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ENVIRONMENTAL IMPACTS OF ECO-LOCAL FOOD SYSTEMS

– final report from BERAS Work Package 2

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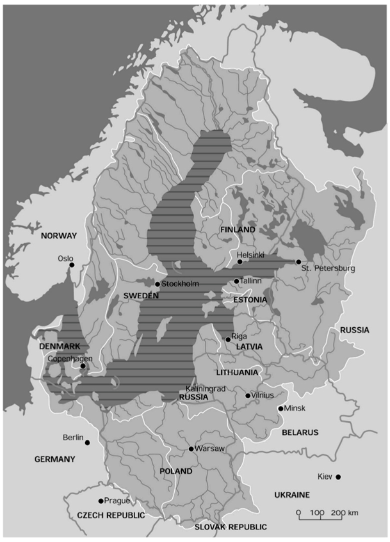

Baltic Ecological Recycling Agriculture and Society (BERAS) Nr. 5

Baltic Sea Region INTERREG III B

Centrum för uthålligt lantbruk

NITROGEN AND PHOSPHORUS LEAKAGE IN ECOLOGICAL RECYCLING AGRICULTURE

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Organic farming is often considered as one solution to reduce eutrophication of the Baltic Sea. However, the efficiency of organic agriculture in reducing nutrient leakage from primary food production to the aquatic environment is still questioned. The most crucial part of organic agriculture for reducing nutrient leakage is nutrient management in the crop rotation.

Nutrient balance studies showed that ecological recycling agriculture (ERA) had lower nutrient surplus and thus, lower potential of leakage (this report and Granstedt and others, 2004). However, direct measurements of nutrient leakage in ecological agriculture are scarce. Bergström and Kirchmann, 2000 reviewed the available literature on nitrogen leakage in organic agriculture and concluded that organic agriculture seems to have lower nitrogen leaching per hectare than conventional systems but differences were small and they were sensitive for small changes in either production system. The nitrogen leakage per mass of produced crops was higher in organic agriculture. They summarized, that nitrogen leakage is more a question of nitrogen management, e.g. crops and crop rotation, than of production system. They believed that a decrease of nitrogen leakage can be achieved by optimizing the conventional system. However, Bergström and Kirchmann, 2000 did not consider differences of different organic systems. ERA is a nutrient extensive system based on an animal density adjusted to the own fodder production on each farm unit, which has a potential of low N-leakage (Granstedt and others, 2004).

In this report we quantify nitrogen and phosphorus leakage on three ERA farms in the BERAS project. The study is based on direct measurements of nitrogen and phosphorus concentration in drainage water and water flow measurements. The results are compared with calculated standard leakage as reported to the HELCOM PLC-4 report (Brandt and Ejhed, 2002, HELCOM, 2004).

Methods

Physical settings of the test fields

The test sites in Sweden are located at Skilleby farm in Järna, 50 km south of Stockholm, and on Solmarka farm, 20 km south of Kalmar (Figure 4-1 and Figure 2-3). Both Skilleby and Solmarka farm are managed according to the biodynamic farming practice since the 1960:s and 1970:s, respectively. The five-year crop rotation consists of three years of ley followed by winter cereals and spring cereals with insown clover grass. Skilleby farm is managed by the nearby Yttereneby farm and the animal density corresponds to 0.6 au/ha. Solmarka has its own cows and cattle and an animal density of 0.7 au/ha.

The Finnish test site is located in Juva 270 km north of Helsinki (Figure 4-1 and Figure 2-3). Organic farming practices have been applied since 1985. The six year mixed crop rotation consists of one year of spring cereal and grass seeds, two years of grassland followed by winter cereal, green manure, and spring cereal. Approximately 30 t/ha cattle sludge is spread continuously on the 1st year plot which equals about 0.3 au/ha for the whole crop rotation per year. Harvested grain yields as net yields amounted to about 2 t DM/ha and grass yields to about 6 t DM/ha.

The physical characteristics of the test fields are summarized in (Table 4-1). For more background information on the three test site farms see Seppanen (2004) and Granstedt et al. (2004).

