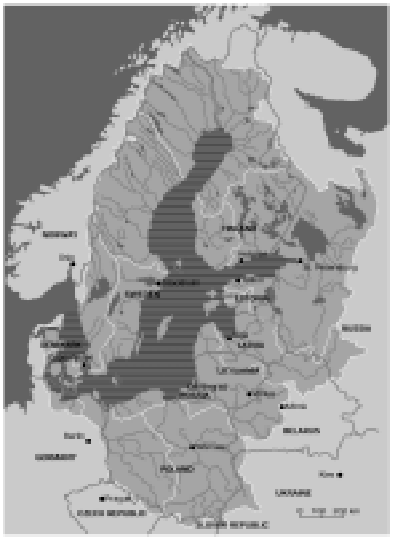
EKOLOGISKT LANTBRUK NR 41 • DECEMBER 2004

Effective recycling agriculture around the Baltic Sea

Background report

Artur Granstedt, Pentti Seuri,
Olof Thomsson



Baltic Ecological Recycling Agriculture and Society (BERAS) Nr. 2

Baltic Sea Region INTERREG III B

Centrum för uthålligt lantbruk

Ekologiskt lantbruk nr 41
Effective recycling agriculture around the Baltic Sea
Background report

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Ecological Agriculture nr 41
Effective recycling agriculture around the Baltic Sea
Background report

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ISSN 1102-6758
ISRN SLU-EKBL-EL--29--SE
ISBN: 91-576-6636-9
Antal sidor: 42
Ämnesord/*Key words: Organic farming, Organic food, Local food, Sustainability, Resource management, Food systems, Rural development*

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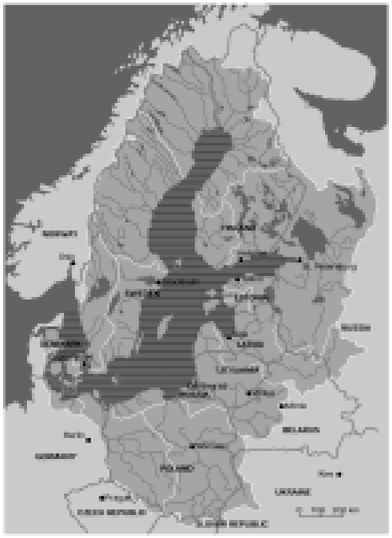

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Contents

Baltic Sea Region
INTERREG III B

Introduction to the BERAS project

Artur Granstedt

The serious environmental situation in the Baltic Sea is a consequence of agricultural specialisation, pollutin˙ from industries, incorrect waste management and the unsustainable lifestyle prevailing in the countries around the Baltic Sea (i.e. in its drainage basin). Reduced use of non-renewable energy and other resources and the elimination of pesticides would result in less pollution of air, water and soil. Increased recycling of nutrients within the agricultural systems through integration of plants and animals in the farming system would decrease the amount of nutrients in the system.

The aim of this project is to learn about and promote more sustainable food systems. The project is an EU-funded Interreg III B project. A knowledge base that can be used to reduce the negative environmental impacts of production, distribution, processing and consumption of food in the Baltic Sea drainage area will be developed. It is based on case studies, complemented with scenarios and consequence analyses, of ongoing practical, local ecological initiatives to promote local food supply cooperation between consumers and ecological producers in rural villages in the eight EU and EU-candidate countries around the Baltic Sea.

Methodologically the project is based on studies of 35 selected ecological recycling farms representing different farming conditions and 10 examples of more or less local and/or regional food systems located in the eight partner countries.

The first work package (WP 1) builds on activities and cooperation with representatives from already established local ecological food initiatives and recycling farms in each country. It includes evaluation, promotion and exchange of experiences with other initiatives in and among the project countries. The first BERAS report is presented in ”Ekologiskt lantbruk nr 40”.

In the second work package (WP 2) we are studying and quantifying the environmental benefits that can be achieved through local ecological consumption, processing and ecological, integrated recycling farming, in comparison with conventional food systems. The results will feed into the evaluation process and is now available to the actors through this report.

The third and fourth work packages (WP 3 and WP 4) will evaluate the economic and social consequences at the societal level, including rural development and job opportunities. The final work programme (WP 5) will produce recommendations for implementation and disseminate this to concerned actors, including policy and decision makers.

Effective recycling agriculture around the Baltic Sea

Preface

Artur Granstedt

This second report within the BERAS-project is a background report to quantify the environmental benefits that can be achieved related to the Baltic Sea through ecological, recycling farming systems, integrating plants and animals. This is based on results from previous studies partly by the main author and with descriptions and analysis of the current situation in the eight partner countries involved in the BERAS-project. The aim is to recognise the potential of more effective recycling agriculture to reduce nitrogen and phosphorus loads to the Baltic Sea. The report includes an appendix with a description of methods for calculation of plant nutrient balances and flows of nutrients within the system. This includes descriptions of the plant nutrient pools in the agriculture/community ecosystem and how to calculate them, as well as a method for evaluating nutrient utilisation.

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At the web address **www.jdb.se/beras/** you can find the names of all the BERAS project group members.

Acknowledgements

We warmly thank our colleagues in the BERAS project who have collected and prepared data and in different ways have contributed to this publication, including Daphne Thuvesson and Nora Adelsköld for their editing and important assistance in making the text and figures clearer and more understandable. Special thanks also to Ulrika Geber, CUL, for her valuable comments.

Authors

Summary

Annual loads of nitrogen and phosphorus within the Baltic Sea catchment area in 2000 have been estimated at 814 000 and 42 010 tons, respectively. These loads include discharges from point sources and the losses from diffuse sources including natural background loads. They are higher than the estimated loads for 1995. There has been no significant decrease of the total load during the past 30 years when the Helsinki Commission has been working for the protection and improvement of the Baltic Marine Environment.

Agreements to halve the quantity of nutrients reaching the marine environment by 1995 were made within the Helsinki Commission (base year 1987) and at the North Sea Conference/Paris Commission (base year 1985). This goal has not been achieved. On 23 October 2000 the EU Water Framework Directive (WFD) was finally adopted. The ultimate aim of this Directive is to achieve the elimination of priority hazardous substances and contribute to reducing concentrations in the marine environment to near background levels for naturally occurring substances.

Agriculture is responsible for a large share (about 50 % of the total anthropogenic load) of the leaching of nutrients to watercourses (including groundwater), lakes and finally the sea.

In this report the historical background and present situation of the plant nutrient balances and surplus of plant nutrients within the agricultural sector in the eight countries of the Baltic Sea catchments area (Sweden, Finland, Estonia, Latvia, Lithuania, Poland, Denmark, Germany and Russia) are presented and analysed. Only the small part of Germany and Russia that are located in the Baltic drainage area are included in this analysis. No decrease, and in some instances even an increase, of surplus nitrogen has been observed in Finland, Sweden, Germany and Poland. Only Latvia, Estonia and Russia have reported a decrease for the year 2000 compared to 1995.

From 1950 to 1980, the inputs of nitrogen, phosphorus and potassium in the form of artificial fertiliser greatly increased in relation to their outputs in the form of agriculturally produced foodstuffs such as milk, meat and bread/cereal grain in Sweden and Finland. After 1980 this surplus of nitrogen has remained at the same level in these countries. The results of plant nutrient studies presented here conclude that the specialisation of farms is one main reason for the high losses of plant nutrients to the environment. One type of farm specialises in crop production based on the use of artificial fertilisers, another in animal production with high inputs of purchased fodder and a surplus of plant

nutrients in the form of ineffectively utilised manure from the animals. In addition the regional concentration of animal production farms to certain geographical areas further exacerbates the situation. If the goals agreed upon in the various Commissions and the EU WFD mentioned above, are to be reached this existing specialised agriculture production system with its high surplus and losses of nutrients to the environment must be replaced by a system that more effectively recycles nutrients. The Baltic Ecological Recycling Agriculture and Society (BERAS) project is evaluating the consequences of converting the whole agricultural sector according to recycling principles. This analysis is being based on data from selected ecological recycling farms within the Baltic drainage area and will be presented in a series of project reports of which this is the first for Work Package 2, Effects on environment, natural resources and health.

Present situation

Excessive nutrient inputs to the Baltic Sea

Excessive nutrient inputs into the Baltic Sea produce harmful effects: the extensive blue-green algal blooms observed in the Baltic Sea are obvious signs of eutrophication. Increasing eutrophication and the resulting increase in produced organic matter cause environmental problems when their decomposition consumes oxygen, and is contributing to depletion in deeper waters. Anoxic conditions have been a frequent phenomena in the deeper basins of the Baltic Proper for a long time (Figure 1 and Figure 2). Eutrophication causing anoxic conditions is also affecting, with increasing frequency, vast areas in the Baltic Sea and the Gulf of Finland.

Annual loads of nitrogen and phosphorus within the Baltic Sea catchment area in 2000 are estimated at 822 250 and 41 200 tons, respectively. Large proportions of these originate far away from the Sea. These loads include discharges from point sources as well as the losses from diffuse sources including natural background loads (HELCOM, 2004). Phosphorus and nitrogen levels in the Baltic are currently 8 and 4 times higher, respectively, than they were in 1900 (Enell, 1996). This increase is a result of human activities around the Baltic Sea, both. Agriculture is responsible for a large share of the leaching of nutrients to watercourses (including groundwater), lakes and finally the sea. In Sweden about 50 % of the anthropogenic load of nitrogen (53 % of the gross load) and close to 50 % of the anthropogenic phosphorus load (46 % of the gross load) can be attributed to agriculture. These estimates are from the most recent calculations covering the period 1985–1999 and published in reports from the Swedish Environmental Protection Agency (Brandt & Ejhed, 2002; Johnsson & Mårtensson, 2002). In Finland, the corresponding estimates are some-

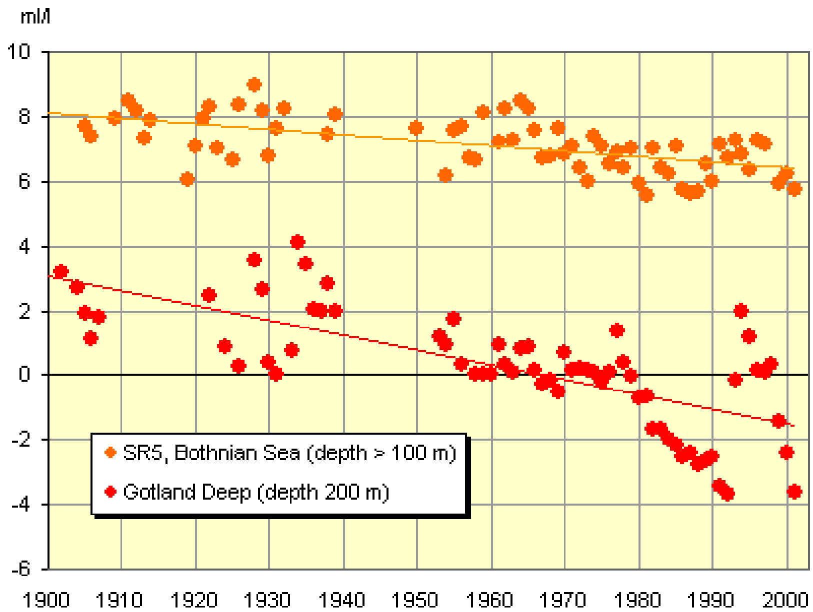


Figure 1. *Oxygen trends in the Bothnian Sea and the Baltic proper (Gotland Deep) ml/l. (Source: Swedish Environmental Protection Agency, www.internat.naturvardsverket.se/ pollutants)*

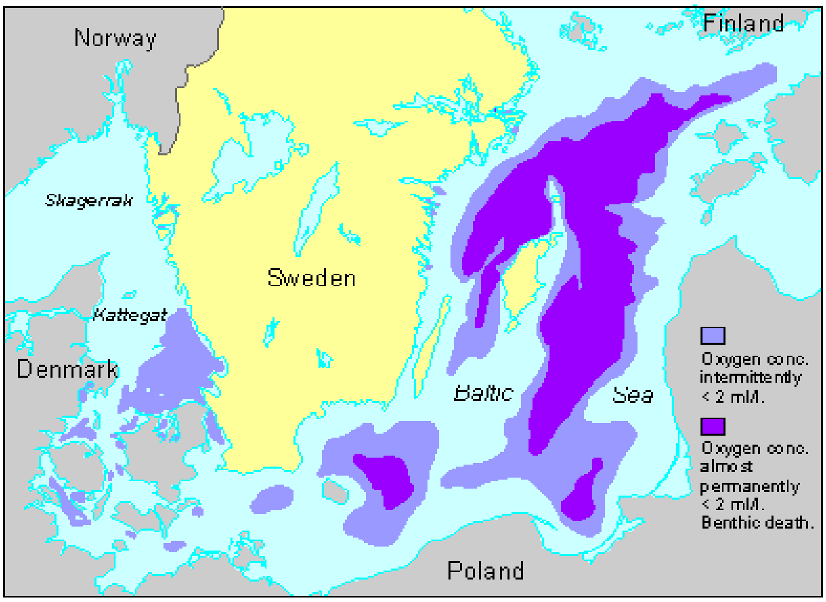


Figure 2. *Oxygen deficiency near the sea bottom. (Source: Swedish Environmental Protection Agency: www.internat.naturvardsverket.se/pollutants)*

what higher. Other European countries have reported similar values for agriculture's share of anthropogenic losses.

