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Ecological Recycling Agriculture to Reduce Nutrient Pollution to the Baltic Sea

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ABSTRACT

HELCOM (Helsinki Commission) has adopted a programme with a vision of a healthy Baltic Sea Environment, with diverse biological components functioning in balance, resulting in good environmental status and supporting a wide range of sustainable human economic activities. HELCOM assessments presented in the Stakeholder Conference plan of 2007 clearly show that problems with eutrophication exist in most of the sub-basins of the Baltic and that good environmental status has not been achieved. Agriculture is responsible for a large share of the leaching of nutrients to watercourses, including groundwater lakes and finally the sea. The analysis of data presented in this paper concludes that specialized agriculture with its separation of crop and animal production results in a high load of nitrogen and phosphorus to the Baltic Sea. This agricultural specialization took place throughout the Scandinavian countries after World War II and has resulted in farms with a high density of animals and great surpluses of plant nutrients concentrated to certain regions. Examples from Sweden are presented in this paper. This trend of increasing products per animal and per hectare on fewer farms and a higher surplus of nutrients on each of them is continuing in Sweden and is likely to spread to new EU member countries within the Baltic Sea drainage area with the probable consequence of increasing nutrient loads. Ecological Recycling Agriculture (ERA) is defined as an agriculture system based on local and renewable resources that integrate animal and crop production on each farm or farms in close proximity. As a result a large part of the nutrient uptake in the fodder is effectively recycled. This in effect means that each farm strives to be self-sufficient in fodder production, which in turn limits animal density and ensures a more even distribution of animals geographically. This study of 12 Swedish farms confirms earlier results that agriculture based on these principles of ecological recycling can lead to a decrease in the potential emission of reactive nitrogen by half as well as a significant reduction in the accumulation and loss of reactive phosphorus. Application of these agricultural principles throughout the Baltic region in all EU countries would result in the halving of reactive nitrogen losses and minimizing losses of reactive phosphorus. In this way the goals, set by the states of the region, could be met and the process leading to the worst-case scenario of greatly increased nutrient loads to the Baltic Sea could be stopped.

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INTRODUCTION

This study concerns ecological recycling agriculture, where ecological, a term used in the Scandinavian countries, is a synonym for organic. Recycling refers to a system that uses and re-uses resources several times.

HELCOM (Helsinki Commission), the governing body of the 'Convention on the Protection of the Marine Environment of the Baltic Sea Area' has adopted an environmental protection programme with a vision of a healthy Baltic Sea environment, with diverse biological components functioning in balance, resulting in good ecological status and supporting a wide range of sustainable human economic activities (HELCOM, 2007).

In 1991 the European Commission adopted the nitrate directive (91/676/EEC) with the objective of reducing water pollution caused or induced by nitrates from agricultural sources and preventing further such pollution. Agreements to halve the quantity of nitrogen and even reduce phosphorus compounds reaching the marine environment by 1995 were made within HELCOM (base year 1987) and at the North Sea Conference/Paris Commission (base year 1985). The concerned countries within the Baltic Sea drainage area did not achieve these goals during the agreed period from 1987 to 1995, nor were improvements observed between 1995 and the year 2000 (HELCOM, 2005). In addition, no significant decrease of the total load was achieved in streams draining into the Baltic Sea (HELCOM, 2003).

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 (Brandt & Ejhed, 2002; Johnsson & Mårtensson, 2002). In Finland, the corresponding estimates are somewhat higher (HELCOM, 2005). 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 fertilizers in specialized conventional farming systems (Granstedt, 2000). No significant decrease, and in some cases even an increase between 1995 and 2000, has been reported from Finland, Sweden, Germany and Poland (see Table 1; HELCOM, 1998; HELCOM, 2005). Of the calculated load in 2000, 28% was from Poland, 21% from Sweden and 18% from Finland. However, per-human capita output levels of nitrogen were almost four times higher for Sweden and five times higher for Finland than for Poland.

The EU Water Framework Directive (WFD, 2000/60 EU) and the action plan from the HELCOM Conference (HELCOM, 2007) state that severe problems with eutrophication in most of the sub-basins continue and that good environmental status has not been achieved. Earlier studies of nutrient balances and nutrient flows for the agricultural sector in Sweden showed that during the period from 1950 to 1980 total surplus of nitrogen including inputs from inorganic fertilizers, imported fodder, nitrogen fixation and atmospheric

TABLE 1

Total land area, area of arable land and total loads of nitrogen tonnes according to HELCOM reports for the year 1995 and 2000. Only a part of Germany and Russia (Leningrad and Kaliningrad) that are located in the Baltic drainage area are covered by the statistics. Additional load also from part of Belarus is not included in this figure.

	Land (1000 ha)			Loads (N t year^{-1})	
Country	Total land	Arable land	People × 1000	Year 1995	Year 2000
Germany	3604	400		21347	33500
Poland	32325	14652	37764	214 747	230 400
Lithuania	6520	2152	3446	36894	37200
Latvia	6460	1740	2606	91964	54000
Estonia	4510	1144	1595	46468	33700
Russia	21310	2900		84647	61500
Filnland	33815	2185	4938	66073	122 700
Sweden	44996	2592	8500	130 872	175 600
Denmark	4309	2395	5155	68680	65400
Total	157 849	30160		761 692	814 000

pollution increased from 36 to 80 kg nitrogen ha^{-1} year^{-1} and the surplus of phosphorus increased from 7 to 17 kg ha^{-1} year^{-1}. After 1980 the surplus of nitrogen continued to increase but at a slower rate up until 1995 (Granstedt, 1995, 2000). The situation in Finland was found to be similar to Sweden but with a later culmination of the surplus to the year 1993 after which the previously higher nutrient surplus per hectare and year fell to the same level as Sweden. In 1970 the surplus of phosphorus was up to 17 kg ha^{-1} year^{-1} in both countries but had declined in 1990 to 10 kg in Finland and in 1995 to 8 kg in Sweden (Granstedt, 2000).

The causes for the increased surplus of plant nutrients from the agricultural sector after 1950 have been discussed by Granstedt (1992a, 1992b, 1995, 2000). Although a surplus of nitrogen (N) or phosphorus (P) does not measure the actual loss, it does express the potential loss over the long term if appropriate management measures are not taken (Halberg, 1999). Once a farm system is stabilized, no additional accumulation of nitrogen occurs (Jansson, 1986; Schröder *et al.*, 2003) thus a nitrogen surplus is a potential source for losses to the environment (Kristensen *et al*., 2005). Based on studies of nutrient flows and nutrient balances at farm, county and country levels, the following was concluded: (1) The local and regional specialization of farms in countries with an agricultural structure like Sweden and Finland resulted in high surpluses and potentially high losses of plant nutrients to the environment. One type of farm specializes in crop production based on the use of artificial fertilizers, while the other specializes in animal production with high inputs of purchased fodder and a surplus of plant nutrients in the form of ineffectively utilized manure from the animals. This flow of nutrients with high input to the crop farms, transfer of nutrients via fodder to the specialized animal farms and output of the surplus to the environment can be described as a linear nutrient flow. (2) To minimize the high surplus and potential for losses of plant nutrients from the agricultural system the input of nutrients to the system needs to be reduced. This can be done by increasing the recycling of plant nutrients within the farming system through the better integration of animal and crop production. This is achieved when the number of animals on the farm is in balance with the amount of fodder the farm can produce. (3) By applying the recycling principles throughout the Baltic Sea drainage area it would be possible to halve nitrogen losses and minimize losses of phosphorus, thereby meeting the goals set by the states of the region.