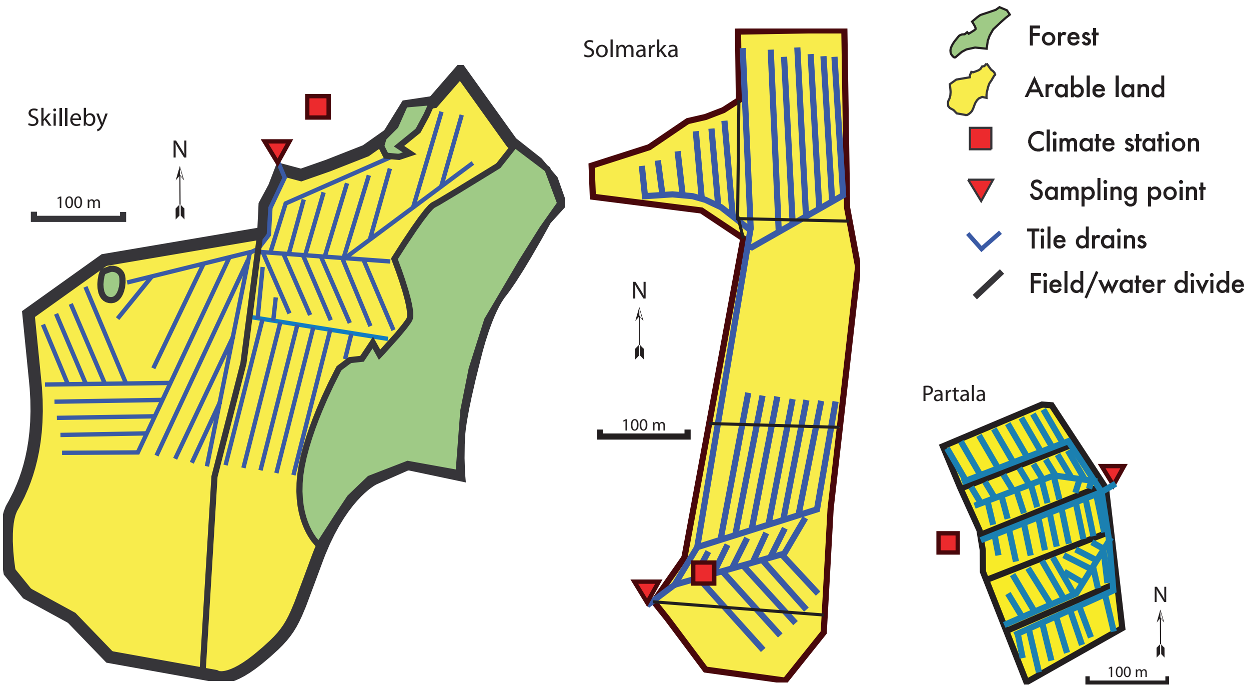

Figure 4-1. Map of investigation fields in Skilleby (6), Solmarka (10) and Partala (14) with sampling site, drainage area and drainage system. Number in brackets according to location map (Figure 2-3). Farm characteristics are shown in Table 4-1.

Table 4-1. Characteristics of test fields at Skilleby, Solmarka and Partala farm.

	Skilleby farm	**Solmarka farm**	**Partala farm**
Available data	030701–050630	040701–050630	01/2005–04/2005
Soil type	Clay	Sandy loam–silty loam	Moraine
Mean air temperature (°C)	6.6	7,3	4[1]
Mean precipitation (mm/a)	518	566	620[2]
Total drainage area (ha)	22.7	11.0	4.87

[1] Juva 1997–2003.
[2] Mikkeli 1997–2004.

Data sampling

Skilleby farm. Water samples were sampled manually every second week at the outlet of a drainage pipe from the test field. The samples were analysed on N-and P-concentration in accredited laboratories. Nutrient concentration was interpolated linearly between two sampling events. Water stage was measured continuously at a V-notch thin plate weir (90°) by a pressure transducer. Stage values were transformed into discharge data by applying standard hydraulic equations (e.g. Shaw, 1993). The product of daily mean values of water discharge and interpolated nutrient concentration data yielded nutrient load from the test site.

Air temperature and precipitation were measured continuously by an automatic climate station located in the test field.