No significant improvements to date

The reported annual loads into the Baltic Sea for 2000 are not lower than the 1995 estimates. High area-specific nitrogen and phosphorus loads are related to high rates of agricultural activity, including large scale intensive livestock farming as well as the intensive use of fertilisers in specialised conventional farming systems (Granstedt, 2000). No decrease of annual loads, and in some cases even an increase, was observed in Finland, Sweden, Germany and Poland. A decrease was reported only from Latvia, Estonia and Russia for 2000 compared to 1995.

Of the calculated load in 2000, 24 percent originates in Estonia, Latvia, Lithuania and Russia, 28 percent in Poland, 21 percent in Sweden and 18 percent in Finland (Table 1). However, per-capita output levels of nitrogen are almost four times higher for Sweden and Finland than for Poland.

The goals and the reality

Agreements to halve the quantity of nutrients (from all sources) reaching the marine environment by 1995 were made within the Helsinki Commission (base year 1987) and at the North Sea Conference/Paris Commission (base year 1985). The concerned countries have not achieved these goals during the agreed period from 1987 to 1995. Nor were improvements observed between 1995 and the year 2000 according to the executive Summary of the Fourth Baltic Sea Pollution Load Compilation. Measurements in streams to the Baltic Sea show no significant decrease of the total load (HELCOM, 2003).

In 1991 the European Commission adopted the nitrate directive

Countries	Total drainage area 1 000 ha	Arable land 1 000 ha	People x 1 000	Loads N t/a	N load kg/capita	N load % of total
Germany	2 860	2 051	3 300	31 510	10	4
Poland	31 190	14 247	37 764	229 990	6	28
Lithuania	6 530	3 527	3 446	35 560	10	4
Latvia	6 460	2 826	2 606	54 070	21	7
Estonia	4 510	1 160	1 595	32 990	21	4
Russia	31 480	4 699	9 028	53 720	6	7
Finland	30 130	2 387	4 938	146 560	30	18
Sweden	44 004	2 698	8 500	175 610	21	21
Denmark	3 111	2 077	5 155	62 240	12	7
Total	**160 275**	**35 672**	**76 332**	**822 250**		

Table 1. *Total land area, area of arable land, people, loads of nitrogen tonnes per annum (N t/a), nitrogen load per capita and percent of the total nitrogen load in the Baltic drainage area according to HELCOM reports for the year 2000. Only the small part of Germany and Russia (Leningrad and Kaliningrad) that are located in the Baltic drainage area are covered by the statistics here and more detailed statistics were not available.*

(91/676/EEC) with the objective of reducing water pollution caused or induced by nitrates from agricultural sources and preventing further such pollution. On 23 October 2000, the Directive 2000/60/EC of the European Parliament and of the Council (the EU Water Framework Directive (WFD) was finally adopted. This established a framework for EU action in the field of water policy. Three years later, on 22 December 2003, Member States were to have implemented the WFD in their national legislation. The ultimate aim of this Directive is to achieve the elimination of priority hazardous substances and contribute to reducing concentrations in the marine environment to a level close to background values for naturally occurring substances. An appropriate approach for managing the whole of a water system is by river basin – the natural geographical and hydrological unit – rather than by administrative or political boundaries. Based on a EU-wide approach, EU introduced quality objectives. These oblige member states to also monitor and assess groundwater quality and to identify and reverse trends in groundwater pollution.

Evaluation of recycling agriculture and its contribution to solving the problem

The goal to reduce the nitrogen load to the sea by half between 1987 and up until today has not been achieved. Studies of plant nutrient flows in farming systems over several years indicate that a halving of nitrogen losses is only possible if the structure of agriculture is changed so that the majority of nutrients from field harvested plants can be recycled within the system, instead of exporting them as fodder to specialised large-scale animal production units. As these livestock units have no need for all these nutrients (now in the form of manure), much is lost to the environment. The present system is both wasteful and environmentally damaging (Granstedt, 2000).

The studies concluded that it is necessary to integrate and balance crop and animal production (especially fodder and manure production and use) on each farm or among farms in a local, more closed ecological system. Achieving this local balance between fodder and animal production requires a reduction in the number of animals in areas of high concentration and their dispersal throughout the whole agricultural land area.

Responsible national authorities such as the Swedish Environmental Protection Agency or international authorities such as HELCOM have not yet taken these conclusions into account. However the continuing serious situation makes it necessary to identify and implement alternatives to today's specialised agriculture, alternatives that provide long-term solutions to the problem. Such solutions must be based on more effective recycling at the farm level according to the principles practiced in recycling ecological agriculture. A significant part of the partly EU funded BSR INTERREG project BERAS (Baltic Ecological Recycling Agriculture and Society) is the evaluation of such an approach based on these principles. The BERAS project is carrying out case studies including evaluations of integrated crop-animal organic farms as a possible way of economising on resources and minimising losses of plant nutrients to the environment within the Baltic Sea region.

Objectives for BERAS project and aim of this report

One of the main objectives of the BERAS project is to evaluate the potential to reduce nutrient losses, both from individual farms and from the agriculture sector as a whole, through more effective recycling at the farm level. More effective recycling implies the adjustment of crop and animal production in combination with other known measures to achieve greater plant nutrient economy. This evaluation is being done under different basic agricultural and environmental conditions in the catchment areas in the eight countries participating in the project – Sweden, Finland, Estonia, Latvia, Lithuania, Poland, Germany and Denmark. It is based on studies of selected ecological recycling farms within the Baltic drainage area to estimate the consequences of converting the whole agricultural sector according to recycling principles.

This background report presents the existing situation concerning the plant nutrient balances and surplus of plant nutrients within the agricultural sector in the eight partner countries. It describes the background to the present serious situation with too high plant nutrient surplus and losses in the agricultural systems, analyses the reasons for this and the contributions this project can make to finding appropriate solutions to the problem acknowledging the very different situations in the countries around the Baltic Sea. Target groups for this report are decision makers at concerned government departments and organisations and their expert advisors within the environmental and agricultural sectors. A dialogue will be established to explore how to optimise the system according to the goals of sustainability in the Baltic Sea region.

Methods

Surplus and potential losses of plant nutrients – field and farm gate balances

On the basis of official agricultural statistics and data collected on farms it is possible to calculate the surplus of nitrogen and other plant nutrients from agriculture production. The on-farm data includes the amount of artificial fertiliser and imported fodder used, data for known nitrogen load and estimated nitrogen fixation from the atmosphere (input) and the amount of animal and plant foods produced and sold from the farm (output). The difference between this input and output of plant nutrients is here defined as surplus of plant nutrients and is the same as potential losses.

If the amount of nitrogen immobilised, fixed and stored in soil is at a steady state it is plausible to assume surplus nitrogen as being equal to the average total emission of nitrogen in nitrogen compounds to the surrounding water and atmosphere over a longer time period. This nitrogen can be calculated and classified as potential losses to the environment. The actual emissions (losses) during a specific year will depend on the climatic conditions and the net effect of mobilisation or immobilisation of organic nitrogen compounds.

Calculating plant nutrient balances to estimate potential nutrient losses can be done at field level (*field balances*) or for a whole farm (*farm gate balances*) (Figure 17 in Appendix). Field balances use the amount of manure and fertilisers for input data and the amount of harvested crops for output data. This means that the specific animal production nitrogen losses (mainly ammoniac emissions directly from animals, manure and urine in the stable and stored manure before application on field) are not included. The amount of nitrogen input to the soil is also affected by the conditions during fertiliser/manure application and the techniques used. These factors as well as the difficulties with representative analysis and estimation of the amount of manure deposited in fields by grazing animals limit the reliability of this method.

Farm gate balances are based on the difference between the import of bought fertilisers, bought fodder and atmospheric nitrogen and the export of agricultural products from the farm. This difference provides a basis for estimating total surplus as well as the potential losses to the environment from the whole agricultural system including the losses from the animal production. In addition this method can also be used to calculate balances for a larger system, e.g. a drainage area, an administrative region such as a county or country or the whole Baltic drainage area. However this method gives only aggregated data and the balance will be an average of all the individual agricultural units included in this larger area. How the individual farms, which can be more or less specialised depending on their use of resources, production and losses of nutrients, influence the final result cannot be calculated.

Plant nutrient flows in an agricultural system are also possible to measure using data collected from within the system. On the individual farm this can be based on measurements, samplings and analysis of the flows in different parts of the system.

This report includes presentations of farm gate balances on individual farms and balances of the whole agriculture ecosystem for the countries within the Baltic Sea drainage area. The calculations are based on available agricultural statistics for the regions respectively. The methods for these calculations have been described in earlier publications (Granstedt, 2000) and their special adaptations for this study are described in the Appendix of this report.

Plant nutrient balances at country level
– results and discussion

Sweden and Finland

At country level the inputs of nitrogen, phosphorus and potassium in the form of inorganic fertiliser and imported fodder have greatly increased in relation to their outputs in the form of agriculturally produced foodstuffs such as milk, meat and bread grain from 1950 to 1980 in Sweden and Finland (Figure 3 a and 3 b). Despite programmes to reduce nutrient losses from the society and the agriculture sector the surplus of nitrogen has remained at the same level in these countries during the past decades (Figures 4 a and 4 b).

The total calculated average yearly balances (2000–2002) for nitrogen, phosphorus and potassium for Sweden and Finland are shown

Figure 3 a. *Inputs of mineral fertiliser nitrogen, phosphorus and potassium (kg/ha and year) from 1940 to 1995 and outputs of nitrogen, phosphorus and potassium (kg/ha and year) in the form of animal- and plant-based food products in 1995 in Swedish agriculture. (Granstedt, 2000).*

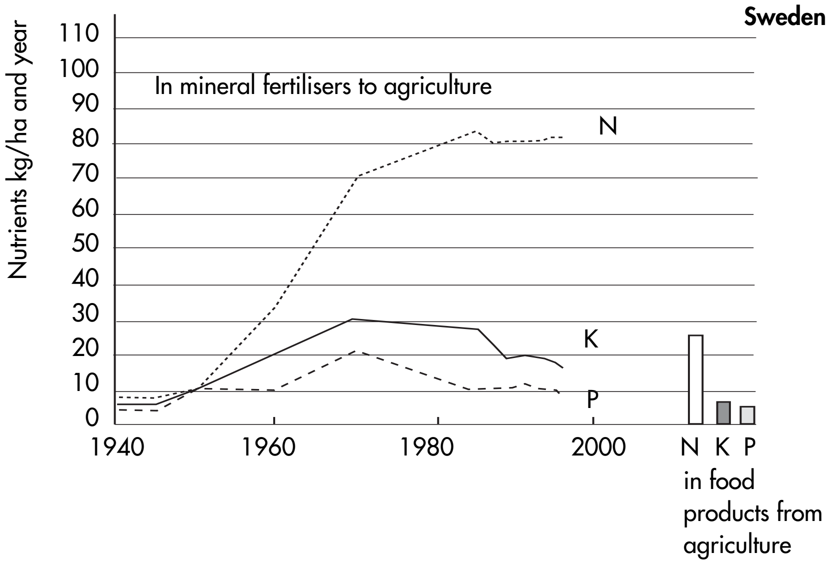
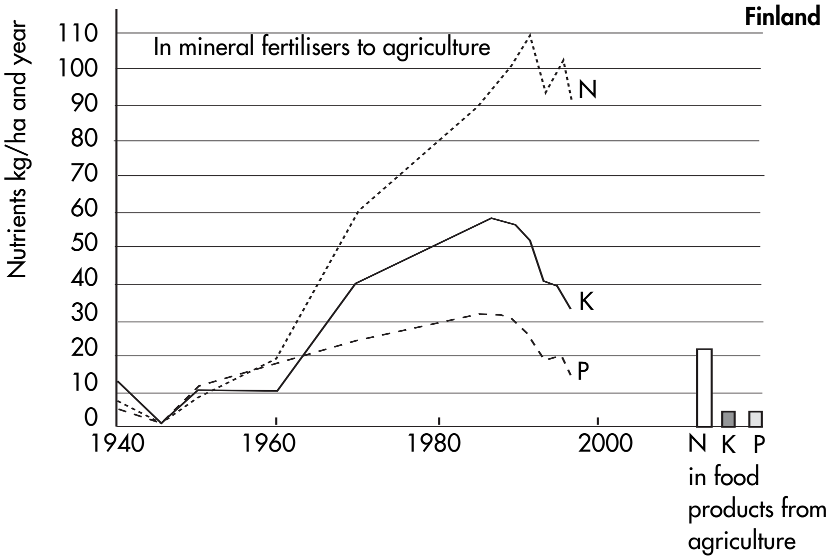


Figure 3 b. *Inputs of mineral fertiliser nitrogen, phosphorus and potassium (kg/ha and year) from 1940 to 1993 and outputs of nitrogen, phosphorus and potassium (kg/ha and year) in the form of animal- and plant-based food products 1993 in Finnish agriculture. (Granstedt, 2000).*



