Reducing the Nitrogen Load to the Baltic Sea by Increasing the Efficiency of Recycling within the Agricultural System[1]

Experience of Ecological Agriculture in Sweden and Finland

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Abstract

Agreements to halve the quantities of nutrients reaching the marine environment by 1995 were entered into within the Helsinki Commission (base year 1987) and at the North Sea Conference/Paris Commission (base year 1985). This goal has not been achieved. Agriculture has contributed substantially to an increase in nutrient leaching. Studies of plant nutrient flows and balances at the farm level (different types of farms), county level and country level were made in Sweden for the years 1990 and 1995 and, to some extent, in Finland to explain the high losses of plant nutrients in agriculture today, and to describe how, with the technological resources available today plant nutrients could be handled more effectively and thereby minimizing losses of nitrogen and phosphorus to the environment. The results of the studies indicate that the local and regional specialization of farms is one important reason for the high losses of plant nutrients that are occurring: one type of farm specializes in crop production based on the use of artificial fertilizers, while another specializes in livestock production with large inputs of purchased fodder and a surplus of nutrients in the form of animal manure. The arable farm mainly produces fodder. This fodder and the nutrients it contains are exported to the intensive livestock farms, where a surplus of manure and urine, and hence of nutrients, accumulates, causing nutrient losses to the environment. By integrating crop and animal production on a farm or farms in closed cooperation it is possible to maximize the efficient use of nutrients in manure, minimize inputs of nutrients, minimize nutrient surpluses and, as a consequence, minimize losses of nitrogen and phosphorus. By applying these agricultural principles throughout the Baltic region it should be possible to halve nitrogen losses and minimize losses of phosphorus, thereby meeting the goals set by the states of the region.

Key words: Agro-ecosystem; Baltic Sea; Farming system; Nitrogen surplus; Nutrient balance; Nutrient leaching; Nutrient recycling efficiency; Organic farming; Ecological agriculture

Zusammenfassung

Verringerung der Stickstoffbelastung der Ostsee durch Erhöhung der Nährstoffeffizienz in der Landwirtschaft

Die Helsinki-Commission hatte bereits 1987 beschlossen, die Nährstoffeinträge in die Ostsee bis zum Jahre 1995 um die Hälfte zu reduzieren. Dieses Ziel wurde bei weitem nicht erreicht. Der Beitrag zeigt als wesentliche Ursache hierfür, am Beispiel von Untersuchungen in Schweden und Finnland, die Spezialisierung in der Landwirtschaft auf und beschreibt, wie mit konsequenter Umsetzung der Prinzipien der ökologischen Landwirtschaft Nährstoffkreisläufe geschlossen und Umweltbelastungen vermieden werden können.

Stichwörter: Agrar-Ökosysteme, N-Überschuss, Nährstoff-Bilanzen, Nährstoff-Auswaschung, Nährstoff-Effizienz, Ökologische Landwirtschaft

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Introduction

Agreements to halve the quantities of nutrients reaching the marine environment by 1995 were entered into within the Helsinki Commission (base year 1987) and at the North Sea Conference/Paris Commission (base year 1985). This goal has not been achieved. Agriculture has contributed substantially to an increase in nutrient leaching. Figure 1 describe inputs of fertilizer nitrogen, phosphorus and potassium (kg ha^{-1} yr^{-1}) and outputs of nitrogen, phosphorus and potassium (kg ha^{-1}) in the form of animal- and plant-based food products (a) in 1995 in Swedish agriculture and (b) in 1993 in Finnish agriculture. From 1950 to 1980, in Sweden and Finland, inputs of nitrogen, phosphorus and potassium in the form of inorganic fertilizers increased substantially in relation to their outputs in the form of agriculturally produced foodstuffs such as milk, meat and bread grain. Since 1980 the surplus of nitrogen and also imported nitrogen in fodder has remained at the same level and the surplus has not decreased.

