing according to organic principles since 1989. The production in the milk recording year 1996/97 was 7 876 kg ECM per cow and the delivery from the farm was 7 127 kg ECM per cow, i.e. one cow produces 7.127 functional units (FU). Since the cows' milk is used to feed the calves, a lower level of the milk actually leaves the farm.

The acreage of the farm is 112.4 ha and there are 52 dairy cows and 51 replacement animals of which 37 are heifers > 10 months. The average replacement rate is 40 %, so principally all the cow calves are kept for replacing older cows.

The whole acreage is used for producing fodder for the animals and organic grown barley and peas are also bought from an adjacent farm as a complement. The manure is mainly slurry, solid manure comes from calves, young heifers and the stable for calving cows

52 cows 51 heifers and calves				
<i>fodder</i> ↑ <i>Land use of the farm (total 112.4 ha)</i>				
↓ <i>manure</i>				
Leys for silage and hay (also grazing in 2 nd cut) 70.2 ha	Pasture	Barley	Peas	Other
	15.5 ha	19.2 ha	5.8 ha	1.7 ha

The crop rotation is three years of ley followed by barley. In fields with little presence of stones, peas are cultivated. On a smaller share of the acreage there are some experimental crops such as whole crop silage. The soils of the farm have a rather fine structure and the soil classes are clay loam - silty clay loam. The organic matter content varies between 3.3 - 5 %.

6.2 Animal production on the farm

The feeding system is the same as on the conventional farm, a Keenan mixer wagon is used. The cows are fed twice a day with all the fodder ingredients. At the beginning of lactation, the feed ration is adjusted to avoid rejected fodder. The cows are weighed monthly and their fat is estimated. After 3 - 4 months lactation, the cow usually gains weight and she is then transferred to the "weight watcher group", meaning that the fodder ration is reduced by 35 % and straw is given as a complement.

6.2.1 Fodder consumption

The fodder consumption per cow during the milk recording year 1996/97 is shown in Table 6.1. The data are based on the continual weighing of the fodder on a daily basis.

In the regulations for organically produced milk, it is emphasised that grazing must be a substantial share of the fodder intake during the summer. The pasture consumption at Tingvall has been estimated from calculations by the breeding organisation and is based on the following: The cows are grazing - day and night - from the May 18th until September 10th. The daily dry matter intake of grass was 5.3 kg cow⁻¹ in May, 8.6 kg cow⁻¹ in June, 8.4 kg cow⁻¹ in July, 5.3 kg cow⁻¹ in August and 0.9 kg cow⁻¹ in September.

Table 6.1 Fodder consumption per cow (1996/97)

	kg per cow	kg per FU
Silage (dry matter)	1869	262
Hay	1355	190.1
Pasture (dry matter)	775	108.7
Straw	170	23.9
Barley	1303	182.8
Peas	1001	140.4
Protein-mix	138.4	19.4
ExPro	204.9	28.8
Minerals	28.4	4
Lime	29	4.1

During the first part of the year, ExPro® (heat-treated rape-seed meal) was used as concentrate feed, but this was later changed to Protein-mix, mainly due to technical circumstances. Thirty-one tons of straw was used as bedding material.

Table 6.2 Fodder consumption per heifer (1996/97)

	kg per heifer
Silage	129.5
Hay	1588.4
Pasture	745
Barley	245.1
Peas	82.4
Minerals	11.2

The calves are given 360 kg milk each from the cows. Since this milk is produced inside the system studied it is not accounted for in the table. Basically all the heifers were grazing from the middle of May to the middle of September.

6.2.2 Diesel use in animal production

The total use of diesel for the machinery of the farms was approximately 10 100 l diesel in 1996. Of this approximately 8 004 l diesel was used for the crops of the farm, which is explained in section 6.4 (spreading manure is done by a hired contractor so the diesel for this work is included in the field operations seen in table 6.3 but excluded from the farms total diesel use). The difference, 2 096 l diesel is used for the machines in the daily feeding routines and general chores such as maintenance work, snow clearing, etc. This corresponds to 40 l diesel per cow which will be accounted for as energy consumption in feeding operations.

6.2.3 Direct energy use

The electricity consumption of the Tingvall farm was 1 360 kWh per cow during 1996. In section 5.2.3, the lack of data on electricity consumption in Swedish milk production was discussed. The farm's electricity consumption seems to be within a higher range.

6.3 Emissions from animal production

6.3.1 Methane

Swedish sources for methane emissions from high yielding dairy cows (> 7 000 kg milk) were referred to in chapter 5.3. The feeding system in organic production is to a greater extent based on roughage than in conventional milk production where grain and concentrate feed represent a larger part of the cows' feed intake. This difference in fodder intake results in a methane production that is 12 - 15 % higher in organic milk production systems than conventional systems (Murphy, M. priv. comm 1998). The methane production from cows is estimated at 174 kg CH₄ per cow in the organic system. The heifers feed ration do not differ considerable between the systems and 67 kg CH₄ heifer⁻¹ is also here calculated as emission for the replacement animals.

6.3.2 Ammonia

In chapter 7.4.2 the N-losses of the organic system are discussed in more detail. Ammonia losses during manure spreading, 939 kg NH₃-N, are allocated to the fodder production. Remaining ammonia emissions (stables, manure storage, grazing, crop residues) is 1 732 kg NH₃-N corresponding to 33.3 kg NH₃-N cow⁻¹

6.4 Fodder production

The cultivation of fodder crops is summarised in table 6.3. Just as in the case of Rossared, the yields of silage and hay are the amount of fodder finally consumed by the livestock and not the actual yield in field.

Silage was harvested on 21 ha in the 1st cut and 24 ha in the 2nd cut. Manure was applied in April with a 6 m³ band spreader. The grass is pre-dried for about 1 day and then transported to a ground silo where the grass is packed. To promote the conservation process, 5 l myric acid per ton of grass are added. The diesel consumption in silage production is very much due to the spreading of manure.

Grass for hay is cut on 49.2 ha and the re-growth was grazed. The mechanised system in the hay harvest is a self loading wagon that collects the loose grass and transports it to the farm where a large hay fan transports the grass to the store where it is ventilated for approximately two weeks demanding 7 730 kWh electricity corresponding to 157 kWh ha⁻¹.

The total consumption of pasture in the grazing period is estimated at 78 300 kg DM. The grazing after the hay harvest is estimated to be 600 kg DM/ha and by then the grazing in the pastures (15.5 ha) is estimated at 3 150 kg DM/ha. The diesel consumption in this acreage is for mowing which is done 1 - 4 times per season.

Table 6.3 Summary of data on cultivation of fodder on the organic farm

	Silage	Hay	Barley	Peas	Pasture
Yield, kg ha ⁻¹	4 613 (dm)	3 080	2 591	3 017	3 150 (dm)
Seed	125 kg total	260 kg total	190 kg ha ⁻¹	240 kg ha ⁻¹	
Manure	50 m ³ slurry ha ⁻¹	10 m ³ slurry ha ⁻¹	3.3 m ³ slurry ha ⁻¹ 15.5 ton solid manure ha ⁻¹		
Field operations Diesel, l ha ⁻¹	133	73	147	111	23
Fodder treatment	5 l myric acid ton grass ⁻¹	157 kWh El. ha ⁻¹	see text	see text	
Lime, kg ha ⁻¹	300	300	300	300	

Barley and peas are cultivated as ordinary grain crops. No mechanical weed regulation is carried out. The establishment of new leys is done by mixing the ley seed with the barley seed. The spreading of manure claims almost a quarter of the diesel consumption for the barley crop.

Peas and barley are dried on the average from 18 % to 15 %. Approximately 100 kg water ha⁻¹ should be removed by this. Standard data from Sonesson (1993) is used for this calculation. In a hot air drier (Akron 2A-166), the oil consumption is 0.155 kg oil water⁻¹ corresponding to 15.5 kg oil ha⁻¹. The electricity consumption for drying grain in this system according to Sonesson is 0.017MJ kg grain⁻¹ corresponding to 45.7 kWh ha⁻¹.

All the straw from the barley is collected and baled in rolled bales. The diesel consumption for baling and transporting the straw is 13 l ha⁻¹ and the straw yields approximately 1 500 kg ha⁻¹

6.5 Fodder production on adjacent farms

Just as the conventional farm, Tingvall purchases grain and also peas from an adjacent farm. Thirty-eight % of the barley and 69 % of the peas are cultivated outside the farm and "imported" from adjacent areas. Since this fodder has to be organically produced, it is not always possible to acquire it locally. The purchased barley and peas come from a farm 40 km from Tingvall and are transported by lorry.

Data on cultivation of organic crops in this area are based on cost estimates of organic barley and peas from the County Administration Board of Bohuslän (*Bidragsskalkyler, växtodling i skogsbygd*, 1996).

Table 6.4 Data on cultivation of organic barley and peas in northern Bohuslän

	Organic barley	Organic peas
Yield, kg ha ⁻¹	2 400	2 500
Seed, kg ha ⁻¹	180	250
Lime, kg ha ⁻¹	300	300
Diesel, l ha ⁻¹	99	137

The farm from which Tingvall buys peas and barley is an arable farm with little access to farmyard manure. Therefore it is assumed that green manure is grown as a pre-crop before some of the grain production. According to the cost estimates for organic farming, one hectare of green manure takes a seed amount of 10 kg ha⁻¹ and diesel consumption of 30 l ha⁻¹. An average of ½ hectare of green manure is assumed to be cultivated as a pre-crop to barley in this crop rotation, after which 15 l ha⁻¹ diesel and a seed amount of 5 kg ha⁻¹ will be added to the organic barley. Data for drying are according to Sonesson (1993).

7 Nutrient balances and emissions

The nutrient balance is a useful tool when quantifying the flows of macro nutrients and emissions to air and water. When imbalances exist between imports and exports of nutrients in agricultural production systems, either the soil nutrient store is depleted (exports exceeding imports) or nutrients are accumulated in the soil or are emitted to the environment (imports exceed exports).

The nutrient balance can be considered in a variety of spatial scales: field, farm and on regional or national levels. A model for calculating macro nutrient flows in agricultural systems is shown in Figure 7.1 and similar models have been used in Danish and Dutch studies (van der Werff *et al.* 1995, Dalgaard *et al.* 1997).