In Sweden an input/output accounting system for calculating nutrient balance has been developed (Granstedt, 1992b, 1995, 2000). The nutrients nitrogen (N), phosphorus (P) and even potassium (K) are included in the calculation. The input of nutrients to the farm includes those in fodder and fertilizers as well as atmospheric nitrogen through biological nitrogen fixation and deposition. The output of nutrients includes those in agricultural products, both in animal products like milk and meat and in crop products like bread grain and horticultural products. This calculation can now be done with the help of a data based calculation programme, STANK, using collected data and standard values for different agricultural resources (Jordbruksverket, 1998), which is available for use by farmers and advisers. This programme for nutrient balance calculations is in accordance with the recommendations in the OSPAR Convention as an environmental indicator for plant nutrient reduction (SCB, 2003a). The 1992 OSPAR Convention is the current instrument guiding international cooperation on the protection of the marine environment of the North-East Atlantic the North Sea. This indicator programme has been evaluated as being an effective method comparable to other environment indicator programmes in use in Europe (Cederberg & Flysjö, 2004; Cederberg, 2006). Today more than 6000 farmers in Sweden are included in this monitoring system called Greppa näringen (in English 'Catch the nutrients'). The Swedish Board of Agriculture reports regularly to farmers and the extension service the results of this monitoring (Greppa näringen, 2005). These reports show that the most productive dairy farms have more than 150 kg nitrogen surplus ha^{-1} $year^{-1}$. This is almost twice the average surplus for the whole of Sweden.

In Finland, nutrient balance studies combined with measurements of the leaching of phosphorus show that farms with a high animal density have a large surplus of nutrients leading to an accumulation of phosphorus in the soils and a resulting increase in the amount of soluble phosphorus (Uusitalo & Jansson, 2002). Uusitalo *et al.* (2007) conclude from studies in Finland that in those parts of the countryside that have high animal densities, typically associated with substantial P surpluses, agricultural P losses may increase in the future.

Also high positive N balances are associated with high accumulation of N in soil and further high risk of N leaching during rainy seasons (Rankinen *et al.*, 2007).

Despite the increasing use and proper implementation of agricultural Best Environmental Practice (BEP) and Best Available Technology (BAT), (HELCOM, 2003; Larsson *et al.*, 2005), such as use of cover crops, better timing for soil treatments and improved storing and application of manure, the accumulation of nutrients on farms with a surplus of manure continues. Implementation of the Nitrate Directive and WFD can limit the excessive overuse of manure, but the accepted limitation of 170 kg N in manure is not sufficient to handle the critical situation in the Baltic Sea. In Sweden animal density is regulated to a maximum of 22 kg P ha^{-1} in the manure spread on fields (Henriksson, 2007). According to the Nitrate Directive this automatically limits the amount of N spread in the manure. As a result of this regulation, many animal farms have contracted arable land on which to distribute excess manure. Despite these measures, Sweden is, next to Denmark, the highest polluter of nitrogen per hectare and next to Poland the highest polluter of both nitrogen and phosphorus to the Baltic Sea. The continuing serious situation makes it necessary to identify and implement alternatives to today's specialized agriculture, alternatives that provide long-term solutions to the problem. This is especially important considering the ongoing changes in the agricultural structure of the Baltic countries and Poland since they joined the EU. Agriculture in these countries is becoming more like the farming systems in Sweden and Finland and in Denmark with its even more intensive system. The establishment of industrial farms in these new EU countries greatly increases the risks for a rapid increase in the nutrient pollution to the Baltic Sea from agriculture (Coalition Clean Baltic, 2007). Farms where less than 10% of the fodder consumption is covered by on-farm fodder production have been categorized as industrial farms (Sere & Steinfeld, 1999). In the 'business as usual' scenario presented in the last HELCOM report (HELCOM, 2007) a possible 100% increase in phosphorus and a 70% increase in nitrogen load to the Baltic proper was estimated.

The background presented above indicates that further studies are necessary in order to better understand the reasons for nutrient pollution from today's farming systems and the possible impact of a more effective recycling farming system. Such information is useful to policy and decision makers responsible for the agricultural sector. The studies presented here are a part of this work. They have been carried out as part of a EU-INTERREG IIIB project BERAS, Baltic Ecological Recycling Agriculture and Society (Granstedt *et al.*, 2004).

MATERIALS AND METHODS

The BERAS project calculated the average nutrient balances and the nutrient flows for the agriculture-community system at country and farm level based on a total of 48 selected ecological farms (ecological farms according EU standards for organic farming EU 2092/91, up to date Organic Standards, Certification and Regulations www.organicstandard.com) under different farming conditions in the eight EU countries around the Baltic Sea during the three years from 2003 to 2005. Results from nutrient balance studies for the whole of Sweden and the results from 12 ecological farms (Appendix 1) in Sweden are presented and analysed here. These 12 farms were included in the BERAS project and the data was collected during 3 years from 2002 to 2004, for two of the farms during 2 years and for ten farms during 3 years. The results are also compared with other relevant studies covering additional farms and a broader spectrum of agricultural conditions. The potential to reduce nitrogen and phosphorus pollution through conversion to ecological recycling agriculture is further discussed based on these results. The analysis is based on agriculture nutrient balance calculations for the country as a whole and on farm level and is representative for the country average. They are compared with nutrient balance calculations from selected Ecological Recycling Agriculture (ERA) farms.

Criteria for selecting ERA farms

In addition to fulfilling EU criteria for organic farms the selected ERA farms have a high rate of nutrient recycling based on integrated crop and animal production. The ERA farms have an animal density of < 0.75 au ha^{-1} (Appendix 3) and an external fodder rate (EFR) of < 0.15, i.e. less than 15% of the total fodder used based on nitrogen content is produced and bought from outside the farm. These test-farms, dots 1 to 12 on Figure 1, are representative of the main agricultural conditions and drainage regions in the country.

Nutrient recycling, field and farm gate balances

The methods for calculating nutrient flows within the farming systems and nutrient balances follow those described in earlier studies by Granstedt (1995, 2000) and by Cederberg & Flysjö (2004), Cederberg (2006), Halberg *et al.* (1995a, 2000), Kristensen *et al.* (2005) and Steinshamn *et al*. (2004). In these studies the nutrient surplus is defined as the difference between input and output of nutrients into the system. This difference can be calculated based on nutrient balances for the farm as a whole (farm gate balance) or at field level