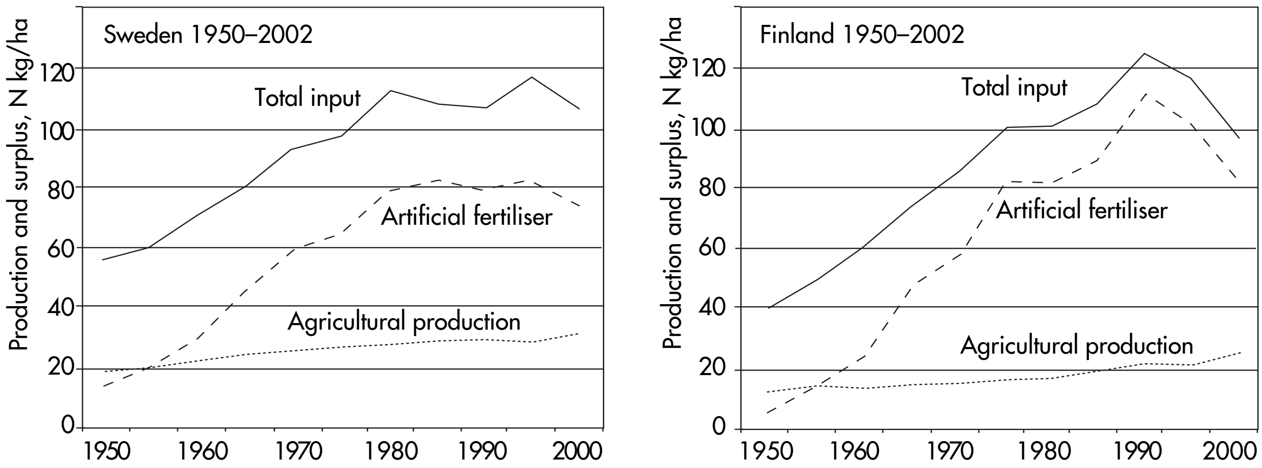


Figure 4 a and b. *Input of N in fertilisers, N in agricultural production and surplus (difference between total input and production) of nitrogen in Sweden and in Finland 1950–2002. The difference between total input and agricultural production shows an increasing surplus, i.e. losses of reactive nitrogen.*

in the flow diagrams in Figure 5 a and 5 b. Plant nutrient flows are divided into three main groups: import, transfer and export. These are related to the different pools: the soil pool, the plant pool, the domestic animal pool and the human pool. The arrows refer to flows (import and export) to and from the pools as well as import and export in relation to the whole agricultural-community ecosystem. The calculations include:

- **The flow** between the soil, crop, animal and manure pools within the agricultural system.
- **The inputs** in the form of artificial fertilisers, atmospheric deposition, biological nitrogen fixation, imported fodder, and food.
- **The outputs** in the form of agricultural food products and the surplus (difference between inputs and outputs).
- **The surplus** is the potential total losses to the environment (including leaching and for nitrogen emissions to the atmosphere) and in reality can vary from year to year depending on climatic and soil conditions. The surplus of phosphorous is mainly accumulated in the soil.
- **The partial losses to the atmosphere** in the form of gaseous losses of nitrogen compounds from animals, manure during storage and in fields.
- **The losses from soil**, partly as leaching and partly gaseous losses of nitrogen mainly through denitrification.

Plant nutrients in food products in the community system are further divided into separate pools: slaughter, domestic wastes and the sewage wastes from the human digestive system. Export of agricultural crop products was higher than import during the period in Sweden. In Finland the imports were greater during this period. A small part of slaughter products is used as fodder and some sludge is used as fertiliser.

For Sweden (see Figure 5 a) the difference between the nitrogen import (106 kg N /ha) and export (27 kg N /ha) from the agricultural system out to the community system represents the surplus (79 kg N / ha) that is potentially lost to the environment if there is no change in the level of soil N-content. Although about half of the input of phosphorus is surplus (4 kg of 9 kg P/ha), only a smaller part is lost to the environment. However this is sufficient, when combined with the nitrogen load, to result in the final too high eutrophication in the Baltic Sea.

These calculations of the nutrient balances for the Swedish agricultural system have been compared with the most recent studies of the leaching from the root zones published by the Swedish Environmental Protection Agency (Brandt & Ejhed, 2002; Johnsson & Mårtensson, 2002). They correspond well and give a good confirmation when adjusted to take into consideration the known ammoniac losses from animals and manure in the animal balances and the denitrification

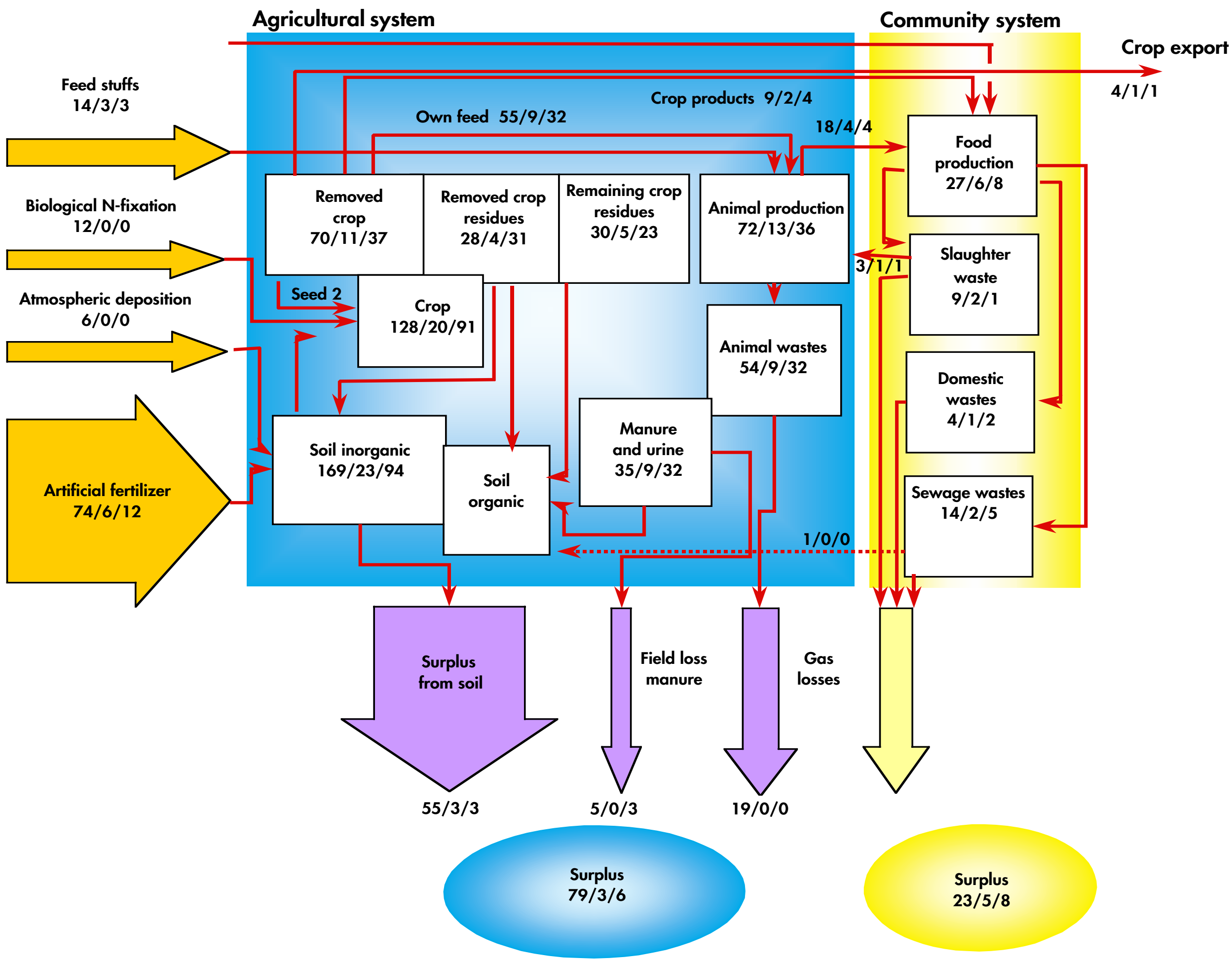


Figure 5 a. *Calculated flow of N, P and K kg/ha and year (2000–2002 average) in the Swedish agricultural and community ecosystem according to methods described by Granstedt, (2000) and in the Appendix of this report. The surplus of nitrogen is equal to the average losses to the atmosphere and to the drainage water assuming a steady state of immobilised humus nitrogen content. The surplus of phosphorus is mostly fixed in phosphate compounds in soil. The surplus of potassium is normally equal to losses.*

Finland 2000–2002. Flow of N/P/K kg/ha and year in the agricultural-community ecosystem.

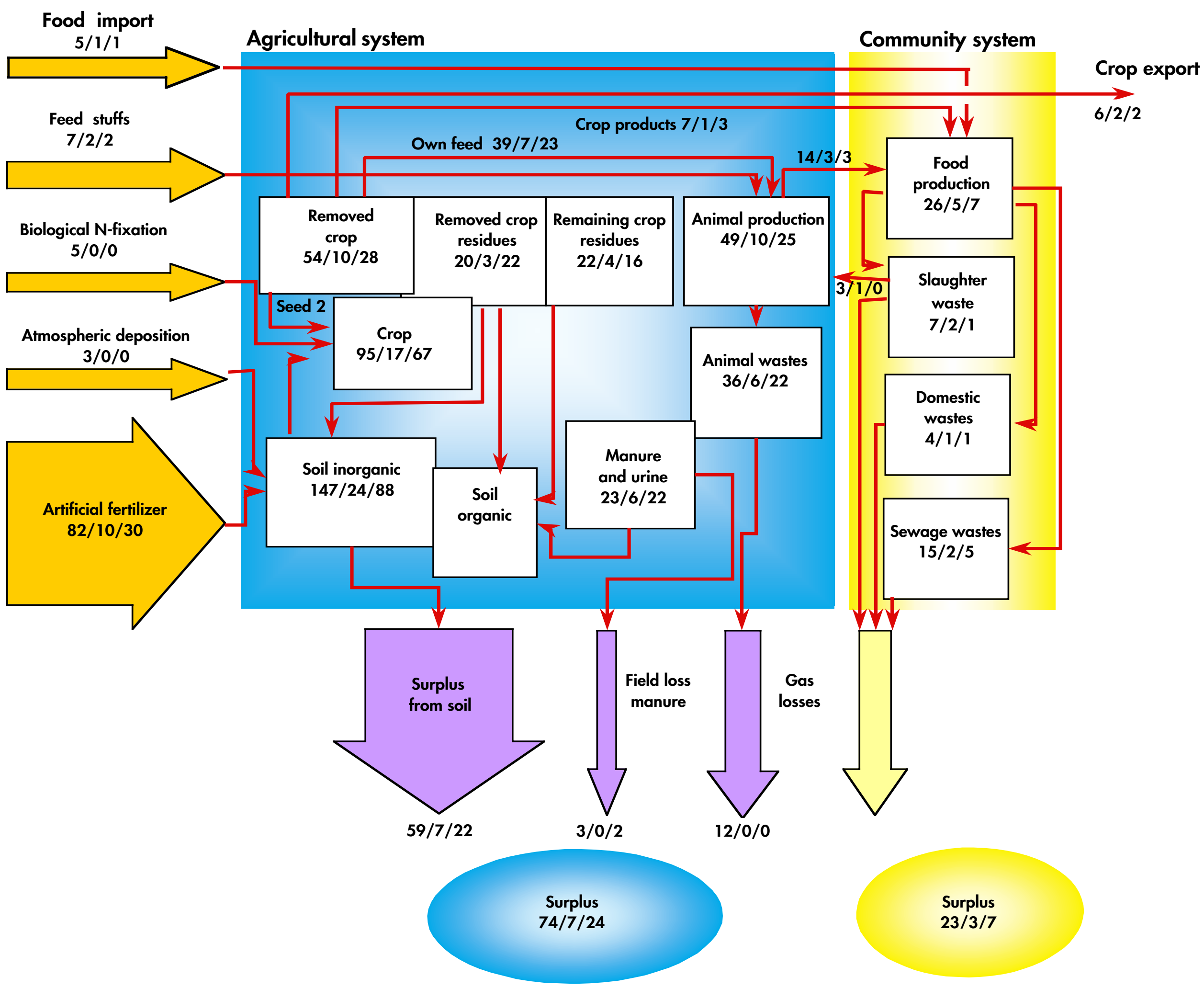


Figure 5 b. *Calculated flow of N, P and K kg/ha and year (20000–2002 average) in Finnish agriculture and community ecosystem according to methods described by Granstedt, (2000) and in the Appendix of this report.*

in fields. Both our study and the studies from the Swedish Environmental Protection Agency (Brandt & Ejhed, 2002) indicate that about 30 % of the total 196 000 tons of nitrogen surplus in the agricultural sector is lost as anthropogenic leaching from the agricultural fields (60 600 tons of nitrogen per year calculated as leaching from the root zones as average for the period 1985–1999) and after retention on average 60 percent of this is lost in the end to the sea. Of the calculated field level surplus, after adjusting for losses in the animal production, 45 % is lost as anthropogenic leaching from the agricultural fields.

The surplus of phosphorus is mainly fixed in the soil but the results indicate the potential losses of phosphorous. Of special importance is the surplus of phosphorus compounds which directly influence the amount of phosphorous leached to the environment. Based on the measurements of drainage water it has been estimated that about 600 tons P/year is leaching from arable land in Sweden. (Gustafson, 1996).