Annual loads of nitrogen and phosphorus from the Baltic drainage area to the Baltic Sea in 1995 are estimated at 761 000 N and 37 500 P Mg (Mg=Tons), respectively (HELCOM, 1998). In Sweden it has been estimated that human activities account for 54 % of the annual input of nitrogen and 55 percent of the annual input of phosphorus to the Baltic Sea (Agriculture 48 %, Municipal sewage 34 %, Industry 9 %, Forestry 9 % of the anthropogenic losses).The ultimate aim is to create the knowledge base needed to develop a strategy for changing Baltic agricultural systems so that losses of nitrogen and phosphorus can be reduced by 50 % (first stage in a larger reduction) in the countries around the Baltic Sea. Studies of plant nutrient flows and balances at the farm level (different types of farms), county level and country level were made in Sweden for the years 1990 and 1995 and, to some extent, in Finland to explain the high losses of plant nutrients in agriculture today, and to describe how, with the technological resources available today plant nutrients could be handled more effectively and thereby minimizing losses of nitrogen and phosphorus to the environment (Granstedt, 1995a; 2000).

Methods

Several methods for quantifying and modeling plant nutrient flows have been developed earlier (Frissel, 1977; 1983; Kaffka, 1984, Biermann, 1995; Bleken et al., 1997). An NPK flow model developed by the author based on case studies made on individual conventional and organic farms (Granstedt, 1990, 1992a). These basic studies were combined with field studies for seven years (1981-1987) in which soil nitrogen mineralization, nutrient uptake in crops, harvested yield and recycling with crop residues, manure and urine on each field were combined with data on inputs in the form of fertilizers, nitrogen fixation, atmospheric pollution, imported fodder and the export of food products. Mean values over all years were used to calculate a total balance for the farm, in kg N per ha per year. Thereafter the model was simplified so that it predicted the flows of N, P, and K without field studies (Granstedt, 1995). This simplified model was based on statistical data from each farm or statistical data allowing the model to be used for a group of farms at the municipality, landscape or country levels. Such studies of NPK flows in Sweden were made in both 1990 (Granstedt, 1995) and 1995 (Granstedt, 2000).

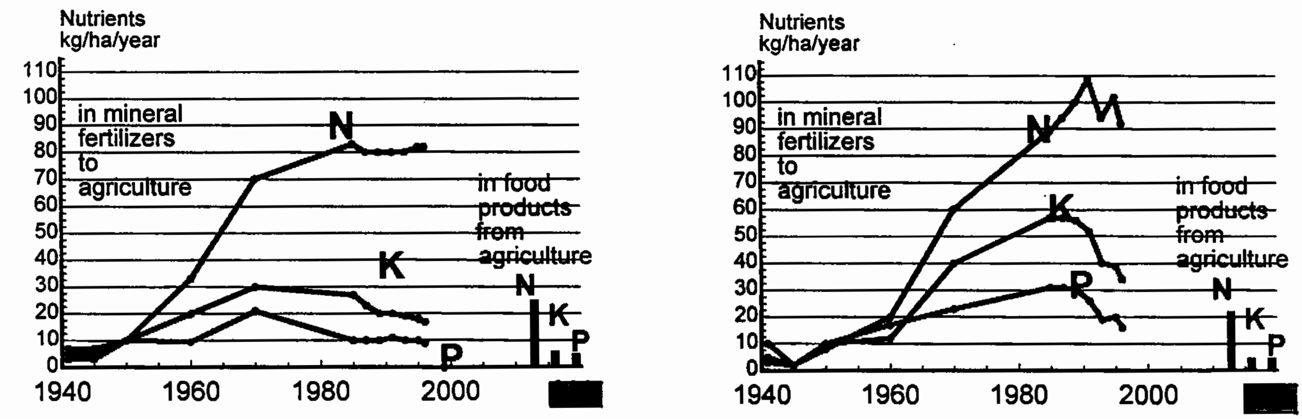

Fig. 1: Inputs of fertilizer nitrogen, phosphorus and potassium (kg ha^{-1} yr^{-1}) and outputs of nitrogen, phosphorus and potassium (kg ha^{-1}) in the form of animal- and plant-based food products (a) in 1995 in Swedish agriculture and (b) in 1993 in Finnish agriculture. Data for the period 1940–95 and 1940–93 for Sweden and Finland, respectively (Granstedt 2000).
Abb. 1: Zufuhr an Düngerstickstoff, -phosphorus und -kalium (in kg ha-1Jahr-1) in den Jahren 1940-1993 und Abfuhr an Stickstoff, Phosphor und Kalium (in kg ha-1Jahr-1) in Form von tierischen und pflanzlichen Produkten (a) in 1995 in der Landwirtschaft Schwedens und (b) in 1993 in der Landwirtschaft Finnlands

Results

Figure 1 describe inputs of fertilizer nitrogen, phosphorus and potassium (kg ha^{-1} yr^{-1}) and outputs of nitrogen, phosphorus and potassium (kg ha^{-1}) in the form of animal- and plant-based food products (a) in 1995 in Swedish agriculture and (b) in 1993 in Finnish agriculture based on data for the period 1940–95 and 1940–93 for Sweden and Finland, respectively. During the period 1950–89 more and more farms specialized in crop production in some regions and in animal production in others, and the use of the nutrients supplied has become less efficient.