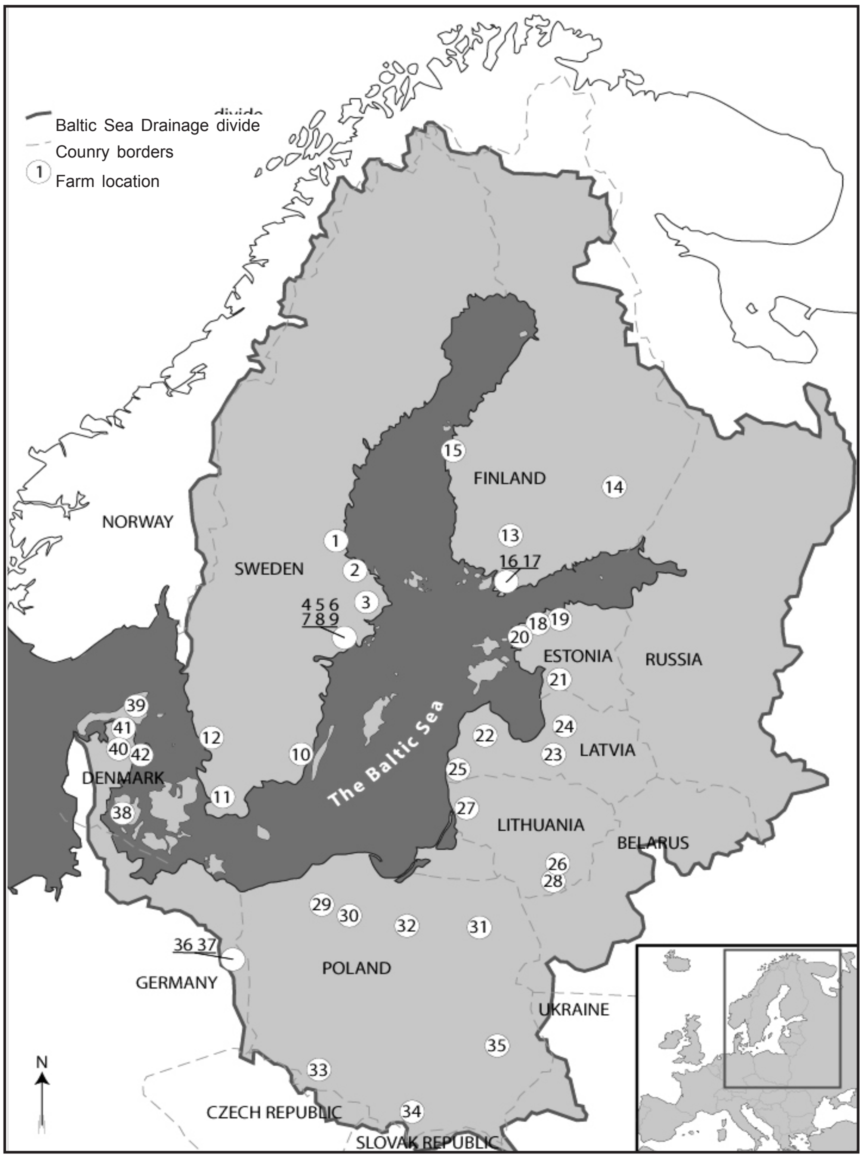

FIGURE 1. The Baltic Sea drainage basin with locations of all ERA farms included in the BERAS project. In this paper the results from the 12 Swedish BERAS-farms are presented. Characteristics of the farms are presented in Appendix 1. Together these farms produce a broad spectrum of crops and animal products needed for human consumption.

(field balance = soil surface balance). In this type of emission-related studies with a focus on the total pollution of nitrogen within the Baltic Sea drainage area the focus must be on leaching per hectare of agricultural land. This is in accordance with the regional Life Cycle Assessment (LCA) presented by Geier & Köpke (1998) and the recommendations of Payraudeau & van der Werf (2005).

Farm gate balances are based on the difference between the import (input) of nutrients including fertilizers, imported fodder, imported manure, nitrogen fixation and precipitation of atmospheric nitrogen and the export (output) of nutrients in agricultural products from the whole farm including both crop and animal production and exported manure. Nutrient use efficiency (NUE) is defined as the ratio of nutrient output in products divided by the total input of nutrients into the system. The nutrient balance calculations in this study have been made in accordance with the STANK programme 2:1 (Jordbruksverket, 1998). This method can also be used to calculate balances for larger systems such as administrative regions or drainage areas. The data used is based on official statistics for the whole country and from farm records, direct information from the farmer and field observation complemented with field samples for estimation of biological nitrogen fixation (BNF). In cases where the farmer has sold manure out from the farm this amount is not included in this balance calculation and is therefore calculated as part of the surplus.

Field balances are based on the difference between input and output of nutrients for crop production at field soil level using the amount of manure and fertilizers for input data and the amount of harvested crops for output data. For calculating the nutrient value in harvested fodder crops, data from studies of average fodder produced on Skilleby experimental farm for milk and meat production have been used as a reference (Granstedt, 1992a). The surplus of nitrogen in farm gate balances is higher than the field balance surplus on animal farms due to the loss of nitrogen from manure during storage and after its application on the field.

Statistics Sweden (SCB) has regularly presented both types of balances (SCB, 2003a). The farm gate balance for the whole of Sweden is based on input (calculated amounts of plant nutrients in imported fodder, atmosphere deposition, calculated nitrogen fixation, used fertilizers) and output (plant nutrients in food products delivered from the farm) data for the whole country per year and calculated as average per hectare based on the area of arable land under cultivation.

Biological nitrogen fixation (BNF) and input through atmospheric deposition

The BNF on the farms in Sweden was estimated using the same methods used in earlier published studies (Granstedt, 2000) and in the STANK 2:1 programme (Jordbruksverket, 1998). Total clover grass yield was estimated based on information from the farmer about the harvested yield and the percentage of clover in the clover grass fields was based on field observation complemented with field samples on each farm each year where the percentage of clover fresh weight was measured after sorting clover and grass to calibrate the visual estimation. This work was done by the same person every year on the studied farms during the three year project period.

Developed from field experiments, the BNF is calculated as the difference between total nitrogen in biomass with clover grass and the total nitrogen in biomass with only grass in field plots on the same plot where both above and below ground biomass was included (Granstedt, 1992a). Trials with different clover percentages provided the basis for the regression line between clover percentage and nitrogen fixation at different yield levels (Fagerberg & Salomon, 1992). Similar methods for the calculation of BNF based on clover percentage and total yield have been developed by Carlsson & Huss-Danell (2003) and Hogh-Jenssen *et al.* (2004). These have been used in field experiments to study clover grass in organic farming also in Finland and have shown good correlation to measure the proportion of clover N derived from the atmosphere according to the method described by Peoples *et al*. (1989) (Nykänen *et al.*, 2008).

In estimating the contribution of nitrogen fixation for the whole of Sweden it has been assumed that 25% of the ley area (SCB, 2001, 2002, 2003b) in all counties is in the form of a first-year ley with legumes producing 100 kg fixed nitrogen ha^{-1}. Fodder peas and beans are assumed to fix 50 kg nitrogen ha^{-1}.

The data for nitrogen deposition are based on measurements of wet and dry deposition made by the Swedish Environmental Research Institute (IVL) (SCB, 2003a), and the value used represents the net effect after evaporation of ammonia to the atmosphere from crops and the soil surface.

RESULTS

Nutrient balances for Swedish agriculture 2000–2002 compared with reported nitrogen and phosphorus leaching to the Baltic Sea

The total calculated average yearly balances (2000–2002) for nitrogen, phosphorus and potassium for Sweden are shown in the flow diagrams in Figure 2. Nutrient flows are divided into three main groups: imports, transfers and exports. These are related to the different pools: the soil pool, the plant pool, the domestic animal pool and the human pool according to the earlier study presented for Swedish agriculture for the years 1990 (Granstedt, 1995) and 1995 (Granstedt, 2000). The arrows refer to flows (imports and exports) to and from the pools as well as imports and exports in relation to the whole agricultural-community ecosystem. Nutrients in food products in the community system are further divided into separate pools: slaughter wastes, domestic wastes and the sewage wastes from the human digestive system.

For Sweden, the difference between the nitrogen import (106 kg N ha^{-1}) and export (27 kg N ha^{-1}) from the agricultural system out to the community system represented the surplus (79 kg N ha^{-1}) that was potentially lost to the environment if there was no change in the level of soil N-content. The nutrient use efficiency (NUE) for nitrogen (total output / total input) was 0.25. Although about half of the input of phosphorus was surplus (6 kg of 11 kg P ha^{-1}), only a smaller part was lost to the environment.