Figure 7.1 Model for calculating flows of plant nutrients in agricultural systems

The Swedish National Board of Agriculture has developed the computer program STANK (*Manure and plant nutrients in re-circulation*) (1996) for calculating nutrient balances on single farms. Data from this program on the content of plant nutrients in agricultural products have been used to calculate the nutrient flows of the farms studied in this analysis.

7.1 The conventional system

In Table 7.1 the input of plant nutrients to Rossared for one year is calculated. The total inflow of plant nutrients to the farm corresponds to 246 kg N ha⁻¹, 19.8 kg P ha⁻¹ and 45.8 kg K ha⁻¹.

The dominant part (> 50%) of the nitrogen input can be traced to the farm's feed import. The nitrogen input in the concentrated feed products Elit and Protein-mix corresponds to as much as 87 kg N ha⁻¹, i.e. nitrogen that has been fertilised or fixated in oil/starch/sugar crops cultivated at far distance from their final use. Since only a smaller part is tied up in milk and meat, most of this nitrogen will end up in the farmyard manure. The inflow of P and K to the farm is only through purchased feed and the protein concentrates also play an important part here.

The farm's use of nitrogen fertilisers is fairly moderate and represents roughly 1/3 of the total N input.

The atmospheric N-deposition of open arable land in the county of Halland is measured at six stations and amounts to 10-12 kg N ha⁻¹ (Anderson & Flodin 1996).

Table 7.1 Inputs of plant nutrients on the Rossared farm

Import fodder and seeds, kg ¹	Nitrogen, N	Phosphorus, P	Potassium, K
Wheat	3 705	692	960
Beet fibre products	1 544	70	842
Concentrate feeds	12 283	1 270	3 045
Calves concentrates	358	96	146
Straw	1 010	144	1 444
Minerals		514	
Seeds	87	17	26
Total fodder, kg	18 987	2 803	6 463
<i>Total, kg ha⁻¹</i>	<i>134.5</i>	<i>19.8</i>	<i>45.8</i>
N-fertilisers	12 204		
<i>N-fertilisers, kg ha⁻¹</i>	<i>86.4</i>		
<i>N-fixation, kg ha⁻¹</i>	<i>15.3</i>		
<i>N-deposition, kg ha⁻¹</i>	<i>10</i>		
Total input on farm, kg	35 043	2 803	6463
<i>Total input, kg ha⁻¹</i>	<i>246.2</i>	<i>19.8</i>	<i>45.8</i>

1) Data for nutrient contents in different fodder products were obtained from STANK's register.

The biological fixation is estimated on the basis of the crops and the amount of legumes. For calculating the size of the N-fixation, data from van der Werff *et al* (1995) were used. Per 1 000 kg yield of red clover the N-fixation is estimated to be 40 kg N ha⁻¹ and year, for white clover 54 kg N ha⁻¹ and year. Peas are assumed to fixate the same amount of N as field beans (*Vicia Faba*); 100 kg N ha⁻¹ and year.

The amount of clover in the leys on the conventional farm was estimated in co-operation with the farm manager (Pettersson, M. priv. comm 1997). In 1996 there were no first year leys on the farm. The second year leys were 23 ha with quite a high proportion of red clover, 30 % weight-basis. The rest of the leys for roughage production had no leguminous plants left. The grazing land of 19 ha of 6.5 ha with fairly new leys with approximately 10 % white clover while the rest of the pasture area was older leys with mainly grass. The total grass/clover harvest is estimated to be 40-50 % higher than the actual fodder harvest shown in table 5.4.

Table 7.2 Estimated N-fixation at Rossared

Crop	Area, ha	Estimated harvest in field	% clover	N-fixation kg N ha ⁻¹	Total N-fixation kg
Second year leys	23	7 000 kg DM ha ⁻¹	30	84	1 932
Grazing land	6.5	6 500 kg DM ha ⁻¹	10	35	227

The N-fixation on the whole farm is estimated to be 2 159 kg corresponding to 15.3 kg N ha⁻¹.

In Table 7.3 the outflow of plant nutrients is calculated, nutrient contents in animal products are data from STANK's register. The outflow is almost exclusively in the milk products of the farm and corresponds totally to 47 kg N ha⁻¹, 10 kg P ha⁻¹ and 14 kg K ha⁻¹

Table 7.3 Output of plant nutrients at Rossared

Products (kg nutrient)	Nitrogen, N	Phosphorus, P	Potassium, K
Milk	5 549	1 047	1 675
Calves, bulls	172	51	12
Cows slaughter	750	222	51
Manure	170	20	170
Total output, kg	6 641	1 340	1 908
Total output, kg ha⁻¹	47	9.5	13.5

7.2 The organic system

In Table 7.4 the inflow of plant nutrients on the organic Tingvall farm is presented. The total inflow of plant nutrients corresponds to 85 kg N ha⁻¹, 5 kg P ha⁻¹ and 9 kg K ha⁻¹.

Table 7.4 Inputs of plant nutrients at Tingvall

Import fodder and seeds, kg ¹	Nitrogen, N	Phosphorus, P	Potassium, K
Barley	500	104	131
Peas	1 356	139	388
Concentrate feeds	1 098	164	245
Straw	140	20	200
Minerals		135	
Seeds	121	20	34
Total fodder, kg	3 215	582	998
Total, kg ha⁻¹	28.6	5.2	8.9
<i>N-fixation, kg ha⁻¹</i>	<i>46</i>		
<i>N-deposition, kg ha⁻¹</i>	<i>10</i>		
Total input on farm, kg	9581	582	998
Total input, kg ha⁻¹	85.2	5.2	8.9

1) Data for nutrient contents in different fodder products were obtained from STANK's register.

The size of the N-fixation is important in this balance since it is the greatest input of nitrogen into the system. For experimental purposes, the Tingvall farm has six plots (30 x 30 m²) where yearly analysis of soil and crop is performed. Concerning the content of clover in grasslands, a botanical analysis is annually performed.

Table 7.5 Percent clover (weight) in leys at Tingvall in 1996

Crop	1 st cut (% clover)	2 nd cut (% clover)
First year leys	36	85
Second year leys	5	10
Third year leys	6	24
Third year leys (grazing)	2	2
Pasture	8	8

The clover content in the pasture and leys for grazing is surprisingly low, considering it is a system with no fertiliser input. This has however been observed in the experimental plots for a number of years (Sundås, S. priv. comm 1997). In Table 7.6 the biological N-fixation on the

organic farm is calculated following the same principles as for the conventional farm. The clover percentage is a weighed average, considering that the highest yield was obtained in the first cut.

Table 7.6 Estimations on N-fixation at Tingvall

Crop	Area, ha	Estimated harvest in field	% clover	N-fixation, kg N ha ⁻¹	Total N-fixation, kg
First year leys	23.4	6 900	53	146	3 416
Second and third year leys	46.8	4 780	10	20	936
Grazing land	15.5	4 725	8	20	310
Peas	5.8	3 017		100	580

The biological N-fixation on the whole is calculated to be 5 242 kg N corresponding to 46 kg N ha⁻¹.

Similar to the conventional farm, milk represents the dominating part of the nutrient outflow of the farm.

Table 7.7 Output of plant nutrients in products from the organic system

Products (kg nutrient)	Nitrogen, N	Phosphorus, P	Potassium, K
Milk	1964	370	593
Calves, bulls	81	24	5
Cows slaughter	229	68	16
Total output, kg	2274	462	614
<i>Total output, kg ha⁻¹</i>	<i>20.2</i>	<i>4.1</i>	<i>5.5</i>

7.3 Comparison to other studies

From the nutrient balances, indicators can be calculated making it possible to compare systems and evaluate their environmental impact. Nutrient efficiency is the nutrient in useful products (milk, meat) divided by the total input of nutrients. Nutrient surplus is the total nutrient input subtracted by nutrient in products. The nutrient surplus can be related to the area or, more interestingly, to the product, in this case milk.

Table 7.8 Indicators of nutrients flows on the studied farms

	N	P	K
Nutrient eff, % - conventional system	19	48	30
Nutrient eff, % - organic system	24	79	62
Nutr-surp, kg ha ⁻¹ - conventional system	199	10.3	32
Nutr-surp, kg ha ⁻¹ - organic system	65	1.1	3.4
N-surp, kg ton milk ⁻¹ - conventional system	22.8		
N-surp, kg ton milk ⁻¹ - organic system ^a	16.8		

a) when allocating 85 % of the surplus to the milk (allocation procedures, see section 2.4.4)

No systematic analysis of present nutrient efficiencies and surplus on dairy farms in Sweden has been carried out. Hallén, P (1997) has presented an analysis of nutrient flows in 14 conventional dairy farms showing nitrogen surplus of 90-250 kg N ha⁻¹. In this investigation, there was a clear connection between animal density and N-surplus. The National Board of Agriculture is monitoring nutrient balances on animal farms. Also in this work, connection is observed between animal density and nutrient surplus (Jacobsson, C. priv. comm. 1998).

Several Danish and Dutch sources have provided data on nutrient balances and indicators in conventional and organic dairy farms. Dalgaard *et al* (1997) present data from 16 conventional and 14 organic Danish dairy farms. This study shows an average N-efficiency of 16 % on conventional dairy farms and 21 % on organic farms. The average N-surplus for the conventional farms was 240 kg N ha⁻¹ versus 124 kg N ha⁻¹ for the organic farms. The N-surplus per ton product in this study was 29 kg N per ton (milk + meat) on conventional farms and 22 kg N per ton (milk + meat) on the organic farms.

Van der Werff *et al* (1995) report an N-efficiency of 31 % on three Dutch organic dairy farms compared with an N-efficiency of 12 % on conventional milk producing farms. Another source, Aarts *et al* 1995, reports an average of 14 % N-efficiency on Dutch dairy farms. The average N-surplus on the Dutch organic farms reported by van der Werff *et al* (1995) was 83 kg N ha⁻¹ compared with 391 kg N ha⁻¹ on conventional farms. Korevaar (1992) reports a N-surplus of 32 - 44 kg N ton per milk on specialised Dutch dairy farms.

When comparing the nutrient balances and indicators from the farms in this study with Danish and Dutch studies on different milk producing systems, it seems evident that the differences in nutrient flows between the farms in this analysis also can be found in other works. In the following section, the background for estimations of nutrient losses in the systems is presented.