Of the surplus 4 kg P/ha it appears that only an average of 0.25 kg P/ha is lost through leaching of organic and inorganic phosphorus compounds. Most phosphorous is bound to insoluble organic and inorganic phosphorus compounds that remain stored in the soil. However the accumulated surplus that, year after year, is stored in the soil can be assumed to be a potential source of losses to the environment for a long time to come.

Excluding the 346 644 ha of controlled ecological production in Sweden (14 % of the total 2 480 000 ha in 2000) that does not use imported artificial fertilisers and pesticides the average use in conventional agriculture of artificial fertiliser is 85.5 kg N/ha and the average surplus about 90 kg N per ha. This is a dramatic increase compared with 1995. Despite all our efforts to reduce this load the amount of surplus has continued to increase (Granstedt 2000). A comparison between Finland and Sweden (Figure 5 a and b) shows that the surplus/losses of nitrogen is a little lower in Finland (74 kg N kg/ha and year in 2001–2002) than in Sweden (79 kg N kg/ha and year in 2001–2002).

Changes in production system give today's high surplus and losses

Specialised agriculture of today – examples from Sweden

In Sweden and Finland today, the input of nitrogen to the agricultural systems is about three times higher than the output of nitrogen in the form of agricultural food products such as bread and cereal grains, milk

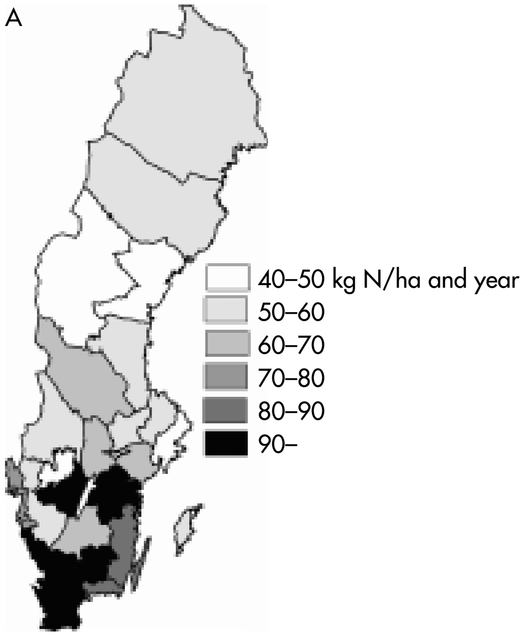
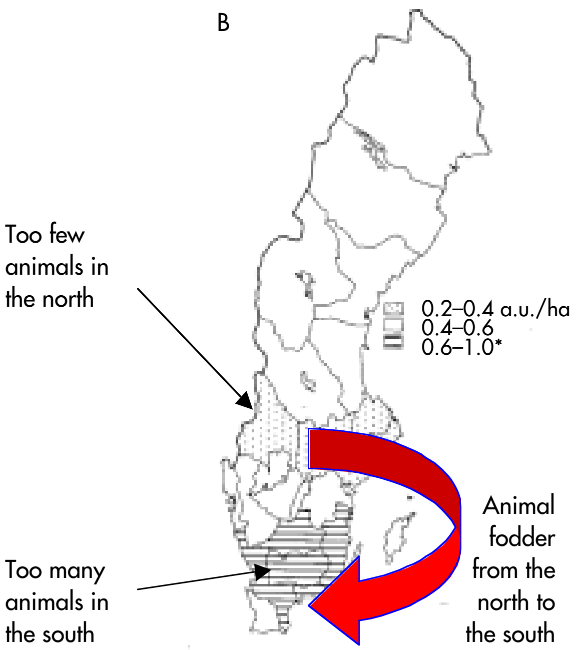
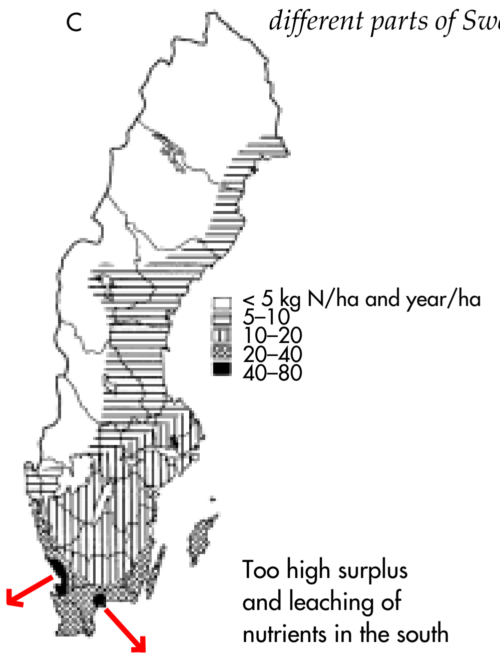


Figure 6.
A. *Surplus of nitrogen in kg/ha arable land and year, calculated for 1995 as the difference between amounts imported and exported nitrogen (Granstedt, 2000).*

B. *The Swedish counties, grouped according to their intensity of animal production. 1 a.u. (animal unit) equals either 1 dairy cow, 2 young cows, 3 sows, 10 fattening pigs or 100 hens.*
**In this interval the counties all have more than 0.8 a.u. per ha.*

C. *Levels of nitrogen leaching in different parts of Sweden.*





and meat. About 80 percent of the arable land is used for producing animal fodder. This was also true in 1950, but during the last 40 years the number of animal production farms has steadily decreased, while the number of animals on the remaining farms has increased. Farms with only crop production and no animals are dependent on artificial fertilisers. They produce mainly fodder for animals. This fodder is exported to the intensively managed animal farms where it results in excessive loads of plant nutrients. For example, about 5 percent of Swedish farming enterprises produce 90 percent of the pork (SCB, 2003). In some counties in southern Sweden and in Finland this concentration is particularly marked (i.e. in Blekinge, Halland and certain parts of Skåne in Sweden, in Österbotten in Finland). This is exemplified for Sweden in Figure 6 with the highest surplus and losses of nutrients. This region animal production is based on fodder partly from regions with low animal density.

A similar trend towards not only local but also regional specialisation in agriculture within a county and within a whole country can be observed in the other European countries. Whole Denmark has a higher specialisation and average density of animal production based on partly imported fodder then the other Baltic countries (0,9 au/a compared to for example Sweden with 0,6 au/ha) but also there with regional differences with special high animal production in some regions.

The results (in terms of plant nutrient surplus/potential losses) of these different management strategies can be studied separately by performing analyses of the plant nutrient balances and flows between defined pools within the agro-ecosystems at farm level (Granstedt, 2000). These are presented in Figures 7, 8 and 9 for three typical farm types with varying degrees of animal production concentration.

The surplus/potential loss of plant nutrients to the environment is lowest from farms with zero animal units per hectare that only produce cereals. Their main product grain, of which 85 % is feed, is exported to specialised animal production farms. This is exemplified in Figure 7 with a farm in Skaraborg county in the southwest of Sweden.

Surpluses/potential losses of plant nutrients on the combined dairy and pig farm in Blekinge, in the southeast of Sweden with three times more animals than can be fed with their own feed production, have been calculated to be 220 kg nitrogen per hectare and year (Figure 8). A real farm has been chosen as a representative farm for the mean value for 450 dairy farms in the county of Skåne in the south of Sweden for the year 1998 (Granstedt, 2000). The surplus/potential losses of plant nutrients on this representative farm have been calculated to be 164 kg nitrogen per hectare and year after sale of some manure in compliance with Swedish regulations to limit the intensity of animal production (Figure 9).

The imbalance between plant and animal production at the country level as well as regionally and locally is one important factor contributing to the mismanagement (i.e. potential loss to the environment) of plant nutrients. This becomes clear when comparing the swine farm, the specialised dairy farm and the cereal-producing farm without animals (Figures 7, 8 and 9) that represent typical farms in Sweden. Plant nutrients are supplied as artificial fertiliser to the cereal farms, where they are mainly converted to fodder that is delivered to the animal producers. There they accumulate as surplus and to a large extent are lost.

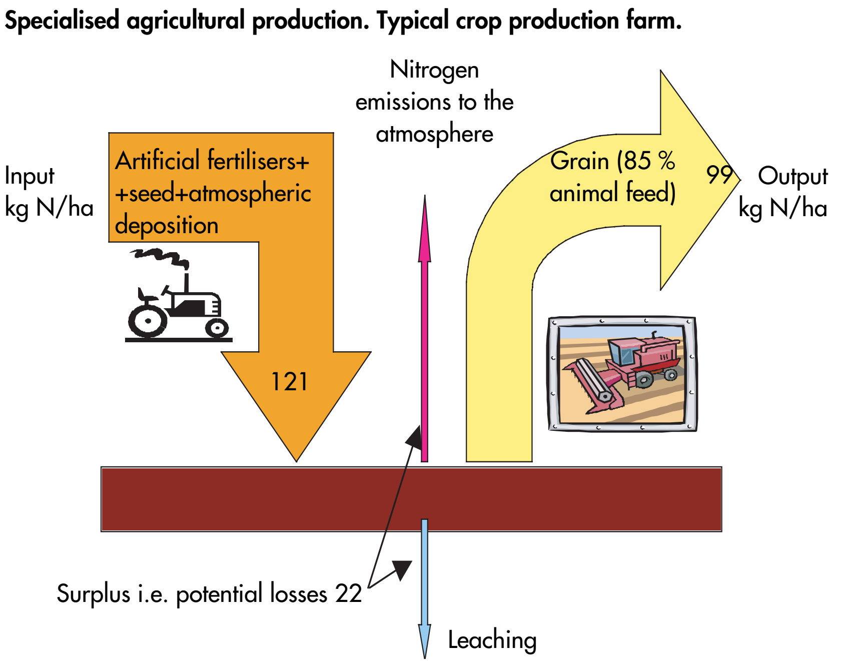


Figure 7. *Plant nutrient (N) flows, in kg/ha and year, for a specialised cereal crop farm in Skaraborg county with no animal units per ha (Granstedt, 2000).*

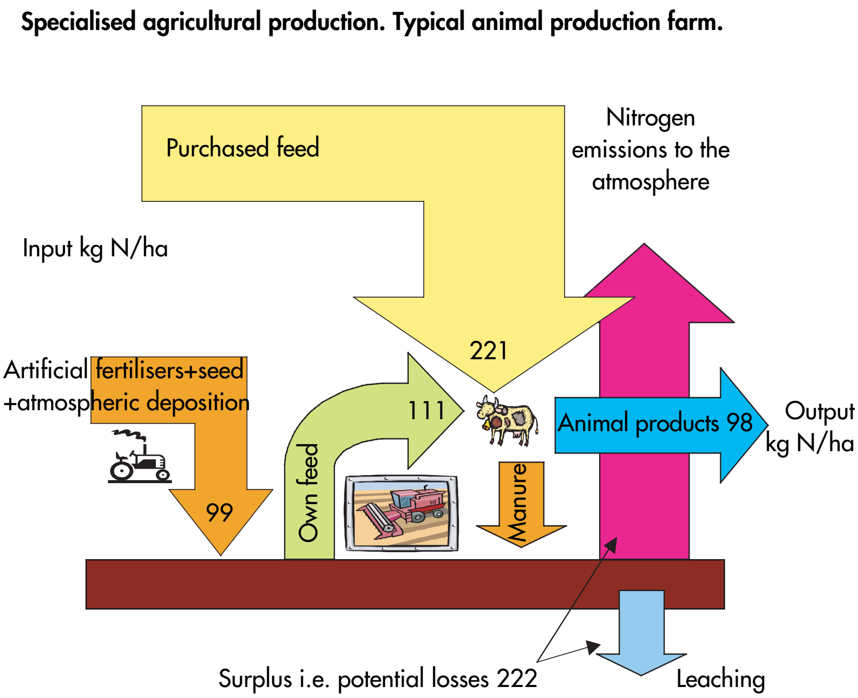
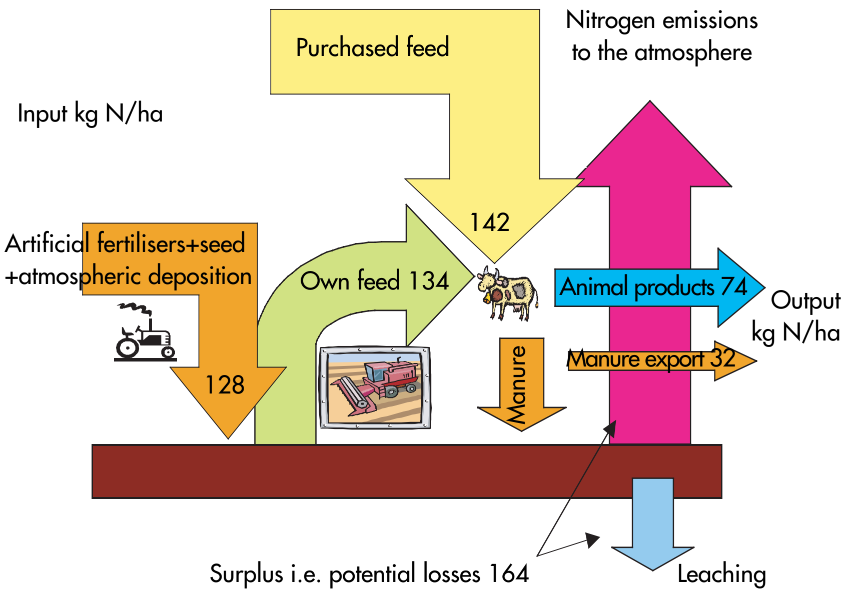


Figure 8. *Plant nutrient (N) flows, in kg/ha and year, for a specialised (swine + dairy) animal production farm in Blekinge county, 50 ha, 15 dairy cows, 10 sows and 680 fattening pigs. The animal density, about 2 animal units per ha, is three times higher than can be fed with own fodder (Granstedt, 1992). This high density was allowed in Sweden before 1995 and it is still allowed in the other BERAS countries.*

Figure 9. *Plant nutrient (N) flows, in kg/ha and year, calculated in 1997 for a specialised dairy farm in Skåne County, 38 ha and 55 dairy cattle. The animal density, about 2 animal units per ha, is more than two times higher than can be fed with own fodder (Granstedt, 2000).*



Calculations have shown that the nutrients in animal manure are more than enough to meet the requirements of the crops on an intensive specialised animal farm, even when gaseous losses associated with manure handling are subtracted. The annual use of manure leads to a higher release of mineral nitrogen on these farms than can be utilised by the plants in the crop production. This is reflected in the balance accounts presented here and confirmed in studies of mineralisation on farms practicing intensive animal husbandry (Granstedt, 1990).