In order to estimate the eutrophication potential, the calculations of the nutrient balances for the Swedish agricultural system were compared with the most recent studies of the leaching from the root zones published in the TRK Transport-Retention-Källfördelning (Transport–Retention–Source distribution)

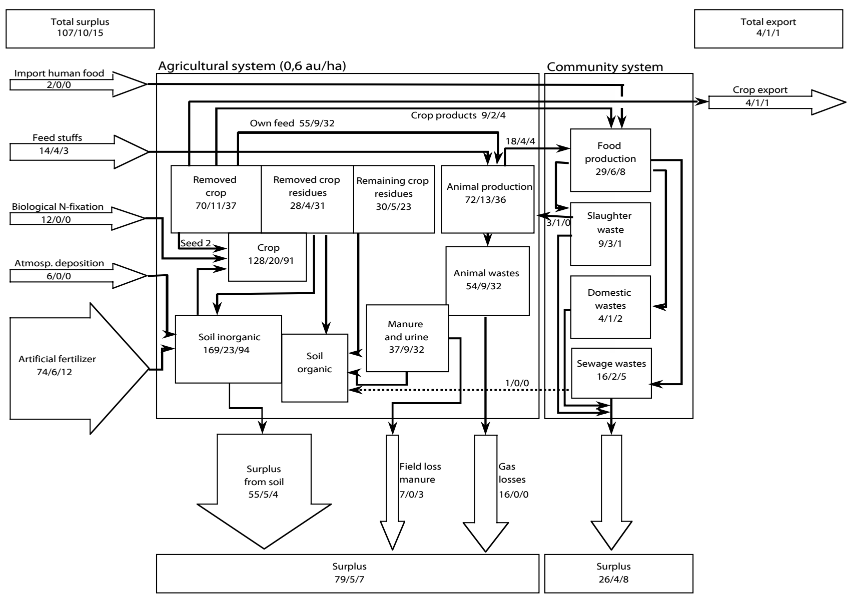

FIGURE 2. Calculated flow of N, P and K (kg ha^{-1} year^{-1}) (2000–2002 average) in the Swedish agricultural (2 480 000 ha)-community ecosystem. The surplus of nitrogen is equal to the average losses to the atmosphere and drainage water assuming a steady state of immobilised humus nitrogen content. The surplus of phosphorus is mostly fixed in phosphate compounds in soil. From Granstedt *et al*. (2004).

report by the Swedish Environmental Protection Agency (Brandt & Ejhed, 2002; Johnsson & Mårtensson, 2002). The calculation of leaching from arable land is based on a field N leaching coefficient (NLC) method and “standard leaching coefficients” which were used in the TRK project to estimate the leaching for 22 production-climate regions in Sweden for 13 different crop groups and 10 soil texture classes. The NLCs are calculated with the simulation model SOILNDB which links input data and data from a parameter database to automatic parameterization procedures for an underlying water and heat model SOIL and the N model (SOILN). SOIL/SOILN are physically-based research models that have been tested and applied to various sites with different soils, climates, and cropping systems, including application to sites in the vicinity of the catchment in concern (Larsson *et al.*, 2005). The calculated values are calibrated to the measured values on monitoring stations situated at the end of the water systems. These amounts, which have been reported to HELCOM as the anthropogenic leaching from agricultural fields, have been calculated as 60600 t of nitrogen year^{-1} leaching from the root zones as an average for the period 1985-1999. Assuming a steady state of stored soil nitrogen, this indicates that about 31% of the total 196 000 t of nitrogen surplus in the Swedish agricultural sector is lost as anthropogenic leaching from the root zones in agricultural fields (24 kg ha^{-1}). Despite governmental programmes to reduce this leaching no significant reduction has been reported. After retention (variation of soil and water system retention depends on environmental soil and climatic factors and duration of water transports), on average 60% of the leaching from fields is calculated as being lost in the end to the sea (Brandt & Ejhed, 2002). No data about uncertainty of this average value is given in the report but some comparisons between calculated and measured values in the mouth of the river system in agricultural districts indicate that calculated values can be 10–15% lower than measured values (Brandt & Ejhed, 2002).

Ammonia losses from agriculture are estimated to be about 40000 tons (SCB, 2003b) indicating that about 20% of the total surplus of 196 000 t of the total calculated nitrogen surplus in agricultural is lost (16 kg ha^{-1}). This means that 30% of the total nitrogen released from farm animals, i.e. the difference between the input of fodder and the output of animal products, is lost in the form of ammonia to the atmosphere. The remaining nitrogen surplus is immobilized in organic biomass and lost from the agricultural system through denitrification (i.e. N_2O and N_2 emissions). In reality it can be assumed that in some areas, mainly characterized by increasing shares of annual crop production and decreasing animal production, the amount of organic nitrogen is decreasing while in other areas with increasing grassland management and application of manure there is generally an accumulation of N in the soil (Jansson & Persson, 1982). Future improvements in the method for calculating nutrient balances and NO_3 losses need to include the effect of crop successions and the evaluation of the soil N pool at the farm level

(Payraudeau *et al.*, 2007). The calculations presented here assume a steady state as an average for the country as a whole.

Of the total annual surplus of 12900 kg P (average surplus 5.2 kg P ha^{-1}) about 1440 t P $year^{-1}$ leaches from arable land according to the TRK report (Brandt & Ejhed, 2002). The average surplus of phosphorus has decreased during this period (2000-2002), 5 kg P ha^{-1} compared with 8 kg ha^{-1} in 1995 and 17 kg ha^{-1} in 1980 (Granstedt, 2000). Despite this, the leaching was about the same. The use of artificial P fertilizers has been reduced on specialized crop farms and some have today a negative phosphorous balance. However on specialized animal farms there is still a high surplus of phosphorus as a result of the input of imported fodder. The accumulated surplus that, year after year, has been built up in the soil on these farms can be assumed to be a potential source of losses to the environment for a long time to come.

Nutrient balances on the 12 Swedish ERA farms compared with average Swedish agriculture

The average nutrient balance calculations for N, P and K for 2002–2004 at farm level are presented in Figure 3. The harvested field production, the second column in each Figure, is an estimation based on cash crops sold from the farm and calculated fodder production based on the difference between purchased fodder and the fodder needed for the number of livestock on the farm. The third column gives information on nutrients in the sold products and the fourth the calculated surplus as the difference between the total input and export. For more detailed results for the different farms see Appendix 2.

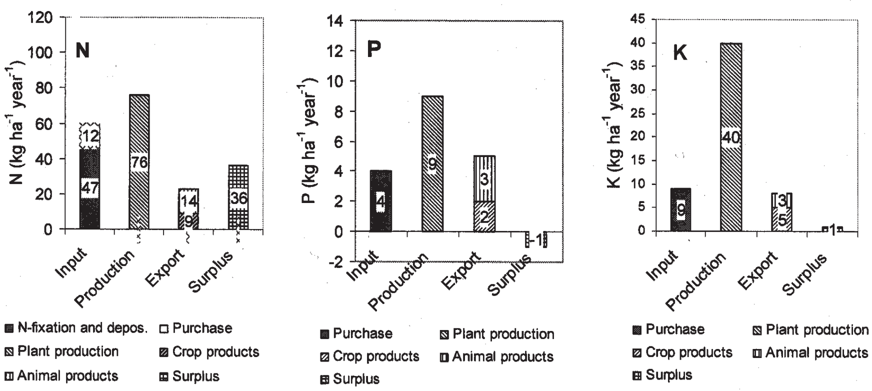

FIGURE 3. ERA farms average input from the atmosphere (N-fixation and deposition), purchase (seed and purchased fodder), plant production and export in form of animal products (milk and meat) and crop products and surplus of nitrogen (N), phosphorus (P) and potassium (K).

The average nitrogen surplus on the ERA farms was 36 kg N ha^{-1} year^{-1} during the study period. This can be compared with the average for Swedish agriculture, which has been calculated to be 79 kg ha^{-1} year^{-1} for 2000–2002 (Figure 4). The calculated crop production in terms of N was higher and food production was about 25% lower in ERA than in conventional agriculture (second column in each Figure). This was due to the higher portion of ruminant clover-grass-based animal production on ERA farms. Conventional agriculture was dominated by grain-converted meat production, which has a lower ratio between input of fodder protein and output of animal protein. Nitrogen surplus is more than 50% lower per hectare on ERA farms which had the same animal density of 0.6 au ha^{-1} but a slightly lower share of animal products (in terms of N) in the total production.

The phosphorus balance on ERA farms was on average negative: –1 kg P ha^{-1} year^{-1} during the study period with a significant surplus only for one farm, which had bought organic fertilizers. Negative balances on six of the 12 farms ranged from –1 to –6 kg P ha^{-1} year^{-1} (Appendix 2). In comparison, the average surplus for conventional Swedish agriculture was calculated to be 5 kg ha^{-1} year^{-1} for 2000–2002. This average surplus hides a wide variation, from a negative balance on some conventional specialized farms to surpluses as high as an average of 9 kg P ha^{-1} year^{-1} on specialized animal farms with more than 1 animal unit (au) per hectare and a high import of P in purchased fodder (SCB, 2003a) according to data from farm reports for 2001.