7.5 N-emissions

Correct estimations of the size of nitrogen emissions are hard to obtain since the nitrogen cycle is influenced by a number of factors in soil, manure and their management and climate. The emissions of ammonia (NH₃), nitrous oxide (N₂O) and NO₃⁻ (nitrate) are however important to quantify when assessing agricultural production since they have important influence on acidification, eutrophication and in the atmosphere's radiative balance. The data sources for calculating the N-emissions of the systems in this study are the following:

Nitrate NO ₃ ⁻	To calculate standard leaching from Swedish arable land, Johnsson & Hoffman (1996) have developed a model, dividing Sweden into nine leaching regions which are characterised by climate, type of production and level of fertilising and production. For each region, standard-leachings are suggested for typical situations consisting of combinations of nine different crops, three soil types and two fertilising strategies (with or without manure in the crop rotation). These data were completed with data from recent research on leaching of organic crops (Torstensson, G. priv. comm. 1998).
Ammonia NH ₃	Data from the computer program STANK (1996) for losses of NH ₃ -N from manure in stables and during storing and spreading of manure. Data from Audsley <i>et al</i> (1997) on NH ₃ -N losses from synthetic fertilisers. Data from Karlsson, S. (1995) on NH ₃ -N losses during grazing. Estimations of NH ₃ -N losses from crop residues according to Agricultural Statistics (SCB, Na 18 SM 9404)

**Nitrous oxide
N₂O**

Methods for calculating emissions of N₂O from agricultural soils are presented by IPCC (1997). The latest revised guidelines for National Greenhouse Gas Inventories are a significant revision on the previous guidelines and deal both with direct (fertiliser-induced emissions) and indirect emissions. The latter emissions are a result of ammonia and nitrate emissions that enhance biogenic N₂O formation in soil and drainage water.

The sizes of ammonia and nitrate losses from agricultural production are rather well investigated and emission factors seem to be reasonably well supported. Concerning N₂O, the emission factors are more insecure and new knowledge is under continual development. This is evident from the Climate Panel's latest guidelines where the N₂O input to the atmosphere from agriculture is considered to have been underestimated by 70 % compared with previous calculations.

In the revised IPCC 1996 Methodology for assessing direct N₂O emissions from agricultural fields, the following equation is suggested:

$$N_2O_{\text{loss}} = (\text{applied synthetic fertiliser} + \text{applied organic manure corrected for NH}_3 \text{ and NO}_x \text{ emissions} + \text{N fixated by N-fixating crops} + \text{N in crops residues}) * \text{emission factor}^1$$

The **emission factor** is (fraction of input, kg N₂O-N per kg N) **0.0125** (range 0.0025-0.0225).

Behind this equation is a general formula by Bouwman (1994) for all soil types:
$$N_2O \text{ (in kg N per hectare)} = 1 + 1.25 \% * N\text{-applied.}$$

Since N₂O has a high global warming potential (310 CO₂-equivalents for time horizon 100 years), a correct estimation will have a significant impact on the result of potential global warming. There are only very few Swedish investigations performed on N₂O-losses from arable land. In the Mellby leaching experiment in southern Sweden, discharges of nitrous oxide and ammonia were measured after spreading liquid manure (Weslien *et al.*, 1998). The emissions of N₂O-N varied between 0.17 - 0.30 % of applied N (corrected for ammonia-losses) for slurry application in the spring and 0.79 - 0.91 % of applied N for slurry application in autumn. One reason for the lower losses in spring can be that the field trial took place during a very dry spring.

As a sensitivity analysis, two emission factors for N₂O-N will be tested in this study. The standard formula according to Bouwman and IPCC (1.25 % of applied N) and a lower one, 0.625% of applied N, which is in the range of N₂O-losses hither to measured under Swedish conditions.

There are also indirect emissions of nitrous oxide from both ammonia emissions and nitrate leaching. When ammonia is deposited on the soil, it acts as a fertiliser and thereby gives rise to possible risks of emission of nitrous oxide. IPCC suggests (1997) the emission factor 0.01 kg N₂O-N per kg emitted NH₃-N. The problem of calculating these indirect emissions is to predict where the pollutant will be emitted (N-saturated/non N-saturated soil, water?) Also nitrate losses from leaching and runoff can be transformed into N₂O. IPCC (1997) suggests an emission factor of 0.025 kg N₂O-N per kg N leaching/runoff.

Due to these uncertainties, indirect emissions of N₂O-N are not included in the analysis.

¹ The original equation also includes an emission factor for cultivated organic soils but since none of the farms studied have this type of soil this is not considered.

7.5.1 Calculated N-emissions in the conventional system

NH₃-N lost in stables and storing

Seven % of total-N is estimated to be lost in a loose housing system with liquid manure (STANK, 1996). Approximately 29.7 tons N enter the stable in the fodder (18.9 tons in purchased fodder and 10.8 tons N in farm-produced fodder). 6 500 kg N leaves the stable in milk and meat. Seven % of the difference is 1 619 kg NH₃-N. During the storing period, 1 % of total-N is estimated to be lost as NH₃-N from liquid manure in a covered tank. This corresponds to 216 kg NH₃-N. The total loss from manure in stables and storing is estimated to be 1 827 kg NH₃-N.

NH₃-N losses in manure during spreading

The average NH₄-N content in slurry (cattle) is 1.9 kg NH₄-N ton⁻¹. Approximately 43 tons ha⁻¹ were spread in the leys, the first time in early spring and the second time in June after the first harvest. Band spreading was used on both occasions. Thirty % of NH₄-N is estimated to be lost in the first spreading and 50 % of NH₄-N in the second spreading (higher temperature) (STANK, 1996). 26 tons slurry ha⁻¹ were broad spread and harrowed in August before sowing winter wheat. 30 % of NH₄-N is estimated to be lost. 30 tons ha⁻¹ were broad spread and incorporated late autumn on the field where whole crop silage was to be sown the following year, 10 % of NH₄-N is estimated to be lost.

Table 7.9 Losses of NH₃-N during manure spreading

	Kg N, total	Kg N ha ⁻¹
Leys, spreading March	2 106	24.6
spreading June	3 515	41.1
Wheat	97	14.7
Whole crop silage	92	5.7

The total NH₃-N losses during manure spreading are summarised to 5 810 kg NH₃-N

NH₃-N losses during grazing

During the grazing period the excrement from the animals is dropped in the pasture and especially the urine part is exposed to ammonia evaporation. International sources have reported ammonia losses as high as 60 % of the urine N during warm conditions (Richardson, M. 1991). On the average during the whole grazing period in Sweden, N-losses due to ammonia evaporation are assumed to be 10 - 20 % of the total nitrogen content in the manure (Karlsson, S. 1995).

Fifteen % is used in this study.

As described previously, it is difficult to estimate the fodder intake during the grazing period. A simplified method will therefore be used. A high yielding dairy cow produces 110-115 kg N in manure and urine yearly (Jordbruksverket 1995) and a heifer > 1 year 47 kg N. The cows on the conventional farm are grazing from May 15th until September 1st during the daytime. The total grazing period is estimated at 2 months. The N-production in manure during this period would thus be 2/12*110 = 18.3 kg N cow⁻¹. If 15 % is lost as NH₃-N this corresponds to 2.75 kg NH₃-N cow⁻¹. The older heifers were grazing for a period of 4 months. The N-production of heifers in pasture would therefore be 4/12*47 = 15.7 kg N heifer⁻¹. If 15 % is lost as NH₃-N this corresponds to 2.4 kg NH₃-N heifer⁻¹.

The average number of grazing animals was 134 cows and 64 heifers > 1 year. The total NH₃-N loss during the grazing period would correspond to 522 kg NH₃-N.

NH₃-N losses from crops and crops residues

Ammonia evaporation from leys have been estimated to 1.5 kg N ha⁻¹ and for grains 1 kg N ha⁻¹. (SCB 199x). If hay is harvested from leys and pre-dried an extended period extra N-losses can occur. This does not occur on the farm. The total N-loss from crops would be 180 kg NH₃-N.

NH₃-N losses from N-fertilisers

Ammonia emissions from synthetic fertilisers vary from 0 - 2 % mostly depending on the pH of the soil. The exception is ammonium sulphate and urea where ammonia emissions can be over 10 % (Audsley *et al* 1997). The fertiliser used is calcium ammonium nitrate and 2 % of applied N is assumed to be ammonia-N losses. The total use of 12 204 kg N x 2 % = 244 kg NH₃-N.

NO₃-leaching

The farm is situated on the borderline of two leaching regions in Johnsson & Hoffmans (1996) model. The standard leaching for the different crops is shown in table 7.10 and all are for clay soils.

Table 7.10 Standard nitrate-N leaching in the conventional system

	Kg N, total	Kg N ha ⁻¹
Leys (clay soil)	1 966	23
Winter wheat	561	85
Whole crop silage	1 288	80
Pasture	437	23
Set-aside	210	15

According to the computer model STANK, 20 % of NH₄-N can be estimated to be lost as nitrate-N (after soil nitrification) when manure has been spread in the autumn. This was the case for wheat and whole crop silage and is included in Table 7.8. Nitrate leaching due to crop rotation effects from the leys has also been considered and this is also shown in the fairly high leaching of wheat and whole crop silage (pre-crops ley). Total nitrate loss is estimated at 4 462 kg NO₃-N.

N₂O-N emissions from soils

12 204 kg N-fertilisers were used, after reduction of NH₃-N-losses, the N₂O emissions will be (12 204-244) * 0.0125 = 150 kg N₂O-N

Approximately 8 000 tons liquid manure were spread on the crops in 1996 corresponding to 27 tons total-N². Approximately 5 810 kg NH₃-N were estimated to be lost during spreading (see table 7.9). (27 000-5 800) * 0.0125 = 265 kg N₂O-N.

Approximately 2 159 kg N were estimated as being biologically fixated in the clover/grass leys. 2 159 * 0.0125 = 27 kg N₂O-N.

The fertiliser-induced emissions of N₂O-N are by this calculation 442 kg N₂O-N. In the sensitivity analysis, emissions factor 0.625 % of applied N will be used due to earlier discussions - the fertiliser-induced loss would then be 221 kg N₂O-N.

² When calculating the loss of NH₃-N in stables and storing, approximately 22 tons N on a yearly basis was estimated to leave the stable and storage after ammonia losses. Due to changes in crop rotation, manure from more than one year's production has been applied in 1996. Another source of the discrepancy between 22 and 27 tons is the N-content of the farm-produced roughage that may have been underestimated when calculating the input of N in stable from farm-produced fodder.