From recycling to the linear system of today

Before the introduction of artificial fertiliser agriculture depended on two main sources of nitrogen for crop production:

- Nitrogen fixation through legume plants in the crop rotation;
- Ruminant animals on each farm that could use coarse crops to produce food and manure so that the major part of the nutrients could be recycled to the soil.

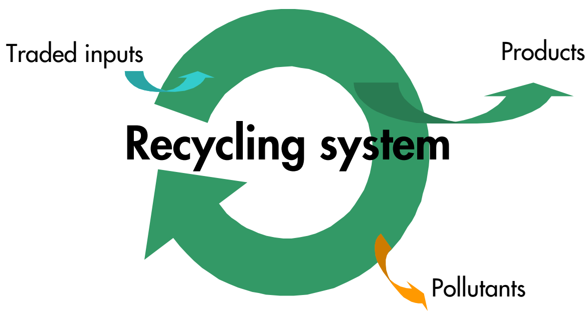
The significance of the introduction of legume plants in Europe and the Nordic countries for the increase of agricultural production during 18th and 19th century is well documented (Kjaergaard , 1994; Granstedt, 1998). The increase in the Swedish population from 2 to 7 million between 1800–1950 was mainly based on internal food production using Sweden's own resources and occurred before the introduction of artificial fertilisers and imported feed concentrates. Fodder for the horse power (about 300 000 horses) was also produced using internal resources. The same evolution has been documented for Finland (Granstedt, 1999) and other Nordic countries.

On each farm unit it was necessary to balance the number of animals and the amount of fodder available, especially that which was produced and stored for the winter. Nutrients like phosphorus and lime were the limiting factors for productivity. For this reason there was a significant degree of recycling both within the agriculture system as well as from the community (human consumption). A high degree of recycling and a high proportion of grassland, including legume plants, in the crop rotation were very important measures to maintain a high humus content and the physical-organic soil fertility. These aspects tend to be more problematic today in areas that are highly specialised in crop production. The high diversity in crop rotation was also important for natural pest and weed control.

This integration of crop and animal production is today broken with the help of an increased input of artificial fertilisers to the specialised crop farms and imported fodder to the specialised animal farms. This has resulted in an increased surplus and losses of plant nutrients

Pre-industrialised multi-functional agricultural system

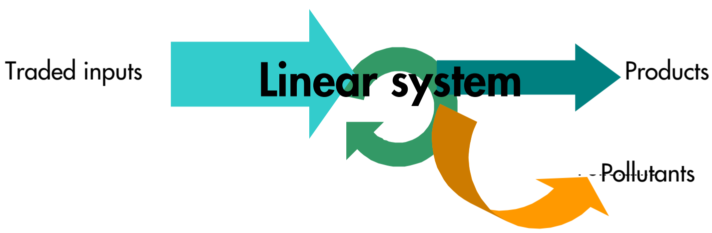
Before introduction of artificial fertilisers it was necessary with integration of crop and animal production. Animals and recycled manure were distributed on all farms.



This gives a more closed and integrated system with a low surplus of plant nutrients.

Industrialised and specialised agricultural system

The super-specialised and industrialised agricultural system of today, in e.g. Western Europe, is based on a high input of imported resources. Animal and crop production is no longer connected and manure is not treated as a resource.



This gives a very open and disintegrated system with a high surplus of plant nutrients.

Figure 10. *From a recycling to a linear system – the consequences. Prior to the introduction of artificial fertilisers the integration of crop and animal production was necessary. Animals and recycled manure were an integral part of all farms. It was a closed recycling system with lower surpluses of plant nutrients. Today we have a linear system that is based on a high input of external resources in specialised plant and animal production units. This results in high surpluses and losses of plant nutrients to the environment.*

to the environment (Figure 4 a and 4 b). Our agricultural production system has abandoned the basic principles of recycling and adopted a linear system dependent on a high input of non-renewable resources, some of which are imported from poorer countries in the world. The high loss of reactive nitrogen and phosphorus compounds to the environment special high in areas with specialised animal production is one of the results (Figure 10). An additional consequence of the specialisation and lower diversity in the crop rotations on farms is the increased need for and use of pesticides. This also influences the environment, as does the increased use of medications in the specialised intensive large-scale animal production farms.

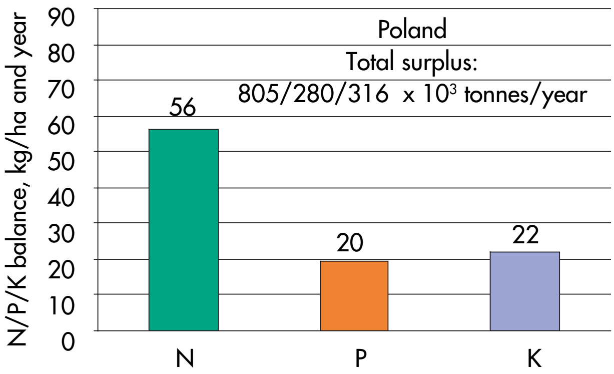
The Baltic drainage area – a diversity of situations today

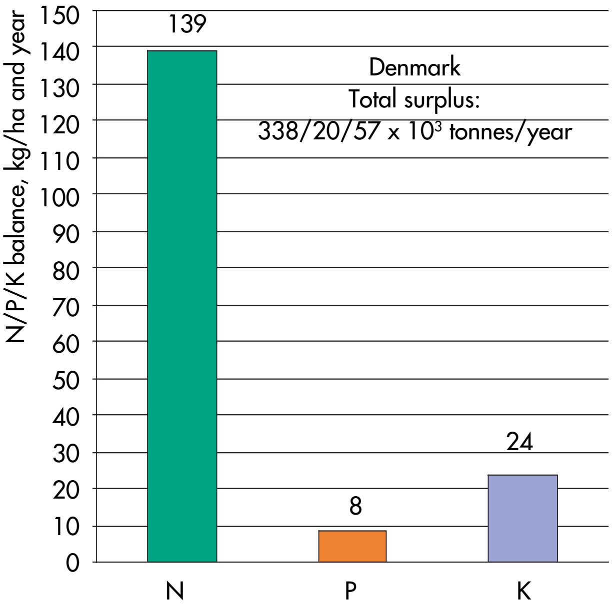
The situation in Sweden as described above is also representative of farms and regions in Finland (Granstedt, 1999) and in other areas of Europe where agriculture is technically more advanced. Oomen et al. (1998) show that the environmental nitrogen problem connected with agriculture in the European Union (EU) is related to the recent specialisation that has led to the separation of animal and crop production. This specialisation can be seen at both farm level and regionally within the countries. Manure produced by cows, pigs and poultry is generally not returned to the regions of the country where their feed is produced.

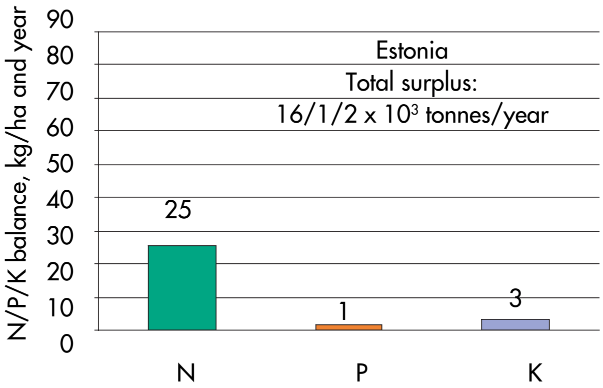
However the Baltic Drainage area also includes large areas where the structure of the agricultural sector is mostly pre-industrial. For example in a large part of Poland there is a low input of artificial fertilisers and a high diversity in both crop and animal production and also in the surrounding landscape. In these areas crop and animal production is integrated and nutrients are recycled within the system. Some of the agriculture production in the Baltic countries has also very low input today. This is a result of the agricultural collapse in the wake of the Soviet Union break-up and the resulting loss of the Russian market coupled with the adaptation to a market economy characterised by cheap imports of heavily subsidised agricultural products from EU countries.

A survey of the current nutrient balances for the low intensive agriculture in the Baltic countries and Poland compared to the more intensive and specialised agriculture in Sweden, Finland and the high surplus agriculture in Denmark is given in Figure 11. According to the HELCOM (2004) report agriculture accounts for about 50 % of the total nutrient load within the Baltic drainage area. These calculated agricultural surpluses include both losses to the atmosphere mainly in the form of ammonia from animal production as well as from reactive nitrogen compounds in the form of N_2O in the soil through denitrification. The leaching of nitrogen accounts for about 22 % of the total agricultural surplus.

Figure 11. *Surplus of N/P/K in BERAS countries. Mean values per year during the period of 2000–2002 (Finland 1999–2002). The data is collected by project members (see www.jdb.se/beras) from available statistics for the regions respectively. In the figures from Germany only the region of Brandenburg is included. Statistics from Latvia are not included at all.*





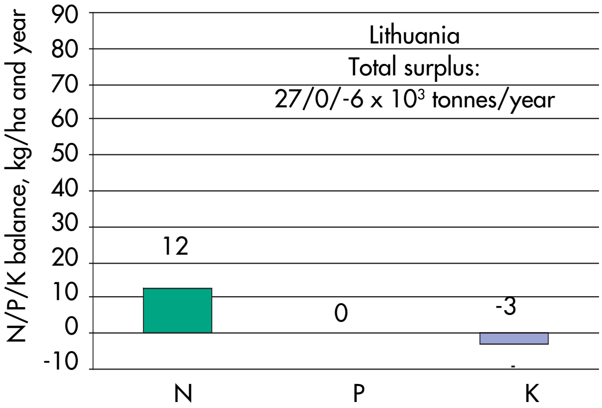


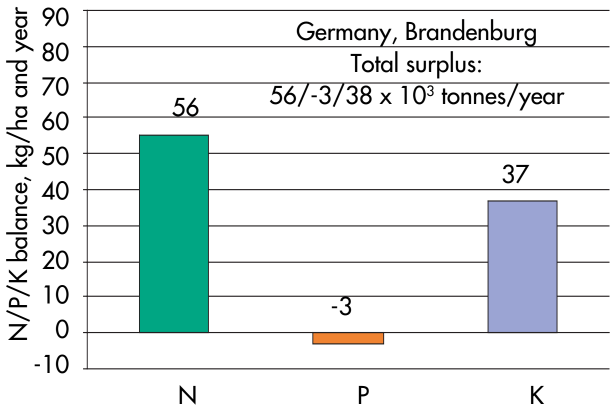
The surplus of nutrients is highest in the countries with a high input of plant nutrients in the form of artificial fertilisers as well as imported fodder. It is estimated that about 20 percent of the fodder protein used in Sweden is imported. The dependence on imported fodder is even greater in Denmark where large amount of animal products are produced on a relatively small agricultural area. The result is a surplus of nutrients, high losses to the environment and serious pollution.

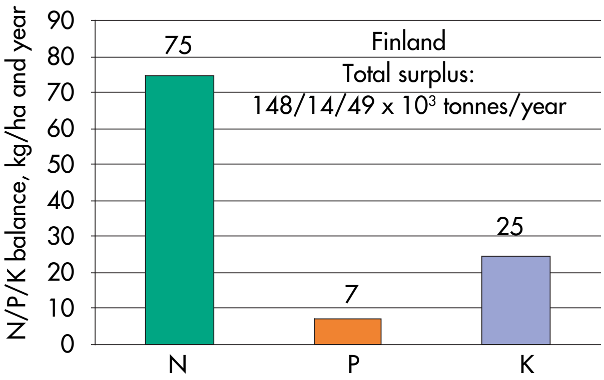
Denmark, like the Netherlands, has greatly increased its specialisation in animal production based on large scale import of high protein feed concentrates like soya mainly from the USA and other poorer countries in South America. This has resulted in a remarkably high total surplus of nutrients.