A majority of the studied ERA farms also had a negative potassium balance (Appendix 2) even if the average value was 1 kg ha^{-1} year^{-1} during the study period. In comparison, the average surplus for Swedish agriculture as a whole was 7 kg ha^{-1} year^{-1}. Surplus potassium is not considered to be

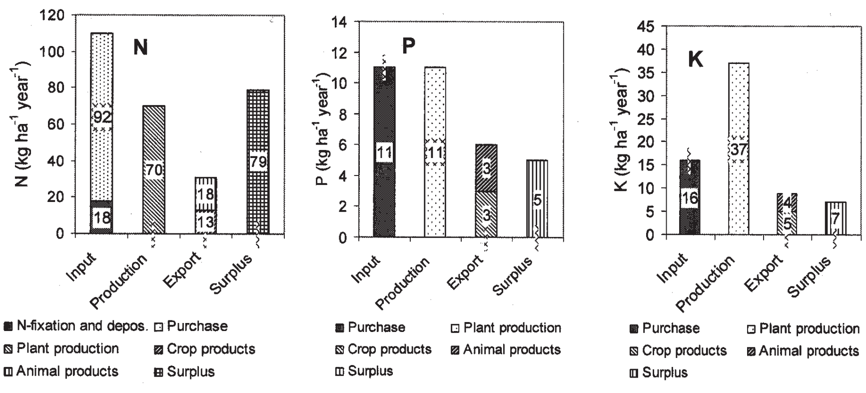

FIGURE 4. Swedish mainly conventional agriculture. Average input from the atmosphere (N-fixation and deposition), purchase (seed, purchased fodder and artificial fertilizers), plant production and export in form of animal products (milk and meat) and crop products and surplus of nitrogen (N), phosphorus (P) and potassium (K) (2000–2002).

an environmental problem. It does, however, represent a cost to the farmer. The case of potassium illustrates how a higher degree of internal recycling on ERA farms than in conventional agriculture can reduce the amount of inputs needed.

ERA farms with no purchased fodder showed limited negative nutrient balances. Potential negative consequences of long term negative P and K balance for soil fertility and crop production have not yet been observed in long term studies. Based on observations of available nutrients in soils it can be argued that the organic system may stimulate the weathering processes of hardly soluble P reserves (Granstedt, 1992b). This question needs to be addressed in the further development of ecological farming systems (Steinshamn *et al.*, 2004). In the future it will also be desirable to increase the extent to which plant nutrients exported from the agricultural system to the community are returned to the farms.

Nitrogen surplus related to farm characteristics and animal density on the 12 Swedish ERA farms

Nitrogen surplus on the 12 ERA farms are presented in Figure 5. The farms are ordered by increased values for nitrogen surplus. The lowest N surplus was found on the more extensive meat and cereal producing farms in Oxsätra and Håknäs. They had the lowest number of animal units per hectare. The highest surplus was on Skogsgård (number 12) with an average animal density of more than 0.8 au ha^{-1}.

The N-surplus was generally lower on ERA farms with a lower animal density (Figure 6) with the exception of Hånsta (number 2), which is the

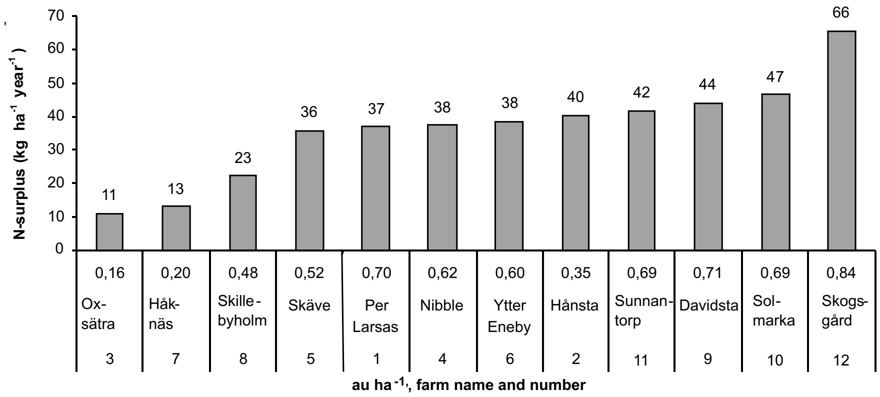

FIGURE 5. Average N-surplus on the 12 Swedish ERA farms ordered after increasing values.

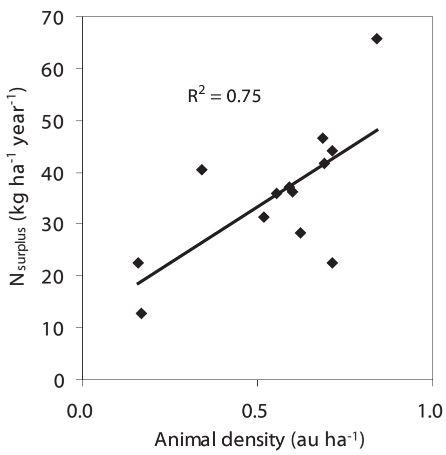

FIGURE 6. Farm N surplus 2002-04 for the 12 ERA farms as a function of animal density (au ha^{-1}).

only poultry farm among the ERA farms. All farms, that fill the criteria for ERA farms i.e., having an animal density below 0.75 au ha^{-1} and an external fodder rate (EFR) of less than 0.15, had an N-surplus below 50 kg N ha^{-1}. On the seven ERA farms with an animal density between 0.5 and 0.7 au ha^{-1} the N-surplus ranged between 36 and 47 kg N ha^{-1} year^{-1}, and the nutrient utilization efficiency ranged between 0.33 and 0.41. The variation in N surplus and nutrient utilization efficiency on the ERA farms with the same animal density and similar type of production could be a result of different agronomical production factors such as climatic and soil conditions. It might also be explained by differences in farm management that result in varying effectiveness in the utilization of fodder and manure within the farming system. Here lies a potential for improvements according to the analysis made of the internal nutrient recycling on an ecological farm in Norway by Steinshamn *et al.* (2004). This study also compared the nutrient efficiency presented in other studies. Strategies to increase the efficiency in dairy farming systems to lower surplus and losses of plant nutrients from very high levels have been developed in the dairy farming system 'De Mark' using the method of prototyping in The Netherlands (van Keulen, 2000). The ERA system goes further than the 'De Mark system' by adapting animal production to on-farm feed production. The External Fodder Rate (EFR) and surplus of nitrogen per hectare and year for the three year period for the ERA farms is presented in Figure 7.

To understand the differences between individual farms and between farming systems it is important to take into consideration possible variations in nutrient content in agricultural products as well as possibilities for an under- or over-estimation of nitrogen fixation (Kristensen, 2002). Increasing the average nitrogen fixation by 25% on the 12 ERA farms increases the average surplus

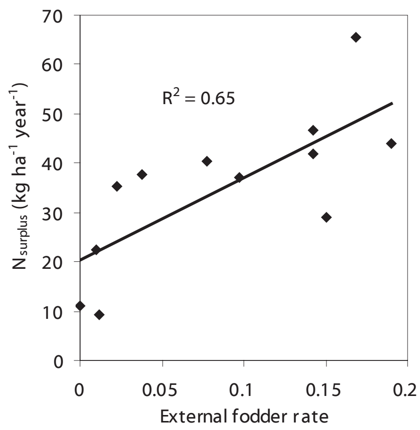

FIGURE 7. Farm N surplus 2002–04 for the 12 ERA farms as a function of external fodder rate (fodder imported from outside the farm as a % of total fodder used).

by 33% to 47 kg and decreases the difference between the ERA farms and the average conventional agriculture from 43 to 32 kg N ha^{-1}. A decrease of nitrogen fixation by 25% decreases the surplus by 33% to 24 kg N ha^{-1} and the difference from 43 to 55 kg N ha^{-1}.