The different management strategies on farm level was studied individually by performing analyses of the plant nutrient balances and flows between defined pools within agro-ecosystems at the farm level (Granstedt, 1995; 2000). Surplus of plant nutrients are lowest from farms that only produce cereals. This is exemplified in Table 1 with a farm in Skaraborg county with 0 a.u. (animal units)ha^{-1}. On the dairy farms number two in Table 1 with 0.75 a.u. ha^{-1} was the surplus higher and the farms number three with intensive pig production and number four, i.e., 2 a.u ha^{-1}, showed the largest surplus of plant nutrients, calculated as the difference between imported and exported amounts (Table 1). In the table one animal unit (a.u.) corresponds to one dairy cow, 2 young cows, 3 sows, 10 fattening pigs or 100 hens.

Surpluses/losses on the swine farm in 1990 (farm number three in Table 1) were assumed to be 166 kg nitrogen, 25 kg phosphorus, and 60 kg potassium per ha. The assumption that nitrogen losses were 166 kg or more was based on the assumption that no further net immobilization of nitrogen occurred during the humus formation process as a consequence of there being no ley and grassland on this type of farm. Today this farm must have access to an additional area (e.g., arable land on a nearby farm) on which it can spread the manure. Even for a representative dairy farm (farm number four in Table 1) in the dairy district of Skåne in 1997 (Sandgren, 1999), which sold some of its manure in compliance with Swedish regulations to limit the intensity of animal production and surplus of manure, estimated losses of nitrogen were very high (164 kg nitrogen per ha).

About 80 % of crop production on cereal farms consists of fodder for animals. The situation is about the same in Finland. Nutrients are supplied in the form of artificial fertilizers to cereal farms, where they are converted into feedstuffs that are supplied to animal producers, there they accumulate and are lost to a large extent (Granstedt, 2000). A comparison of nutrient surpluses in the agricultural system in 1995 with those occurring in 1990 in Sweden shows that the surplus of nitrogen increased, while the surplus of phosphorus decreased only a little.

There is great variation between counties in terms of the import of plant nutrients, plant nutrient contents of foodstuffs, and nutrient surpluses and losses. Table 2 shows the relations between the input and output of plant nutrients for three counties representing a low, average, and high intensity of animal production, respectively. Surplus and losses are normally relatively higher from the agricultural systems compared with from the community system (Municipal sewage). However, in counties where the ratio of agricultural area to inhabitants is lower, losses from the community system are higher.

A similar relationship between the intensity of animal production and high losses of nutrients in regions is docu-

Table 1: Supply, export and surplus of N, P and K (N/P/K) in kg $ha^{-1}year^{-1}$, for the whole of Sweden and for five described farm types in Sweden: cereal farm, combined dairy and cereal farm, pig farm, dairy farm and ecological farm (Granstedt 2000). In the table one animal unit (a.u.) corresponds to one dairy cow, 2 young cows, 3 sows, 10 fattening pigs or 100 hens
Tab.1: Zufuhr, Abfuhr und Überschuss an N, P und K /N/P/K) in kg ha-1Jahr-1 für Schweden insgesamt und fünf Betriebsformen in Schweden, Getreidebau, Getreidebau + Schweinehaltung, Getreidebau + Milchvieh, Schweinehaltung, Milchviehhaltung und ökologischen Landbau (Granstedt, 2000). Eine Grossvieheinheit (GV = animal unit, a.u.) entspricht einer Milchkuh, 2 Färsen, 3 Sauen, 10 Mastschweinen oder 100 Legehennen