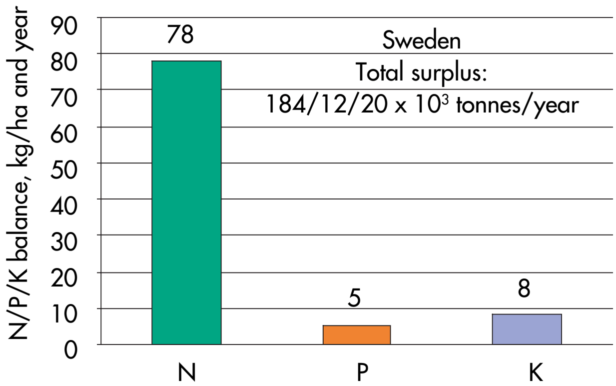
The low intensity of the agriculture in Estonia, Latvia and Lithuania is in great contrast. But the question is what will happen in the future EU. During the Soviet time these countries had a high surplus of nitrogen and phosphorus in their agriculture production and this situation can arise again. Presently producer prices are increasing despite lower production costs than in the western European countries.

The INTERREG II B project BERNET (Baltic Eutrophication Research Network) developed two possible scenarios based on case studies of selected agricultural areas in Germany, Poland, Russia (Kalinengrad),









Estonia, Finland and Sweden:

- If the nitrogen losses were to be raised to the high level of Schleswig-Holstein and Fyn (Denmark), the nitrogen load from the BERNET Region into the Baltic Sea would increase by 50–75 %;
- If the nitrogen losses were to be harmonised at the present level of nutrient losses from Elblag, Pärnu and Kalinengrad, the nitrogen load from all the BERNET regions into the Baltic Sea would be reduced by 40–80 % (Fyns Amt, 2001).

These scenarios clearly demonstrate the importance of reducing nutrient losses from the intensified agricultural regions, and of avoiding a similar development in the regions that have had a less intensive agriculture during the last decade. However the final conclusion of the BERNET study is not acceptable. Their suggestion that new EU countries (i.e. the Baltic countries and Poland) be economically compensated for not increasing the nitrogen leaching to the Baltic Sea is not the only, nor the most appropriate, way to deal with the problem. Rather our results indicate that it is possible for countries like Sweden, Finland and Denmark to reduce their nutrient losses and maintain agricultural production.

The Ecological Recyling Agriculture (ERA)

A model for the future Baltic Sea drainage area agriculture

The farm described in Figures 12 a and 12 b is an ecological farm using biodynamic methods. Apart from this it is representative of farms in the central part of Sweden, with clay loam soils, fairly dry climatic conditions by Swedish standards with an annual average precipitation 550 mm and a yearly average temperature of 6 ℃. The farm is the result of a recent merger of two biodynamic farms, Skilleby and Yttereneby, that have been managed as two separate organic farms during most of the time after 1967. Nitrogen flows on the Skilleby farm (at soil, crop,

Yttereneby-Skilleby 2003

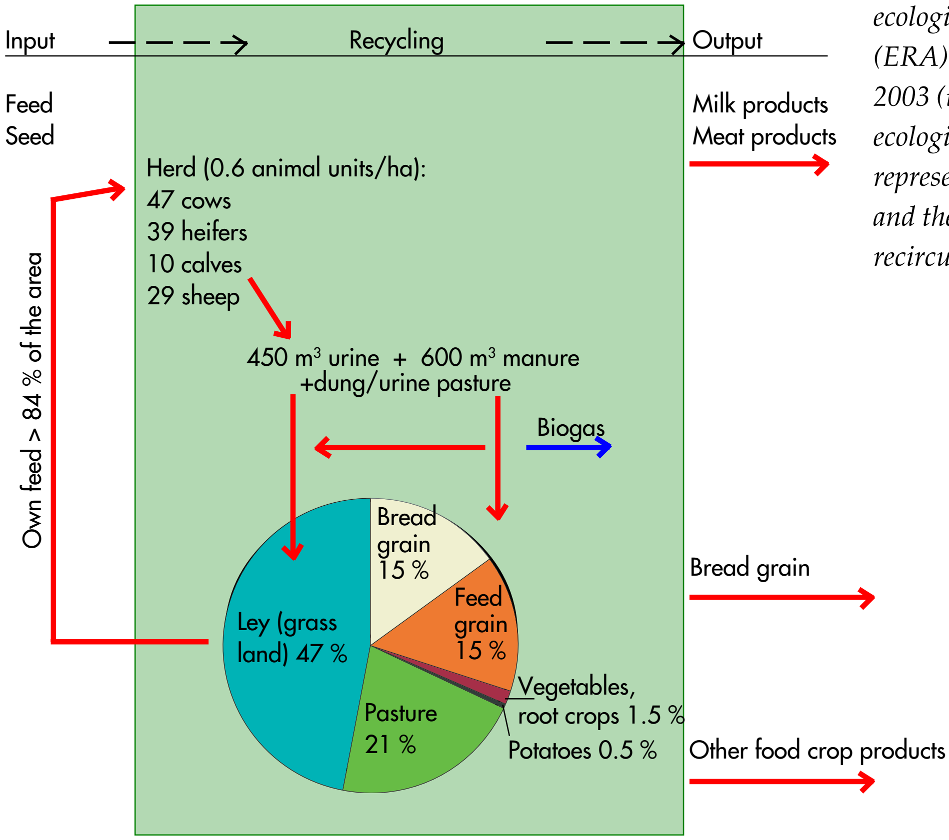


Figure 12a. *Visual description of ecological recycling agriculture (ERA) Yttereneby-Skilleby farm 2003 (two farms working as one ecological unit). The circle represents the total fram area and the rectangle shows the recirculation within the farm.*

Arable land	ha
Crop rotation	106
Pasture	29
Vegetables, root crops and potatoes	2
Total	137
Natural pasture	25

Year	Crop rotation
1	Spring cereals + insowing
2	Ley I
3	Ley II
4	Ley III
5	Winter cereals

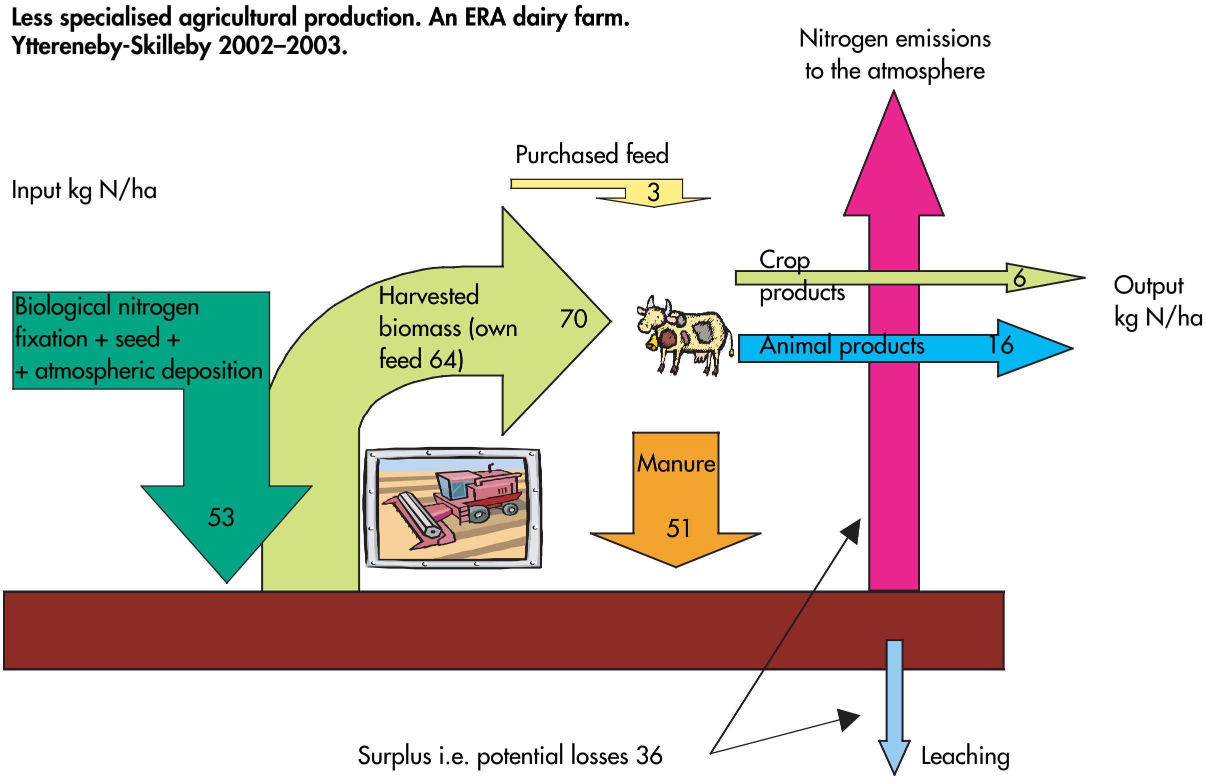


Figure 12b. *Plant nutrient (N) flows, in kg/ha and year, calculated in 2002 and 2003 for the ecological recycling agriculture (ERA) farm Yttereneby-Skilleby, farmed biodynamically since 1967. Detailed plant nutrient calculations are presented in Figure 16 in the Appendix.*

field and whole-farm levels) have been studied over a seven-year period between 1981 and 1987 (Granstedt, 1990; 1992a). Production, calculated in plant nutrients in vegetable products, bread grain and animal products from this farm, averages about 10–20 percent lower than the average for the agricultural sector in Sweden as a whole. The main difference is that animal production is based more on grass and clover/ grass than is the case on an average farm in Sweden.

Figure 12a and 12b describe Yttereneby-Skilleby farm in Järna, Sweden, which is representative of an Ecological Recycling Agriculture (ERA) integrating animal and crop production for a maximal recycling of plant nutrients within the farm. Animal density is adapted to the farm's own fodder production (animal density 0,6 au/ha, which is the same as the average for Sweden) and about 15 percent of the arable land is used for production of food crops (also about average for Sweden). Plant nutrient balances and flows of N, P, K are presented here for the years 2002 and 2003. These have been calculated using the same methods presented in this report and which have been used in earlier studies of plant nutrient flows and balances comparing ecological and conventional agriculture (Granstedt, 2000).

The farm is managed according to the principles of "ecological recycling agriculture" (ERA). These include the use of nitrogen fixation crops instead of artificial fertilisers, no use of pesticides according the standards for organic farming and assume an animal density (0,6 animal units per ha) in balance with the farm's own fodder production from 85 percent of its cropping area. The remaining 15 % is used for food crops like the average for the whole Swedish agriculture. This balance between crop and animal production is in balance with the average consumption of crop and animal products from agriculture.

The farm gate balance in Figure 13 shows that the total surplus of nitrogen is about half as high as the Swedish average. The emissions of ammoniac from animals are about the same as the average for agriculture as a whole and if only the field balances are included in the calculation the surplus and potential losses are about 75 % lower. These results are in agreement with earlier studies (Granstedt, 1990 a, 1995 and 2000).

For the studies of ecological recycling agriculture, an ERA farm (or farms working in close ecological cooperation as one ecosystem unit) is defined as a farm unit that is nearly self-sufficient in fodder, i.e. supplying at least 85 % of total nitrogen needs, Figure 14. Crop and animal production must be integrated and balanced in such a way so that the clover-grass used for nitrogen fixation and soil improvement can be utilised as fodder and the plant nutrients in the manure carefully distributed over the whole farm area during a crop rotation time period (Granstedt, 2000).

This type of recycling management requires that the level of animal production on a given farm is adjusted to the farm's crop production. The optimum level of intensity of animal production for a given farm can be calculated based on its fodder production capacity. If there is a good balance between animal and plant production (0.6 au/ha is optimum in the central part of Sweden) the net outflow of rock mineral plant nutrients is so low that it can be compensated for. This can be done through weathering (about 2–3 kg P/ha calculated as average for the whole farm), normal use of mineral fodder (about 1 kg

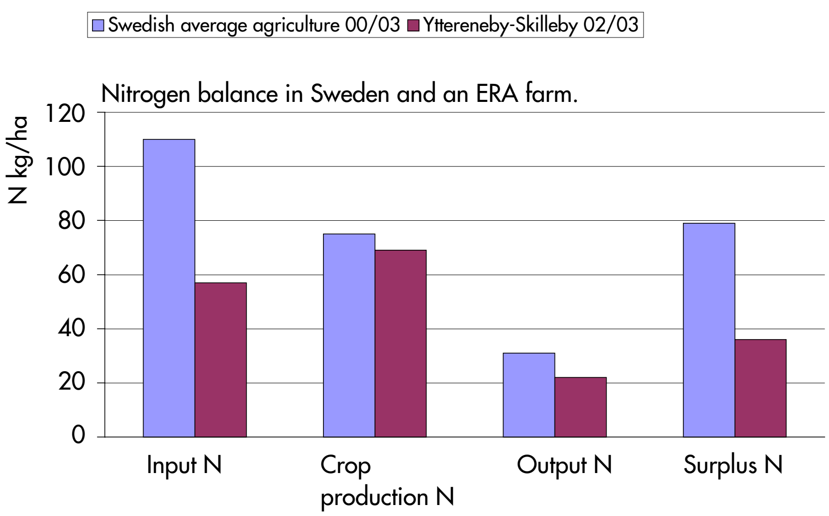


Figure 13. *Farm-gate balance calculations comparing the average Swedish agriculture that includes separate specialised crop and animal farms and the Ytterenenby-Skilleby ERA farm which integrates crop and animal production. The ERA farm has more than 50 % lower nitrogen surplus.*