Table 7.11 Estimated total N-emissions on the conventional farm

		Total, kg N	N kg ha ⁻¹
Ammonia, NH ₃ -N	stable, storing	1 827	12.9
	spreading manure	5 810	41.1
	grazing	522	3.7
	fertiliser, crop residue	424	3
Nitrate, NO ₃ -N	leaching	4 462	31.6
Nitrous oxide, N ₂ O-N	high em factor: 1.25 %	442	3.1
	lower em factor: 0.625%	221	1.6
Total	(higher N ₂ O-em)	13 487	95.4

The N-surplus on the conventional farm was 199 kg N ha⁻¹ (see table 7.8). The N-emissions quantified above are used in the inventory sheet and they cover 48 % of the nitrogen surplus on the farm. Denitrification and fixation in soil organic matter explain part of the discrepancy. Denitrification can be as high as 60 kg N ha⁻¹ in clay soils (Beretning nr. S 1809, 1985) but since the emittent N₂ is a natural part of the atmosphere, no environmental damage is done. However, the loss of NO₃-N through denitrification is an undesirable fate for an applied nutrient which has cost energy (in fertilisers, feed, manure spreading) or land (green manure) to produce. It is probable that the losses of ammonia are greater than the calculations have shown; high protein content in the feed rations can increase ammonia losses in stables.

7.5.2 Calculated N-emissions in the organic system

NH₃-N losses in stables and storing

Approximately 9 600 kg N enter the stable in the fodder (of which approximately 1/3 is produced outside the farm). 2 274 kg N leaves the stable in products. Seven % of total-N in manure is estimated to be ammonia emissions, $(9\,600 - 2\,274) \times 7\% = 510$ kg NH₃-N. Approximately 75 % of the manure on the organic Tingvall farm is liquid manure. The rest is solid manure from calves and the farm's "birth department" (according to the rules for organic farming the cow mother shall be able to stay with her new born calf at least three days after the birth). Storing liquid manure in a covered tank gives ammonia losses of 1 %. Storing solid manure with high content of straw can give ammonia losses around 30 %. A weighed average of the ammonia losses of slurry and solid manure on the farm gives a figure of 9.7 % ammonia losses during the storing period corresponding to 656 kg NH₃-N. The total ammonia-N losses from manure in stables and storing are estimated to be 1 166 kg NH₃-N.

NH₃-N losses from manure spreading

Ten tons ha⁻¹ slurry with 1.9 kg NH₄-N ton⁻¹ were band spread in spring on leys for hay. Thirty % of NH₄-N is the estimated loss, a total of 280 kg NH₃-N. 50 tons ha⁻¹ liquid manure were band spread in early spring in 21 ha leys for silage. Thirty % losses refer to 598 kg NH₃-N. Before sowing barley, 3.3 tons liquid manure ha⁻¹ and 15 tons ha⁻¹ solid manure were broad spread and immediately incorporated. Ten % and 15 % respectively, of ammonia-N in liquid and solid manure (1.3 kg NH₄-N ton⁻¹) are estimated as ammonia losses. Total NH₃-N losses during manure spreading are 939 kg NH₃-N.

NH₃-N losses in the grazing period

The same method as for the conventional system is used for calculating the ammonia losses from the grazing period. The cows in the organic system graze for four months, both day and night. All the heifers are graze during the summer, an average of four months. The N-production in manure and urine is estimated to be 110 kg N cow⁻¹ (Jordbruksverket, 1995). The N-production during the summer is $4/12 \times 110 = 36.7$ kg N cow⁻¹. Fifteen % is assumed to be lost as ammonia-N, i.e. 5.5 NH₃-N per cow. A heifer < 1 year is estimated to produce 22 kg N and heifer > 1 year 47 kg N in the manure per year (Jordbruksverket 1995) and they are

grazing for four months. Average N-production in the manure from one heifer is thereby estimated to be $4/12 * 34 = 12 \text{ kg N heifer}^{-1}$ and if 15 % of this is lost, it corresponds to $1.8 \text{ kg NH}_3\text{-N heifer}^{-1}$. The total ammonia losses from the manure during the grazing period are according to these estimations $378 \text{ kg NH}_3\text{-N}$.

NH₃-N losses from crops and crop residues

Ammonia evaporation from leys is estimated to be 1.5 kg N ha^{-1} , for grain 1 kg N ha^{-1} and for peas (including their crop residues) 7 kg N ha^{-1} . The total ammonia-N loss from the crops this calculated to be $188 \text{ kg NH}_3\text{-N}$.

NO₃-leaching

In Johnssons and Hoffman's model (1996) for calculating standard leaching, there are fertiliser strategies, with synthetic fertilisers only and with a combination of fertilisers and manure. Data for N-leaching from organic systems, where manure and green manure are the main nutrient input are scarce. The standard leaching in Table 7.12 is estimated from the leaching model and discussions with researchers at Division of Water Quality Management, Swedish University of Agricultural Science (Torstensson, G. and Gustafson, A. priv. comm 1998).

Table 7.12 Standard nitrate-N leaching in the organic system

	Kg N, total	kg N ha ⁻¹
Leys (light-medium clay soil)	1 053	15
Barley	672	35
Peas	232	40
Other crops	51	30
Pastures	108	7

The total nitrate-N losses from the organic farm are from these estimations calculated as $2\,116 \text{ kg NO}_3\text{-N}$ corresponding to $18.8 \text{ kg N ha}^{-1}$.

N₂O-N emissions from soil

Approximately $1\,600$ tons liquid manure containing an average of $3 \text{ kg total-N ton}^{-1}$, and 285 tons solid manure containing in average $5 \text{ kg total-N ton}^{-1}$ were spread. $939 \text{ kg NH}_3\text{-N}$ was calculated to be lost during spreading. The loss of $\text{N}_2\text{O-N}$ from the applied manure-N is estimated as $(6\,225-939) * 0.0125 = 66 \text{ kg N}_2\text{O-N}$.

Approximately $5\,242 \text{ kg N}$ was estimated to be biologically fixated in the clover/grass leys and the peas. $5\,242 * 0.0125 = 66 \text{ kg N}_2\text{O-N}$.

The fertiliser-induced emissions of nitrous oxide are by this calculation $132 \text{ kg N}_2\text{O-N}$. In the sensitivity analysis, emission factors of 0.625% of applied N will be used due to earlier discussion - the fertiliser-induced loss would then be $66 \text{ kg N}_2\text{O-N}$.

Table 7.13 Estimated total N-emissions on the organic farm

		Total, kg N	N kg ha ⁻¹
Ammonia, NH ₃ -N	stable, storing	1 166	10.4
	spreading manure	939	8.4
	grazing	378	3.4
	crop residue	188	1.7
Nitrate, NO ₃ -N	leaching	2 116	18.8
Nitrous oxide, N ₂ O-N	high em factor: 1.25 %	132	1.2
	lower em factor: 0.625%	66	0.6
Total	(higher N ₂ O-em)	4 919	43.9

The N-surplus in the organic system was 65 kg N ha⁻¹ (see table 7.8). The N-emissions that are quantified in table 7.13 are used in the inventory sheet and they correspond to 67 % of the farm's nitrogen surplus. When comparing this to the quantified emissions on the conventional farm in table 7.11, it is evident that when using current emission factors, a larger part of the N-surplus in the organic system is explained. Either the losses are underestimated on the conventional farm, or this farm has higher denitrification and/or N-input in soil organic matter.

7.5 Losses of phosphorus

Kyllmar, K. *et al* (1995) present data on average losses of phosphorus from Swedish arable land. During 1977 - 1993 the average loss was 0.32 kg P ha⁻¹ according to a measuring program in fields all over Sweden. However, the variation behind this average data is as high as 0.01 - 2.61 kg P ha⁻¹ year⁻¹. There are no data on differences in P-losses in organic and conventional farming.

Due to higher animal density in the conventional system, the manure application is higher. Therefore, the P losses from the conventional farm are estimated to be 0.35 kg P ha⁻¹ and from the organic farm they are estimated to be 0.25 kg P ha⁻¹ (Gustafson, A. and Torstensson, G. priv.comm 1998). It should be pointed out that these estimations are uncertain.

However, from analysing the nutrient balances on the farms studied, it is clear that there is a phosphorus surplus on the conventional farm as opposed to the organic farm, which has almost a balance in input and output of phosphorus. The P surplus in the conventional system, approximately + 10 P ha⁻¹ (after reducing for losses), will most certainly accumulate in the soil leading to an increase in plant-available phosphorus. In the long term, this accumulation can lead to increasing P emissions. Recent research from the Broadbalk Experiment at Rothamstead, UK, where different fertiliser P levels have been applied in wheat field trials for more than 100 years, shows increasing phosphorus leaching from plots where an excess of P in fertilisers or manure has been applied for a long time. The results from this research at Rothamstead suggest enhanced P losses through subsurface runoff on heavy soils, once the plough layer has exceeded a certain concentration of plant-available P (Heckrath *et al*, 1995). A conclusion drawn from these results is that it is probably not sufficient to assess merely the momentary environmental effect of phosphorus losses from the agricultural system, but also to consider the long term effects of P accumulation in soils.

8 Land use in the systems studied

In food production, "land" is the most important resource and the base of the production. So far quantitative and qualitative assessments of this resource have not been carried out to a great extent in life cycle assessment. However, when performing environmental analysis of agricultural systems and especially when comparing systems that differ in intensity, the use of this resource must be considered. In this report, the qualitative impacts from different crops and the methods of cultivation on the resource "land" are not considered, only the area occupancy for producing fodder. The systems studied exhibit disparities, not only in intensity, but also in the choice of feed ingredients, which lead to different area occupancy.

8.1 Land use for roughage and grain

In the Swedish milk production, three principal groups of fodder are used: roughage (silage, hay, pasture), grain and concentrate feeds. In the feeding advisory service, super pressed pulp (*HP-massa*) is considered a roughage fodder due to its high fibre content and its capacity as a silage substitute.

Generally in Swedish milk production, the roughage and most grain are cultivated on the milk farm or in the general vicinity.

Conventional farm

The conventional farm uses 127.2 ha for production of roughage and grain and purchases wheat corresponding to 37.2 ha. This gives 164.4 ha which divided by each cow is 1.23 hectare per cow and 1 570 m² per FU.

The calculation for the area used for production of super pressed pulp is: one hectare of sugar beets yields 7 100 kg sugar, 2 970 kg super pressed pulp (dry matter) and 600 kg molasses (dry matter). This means that a total of 10 670 kg products (dry matter) are produced on one hectare.