	Supply to the farm					Total supply	Export from the system		Total export	Surplus
Farm type	a.u. ha^{-1}	Feed, seed	Biol. N-fix.	Deposition	Fertilizer		Crop pr.	Anim. pr.		
Swedish agriculture 1995	0.6	7/1/2	12	6	82	110/12/21	8/1/3	18/4/3	26/5/6	89/8/15
Cereal farm	0	2/0/1	7	15	97/24/20	121/24/20	102/17/25		102/17/25	19/7/-4
Comb. farm	0.75	15/6/19	17	15	91/5/0	140/11/20	27/5/7	26/6/7	53/11/14	87/0/6
Pig farm	2	137/43/68	4	15	103/0/0	259/43/68	6/1/1	87/17/7	93/18/8	166/25/60
Dairy farm	2	142/24/71	52	22	53/0/0	270/24/71		106/22/60	106/22/60	164/2/11
Ecol. farm[2)]	0.6	2/2/0	50	10		54/2/1	10/2/2	14/3/4	24/5/6	39/-3/-6

1) The same animal density (a.u. ha^{-1}) as the average for Sweden, but based on an integration of crop and animal production over the entire area of agricultural land. In ecological agriculture, larger proportions of fodder and animal production are based on leys (grass and clover) for ruminants than the average in Sweden.

Table 2: Supply, export and surplus of N, P and K, in kg $ha^{-1}yr^{-1}$, in three counties of Sweden with 0.2, 0.4 and 0.8 animal units ha^{-1} (Granstedt 2000)

Tab. 2: Zufuhr, Abfuhr und Überschuss an N, P und K /N/P/K) in kg $ha^{-1}Jahr^{-1}$ für Schweden insgesamt und fünf Betriebsformen in Schweden, Getreidebau, Getreidebau + Schweinehaltung, Getreidebau + Milchvieh, Schweinehaltung, Milchviehhaltung und ökologischen Landbau (Granstedt, 2000)

		Supply to the farm				Total	Export from the system		Total	Surplus
Farm type	a.u. ha^{-1}	Feed, seed	Biol. N-fix.	Deposition	Fertilizer	supply	Crop prod.	Anim. prod.	export	
Swedish agriculture 1995	0,6	7/1/2	12	6	82	110/12/21	8/1/3	18/4/3	26/5/6	89/8/15
Cereal farm	0	2/0/1	7	15	97/24/20	121/24/20	102/17/25		102/17/25	19/7/-4
Comb. farm	0.75	15/6/19	17	15	91/5/0	140/11/20	27/5/7	26/6/7	53/11/14	87/0/6
Pig farm	2	137/43/68	4	15	103/0/0	259/43/68	6/1/1	87/17/7	93/18/8	166/25/60
Dairy farm	2	142/24/71	52	22	53/0/0	270/24/71		106/22/60	106/22/60	164/2/11
Ecol.farm 1)	0.6	2/2/0	50	10		54/2/1	10/2/2	14/3/4	24/5/6	39/-3/-6

1) The same animal density (animal units, a.u. ha-1) as the average for Sweden, but based on an integration of crop and animal production over the entire area of agricultural land. In ecological agriculture, larger proportions of fodder and animal production are based on leys (grass and clover) for ruminants than the average in Sweden.

mented from Finland, other Nordic countries (Rekolainen and Leek, 1996) and other countries of Europe (Werner and Wodsak, 1995, Brower and Hellegers, 1997). For example, owing to the intensity of crop production and the concentration of livestock, the surplus of nitrogen is significantly higher (120-150 kg ha^{-1}) in the north of Germany than in the rest of that country (Kleinhanss et al., 1997).

The farm number five in Table 1 is a biodynamic farm, which has not used artificial fertilizers or chemical pesticides since 1967 (Granstedt, 1992a). This farm is representative of farms in the central part of Sweden, with clay loam, fairly dry climatic conditions for Sweden (annual average precipitation 550 mm and yearly average temperature 6^{o} C), and a standard yield about the same as the average for Sweden. The case study shows that through recycling and the use of leguminous plants it is possible to successfully run a farm that is self-sufficient in terms of plant nutrients and minimize the losses of plant nutrients. Nitrogen flows on the farm (at the soil, crop, field and whole-farm levels) were studied by the author over a seven-year period between 1981 and 1987 (Granstedt, 1990; 1992a). Production, calculated in plant nutrients in bread grain and animal products from this farm, is comparable to the Swedish average, but total losses of nitrogen are about half as high as the average in Sweden.