The External Fodder Rate (EFR) and surplus of nitrogen per hectare per year for the three year period for the ERA farms is presented in Figure 7. Two farms, the dairy farm Skogsgård, which had the highest N surplus, and the pig farm Davidsta provide illustrative examples. During the study, the animal density increased for the dairy farm Skogsgård and with that also the average N-surplus The pig farm, Davidsta, evolved in the opposite direction during the study period decreasing both animal density and EFR, which resulted in a lower N-surplus (Figure 8).

That increased animal density increases the surplus of nitrogen is clear, as illustrated in Figures 6 and 8. This appears to be a direct result of the higher external input of fodder. The relation between animal density and surplus of nitrogen is also well established in studies of plant nutrient balances on conventional farms using methods similar to those used in this study. Studies of 608 conventional specialized dairy farms with an animal density ranging between 0.6 and 1.5 au ha^{-1} (Myrbeck, 1999), gave an average N-surplus of 131 kg ha^{-1}. On the ERA dairy farms with a lower animal density (average of 0.67 au ha^{-1} and a range from 0.5 to 0.8 au ha^{-1}) the average N-surplus was 43 kg ha^{-1}. Figure 9 illustrates the relation between animal density and nitrogen surplus. Lower surpluses are found on the low animal density ERA farms. Also lower surpluses were found on ERA farms than on conventional farms with the same animal density. Comparable Danish studies have produced similar results (Kristensen *et al.*, 2005).

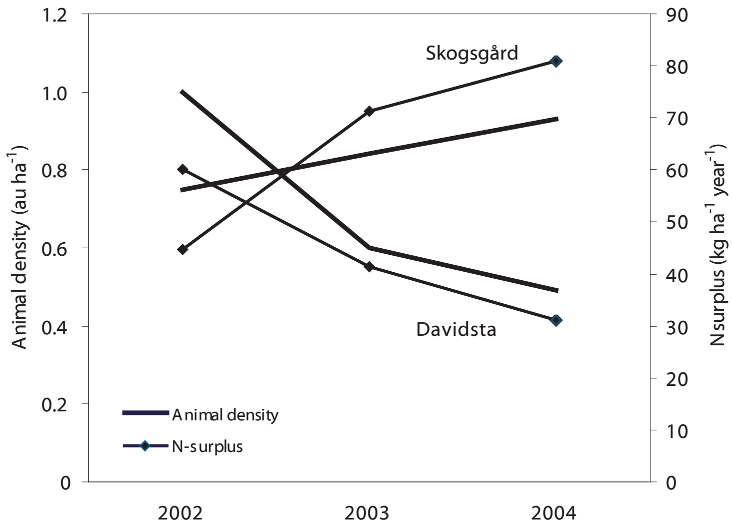

FIGURE 8. Surplus of nitrogen on two farms with different animal densities. The dairy farm Skogsgård is characterised by an increasing N-surplus, increasing animal density and increasing use of purchased fodder (EFR: 8%; 20%; 21%). The pig farm Davidsta is characterised by decreasing N surplus, decreasing animal density and decreasing use of purchased fodder (EFR: 24% b; 16%; 18%)

Field balance surplus in average Swedish agriculture and ERA farms

The ammonia losses from the average Swedish animal production farm were calculated to be 16 kg N ha^{-1} (Figure 2). Ammonia losses can be assumed to be the same on average Swedish farms and ERA farms since they both have the same animal density (0.6 au ha^{-1}) and similar techniques for manure management. The average field surplus on ERA farms, calculated as the difference between the farm gate balance surplus (36 kg N) and ammonia losses (16 kg N) was 20 kg N ha^{-1} compared with 63 kg N average for the whole of Swedish agriculture.

Nitrate leaching can be assumed to be equal to the nitrogen surplus minus ammonia losses, denitrification and net change in soil N status according to Dalgaard *et al.* (2006) and Kristensen *et al.* (2005). In this study no data was available on the denitrification of N and net changes in the soil N status on the ERA farms compared with the average Swedish agriculture. In some long term comparative field studies higher immobilization of nitrogen through increasing humus content in organic farming with recycling of organic manure and clover-grass ley in the crop rotation, than in conventional agriculture without use of organic manure has been documented (Pettersson, 1982; Pettersson *et*

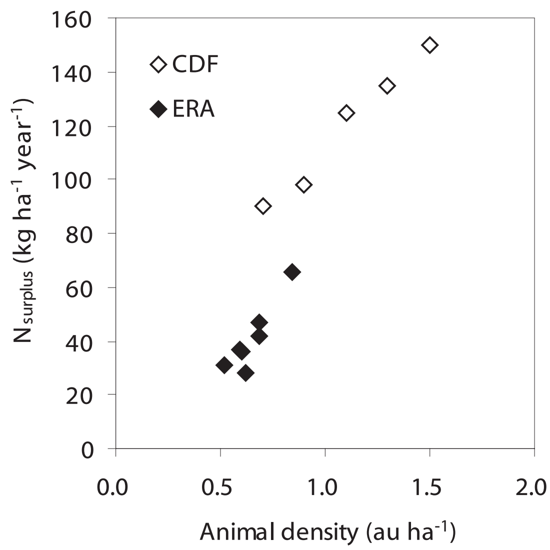

FIGURE 9. The eight ERA dairy farms (ERA) with a low animal density had an average 43 kg N surplus per ha, compared to an average of 131 kg N surplus per ha on 608 conventional dairy farms (CDF) grouped into five animal density clusters ((Myrbeck, 1999).

al., 1992, Hepperly *et al.*, 2006). The significance of grassland in crop rotation to build up the humus content in soil is also well documented in other studies (Jansson & Persson, 1982, Matsson, 2002).

ERA farms have a 30% higher share of grassland that is not ploughed annually than in average Swedish agriculture. If this is taken into consideration it is possible that the leaching of nitrogen from the studied ERA farms is even lower than the amount estimated from nutrient balances. There is a clear need to study this further and compare nutrient balance studies with experimental data (Payraudeau *et al.*, 2007; Salo & Turtola, 2006). Comparison of field leaching studies on different types of ERA and conventional agriculture can provide a basis for alternative scenarios on regional, watershed and country level.

DISCUSSION

The study of nitrogen and phosphorus surplus and flows through the farming system for the whole of Sweden indicates a decrease of nitrogen surplus by 11% and phosphorus surplus by 35% when the year 1995 (Granstedt, 2000) is compared with 2000, the year presented in this study. However, during this period there was a rapid expansion of ecological agriculture, from 53000 ha (2% of used arable land) in 1995 to 413 000 ha (18% of used arable land) in 2002, including both the market certified label KRAV and the ecological production controlled by the Swedish Board of Agriculture (SCB, 2003b). KRAV develops organic standards according the IFOAM standards, inspects to these standards and promotes the KRAV label in Sweden. KRAV is organized as an incorporated association with, at present, 28 members. They represent farmers, processors and traders as well as consumers, environmental and animal welfare interests. If this increase in ecological agriculture, with its lower levels of nitrogen and phosphorus surpluses, is taken into consideration then conventional agriculture has in fact had an increased surplus of nitrogen per hectare and a smaller decrease in the surplus of phosphorus. Despite the decreased surplus of phosphorus during the period 2000–2002, the leaching remains at about the same level. This can be explained by a further specialization with more crop production farms and an increasing animal density on the animal production farms, concentrating a higher surplus and further accumulation of phosphorus and nitrogen to certain areas. The accumulation of P that has been built up in the soil during many years continues here and can be assumed to be an increasing potential source of losses to the environment for a long time to come.