The consumption of super pressed pulp is 309 kg per FU (product) and 83.4 kg per FU as dry matter. By calculating according to mass allocation $83.4 \text{ kg} / 10\,670 \text{ kg} = 78 \text{ m}^2$ per FU. This calculation shows what an effective use of arable land sugar beet crop production is. Besides the yield of 7 100 kg sugar, the co-product super press pulp (2 970 kg dry matter) can substitute approximately 1/2 hectare of grassland.

The total area needed for production of roughage and grain is 1 648 m² per FU (before allocation milk-meat).

Organic farm

The organic farm uses 104.9 ha for the cultivation of roughage and grain. It also purchases approximately 30 450 kg organic barley corresponding to 12.7 ha. As explained in section 6, it was also assumed that green manure was a pre-crop to half of the area of the purchased organic barley, thus corresponding to 6.35 ha.

This gives a total area of 124 ha corresponding to 2.38 ha per cow to produce the roughage and grain in the organic system.

This corresponds to a total area of 3 346 m² per FU (before allocation milk-meat).

8.2 Land use for production of concentrate feed

Contrary to the roughage and grain, the ingredients of concentrate feeds are grown far away from their final use in the milk production. They are co-products in the oil/starch/sugar production and a large proportion is made up of imported commodities. However, the organic system has a different strategy in the choice of concentrate feed, in that this system is not allowed to purchase more than 5 % conventionally produced fodder (10 % before November 1997). Organically grown peas, produced relatively close to the milk production, is therefore an important feed component in this system.

The calculations of the area which is needed to obtain the components in the concentrate feeds are straightforward mass allocations. Due to confidential data, the exact recipes of the concentrate feeds used in this study are not available to the public. When calculating the area needed for the cultivation of the ingredients in the feed products, the recipe used in the example in Table 8.1 is made by the author and not the actual mixture in concentrate feeds used by the farms in the study.

Table 8.1 Area needed for the production of one tonne of the concentrate feeds Elit and Protein-mix

Elit ingredients	kg ton ⁻¹	Protein-mix ingredients	kg ton ⁻¹	Yield kg ha ⁻¹	Area required for production m ² ton Elit ⁻¹	Area required for production m ² ton P-mix ⁻¹
Beet pulp	260			11 280 ¹	230	
Soymeal and soypass	180	Soymeal and soypass	320	2 200 ²	818	1455
Rapemeal and ExPro	160	Rapemeal and ExPro	320	2 840 ³	563	1127
Maize gluten meal	110	Maize gluten meal	320	8 200 ⁴	134	390
Sunflower meal	80			1 870 ⁵	428	
Palm kernel expeller	70			5 070 ⁶	137	
Rape seed	30			2 470 ⁷	121	
Protamyl ⁸	30					
Molasses	30			11 280 ⁹	27	
Fats, vitamins etc	50					
Total area to produce one ton feed					2 458 m²	2 972 m²

1) One hectare sugar beets yields 7 100 kg sugar + 2 580 beet pulp (90 % dm) + 1 600 kg molasses = 11 280 kg products, 260 / 11 280 = 0.0230 ha

2) One hectare soy beans yields 2 200 kg soybeans

3) One average hectare of German and Swedish rape seed yields (2 470 + 3 150)/2 = 2 840 kg rape seed

4) One hectare maize yields 8 200 kg; approximately 5 % is gluten meal

5) One average hectare of Argentinean and French sunflower seeds yields (2 100 + 1 640)/2 = 1 870

6) One hectare palm oil plantation gives (section 4.2.6) 3 909 kg CPO + 532 kg CPKO + 629 kg palm kernel expeller = 5 070 kg products

7) Only Swedish rape seed

8) Not considered due to lack of data

9) Molasses is a co-product from sugar beets, see note 1

As seen in table 8.1, soymeal is the component in concentrate feed that requires the largest area to produce. It is also obvious that the production of concentrate feeds is highly dependent on

“imported” arable land. Approximately 30 % of the beet fibres, half of the rape-seed meal and all of the whole rape seed is of Swedish origin, the other components are imported. Approximately 19 % of the arable land used for the production of the concentrate feeds according to Table 8.1 is of domestic origin.

The organic farm uses ExPro® (heat -treated rape-seed meal) as protein feed, one tonne of this product uses 3 521 m² to grow (2 840 kg rape seed per ha, see note 3 above). The area needed for growing one ton of organic peas is 3 759 m² (weighed average of the farm’s pea yield and purchased peas is 2 660 kg per ha) for the organic farm in this study.

Table 8.2 Land use for producing the concentrate feed used by the farms in the study (not allocated milk-meat)

	Conventional	System	Organic	System
Concentrate feed	Kg feed FU ⁻¹ ^a	M ² FU ⁻¹	Kg feed FU ⁻¹ ^a	M ² FU ⁻¹
Elit	97.2	239	-	-
Protein-mix	120.8	359	19.4	57
Betfor®	8.8	8	-	-
Kalv Krafft	5.2	11		
ExPro®	-	-	28.8	101
Peas			151.8	571
Total land use, m² per FU		617		729

a) including heifers’ fodder consumption, but not allocated between milk/meat.

Finally, in Table 8.3 the total area occupancy for producing milk is shown. The difference between the farms studied in the area needed for roughage and grain is mainly explained by the higher yields in the conventional system, especially of grain; the conventional farm’s use of relatively high yielding winter wheat is area-efficient.

The organic farm’s strategy to use a large proportion of peas in the feeding system also demands more area than the conventional system which has the possibility to use co-products in a much greater extent, e.g. co-products from sugar beets which is an area-efficient crop.

Tab 8.3 Total land use, m² per FU

	Conventional system	Organic system
Roughage and grain	1 648	3 346
Concentrate feed	617	729
Total	2 265	4 075
Total after allocation milk-meat	1 925	3 464

(allocation procedures, see section 2.4.4)

9 Pesticide use

In Table 9.1 a summary of the pesticides used in the cultivation of fodder crops, grassland and grains as well as oil/starch/sugar crops whose co-products will be ingredients in the concentrate feed, is shown. Since the organic system is allowed to use a maximum of 5 % (10 % < november 1997) of the total feed ration from conventionally cultivated crops, the total use of pesticides is significantly lower in this system.

Table 9.1 List of pesticides that are used in crops producing fodder. ⚑ is a red flag classification.

Fodder producing crop	Conventional system	Organic system
Grassland for silage and hay	Glyphosate, bentazon	<i>No pesticide use</i>
Grains	Tribenuronmetyl, propikonazol, pirimicarb	<i>No pesticide use</i>
Peas	<i>Fodder component not used</i>	<i>No pesticide use</i>
Super pressed pulp, beet fibres	Metamitron, fenmedifan, etofusemat, kloridazon	<i>Fodder component not used</i>
Soymeal⚑	Glyphosate, 2,4 - D⚑, monocrotofos⚑, endosulfan⚑, diflubensuron	Glyphosate, 2,4 - D⚑, monocrotofos⚑, endosulfan⚑, diflubensuron
Rape-seed meal	Metazaklor, esfenvalerat, iprodion	Metazaklor, esfenvalerat, iprodion
Maize gluten meal⚑	Atrazine⚑, alachlor, lambda-cyhalotrin	Atrazine⚑, alachlor, lambda-cyhalotrin
Sunflower meal	Trifuraline, fluorchlorine, fenpropimorf, deltametrin	<i>Fodder component not used</i>

Red-flagging is a method for explicitly pointing out hazardous chemicals, see section 2.4.5. The red-flagging of soymeal is due to the use of a number of toxic pesticides in soybean cultivation. Monocrotofos and endosulfan are two commonly used insecticides, both substances being highly toxic (Class I). Alho and Vieira (1997) describe the problem of legislation and pesticide use in the agriculture of the Pantanal wetlands, one of the world's largest wetland ecosystems. Due to the large increase of the soybean acreage in Brazil including the Pantanal region, small-scale cattle ranching on the cerrados (savanna vegetation) has been transformed into the cultivation of agricultural crops, mainly soybeans. In addition to monocrotofos and endosulfan, toxic insecticides like parathion are used.

Red-flagged herbicides are also used. The use of 2,4-D was prohibited in Sweden in 1991 because of suspected carcinogenic effects on workers using this pesticide. Another herbicide, picloram, used in soybean cultivation in the Pantanal region, is highly mobile and during the rainy season it can easily be transported long distances and affect the wetland ecosystem. For example, Alho and Vieira (1997) report on one case of the massive death of fish in Pantanal in

1985; it was confirmed by samples of fish tissues that the cause was the herbicides 2,4 - D and picloram. The source of the pesticide discharges was never confirmed in this case.

Atrazine has not been allowed to be sold in Sweden since 1989 and in 1992, the use of the herbicide was prohibited; hence the red flag for maize gluten meal. This herbicide is persistent and has a high soil mobility, leading to a high risk for groundwater contamination. Atrazine is the standard herbicide used in maize; on the European continent as well as in the United States.

In Table 9.2 the total use of pesticides in the fodder production is shown. The allocations of the pesticides used in the oil/starch/sugar crops are the price allocations described in section 4.

Table 9.2 Pesticide use per functional unit.

	Conventional system	Organic system
Herbicides, g	80.28	5.48
Insecticides, g	4.30	0.37
Fungicides, g	3.49	0.37
Total, g	88.07	6.22
Total, g after allocation milk-meat	74.86	5.29

(allocation procedures, see section 2.4.4)

The intense use of chemicals in soybean cropping has a direct impact on pesticide use in conventional milk production. Since the conventional system uses considerable amounts of soymeal per 1 000 kg milk, as much as 75 % of the insecticide use per FU is explained by the insecticide applications in soybeans. Of total herbicide use per functional unit in the conventional system, 28 % are herbicides used in soybean cultivation.

10 Results

In this section, the results from the analysis of resource use and emissions in the studied conventional (CONV) and organic (ORG) systems are presented. The functional unit, FU, is 1 000 kg ECM milk leaving the farm gate.

10.1 Resources : energy

The use of energy is greater in the conventional system than in the organic system, see Table 10.1.