Solmarka farm. The drainage period at Solmarka is shorter than at Skilleby due to more permeable soils and dryer climate. Thus water samples were taken more often than at Skilleby. During the drainage period samples were taken every week at the outlet of a drainage pipe from the text field. The samples were analysed on N-and P-concentration according to accredited methods. Nutrient concentration was interpolated linearly between two sampling events. Water discharge was measured directly during the sampling events by means of a calibrated bucket and was interpolated linearly between sampling events. Discharge data was multiplied with measured nutrient concentration to obtain nutrient load. Air temperature and precipitation were measured continuously by an automatic climate station located in the test field.

Partala farm. The test field at Partala consists of five plots with five of six crops in an entire crop rotation cycle. The drainage water from the plots is directed to a V-notch weir where water stage is measured continuously with a pressure transducer. Water samples were taken manually in proportion to water flow (once a day to once a week). The water samples were analysed for both total and soluble nitrogen and phosphorus, total solids, pH and conductivity. Nutrient concentration will be interpolated linearly between two sampling events. An automatic climate station located nearby the test field measured air temperature continuously and precipitation is measured manually every day. However, measurements at Partala started in April 2005, thus, no results on nutrient leakage are available yet.

Comparison with TRK

The obtained results at Skilleby and Solmarka on annual nutrient leakage were compared with official Swedish leakage data published as the TRK-report (Brandt and Ejhed, 2002) and reported to the Helcom pollution load compilation (HELCOM, 2004).

The TRK data was based on modelling nitrogen leakage with the SOIL-N (Johnsson and others, 1987) and HBV-N model (Arheimer and Brandt, 1998). The models simulate nitrogen leakage depending on soil type and crops. The TRK-dataset was normalized for long-term climatic fluctuations. In order to obtain comparable values of nutrient leakage, the standard values for the test fields were calculated from the standard leakage data in the TRK area 22 (Solmarka) and 60 (Skilleby) as presented in Table 4 in the TRK-report (Brandt and Ejhed, 2002). The standard nitrogen leakage was calculated for soil type and grown crops.

Standard phosphorus leakage, P_L, (kg km²/year) was calculated according to Brandt and Ejhed (2002) and Ulén et al. (2001) by the following equation:

$$P_L = (-0.0803 + 0.1 * LD + 0.003 * S + 0.0025 * P_{HCl}) * Q, \quad (1)$$

$$\text{where } S = (8.0 * x_{clay} + 2.2 * x_{silt} + 0.3 * x_{sand}) * \rho * 0.001 \quad (2)$$

LD	Livestock density (livestock unit ha^{-1})
S	Soil specific area ($m^2\ m^{-3}\ 10^{-6}$)
P_{HCl}	HCl extractable phosphorus (mg/100 g dry soil)
ρ	Bulk density of soil = 1250 kg m^{-3}
x_{clay}	Clay fraction in top soil (0–30 cm), < 2 μm
x_{silt}	Silt fraction in top soil (0–30 cm), 2 mm – 60 μm
x_{sand}	Sand fraction in top soil (0–30 cm), 60 mm – 200 μm
Q	Runoff (mm)

Table 4-2. Nitrogen leakage at Skilleby calculated from standard leakage defined in TRK report (Brandt and Ejhed, 2002). N_{TRK}-standard leakage depending on soiltype, crops and climate zone according to TRK. $N_{TRK\text{-}Skilleby}$ is calculated as the product of N_{TRK} and the share of the respective soiltype and crop.

	Area ha	Share	Soiltype	Crops	N_{TRK} kg/ha year	$N_{TRK\text{-}Skilleby}$ kg/ha year
2003	8,08	35%	Clay	Oats	12	4.2
	9,73	43%	Clay	Ley	2	0.9
	5,07	22%		Forest	1	0.2
	22.9					**5.3**
2004	8,08	35%	Clay	Ley	2	0.7
	9,73	43%	Clay	Winterwheat	10	4.3
	5,07	22%		Forest	1	0.2
	22.9					**5.2**

Table 4-3. Nitrogen leakage at Solmarka calculated from standard leakage defined in TRK report (Brandt and Ejhed, 2002). N_{TRK}-standard leakage depending on soiltype, crops and climate zone according to TRK. $N_{TRK\text{-}Solmarka}$ is calculated as the product of N_{TRK} and the share of the respective soiltype and crop.