This type of management requires that the level of animal production on a given farm be adjusted on the basis of 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. Due to the good balance between animal husbandry and plant production (0.6 a.u/ha is optimum in this part of Sweden) the net outflow of plant nutrients is so low that it can be compensated for through weathering, small inputs of fodder and nitrogen fixation by leguminous ley crops (Granstedt, 1992b). In studies done in Finland by the author similar results were obtained for Finnish conditions (Granstedt, 1996; 1999).

Oomen et al. (1998) have described the benefits of mixed farming in the Netherlands, compared with traditional agriculture, illustrated by the favorable nitrogen balances of two designed prototypes where arable, dairy and sheep farming are integrated to a high degree.

Discussion

The results of the described studies indicate that the local and regional specialization of farms is one important reason for the high losses of plant nutrients that are occur-

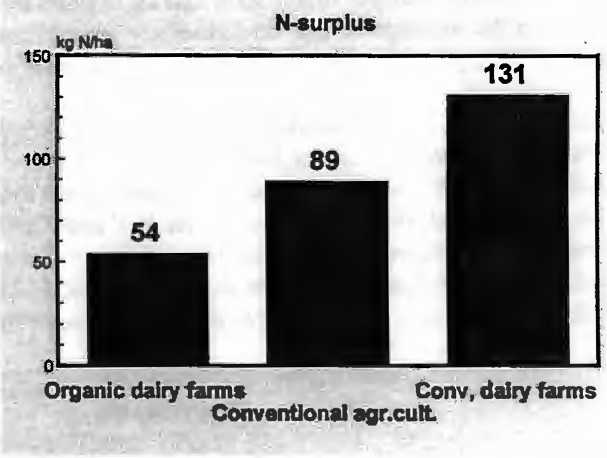

Fig.2: Surplus of nitrogen in kg $ha^{-1}yr^{-1}$ on organic dairy farms with 0.74 a.u./ha (average of 41 farms), conventional farms in Sweden with 0.6 a.u./ha (average of about 88 000 farms) and conventional dairy farms (average of 557 farms). Revised from Myrbeck 1999 and Granstedt 200O

Abb.2: Stickstoffüberschüsse (in kg $ha^{-1}Jahr^{-1}$) auf ökologisch wirtschaftenden Milchviehbetrieben (0,74 GV/ha), konventionell wirtschaftenden Betrieben (0,6 GV/ha) und konventionellen Milchviehbetrieben mit 1 GV/ha.