Table 10.1 Energy use (primary) in the systems

	CONV	ORG	Difference, %
MJ per FU	2 845	2 406	- 15 %

Due to differences in feeding strategy, the sources of energy are not the same in the two systems. The organic system uses almost solely diesel for tractors as an energy source since most of the fodder is produced on the farm or on neighbouring farms. The conventional system has a larger variety of energy sources, due to the fact that a greater share of the feed production is in the feed industry, including transportation of feed commodities. The lion's share of the natural gas consumption in the conventional system is due to the use of N-fertilisers.

Table 10.2 Energy use (%) from different sources in the systems.

	CONV, MJ kg ⁻¹	CONV, %	ORG, MJ kg ⁻¹	ORG, %
Coal	0.06	2.1	-	-
Diesel	0.97	34.0	1.54	63.8
Diesel, boat	0.18	6.3	0.01	0.6
Oil	0.33	11.6	0.12	5.0
Natural gas	0.69	24.2	0.05	1.9
Other	0.02	0.6	0.01	0.38
Biofuel	0.02	0.7	0.002	0.06
Electricity	0.58	20.5	0.68	28.3
Total	2.85	100	2.4	100

The results for energy use in milk production are consistent with unpublished Danish research (Dalgaard *et al*, 1998 in prep). In the Danish study, the use of diesel on 36 conventional and organic farms was registered and used for modelling. According to these investigations, energy requirements for organic milk production under non-irrigated conditions are in the range of 2 010 - 2 370 MJ per 1 000 kg milk, and energy requirements in conventional milk production under the same premises are in the range of 3 070 - 3 340 MJ per 1 000 kg milk.

There are however some differences in energy calculations between this study and the Danish investigation. The Danish data are correlated for the total energy cost for producing electricity, i. e. secondary energy as well. This is, however, not done for the use of energy in diesel, natural gas etc (thermal energy). A standard energy norm for electricity use in stable corresponding to 673 kWh per cow and heifer is used in the Danish analysis which is lower than the electricity consumption on the farms in this study. On the other hand, higher energy requirements are used for the calculations of concentrate feed in the Danish study. The Danish data for concentrate feeds are based on older references than in this study, but there are also differences in the choice of feed ingredient; for example dried grass pellets which are very energy-demanding to process are used more frequently in Danish concentrate feed. Higher energy data for concentrate feed has a greater impact on the energy cost for conventional milk production than

it has on organic production since the former uses more concentrate feed, this was shown in the Danish study as well as in this one. Finally, in the Danish investigation, energy requirements for machinery and buildings are included.

10.2 Resources : materials

In table 10.2 the systems' use of materials is shown. Since machinery is not included in the analysis, the material use is very much dependent on energy and fertiliser consumption.

Table 10.3 Use of materials, kg per FU

Inflow parameter	CONV	ORG	difference, %
Coal	3.5	1.1	- 69
Crude oil	38.3	43.1	+ 12
Natural gas	16.8	2.3	- 86
Natural uranium ¹	0.00183	0.00217	+ 19
Hydro power ²	0.268	0.319	+ 19
Phosphorus	1,92	0,82	- 57
Potassium	1,86	0,31	- 83
Limestone	35.8	84.6	+ 136

1) 1.0 g of natural uranium corresponds to 504 MJ heat, assumed efficiency 0.35 in nuclear power.

2) Kg el. from hydropower refers to MJel.

The organic system has a higher consumption of electricity per cow and FU and will therefore use more uranium and hydropower for electricity production. Although the organic system has fewer transports of concentrate feeds, for example less intercontinental transports of feed, it still uses more crude oil than the conventional system. This is mainly because of a larger diesel use in the organic system due to a larger fodder production on the farm and on neighbouring farms. The higher use of natural gas in the conventional system is to a great extent explained by the synthetic N-fertilisers. The difference in coal consumption is due to the refining of components in the concentrate feeds, mainly the drying of beet fibres.

The use of phosphorus and potassium is dependent upon synthetic fertiliser application in conventionally purchased wheat and in oil/starch/sugar crops whose co-products will end up in concentrate feeds. Minerals for feeding are the main phosphorus input into the organic system.

10.3 Resources : land

The area occupied for producing 1 000 kg milk is shown in fig 10.1. The organic system claims a substantially larger area than the conventional system.

In the 1960s and early 1970s, Georg Borgström analysed resource consumption in terms of "ghost acreage" which referred to the imported agricultural carrying capacity. For the production of milk, there is ghost acreage for the production of concentrate feeds, especially soymeal. The conventional system has a ghost acreage of approximately 480 m² per FU and the organic system a ghost acreage next to 100 m² per FU (see section 8). This area is included in the graphs for concentrate feed in Figure 10.1.

Figure 10.1 Land use for the production of 1 000 kg milk (m² per FU)

10.4 Human health : pesticide use

The amount of used pesticides (as active substances) in the fodder production in the two systems is shown in Fig. 10.2.

Fig. 10.2 Pesticide use (gram active substance per FU) in the two systems

Of the total pesticide use, herbicides are the dominating substances corresponding to approximately 90 % of the total use. The insecticide use in the conventional system is to a great extent caused by an intense insecticide use in Brazilian soybean cultivation. Since many of the insecticides used in this crop are very toxic, the human and environmental impact of this use may be significant. As an example, Seager (1995) estimates that 2 % of the Brazilian population are poisoned by agricultural chemicals yearly.

Pesticides used in the life cycle of milk and prohibited in Sweden were red-flagged. Criteria for red-flagging were explained in section 2.4.5 and red-flagged pesticides were pointed out in Table 9.1.

10.5 Ecological effects

10.5.1 Global Warming

An increasing amount of greenhouse gases in the earth's atmosphere leads to an increasing absorption of heat radiation energy. CO₂ are considered to be the most important greenhouse gas, however, when analysing an agricultural system, discharges of methane and nitrous oxide are of the greatest interest since these gases have high radiative forcing abilities. In Table 10.4 the weighting factors are shown.

Table 10.4 Weighting factors of greenhouse gases

	GWP - 20 yrs	GWP - 100 yrs	GWP - 500 yrs
Carbon dioxide, CO ₂	1.00	1.00	1.00
Methane, CH ₄	56	21	7.5
Nitrous oxide, N ₂ O	280	310	180

Source: Climate Change 1995. Intergovernmental Panel of Climate Change

The emissions of greenhouse gases in the milk production systems are shown in Table 10.5. As explained previously, two emission factors of nitrous oxide are presented, due to the uncertainty of the estimations of the size of emissions from this gas. In the lower estimate, N₂O-N losses of 0.625 % of applied nitrogen (fertilisers, manure, biological N-fixation) are calculated on the farms' N-supply and on the N-application in the purchased grain and peas.

Table 10.5 Discharges of greenhouse gases; kg emissions per FU

	CONV	ORG
CO ₂	178.125	147.6
CH ₄	24.38	28.623
N ₂ O (emission factor 1.25 %)	0.968	0.624
N ₂ O (emission factor 0.625 %)	0.642	0.330

Characterisation results for global warming are shown in Figure 10.3 and 10.4.

Figure 10.3 The potential contribution to global warming, kg CO₂-equivalents per 1 000 kg milk. Emission factor for N₂O is 1.25 %. Time horizon 100 years.

It is evident that the potential contributions to global warming from milk production is, to only a minor extent, related to the use of fossil fuels. The methane emissions are responsible for more than half of the contribution and in the organic system this greenhouse gas is responsible for as much as 64 % of the total contribution. The total potential contribution to global warming is approximately 990 kg and 940 kg CO₂-equivalents in the conventional and organic systems, respectively. Due to the uncertainty of the calculations of emissions of CH₄ and N₂O, these differences may not be considered significant enough to be able to promote one production system rather than the other one, from a global-warming perspective.

Figure 10.4 The potential contribution to global warming, kg CO₂-equivalents per 1 000 kg milk. Emission factor for N₂O is 0.625 %. Time horizon 100 years.

When using the emission factor of 0.625 % N₂O-N losses of totally applied nitrogen, the total potential contribution to global warming is reduced by approximately 100 kg CO₂-equivalents which can be compared to the total emissions of 147 and 178 kg CO₂-equivalents in the organic and conventional systems respectively; this is due to the use of fossil energy. This sensitivity analysis shows how important it is to have access to correct emission factors for N₂O when analysing food production systems' potential contribution to global warming. Also, more research appears to be needed on emission factors of methane due to feeding strategy since this parameter has a very large impact on milk production's global warming potential.

10.5.2 Acidification

Acidification is caused by emissions of gases which, combined with other molecules in the atmosphere and deposited as "acid rain", cause damage to soil and plants, directly, or indirectly by oxidation in the soil (NH₃, NH₄⁺). Acidification is measured as SO₂-equivalents.

Table 10.6 Weighting factors for acidification, maximum scenario

Substance to air	Acidification potential, g SO ₂ -equivalents per g
SO ₂	1
HCl	0.88
NO _x	0.7
NH ₃	1.88

Source: Nordic Guidelines for Life-Cycle Assessment (Lindfors *et al* 1995)

Emissions of the acidifying compounds are shown in Table 10.7.

Table 10.7 Emissions of acidifying gases, kg per FU

	CONV	ORG
NO _x	1.828	2.117
SO ₂	0.518	0.300
NH ₃	8.46	7.45

Due to the larger quantities of tractor diesel in the organic system, the NO_x-emissions are higher. The difference in SO₂-emissions between the systems can to a great extent be explained by the long-distance boat transports of soymeal, sunflower meal and palm kernel expeller; these feed components are much more used in the conventional system. Also the drying of imported beet fibre, which requires coal as its major source of energy, contributes to SO₂-emissions in the conventional system. However, the acidifying emissions due to the use of fossil fuel, are almost negligible in comparison with the key parameter ammonia. Approximately 90 % of the total acidifying potential is due to ammonia losses in both systems (see Figure 10.5). As was described in chapter 7, these losses are almost solely related to ammonia evaporation from farmyard manure.

The losses of NH₃-N and NO₃-N were calculated according to current Swedish procedure. Ammonia losses were estimated according to STANK, a computer program from the National Board of Agriculture (see section 7). However, there are research results from the Netherlands showing great variations in ammonia emissions from dairy cows due to different feeding strategies (Smits *et al*, 1995). In this research, dairy cows were fed with a high protein which was alternated with a low protein diet. There was no difference in milk yield between the feeding strategies, but the urea content in the urine of cows fed a low protein diet was 42 % lower than for cows fed with a high protein diet. This difference in urea content resulted in a reduction of ammonia emissions by 39 %. The overall conclusion drawn by Smits *et al* (1995) was that nutrition management may substantially contribute to reducing ammonia emission.