During the 15 years from 1990 to 2005 the number of animal production farms has decreased but total animal production has remained at the same level. This means that the number of animals on each farm has continued to increase. In1990 there was an average of 144 pigs per farm, in 1995 this had increased to 253 per farm; in 2000 to 278 per farm and in 2005 to 478 per farm (SCB, 2006). The same trend with more animals on fewer farms is similar for all types of animal production. These fewer farms with larger numbers of animals utilize the maximum animal density permitted in Sweden, which is regulated to a maximum of 22 kg P ha^{-1} in the manure spread on fields (Henriksson, 2007). This is about 100% more than the average utilization in crop production and based on the assumption that 50% of the phosphorus in fertilizer is immobilized and not available to the crop. The delivery of phosphorus from the soil pool is not taken into consideration in this assumption. The nutrient flows in the Swedish farming systems (Figure 2) show that about 80% of the average harvested nitrogen and phosphorus (79 and 82%, respectively) is used as fodder. This amount is being used on fewer and fewer farms that have the highest surplus of nutrients and the greatest potential for nutrient losses to the environment. The system error which has been documented in this and earlier studies (Granstedt, 2000) is constituted by what is, in principle, a 'linear', i.e. non-cyclic, flow of nutrient inputs into crop production, which is transformed, via fodder, into high surpluses of nutrients on farms with high animal density. This is amplified by today's trends of an increasing number of farms without livestock and the concentration of animal production to specific regions where there are a decreasing number of larger farms with more animals on each. The analysis of statistics from recent years and the calculations and analysis presented here show how this process of specialization and concentration is continuing despite earlier reports about the serious environmental consequences (Granstedt, 2000) as well as political initiatives to decrease the nutrient pollution from the agriculture sector (HELCOM, 2007). The regional concentration of animal production farms with high animal density and a high surplus of phosphorus has recently been documented for all the countries around the Baltic Sea (Henriksson, 2007). It is in these animal dense regions that the losses of phosphorus occur (Uusitalo & Jonsson, 2002; Uusitalo *et al.,* 2007).

The nitrogen surplus was lowest on ecological farms with low animal density (Figure 9) and especially on ERA grassland ruminant animal farms producing meat and cereals. The results presented in this study clearly indicate the relation between animal density, i.e. degree of self sufficiency in fodder, and nitrogen surplus on the same farm. Low external input of nutrients in fodder results in low surpluses and low potential nutrient losses. This study and Danish studies (Halberg *et al.*, 1995b; Kristensen *et al.*, 2005) show that the surplus of nitrogen can be lower on ecological farms than on conventional farms even with the same stocking rate. This can be explained by the fact that, because ecological farms do not use artificial fertilizer, the limiting production factor is nitrogen availability. This limits the yield level but also ensures a high rate of nitrogen utilization, which is not the case with conventional agriculture. This and earlier reported farm studies show that, on each farm or group of co-operating ERA farms, success depends on the effective utilization of nutrients, both in the manure, in the relation to the needs of different crops, as well as in the fodder, and on the manure being well distributed over the land area during the whole crop rotation. To develop such environmentally sound farming systems further, additional studies of ecological farms with a high degree of plant nutrient recycling are required. Steinshamn *et al.* (2004) have observed from their farm study in Norway that the conversion efficiency of the soil/crop component was high (90%) but that in all the other components there was potential for improvements.

Assuming that ERA principles are followed, it is possible to roughly predict the future regional characteristics of crop and animal production in Sweden and other countries around the Baltic Sea. These will include an ecologically sound, resource-conserving agricultural system with a balance between plant production and recycled animal manure. In such an agricultural system not every farm enterprise needs to produce both animal and plant products. For instance, forms of co-operation could be established between neighboring farms whose products complement one another. It is, however, necessary to achieve a local and regional balance between crop and animal production throughout Sweden and the other countries around the Baltic Sea.

CONCLUSIONS

Agriculture is responsible for a large share of the leaching of nutrients to watercourses (including groundwater), lakes and finally the sea. The 2nd HELCOM Stakeholder Conference plan of 2007, Towards a Baltic Sea Unaffected by Eutrophication, states that HELCOM assessments clearly show that problems with eutrophication exist in most of the sub-basins and that good environmental status has not been achieved.

Specialized agriculture with its separation of crop (in Europe about 80% of crop land is used for fodder production) and animal production results in an increased load of nitrogen and phosphorus from agriculture to the Baltic Sea. This restructuring of the agriculture sector took place throughout the Scandinavian countries after World War II and has resulted in farms with a high density of animals and great surpluses of plant nutrients, concentrated in certain regions. Examples from Sweden are presented in this paper. This trend of increasing concentration of animal production in Sweden is continuing and, if appropriate action is not taken, is likely to spread to new EU member countries within the Baltic Sea drainage area with the probable consequence of increasing nutrient loads.

Ecological Recycling Agriculture (ERA) is defined as an agriculture system based on local and renewable resources, which integrates animal and crop production on each farm or farms in close proximity. As a result a large part of the nutrient uptake in the fodder production is effectively recycled. This in effect means that each farm strives to be self-sufficient in fodder production, which in turn limits animal density and ensures a more even geographic distribution of animals. This study of 12 Swedish farms confirms earlier results that agriculture based on these principles of ecological recycling would lead to a decrease in the nitrogen leaching by half as well as a significant reduction in the loss of phosphorus.

Application of these agricultural principles throughout the Baltic region in all EU countries would result in the halving of nitrogen losses and minimizing losses of phosphorus. In this way the goals, set by the states of the region, which were presented in the introduction to this paper, could be met and the process leading to the worst case scenario could be stopped.

There is a need for further studies including field leaching studies on different types of ERA and conventional agriculture to analyze the relation between potential and real losses of nitrogen and phosphorus to better understand and further improve nutrient efficiency in ERA agriculture.

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APPENDIX 1

Characteristics of the BERAS farms.

No on map	Farm name, region, study period years	Arable land/ pasture (ha) Soil type	Utilized area 2003: Clover grass ley, other fodder crops, cash crops. Production level: milk, bread grain	Animals 2003
1	Per Larsas, Hälsingland 2002–2004	61/6 Clay-silt	36 ha ley 25 ha fodder crops Milk: 8000 ECM cow^{-1} Oats, barley: 3500 kg ha^{-1}	25 dairy cows 11 heifers 16 calves
2	Hånsta, Uppsala County 2003–2004	79/7 Silty loam	20 ha ley 54 ha fodder crops Winter wheat: 4300 kg ha^{-1}	6 mother cows with calf 5 young cows 8 mother sows 1000 hens
3	Oxsätra, Uppsala County 2003–2004	68 Silty loam – clay	22 ha ley 34 ha fodder grain 14 ha cash crops Winter wheat: 3800 kg ha^{-1}	5 mother cows with calves 23 bulls
4	Nibble, Stockholm County 2002–2004	89 Silty loam – clay	60 ha ley 14 ha fodder grain 11 ha bread grain Milk: 6500 ECM cow^{-1} Winter wheat: 3800 kg ha^{-1}	42 dairy cows 18 heifers 16 calves 2 horses 5 mother sheep 2 pigs
5	Skäve, Stockholm county 2002–2004	135 Silty loam – clay	69 ha ley 54 ha fodder grain 12 ha bread grain Milk: 7900 ECM cow^{-1} Winter wheat: 4000 kg ha^{-1}	47 dairy cows 20 heifers 18 calves 2 horses 5 mother sheep 2 pigs
6	Yttereneby-Skilleby, Stockholm county 2002–2004	135 Silty loam – clay	59 ha ley 56 ha fodder grain 20 ha bread grain Milk: 7000 ECM cow^{-1} Winter wheat: 4000 kg ha^{-1}	47 dairy cows 18 heifers 32 calves 2 horses 28 mother sheep
7	Håknäs, Stockholm county 2002–2004	58 Silty loam – clay	20 ha ley 23 ha fodder grain 9 ha bread grain Winter wheat: 4000 kg ha^{-1}	17 bulls