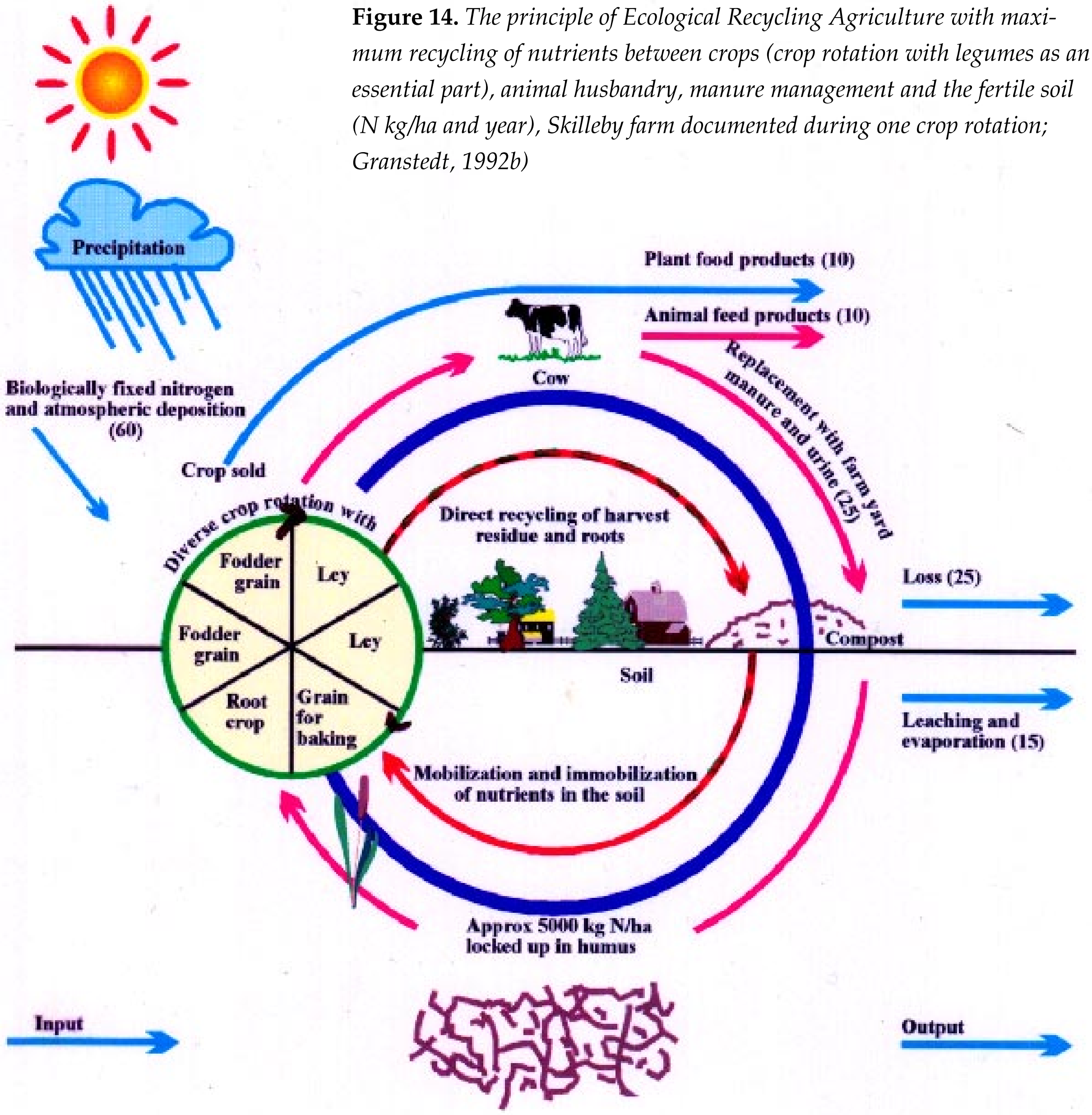


Figure 14. *The principle of Ecological Recycling Agriculture with maximum recycling of nutrients between crops (crop rotation with legumes as an essential part), animal husbandry, manure management and the fertile soil (N kg/ha and year), Skilleby farm documented during one crop rotation; Granstedt, 1992b)*

P/ha) and nitrogen fixation by leguminous crops (average 40–60 kg N/ha) (Granstedt, 1992b). Studies done in Finland gave similar results for Finnish conditions (Granstedt, 1996; 1999). Oomen et al. (1998) have described the benefits of mixed farming in the Netherlands, compared with conventional agriculture. This was illustrated by the favourable nitrogen balances of two designed prototypes where crop, dairy and sheep farming are integrated to a high degree.

These and earlier published case studies on ERA farms show that through a high degree of recycling, the integration of animal and plant production and the use of leguminous plants it is possible to manage a farm so that is self-sufficient in terms of plant nutrients. This makes it possible to minimise the surplus of plant nutrients by half or more compared with a system that separates crop and animal production.

Possibility of meeting our commitments

Effective recycling agriculture demands the use of the best available technology for conservation, both in the animal-manuring and the crop-soil systems. Farm studies (Granstedt, 2000) conclude that, on each farm or group of co-operating farms, it is essential that nutrients in the manure be effectively utilised in relation to the needs of the different crops in the crop rotation. If this principle is applied to Swedish agriculture, animal production would decrease in the southern regions of the country and increase by the same amount in central Sweden. Similar restructuring would occur in the other BERAS countries.

If clover is used for nitrogen fixation in the leys in the crop rotation the nitrogen requirements of a farm can be met without having to use artificial fertilisers. In this way it is possible to also reduce the use of fossil fuels presently used in the industrial fixation of nitrogen from the atmosphere for use in agriculture.

By integrating crop and animal production it is possible to effectively utilise the plant nutrients in manure, minimise the input of nutrients in the form of artificial fertilisers, minimise the surplus of nutrients and, as a consequence, minimise losses of nitrogen and phosphorus. To better understand factors affecting the optimal implementation of ERA under different climatic and soil conditions more case studies are required. In addition to the increased understanding these can also provide good examples and serve as an inspiration to extension services as they are related to specific site conditions (Figure 15). By applying these agricultural principles throughout the Baltic region it would be possible to more than halve the nitrogen surpluses and minimise the surpluses of phosphorous, thereby achieving the goals set by the states of the region presented in the introduction to this paper.

Figure 15. *Selected BERAS farms (dots) in Sweden and in all the eight partner countries in the Baltic drainage area. These farms will serve as the basis for analysing possibilities to minimise nitrogen and phosphorus losses from the agricultural sector in the main drainage areas. The selected cases represent the main agricultural conditions in the respective countries, and together cover, as adequately as possible, the diverse needs of the different agricultural food production situations of the 80 million people living here. The rectangles represent different local ecological food system initiatives.*

Case studies on BERAS farms

– effective recycling-based agriculture in the Baltic Sea drainage area

It is clear that more studies are needed, especially at the farm level, to better understand factors affecting the optimal implementation of effective recycling agriculture (ERA) under different climatic and soil conditions. This need is evident in Sweden and other countries of the Baltic region as well as the rest of Europe where there are similar problems to be solved. These studies must also take into account the need and use of agricultural products in each country focusing on the local market and food consumption.

Another issue to be addressed is the adoption of new farming systems strategies within current economic and social structures. This is equally relevant for countries with an established agricultural structure based on agricultural specialisation (e.g. Sweden), as it is for countries where a more traditional agricultural structure still exists in many areas and which is about to undergo major changes (e.g. Poland) as well as countries which are in the process of rebuilding their agricultural sector (e.g. Baltic states). The implementation of ERA necessitates the inclusion of the society. The partly EU-funded BERAS (Baltic Ecological Recycling Agriculture and the Society) project will attempt this in a systematic fashion building on a number of case studies spread throughout the countries concerned.

Without a clear strategy to establish sustainable recycling agriculture based on integration of crop and animal production the worse BERNET scenario, cited above, with increased pollution of plant nutrients and continued eutrophication and expanding dying areas of the Baltic Sea is the ultimate consequence. The BERAS project will contribute to developing this strategy through the analysis of practical examples that can provide the long term perspective required for the evolution of an environmentally, economically and socially sustainable agricultural food production in the region. The case studies include selected ecological recycling farms within the Baltic drainage area and provide the basis for evaluating the consequences of converting the whole agricultural sector according to ERA principles.

Appendix

Methods for calculation of plant nutrient balances and flows of nutrients within the system

Plant nutrient pools in the agriculture-community ecosystem

Data on plant nutrients are presented here in kg/ha and year for arable land. Arable land is defined in this report as the area used for crop production within a farm, county or country. To illustrate the circulation of plant nutrients the ecological system, including farms and the community, can be visualised as being composed of different pools: the soil pool, the plant pool, the domestic animal pool and the human pool. Plant nutrient flows between these different pools can be calculated, as can the balance.

This study is based on available Swedish official statistics (SCB, 2000, 2001, 2002 and 2003) and corresponding statistical information in the other countries. At the farm level it also uses information obtained from accounting records. Plant nutrient stores within the different pools have not been estimated, nor has long-term variation been considered here.

Import of plant nutrients to the agro-ecosystem

Nitrogen is imported into the agro-ecosystem through bacterial nitrogen fixation by legumes, atmospheric deposition, application of fertilisers and consumption of purchased fodder. Phosphorus and potassium are imported into the agro-ecosystem through application of fertilisers, consumption of purchased fodder and soil weathering. In estimating the contribution of nitrogen fixation in Sweden it was assumed that 25 % of the ley area is in the form of a first-year ley with legumes producing 100 kg fixed nitrogen per ha. Fodder peas and beans were assumed to fix 50 kg nitrogen/ha. In Finland the first year ley of organic farms is more grass dominated.

The figures for nitrogen deposition in Sweden are based on measurements of wet and dry deposition made by the Swedish Environmental Research Institute (IVL) for the period 1995–2000 (SCB, 2002), and the value used represents the net effect after evaporation of ammonia to the atmosphere from crops and the soil surface.

To calculate the import of nutrients from purchased fodder and foodstuffs for the country as a whole, the official trade balance for agricultural products was used (SCB, 2000, 2001, 2002 in Sweden and corresponding statistic information in the other countries). At farm level information about the import of nutrients is based on the farmer's bookkeeping. On farms with more than one animal unit fodder production is normally not sufficient to meet the fodder needs for animal production. One animal unit corresponds to one dairy cow, 2 young cows, 3 sows, 10 fattening pigs or 100 hens.

Transfer of plant nutrients within the system

Estimates of the amounts of crop nutrients removed at harvest are based on the total calculated amounts of plant nutrients in fodder and marketed food crops produced in each respective area. Values for the nutrient contents of agricultural products are based on Swedish statistics (Swedish National Food Administration, 2002) and published results from our own studies on nitrogen supply in conventional and ecological agriculture (Granstedt, 1990). Amounts of plant nutrients taken up by roots were assumed to constitute 25 % of the total uptake by the crop (Hansson, 1987; Granstedt, 1992a). It was also assumed that 40 % of the dry matter (DM) production below and above ground in ley crops was returned to the soil as residues.

In this study annual mineralisation was assumed to correspond to the amount of organic nitrogen supplied every year through the decomposition of crop residues and animal manure. For the country as a whole, it is difficult to determine whether there has been a net increase or a net loss of organically bound nitrogen in the soil. Of course, there are also regional differences. In the NPK-balance for the whole of Sweden we used statistics for 1995 to calculate the amount of nutrients provided to the fodder industry in the form of slaughter waste and to agricultural fields from the spreading of wastes from community sewage treatment plants (Granstedt, 1992a).

Export of plant nutrients from the agro-ecosystem

Significant losses of organically bound phosphorus occur when animal manure is spread under unsuitable conditions. Losses of phosphorus and potassium through leaching and runoff were assumed to be around 5 percent and 10 percent, respectively, of the amounts supplied to the soil in the form of animal manure. Phosphorus in manure is mostly in organic form, and only a small part is soluble. It is assumed that about 30–40 percent of the nitrogen is lost through storage and that 10–20 percent is lost in the field, although this figure will vary depending on the species of animals and manure-handling techniques. (Lundin, 1988; Claesson and Steineck, 1991).

Soil nitrogen can disappear from the agro-ecosystem through denitrification, ammonia volatilisation and leaching. Soil denitrification is higher in clay soils than in sandy soils. However, the proportion of nitrogen lost through leaching is larger in sandy soils than in clay soil. (Gustafson, 1996). Recently it was discovered that substantial losses of nitrogen can occur from wilting organic material. (Whitehead et al., 1998). These losses were included when calculating nitrogen losses from the soil. The surplus of nitrogen was calculated as the sum of total nitrogen supplied to the soil in crop residues and manure and mineral nitrogen supplied in fertiliser minus the nitrogen taken up by the plants.