The same emission factor for ammonia emissions from stable and manure storing were used for the systems studied in this work. The cows on the conventional farm have a higher protein intake than those on the organic farm. Actually, during the past years it has become more common to increase the protein intake at the beginning of the lactation period in conventional production in Sweden (Danielsson & Lindahl, 1997). Meanwhile, the rules for organic milk production have become more stringent and when only 5 % of the yearly fodder intake is now allowed to be conventionally produced, the support of protein is probably lower. Feeding trials on organic farms have shown that 7.6 AAT¹ per MJ metabolised energy is sufficient to feed even high yielding cows. In conventional feeding norms, a protein intake of 8.5 - 9 AAT per MJ is often calculated and used at the beginning of lactation (Danielsson & Lindahl 1997).

The acidification potential is approximately 10 % lower in the organic system. As shown in the farms' nutrient balances, a larger part of N-surplus in the conventional system was unexplained. This may imply that ammonia losses are underestimated and that the acidifying potential thereby could be greater in the conventional system. There are good reasons for drawing the conclusion that the input of protein to the system (i.e. the cow) should be one base for calculating ammonia emissions from milk production. This is generally not done in Sweden today and it has not been done in this study.

The maximal potential contributions to acidification are shown in Figure 10.5

¹ AAT stands for amino acids absorbed in the small intestine

Figure 10.5 The maximal potential contributions to acidification

10.5.3 Eutrophication

Eutrophication is the enrichment of ecosystems of nutrients, emitted mainly via water but also via air, leading to affects of the relative growth pattern. This may lead to undesirable shift on the number of species. The main nutrifying elements are nitrogen and phosphorus but emissions of organic material may also be included.

Weighting factors for eutrophication (maximum scenario, both N and P) are shown in Table 10.8.

Table 10.8 Weighting factors for eutrophication (maximum scenario)

Substance	Maximum (g O ₂ / g)
NO _x to air	6
NH ₃ to air	16
NO ₃ to water	4.4
PO ₄ to water	46
COD	1

Source: Nordic Guidelines for Life Cycle Assessment (Lindfors et al 1995)

The estimations of the P-losses are based on data with high uncertainty since there are great variations in P-losses from arable land (see sect 7.5). Fifty % of total P-losses were estimated to be lost as PO₄ - P (Kyllmar *et al*, 1996; Gustafson, A. priv comm. 1998). Since the organic farm uses substantially larger area to produce fodder, estimated phosphorus losses per FU are higher.

Table 10.9 Discharges of nutrifying substances, kg per FU

	CONV	ORG
NO _x	1.828	2.117
NH ₃	8.46	7.45
NO ₃	24.016	34.5
PO ₄	0.1038	0.1436

Although the organic farm has a lower average nitrate leaching per hectare ($19 \text{ kg NO}_3\text{-N ha}^{-1}$ compared with $32 \text{ kg NO}_3\text{-N ha}^{-1}$ on the conventional farm, see table 7.11 and 7.13), the nitrate loss per FU is higher. There are two explanations for this. The overall yields are generally higher in the conventional system so consequently the nitrate loss per kg fodder for many of the feed components in this system is lower. For example, the leaching of 40 kg N per hectare in the purchased conventional wheat that yields 6 ton per ha is much lower per kg grain than the nitrate leaching per kg purchased organic grain (barley: yield $2\,400 \text{ kg per ha}$, estimated leaching 35 kg N per ha).

The other important difference is the choice of concentrate feed. The organic farm uses a considerable amount of peas, approximately $1\,000 \text{ kg}$ per cow and the nitrate leaching in relation to the yield is high for this feed. The conventional farm, on the other hand, uses significant amounts of the feed products Protein-mix and Elit which have lower nitrate discharges per kg feed than the organic peas. Since these concentrate feed products are based on co-products from oil/starch/sugar crops, the nitrate leaching from these crops is divided through the allocation procedure between the main product and the co-products. The peas that are the main concentrate feed in the organic system have to carry the whole nitrate loss themselves since there are no co-products to share this environmental burden.

In Figure 10.6, the maximal potential contribution to eutrophication is shown and it is approximately 13 % higher for the organic system. However, the ammonia emissions have a large impact on this index, actually for the conventional system this emission appears to be more important than the nitrate leaching. As previously described, the ammonia emissions might be underestimated in the conventional system and this uncertainty makes it hard to reach a clear cut conclusion concerning the differences between the two alternatives.

Figure 10.6 The maximum potential contribution to eutrophication, kg O_2 per functional unit

10.5.4 Photo-oxidant formation

Increasing levels of ozone can have impacts on human health as well as ecological effects. Photo-oxidants, i.e. ozone, are formed through reactions between NO_x and hydrocarbons under the influence of UV-light. The Nordic Guidelines suggest characterisation of Volatile Organic Substances with respect to ozone formation based on the concept of POCP (Photochemical Ozone Creation Potentials). The POCPs are expressed as ethene-equivalents. There are several

data-sets for POCP-values in the Nordic Guidelines, two of which are presented in Table 10.10 with the compounds in the analysis that have been classified into this impact category.

Table 10.10 POCP-values from two data-set for compounds classified as contributors to ozone formation.

Compound	<u>Regional effects</u>	<u>Local effects</u>
	Data set 1 (Finnveden) 4 days average, Swedish back-ground (lower NO _x areas)	Data set 2 (Heijungs) Peak ozone data (local effects, Europe)
CO	0.04	
HC (hydrocarbon average)		0.416
Hexane	0.452	0.421
Methane		0.007

Source: Nordic Guidelines for Life-Cycle Assessment (Lindfors *et al* 1995)

There are difficulties in assessing the impact category photo-oxidant formation. No single data set has weighting factors for all emissions. Furthermore, the emissions take place under different conditions, with varying background concentrations of NO_x and organic species and varying sun-intensities.

As seen in Table 10.11 the emission of NO_x, which is the catalyst in the reaction, is greater in the organic system. This is due to a higher use of diesel per FU which also leads to larger emissions of CO and hydrocarbons. Also methane, being a hydrocarbon, can contribute to photo-oxidant formation. Actually, when classifying all emissions that can contribute to this impact category, only hexane discharges are higher for the conventional system. All other parameters show higher emissions in the organic system.

Table 10.11 Discharges of compounds contributing to photo-oxidant formation, kg per FU

Compound	CONV	ORG	Difference, %
NO _x	1.828	2.117	+ 16
CO	0.336	0.478	+ 42
HC	0.237	0.332	+ 40
Hexane	0.0045	0.0011	- 75
Methane	24.38	28.623	+ 17

Due to the difficulties of weighting the emissions into POCPs, only the separate emission data are presented in Table 10.11. It is however clearly evident, that the conventional system is a somewhat better alternative in terms of ozone formation.

10.5.5 Ozone depletion

Emission of some gases leads to damage of the stratospheric ozone layer. This leads to increased harmful ultraviolet radiation.

In LCA characterisations, Ozone Depletion Potentials (ODPs) are used as weighting factors. ODPs are dependent on the atmospheric lifetime of the compounds, the release of reactive chlorine and bromine from the compounds and the corresponding ozone destruction within the stratosphere. Although machinery was not included in this analysis, the cooling medias in dairy farms' milk cooler equipment are worth mentioning. On Swedish dairy farms, all cooler tanks containing CCl₂F₂ (R12) are replaced and during 1998 cooler tanks containing CHClF₂ (R22) are to be replaced (Ahlmén, K. priv. comm. 1998).

Apart from the chemicals with ODPs according to the WMO (World Meteorological Organisation), there are other compounds which can affect the ozone layer (Lindfors *et al*, 1995). Compounds such as methane, nitrous oxide, carbon monoxide etc. can directly or indirectly influence stratospheric ozone depletion. Due to the complexity and the incomplete understanding of processes, no ODPs have been calculated for these compounds.

Due to the lack of data on ODPs for emissions recorded in this study (e.g. N₂O and methane), no characterisation is done.

11 Discussion

11.1 Hotspots in milk production

Use of energy, photo-oxidant formation

Due to feeding strategy, the use of energy is lower in the organic system. In Table 11.1 total use of energy for fodder production for the dairy cows is divided between roughage, grain and concentrate feed. The greater input of concentrate feed in conventional milk production leads to a higher energy demand. The same conclusion was drawn in the Danish investigation on the use of fossil fuel on dairy farms (Dalgaard *et al*, 1998 in print). In the Danish study, imported feed contributed to an average of 38 % of total energy use on conventional dairy farms while on organic dairy farms the imported feed accounted for approximately 25 % of total energy use.

Table 11.1 Energy cost for the principal groups of fodder, MJ per kg milk (leaving farm gate, 85 % allocation to milk).

	CONV, MJ kg milk ⁻¹	CONV, %	ORG, MJ kg milk ⁻¹	ORG, %
Roughage	0.546	34	0.445	36
Grain	0.325	21	0.396	32
Concentrate feed	0.714	45	0.403	32
Total¹	1.585	100	1.244	100

1) NB that this only includes the direct primary energy cost for producing fodder for dairy cows, fodder for heifers are not included

However, the higher energy demand in conventional production does not necessarily mean that fuel-related emissions are worse in the conventional system. The proportionately greater use of diesel in the organic system in this study leads to higher discharges of NO_x, CO and hydrocarbons, emissions that promote photo-oxidants. The use of natural gas, which is considerably higher in the conventional system, is in this aspect a cleaner energy input.

Use of materials

Phosphorus is a limited resource. According to Louis (1992), current reserves (referring to tonnage that could be produced with current techniques, infrastructure and economy) are adequate to sustain production at present level for 200 years. Since phosphorus is an element that can not be substituted and is almost exclusively used in agriculture as fertiliser and fodder minerals, long-term sustainable food production must deal responsibly with this resource.

As seen in Table 10.3, the use of phosphorus per functional unit is higher in the conventional system due to fertiliser application in the imported feed. It should, however, be noted that the method of dividing co-products from the cultivation of oil/starch/sugar crops according to price allocation puts the P-flow in the conventional system in a better light than it is in actual practice. The P-flow is more likely to follow the mass when it is divided between the co-products from the crops that provide the raw material for the feed industry. In this respect, the nutrient balance of the farm gives more correct information on the true phosphorus flow. As seen in section 7, the conventional system showed a substantially higher P-surplus. There are two important environmental aspects to consider in terms of this finding. 1) It means an inefficient use of this limited resource. Feed is exported from arable farms to animal producing farms and P-fertiliser must replace nutrient losses following the harvest products from arable farms. 2) Accumulation of plant-available phosphorus in soil due to P-surplus on animal producing farms can lead to a future leaching problem.