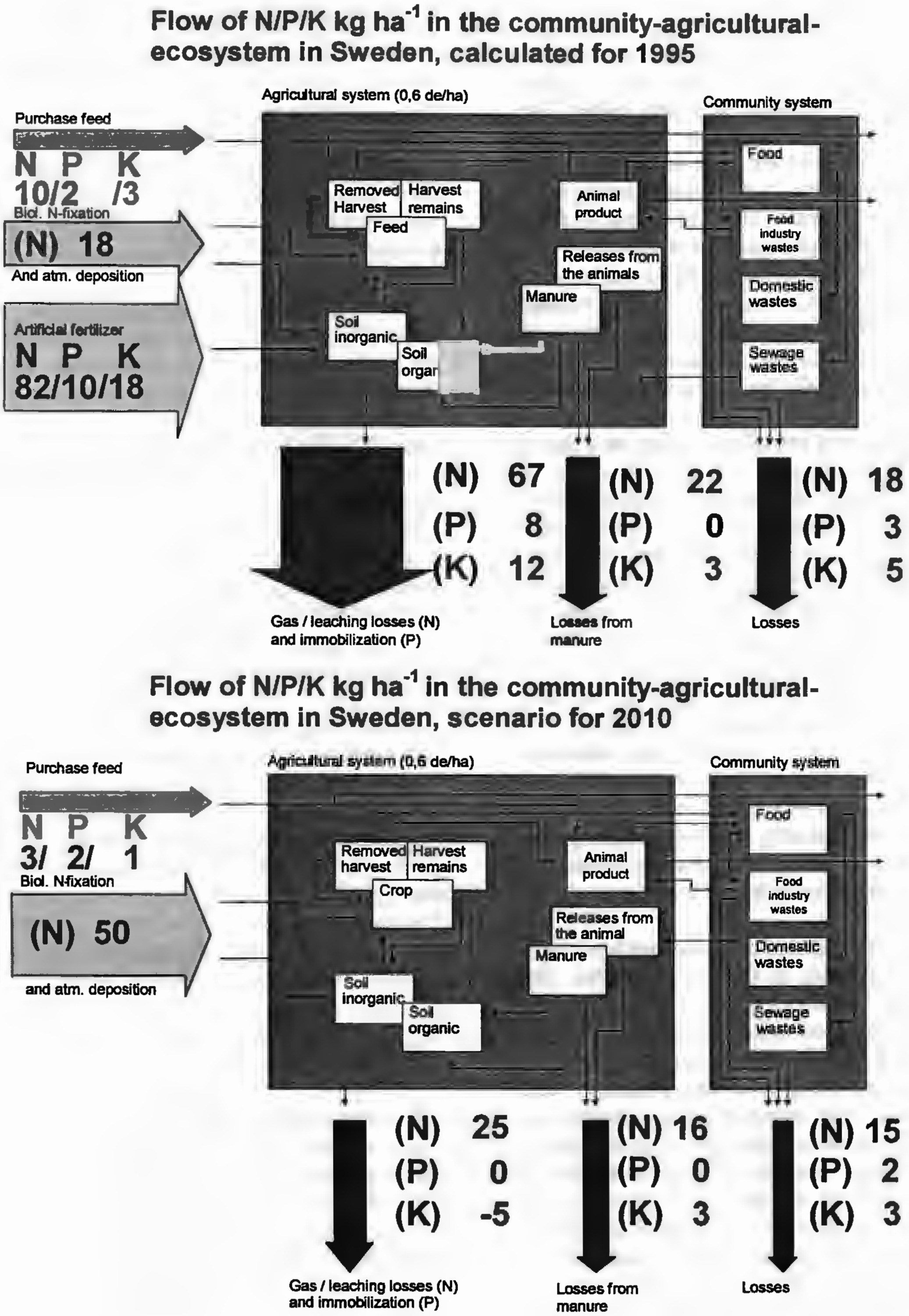

Fig. 3: Plant nutrient (N, P and K) flows, in kg ha^{-1}yr^{-1}, on arable land in the Swedish community-agricultural ecosystem in 1995 and in a scenario for 2010 with halved losses of nitrogen resulting from increased integration of crop and animal production. (Granstedt 2000)

Abb. 3: N- P- und K-Flüsse (in kg ha^{-1}Jahr^{-1}) in schwedischen Ackerbaubetrieben in 1995 und in einem Szenario mit halbierten N-Austrägen für 2010 (Granstedt 2000) ring: one type of farm specializes in crop production based on the use of artificial fertilizers, while another specializes in livestock production with large inputs of purchased fodder and a surplus of nutrients in the form of animal manure. The arable farm mainly produces fodder. This fodder and the nutrients it contains are exported to the intensive livestock farms, where a surplus of manure and urine, and hence of nutrients, accumulates, causing nutrient losses to the environment. These two types of farms are concentrated in different regions of the country.

An additional reason for the large surplus and losses of plant nutrients is that farms with a high intensity of animal production also import artificial fertilizers, rather than making efficient use of their own animal manure. Nutrient management should also take the total nitrogen content of manure into account.

By integrating crop and animal production on a farm it is possible to maximize the efficient use of nutrients in manure, minimize inputs of nutrients, minimize nutrient surpluses and, as a consequence, minimize losses of nitrogen and phosphorus. To minimize the surplus and the losses of nutrients *from* the agricultural system, the input of nutrients *to* the system needs to be reduced. Increasing recycling within the system can achieve this. This is exemplified in on the biodynamic farm in Table 1.

In organic farming we find good examples of recycling and integration of crop and animal production. True organic farming with effective recycling also minimizes the need for non-renewable energy, by means of biological nitrogen fixation. But I should also emphasize that this resource must be used carefully, with for example proper timing and techniques for green manuring (Granstedt, 1995b) and ploughing/terminating of ley (Granstedt and L-Baeckström, 2000).

In recent years, plant nutrient balances have been introduced in advisory services to farmers in Sweden. The largest study so far of nutrient balances in Sweden (and also I think in the Nordic countries), which involved 1300 farms, also included 41 organic dairy farms. In this study, surpluses of nitrogen, phosphorus and potassium were positively correlated with increased animal density, but with considerable variation within the farming systems studied. The 41 organic dairy farms in the study had on average a better nitrogen utilization efficiency than the 557 conventional dairy farms (i.e. nitrogen in products in relation to the input). For a correct comparison between farming systems, animal density must be taken into account. A diagram (Figure 3) showing results from this study compared to own data. The nitrogen surplus for the 41 organic farms was on average 39 % lower than the average for Sweden, in spite of the fact that the animal density on these farms was higher than the average. Again, when animal and crop production are integrated, it is possible to have a higher recycling efficiency, a lower need for inputs and a lower surplus. In my experience, this has hitherto proved to be the case on most organic farms.