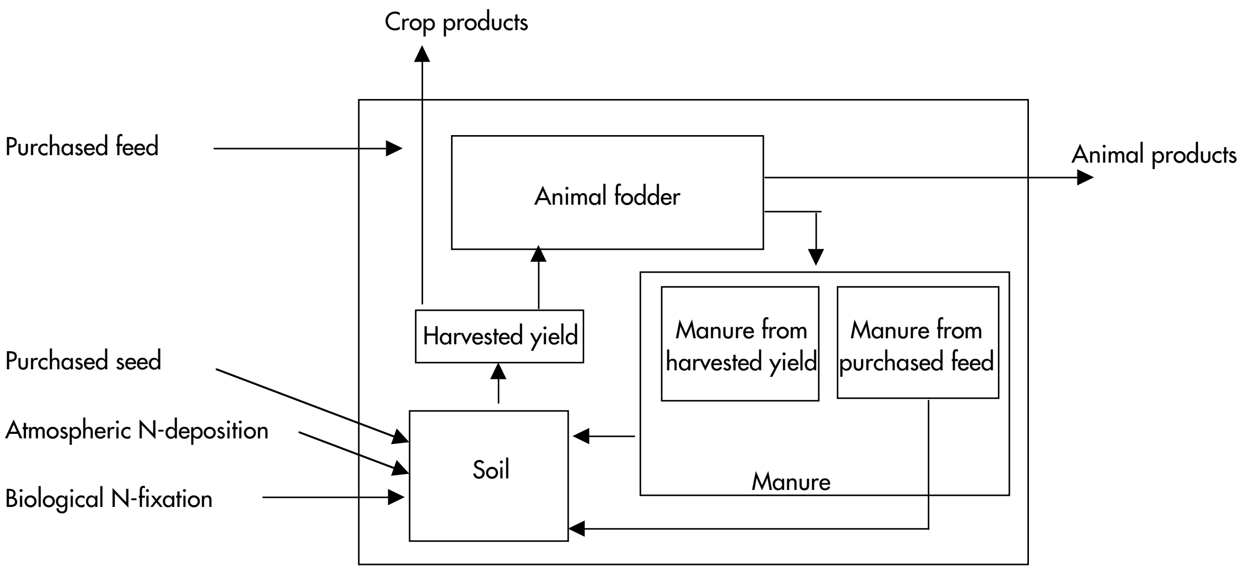
The actual emissions (losses) during a specific year will depend on the climatic conditions and the net effect of mobilisation or immobilisation of organic nitrogen compounds (discussed on page 9).

Plant nutrients in the wastes from food processing is calculated for animal products (Granstedt, 2000). The animal parts not used for human consumption (wastes from the slaughterhouses) were considered as contributing to the surplus of nutrients from the food production. One part is used by the fodder-processing industry; i.e. the nutrients are reused in fodder. This is taken into account in the figure for Sweden as a whole. These wastes from slaughterhouses are, like the wastes from the human population, a potential agricultural resource. N, P, and K contents of whole animal bodies are 2.6, 0.5 and 0.2 percent for pork and 2.5, 0.7 and 0.2 percent for beef, respectively. The calculations are based on total live weight; values vary with age (Fagerberg and Salomon, 1992; Kirchmann and Witter, 1991). Based on the relation between animal production and actual consumption of the animal products (SCB, 1994), it was estimated that only 50 percent of the nitrogen, 57 percent of the phosphorus and 64 percent of the potassium are present in the consumed parts of the animal body. The rest is waste.

Evaluation of nutrient utilisation

There is a very obvious difference in utilisation of plant nutrients in a natural ecosystem and an agro-ecosystem. In a natural ecosystem there is hardly any external nutrient input into the system and the same nutrients are re-circulating in the system and reused again and again. An agro-ecosystem works very differently and is not nearly so effective. External nutrients are imported into the system and utilised only once. When a crop is harvested the nutrients are lost from the system and the following year new nutrient inputs are needed. Several methods have been developed to measure and evaluate nutrient utilisation in various agro-ecosystems. One is a nutrient balance method. However this method does not allow for comparison between specialised crop production farms and crop-animal, mixed farm. With almost no exception the nutrient balance is better in crop production systems compared to crop-animal -system. However the nutrient balance does not say much about the effectiveness of the system in its wider context as it only compares inputs and outputs.

Seuri (2002) introduced the concept of primary nutrients (p) and secondary nutrients (m). With the help of these the concept of a nutrient balance that is not influenced by the final output (crop vs. animal



Farm gate balance: atmospheric deposition + biol. N-fixation + purchased seed + purchased feed - crop products - animal products.
Surface balance: atmospheric deposition + biol. N-fixation + purchased seed + manure - harvested yield.
Primary nutrient balance: atmospheric deposition + biol. N-fixation + purchased seed + manure from purchased feed - harvested yield.

Figure 16. *The difference between farm gate balance, surface balance and primary nutrient balance. Note: All the balances can be presented as absolute values (difference between inputs and outputs), or relative values (ratio between outputs and inputs).*

products) was developed. This balance is called primary production balance (P). Primary production balance can be calculated from the following equation:

P = u x c, where P = primary production balance u = utilisation rate, surface balance c = circulation factor = (p +m)/p

A primary nutrient is any nutrient imported from outside the system (system=farm) into crop production (i.e. into primary production). This means that e.g. any purchased fodder is considered to be a primary nutrient only after it has been fed to animals. That is, the part of purchased feed that goes into animal products is NOT a primary nutrient, but the manure produced from purchased feed is.

A secondary nutrient is any nutrient harvested from inside the system and put into crop production. This means that manure from feed produced on the farm is a secondary nutrient, while manure from purchased feed is a primary nutrient. Also nutrients released from the soil (both the organic and inorganic pools) are not counted at all because of the steady state assumption, i.e. system is in balance, there is no change in the level of reserve nutrients. If nutrients from decomposition and weathering were to be included into the equation they would be considered to be primary nutrients.

If straw that is used for litter is harvested from within the system, it is considered to be a secondary nutrient. If it is purchased, it is a primary nutrient. The straw from within the system does not need to be included in the calculations as long as it is not counted as yield. Seeds produced on the farm represent secondary nutrients. The differrence between farmgate balance, surface balance and primary nutrient balance is clarified in Figure 16.

Example Yttereneby-Skilleby farm

The primary production balance (for nitrogen only) has been calculated for the Yttereneby-Skilleby organic farm system presented in Figures 12 a, 12 b and 17:

P = u x c, where
P = primary production balance,
u = utilisation rate, surface balance and
c = circulation factor = (p +m)/p

The utilisation rate (u) is, by definition, equal to the surface balance and is calculated as a ratio between input nutrients into the field and harvested nutrients from the field. However, because a steady state is assumed, the inorganic and organic soil nutrients and the nutrients in post-harvest crop residues are considered to be part of the internal nutrient circulation and are not included in the calculations. Input nitrogen into the field includes manure (31 kg/ha), atmospheric deposited nitrogen (8 kg/ha), biologically fixed nitrogen (45 kg/ha), artificial (0 kg/ha) and seeds (1 kg/ha) - in total 85 kg/ha. Output nutrients in the removed harvest only (excluding crop residues) are 69 kg/ha

Flow of N/P/K in kg/ha in 2002–2003. The agricultural ecosystem at Yttereneby-Skilleby farm (0.6 animal unit/ha).

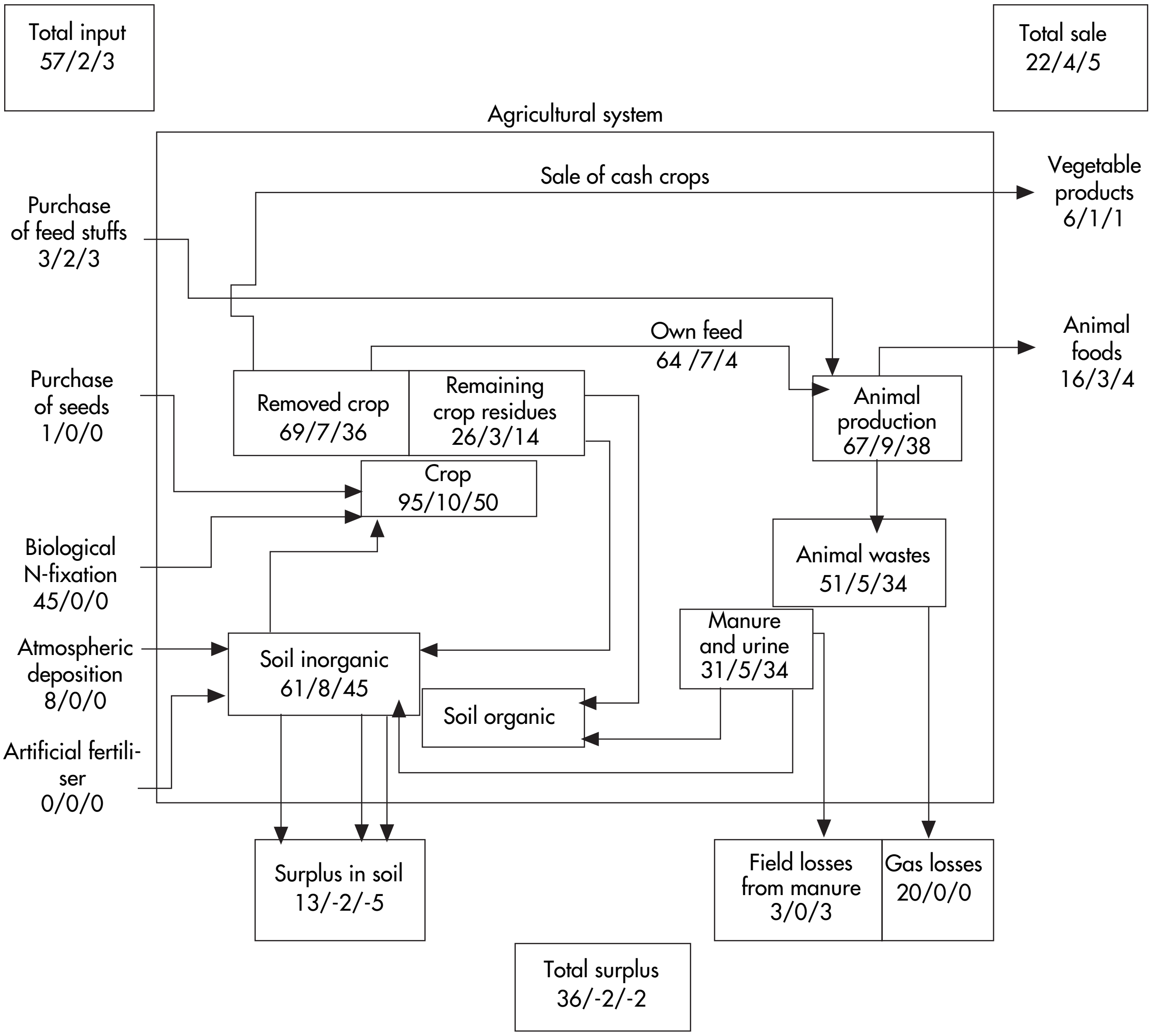


Figure 17. *Plant nutrient calculation of Yttereneby-Skilleby farm 2002–2003 (See also the Figures 12 a and 12 b).*

respectively. The utilisation rate (u) is 0.81 (the ratio 69/85). In other words 81 % of the total nutrient input into the field is harvested.

Primary nutrients (p) in the system include: purchased feed (3 kg/ha) - animal products from purchased feed (16/67 x 3 = 0.7 kg/ha) - losses from manure from purchased feed before soil application (23/51 x (3-0.7) = 1 kg/ha) + biologically fixed nitrogen (45 kg/ha) + atmospheric deposited nitrogen (8 kg/ha) + artificial fertilisers (0 kg/ha) + purchased seeds (1 kg/ha) - in total 55.3 kg/ha.

Secondary nutrients (m) in the system are all the nutrients in manure from feed produced on farm - losses from this manure before soil application: in total 29.7 kg/ha.

The circulation factor (c) = (p +m)/p = (55.3 + 29.7)/55.3 = 1.36

The primary production balance (P) is the utilisation rate (u) 0.81 x the circulation factor (c) 1.36 = 1.1.

The results indicate that 1.1 times more nitrogen is harvested in the yield than is imported as external inputs to the plant production (directly and in manure from purchased fodder - primary nutrients), i.e. the efficiency of nitrogen use is 110 %.

In any crop production system without recirculation from consumption of plant products (e.g. animal husbandry) it is not possible in the long run to have more than 100 % nitrogen utilisation. (100 % is the theoretical maximum, in practice only a lower utilisation rate can be reached.) If the utilisation rate is higher then it means that nitrogen reserves are being depleted, the steady state assumption is not valid and system is not sustainable.

However, in this example, the efficiency of nitrogen use is 110 % with the help of re-circulation through animal husbandry. The circulation factor (1.36) indicates that the nitrogen input from outside the farm to plant production (primary nutrients) is expanded by a factor of 1.36, i.e. the nitrogen is re-used 1.36 times with the help of re-circulation.

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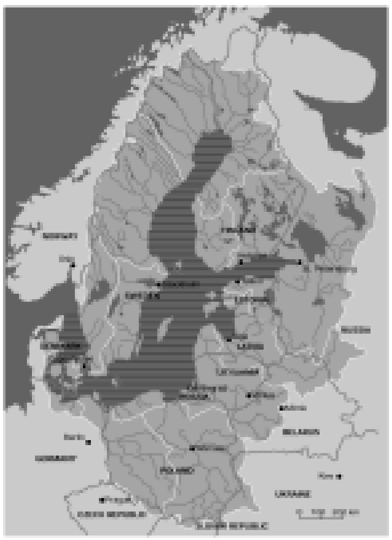

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