Appendix 1 continues overleaf

Appendix 1 continued

No on map	Farm name, region, study period years	Arable land/ pasture (ha) Soil type	Utilized area 2003: Clover grass ley, other fodder crops, cash crops. Production level: milk, bread grain	Animals 2003
7	Håknäs, Stockholm county 2002–2004	58 Silty loam – clay	20 ha ley 23 ha fodder grain 9 ha bread grain Winter wheat: 4000 kg ha^{-1}	17 bulls
8	Skillebyholm, Stockholm county 2002–2004	17 Silty loam – clay	6 ha ley 13 ha fodder grain 2 ha bread grain and root crops Milk: 5000 ECM cow^{-1} Winter wheat: 4000 kg ha^{-1}	7 dairy cows 2 heifers 3 calves 2 horses
9	Davidsta, Sörmland county 2002-2004	260/30 Silty loam – clay	108 ha ley-grass 98 ha fodder grain 54 ha bread grain and root crops Winter wheat: 3700 kg ha^{-1}	70 mother cows with calf 70 young cows 20 mother sheep 15 mother sows
10	Solmarka, Kalmar county 2002–2004	73 Sandy loam – silty loam	31 ha ley 29 ha fodder grain 1 ha bread grain 12 ha potatoes and root crops Milk: 5500 ECM cow^{-1} Winter wheat: 5000 kg ha^{-1}	36 dairy cows 8 heifers 22 calves
11	Sunnantorp, Skåne county 2002–2004	64 Silty loam – clay	43 ha ley and green fodder 21 ha fodder grain Milk: 6700 ECM cow^{-1} Winter wheat: 3800 kg ha^{-1}	31 dairy cows 7 heifers 20 calves
12	Skogsgård, Halland county 2002–2004	164 Sandy loam – silty loam	111 ha ley and green fodder 49 ha fodder grain Milk: 8000 CM cow^{-1} Winter wheat: 3800 kg ha^{-1}	110 dairy cows 25 heifers 66 calves 80 mother sheep

APPENDIX 2

Nutrient balances. Swedish BERAS farms 2002–2004.

No		au ha^{-1}	ha	Total input (kg ha^{-1} $year^{-1}$)	Purchased (kg ha^{-1} $year^{-1}$)	N-fix. and deposition (kg ha^{-1} $year^{-1}$)	Plant production (kg ha^{-1} $year^{-1}$)	Exported in milk (kg ha^{-1} $year^{-1}$)	Exported in meat (kg ha^{-1} $year^{-1}$)	Exported in crops (kg ha^{-1} $year^{-1}$)	Total export (kg ha^{-1} $year^{-1}$)	Surplus (kg ha^{-1} $year^{-1}$)	Efficiency export/ input
	Nitrogen												
1	Per Larsas	0.70	61	55	10	45	74	15	3	0	18	37	0.33
2	Hånsta	0.34	79	59	8	51	85	0	8	10	18	40	0.31
3	Oxsätra	0.16	68	31	10	22	71	0	5	15	20	11	0.65
4	Nibble	0.62	89	57	19	38	78	13	2	4	19	38	0.34
5	Skäve	0.52	135	61	3	58	79	11	3	11	25	36	0.48
6	Yttereneby	0.60	135	65	6	59	84	12	4	11	27	36	0.41
7	Håknäs	0.20	58	49	3	46	85	0	5	31	36	13	0.75
8	Skillebyholm	0.48	17	43	3	40	68	4	7	9	20	23	0.48
9	Davidsta	0.71	260	65	21	45	59	0	11	11	21	44	0.33
10	Solmarka	0.69	73	70	21	49	78	13	2	8	23	47	0.36
11	Sunnantorp	0.69	64	61	15	46	69	14	3	2	20	42	0.32
12	Skogsgård	0.84	164	94	28	65	94	22	6	0	28	66	0.30
	Mean	*0.55*	*100.3*	*59*	*12*	*47*	*76*	*9*	*5*	*9*	*23*	*36*	*0.42*
	Phosphorus												
1	Per Larsas	0.70	61	2	2		10	3	1	0	4	-2	> 1.00
2	Hånsta	0.34	79	3	3		8	0	1	2	3	0	0.96
3	Oxsätra	0.16	68	9	9		7	0	1	3	4	5	0.46
4	Nibble	0.62	89	5	5		8	3	1	2	6	-1	> 1.00
5	Skäve	0.52	135	1	1		9	2	1	3	6	-5	> 1.00
6	Yttereneby	0.60	135	2	2		9	2	1	1	5	-3	> 1.00
7	Håknäs	0.20	58	1	1		7	0	1	5	7	-6	> 1.00

Appendix 2 continues overleaf

Appendix 2 continued

No		au ha^{-1}	ha	Total input (kg ha^{-1} year^{-1})	Purchased (kg ha^{-1} year^{-1})	N-fix. and deposition (kg ha^{-1} year^{-1})	Plant production (kg ha^{-1} year^{-1})	Exported in milk (kg ha^{-1} year^{-1})	Exported in meat (kg ha^{-1} year^{-1})	Exported in crops (kg ha^{-1} year^{-1})	Total export (kg ha^{-1} year^{-1})	Surplus (kg ha^{-1} year^{-1})	Efficiency export/ input
8	Skillebyholm	0.48	17	1	1		8	1	2	2	4	-4	> 1.00
9	Davidsta	0.71	260	4	4		8	0	2	2	4	0	0.94
10	Solmarka	0.69	73	5	5		8	3	1	2	5	0	0.95
11	Sunnantorp	0.69	64	2	2		9	3	1	0	4	-2	> 1.00
12	Skogsgård	0.84	164	7	7		13	3	3	0	6	1	0.90
	Mean	*0.55*	*100.3*	*4*	*4*		*9*	*2*	*1*	*2*	*5*	*-1*	*> 1.00*
	Potassium												
1	Per Larsas	0.70	62	4	4		40	4	0	0	5	-1	> 1.00
2	Hånsta	0.34	79	3	3		49	0	1	3	4	-1	> 1.00
3	Oxsätra	0.16	68	0	0		57	0	0	4	4	-4	> 1.00
4	Nibble	0.62	89	19	19		28	4	0	3	7	12	0.39
5	Skäve	0.52	135	2	2		34	4	0	2	6	-4	> 1.00
6	Yttereneby	0.60	135	3	3		37	4	0	2	6	-3	> 1.00
7	Håknäs	0.20	58	2	2		19	0	0	16	16	-14	> 1.00
8	Skillebyholm	0.48	17	2	2		34	1	0	10	11	-9	> 1.00
9	Davidsta	0.71	260	7	7		42	0	1	6	7	0	0.99
10	Solmarka	0.69	73	25	25		40	4	0	8	12	13	0.49
11	Sunnantorp	0.69	64	11	11		37	4	0	1	5	6	0.49
12	Skogsgård	0.84	164	21	21		61	7	0	0	7	14	0.33
	Mean	*0.55*	*100.3*	*9*	*9*		*40*	*3*	*0*	*5*	*8*	*0*	*> 1.00*

APPENDIX 3

Definitions of Swedish animal units (AU).

Sweden[1]	Animals/AU
Dairy cows, also dry cows	1
Other cattle, > 6 months	3
Calves, 1–6 months	6
Sheep and goats, > 6 months	10
Lambs and kids < 6 months	40
Sows, incl. piglets < 12 weeks	3
Fattening pigs < 12 weeks and boars	10
Hatching hens and chicken mothers, > 16 weeks	100
Pullets, < 16 weeks	200
Broilers (slaughter weight)	200

[1]Jordbruksverket (Swedish Board of Agriculture) (1998). *Förordning om miljöfarlig verksamhet och hälsoskydd*. Jönköping, Sweden.