In the LCA methodology, only momentary emissions of nutrifying substances are considered. When assessing the environmental risks of phosphorus fertilising, long-term effects should also be considered, similar to the different time horizons when calculating GWP index. This analysis shows a higher phosphate loss per 1 000 kg milk in organic production, which is due to the substantially higher land use for producing organic milk. However, in the long term perspective, the conventional system has a greater risk of P-losses since this system results in accumulation of phosphorus in the soil.

Use of land

The area needed to produce milk is substantially larger in the organic system. Although there is an excess of arable land in Europe today, leading to a set-aside program in the EU, the larger area occupancy must be seen as a hotspot for organic food production systems. However, it is not sufficient to evaluate the land resource in merely quantitative terms. A number of environmental goals are connected to arable land use and apart from direct impacts such as soil erosion and soil compacting, indirect effects of land use must be considered. Indirect effects are more subjective ones and contain aspects of aesthetic values such as preservation of the beauty of scenery, open landscape, cultural heritage, etc. For example, one important problem connected to agricultural land use in Sweden today is the lack of grazing ruminants preserving valuable biotopes (Mattsson *et al* 1998).

One opinion often expressed is that intense production systems can liberate areas for other purposes, for example growing energy crops. Had the organic farm in this analysis followed a conventional production scheme using N-fertilisers and importing feed components, *Salix* (willow) could have been cultivated on surplus area. This option is however strongly conflicting with environmental goals for the agriculture in this region. The farm is situated in a rural area where open landscapes are highly valued and relinquishment of arable land is considered a problem. Financial support according to the EU environmental programme is given for growing ley and grassland in order to preserve arable land in this region. In this particular case a larger use of land, especially of grassland, for producing milk promote important environmental goals.

Pesticide use

This parameter can be considered a hotspot in both systems. Although to a very small extent, the organic production is permitted to use feed ingredients from imported crops where very hazardous pesticides are frequently applied. It can be argued that pesticide use should be one base for determination of how much and which conventionally produced feed can be allowed in organic production.

In conventional agricultural production in Sweden today, great efforts are being made to reduce the negative effects of pesticide use and to ensure the safe handling of pesticides through hard legislation. This analysis, which takes us through the complete life cycle of the imported protein feeds, shows that the environmental impact from pesticide use abroad should also be considered if the long term goal of an environmentally-friendly production can be achieved. The use of imported feed has increased in Swedish feed industry during the 1990s (Foderstatistik 1996) and as was shown in section 9, the pesticide use is considerable in some of the crops providing raw material for the concentrate feed.

Global Warming Potential

Emissions of the potent greenhouse gases methane and nitrous oxide are critical parameters when assessing agricultural production. The relations between methane emissions and feeding strategy appear to be an important issue requiring further investigation. From present knowledge it can be concluded that organic milk production should not be too extensive in terms of a great use of roughage fodder. However, there are probably differences in methane emissions due to the quality of roughage which should be further investigated.

Emissions of nitrous oxide are closely connected to nitrogen application and nitrogen turnover in soil. Hence its potential negative effect on global warming is more apparent in a conventional system due to the higher fertiliser rates. Moreover, synthetic fertiliser production also induces direct N₂O emissions.

Modern food production is responsible for a major share of N₂O emissions which have increased remarkably during the past decades. Kroeze (1994) estimates that anthropogenic N₂O emissions have doubled between 1960 and 1985 in Europe and that the European emissions in 1985 were 31 % of worldwide N₂O emissions. To reach a climate goal preventing the temperature to increase by more than 0.1 C per decade, Kroeze outlines three scenarios for future emissions of this greenhouse gas. The most optimistic scenario in the perspective of reducing emissions in Kroeze's analysis includes drastic changes in food production in Europe, reduction of synthetic fertiliser to 1965 - 70 levels and reduction of farmyard manure by reducing per capita livestock by 23 - 54 %. According to Kroeze's analysis, this is probably not sufficient to reach climate goals.

The conventional system appears to generate N₂O emissions that are 35 - 45 % greater than the organic system. The combination of both synthetic fertilisers and farmyard manure results in a larger nitrogen flow in the system. Losses of nitrous oxide appear to be one crucial environmental parameter in nitrogen-intense food production systems.

Acidification and eutrophication

Emissions of the nitrogen pollutants ammonia and nitrate are major sources for acidification and eutrophication, environmental problems which began drawing public attention in the 1970s. These emissions are hotspots in both systems in this study and are connected to most agricultural production, especially the production of milk, meat and eggs.

Ammonia, being an acidifying as well as a nutrifying compound, is closely connected to the handling of farmyard manure and a number of measures have been and will be implemented to decrease ammonia emission from the agricultural sector in Sweden. Despite this, the goal of reducing ammonia emission by 25 % between 1990 and 1995 has not been accomplished, and according to the official ammonia investigation the emissions have actually increased during the 1990s, due to increasing intensity in animal production (Jordbruksverket 1997). One area the ammonia investigation points out as problematic is the increasing protein feeding in milk production which has probably led to increased ammonia losses. Seeing this in the terms of this compound's dominating share of milk productions' total potential acidification (see Figure 10.5), ammonia emissions are definitely hotspots in milk production, regardless of the production system.

The greater nitrate leaching per functional unit in the organic system shows that a low input system is not automatically a guarantee for a lower environmental impact. There is always a "base leaching" from agricultural land and the substantially higher area needed to produce organic milk leads to a relatively high nitrate loss per kg organically produced grain and peas. One less positive effect of the more stringent regulations for organic milk production, which now only permit 5 % conventionally produced fodder, may be that peas, a crop sensitive to nitrate leaching, will make up a greater share of the feed ration.

This analysis also shows that when using the nutrient balance as an instrument for analysing nutrient flows and their environmental effects on the single farm unit, nutrient losses on areas producing fodder outside the studied farm unit also should be considered.

11.2 Improvements

Some possibilities for improvements of the systems studied are:

Organic production

Differentiation in limits of purchased feeds Today a maximum 5 % of conventionally produced feed is allowed in organic milk production. This is a very coarse limit and the environmental impact of cultivation, processing and transportation of different feeds are not considered. This analysis shows, however, that there are considerable differences. Comparing 1 kg of heat-treated rape-seed meal and 1 kg of soymeal at the gate of feed industry, the energy use of soymeal has been doubled that of rape-seed meal. The two feed products are almost interchangeable. An even more important aspect is the intense use of toxic pesticides in soybean cultivation compared to the pesticide use in the cultivation of Swedish and German rape seed. By using a differentiation and allowing for example 10 % conventionally produced heat-treated rape-seed meal, the total environmental impact would be less than if 5 % conventionally produced soymeal were used. A greater use of concentrate feed in organic production (providing this feed has a relatively low environmental burden) can also favour the emissions of methane since these are connected to the feed quality and to the amount of roughage fodder fed to ruminants.

Self-supporting capacity The organic farm exemplified in this study should increase its' own fodder production. The input of barley and peas imported from other farms claims land area and is responsible for part of the high nitrate loss per functional unit. One way of increasing a self-supporting capacity is to reduce the replacement rate so that fewer heifers have to be fed from the farms acreage. Increasing feed production on a farm by cultivating fodder beets is suggested by Aarts *et al* (1996) as a method for Dutch dairy farming to reduce input of purchased feed. Growing fodder beets has been practised in southern Sweden but is now only sporadically done. The crop can give a high fodder yield from small area and, due to its long growing season, it can use mineralised soil nitrogen well. It should be of interest to develop this crop for milk production systems with the aim of a high self-supporting capacity of fodder production.

Emissions from diesel use Although important in all agricultural production, it appears to be even more important in organic production to reduce combustion emissions in tractors since this production form is very dependent on this energy source. One way of reducing these emissions is to economise the fuel, another is to replace some of the mechanised feeding routines with other machinery, for example by electrically powered forklifts.

Conventional production

Choice of concentrate feed Similar to organic production, alterations in choice of concentrate feeds can lead to a lower environmental impact. Also in this system, an increased use

domestic/regionally produced heat-treated rape-seed meal instead of large use of feed ingredients imported from other continents would lower the environmental burden.

The high proportion of dried beet pulp in the concentrate feed product Elit contributes to this product's high energy cost. An increased use of the wet product super pressed pulp (HP-massa) instead of dried beet pulp is a good feeding alternative from an environmental stand-point for dairy farms in the south of Sweden.

Improve nutrient balance

The large inflow of feed is responsible for the P-surplus on the farm, a common situation for animal producers with high animal density. Similar to the organic farm, the self-supporting capacity of fodder production should be increased as much as possible. A lower replacement would mean fewer heifers to feed. Since grain is imported from a very close distance, manure from the farm should be exported to this acreage thus replacing nutrient losses and replacing P-fertilising on this area. By exporting manure, N-losses could also decrease by avoiding spreading manure more than once per season in the leys. Moreover, if manure did not need to be spread in autumn, but instead only in spring on the farm itself and on the imported area where wheat is grown, both ammonia and nitrate losses could be reduced.

Pesticide use

Due to the high ambitions of Swedish farmers to develop their agricultural methods towards an environment-friendly production, attention should also be drawn to production methods of imported resources, such as fertilisers and feeds. For example, there seems to be a large variation in energy consumption among N-fertilising producers.

Soymeal is, beyond all comparison, the greatest import feed component. Due to the GMO debate, this feed is now exclusively provided by the Brazilian agriculture. Demands should be voiced not only concerning the non-use of gene-modified fodder, but also as regards the use of less toxic pesticides in the soybean cultivation. Since there are methods for biological control of some important pests and these methods could contribute to reducing the use of hazardous insecticides in Brazilian agriculture, these production methods should be encouraged when purchasing soymeal to the Swedish feed industry.

The overall conclusion of this study is that feeding strategy and methods of fodder cultivation have a strong influence upon the key environmental impacts of milk production. Cultivation methods of fodder influence emissions of nitrate and nitrous oxide from agricultural soils as well as pesticide use. Feeding strategy has a major impact on emissions of ammonia and methane from ruminants.

When designing future milk production systems, regardless of whether these systems are following conventional production schemes or organic production schemes, these environmental aspects must carry great weight and be seriously taken into account.

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