In the conventional system, with specialization in crop production or intensive animal production, in which fodder has to be purchased, the nutrients in manure cannot be recycled to the soil from which they originate. Specialized crop production needs more artificial fertilizers and specialized animal production has too large a surplus, resulting in excessive losses. In addition, many conventional dairy farms buy both fodder *and* artificial fertilizers, increasing the surplus, which is the reason for the large average surplus for the 557 conventional dairy farms in the figure.

Studies of nitrogen leaching which compare organic and conventional systems under representative and comparable Nordic conditions have been carried out in Norway (Korsäth and Eltun, 2000). N runoff from the systems was in the range of 18–35 kg N ha^{-1} yr^{-1}, with the highest losses from the two conventional systems and the lowest from the two ecological systems and the integrated farming system.

By integrating crop and animal production it is possible to achieve effective utilization of the plant nutrients in manure, minimize the input of nutrients in the form of artificial fertilizers, minimize the surplus of nutrients and, as a consequence, minimize losses of nitrogen and phosphorus for whole Sweden (Fig. 3) and also in other countries.

In a recycling-based agricultural system not every 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 would also be desirable to increase the extent to which plant nutrients exported from the agricultural system to the community are returned to the farms. This recycling should also include quality tested wastes from the food industry. Special restrictions with animal and crop production must also be accepted in the coastal regions.

Conclusions

To achieve high levels of production and recycling efficiency, a good balance is required between the intensity of animal production and crop production hectarage at the local, regional and national levels. On each farm or within each group of cooperating farms, it is essential that nutrients in manure be effectively utilized in relation to the needs of the different crops in the crop rotation over the entire area of agricultural land on the farm or farms concerned.

By applying these agricultural principles, combined with other known methods of minimizing nutrient losses from soil, crops and manure, throughout the Baltic region it should be possible to halve nitrogen losses and minimize losses of phosphorus, thereby meeting the goals set by the states of the region, presented in the introduction to this paper.

What is clear is that more studies are needed, especially at the farm level, to develop means of achieving optimum implementation of efficient recycling-based agriculture under different climatic and soil conditions, in Sweden, in the other countries of the Baltic region and in the rest of Europe, where there are similar problems to be solved.

Another question is how to adopt new strategies for farming systems within the current economic and social structure of agriculture in countries with an established agricultural structure involving a different type of agricultural specialization, or in other countries like Poland, which to some extent have an older agricultural structure that has yet to undergo major change. Today, according to the latest statistics from HELCOM (1998), nutrient losses in Poland are much lower per hectare than in Sweden, for example, but owing to the large area of farmland they are nevertheless very important for the environment of the southern Baltic Sea. Also in the other countries of the Baltic region which are restructuring their agriculture after becoming independent of the former Soviet economy, it is important to learn from the unfavourable lessons of Sweden and Finland, with the specialization of crop production described here, which has resulted in increased demand for and inputs of plant nutrients to crop production and an increased surplus in specialized livestock production.

Proposals for the future strategies to minimize the high surplus and losses of nitrogen and phosphorus from the agriculture

Take into consideration the conclusion that the local and regional specialization of farms in crop and animal production is one important reason for the large surpluses and losses of plant nutrients.

Support studies to develop means of achieving optimum implementation of efficient recycling-based agriculture (farms or groups of closely cooperating farms with integrated crop and animal production) under different climatic, soil and retention conditions in the countries of the Baltic region. Estimates of plant nutrient balances, recycling analysis, should be combined with field studies to measure actual losses of nutrients. There is also a need for social and economic analysis of the consequences of a larger-scale conversion process.

Recommend the member states in HELCOM to develop a strategy for efficient recycling and utilization of plant nutrients in animal manure, so as to decrease the inputs and surpluses of nutrients which are currently causing losses to surface waters, coastal waters and the open sea. This strategy must include integration of crop and animal production on local and regional level, taking into account the results of the presented studies.

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