	Area ha	Share	Soiltype	Crops	N_{TRK} kg/ha year	$N_{TRK\text{-}Solmarka}$ kg/ha year
2004	0,93	8%	Sandy loam	Ley	6	0,5
	7,47	68%	Silty loam	Ley	3	2,0
	0,74	7%	Silty loam	Potatoes	31	2,1
	0,74	7%	Silty loam	Winter wheat	24	1,6
	0,37	3%	Silty loam	Broccoli	27	0,9
	0,75	7%	Silty loam	Oats	30	2,0
	11. 0				**9.2**	

Table 4-4. Input data from Skilleby farm to calculate phosphorus leakage according to TRK (Brandt and Ejhed, 2002). P_{forest} *is standard leakage for forest, other parameters are defined in the text.*

Parameter		Units	References
Area	22.6	ha	
Forest	20%		
Arable land	80%		
LD	0.6	LU/ha	Granstedt and others, 2004
S	5.93	10^{-6} m^2/m^3	
P_{HCL}	55	mg/100 g dry soil	SBFI, 2002
ρ	1250	kg/m^3	Ulén and others, 2001
x_{clay}	0.43		Granstedt, 1990
x_{silt}	0.57		Granstedt, 1990
x_{sand}	0.24		Granstedt, 1990
$Q_{2003/04}$	121	mm	
$Q_{2004/05}$	185	mm	
P_{forest}	0.045	kg/ha a	Ulén and others, 2001

Table 4-5. Input data from Solmarka farm to calculate phosphorus leakage according to TRK (Brandt and Ejhed, 2002). All parameters are defined in the text.

Parameter		Units	References
Area	11.0	ha	
LD	0.7	LU/ha	Granstedt and others, 2004
S	3.13	10^{-6} m^2/m^3	
P_{HCL}	50	mg/100 g dry soil	Eriksson, 1997
ρ	1250	kg/m^3	Ulén and others, 2001
x_{clay}	0.15		Bernhard, 2005
x_{silt}	0.55		Bernhard, 2005
x_{sand}	0.30		Bernhard, 2005
$Q_{2003/04}$	163	mm	

Results and discussion

Standard leakage – TRK

Nitrogen leakage from the test fields calculated according to the method described in the TRK-report (Brandt and Ejhed, 2002) was 5.3 kg/ha year in Skilleby and 9.2 kg/ha year in Solmarka (Table 4-2 and 4-3).

Standard phosphorus leakage was calculated according to equation (1) to 0.13 kg/ha year in Skilleby and to 0.14 kg/ha year in Solmarka. Input data are summarized in Table 4-4 and 4-5.

Climatic and hydrologic conditions

Measured precipitation is often lower than real precipitation because of losses due to evaporation from the rain gauge and due to wind effects. Results from discharge and precipitation measurements were compared with official data from the Swedish Meteorological and Hydrological Institute (SMHI). Precipitation at Skilleby was ~20 % lower and runoff was ~30 % lower than at the surrounding SMHI stations (Table 4-6). The difference in precipitation fits into the general precipitation pattern. However, the difference in runoff might have been caused by measuring errors e.g. ice damming in winter and during the spring flood event or leakage of water besides the gauging station. Accordingly, measured runoff was assumed to underestimate real runoff by 10 %.

Differences were larger at Solmarka. Runoff at Ljungbyån was three times as large as at Solmarka whereas precipitation was similar to that at the SMHI station. The lower runoff at Solmarka is most probably an underestimation of real runoff due to the lack of continuous measurements and difficulties of measuring high discharges at the outlet of the drain pipe. Additionally, there is only one year of data available. More data is needed to draw reasonable conclusions. All results from Solmarka are based on corrected runoff, where measured runoff was multiplied by 3.3 according to the relationship between runoff at Solmarka and runoff at Ljungbyån (Table 4-6).

The regions of Skilleby and Solmarka had similar climatic conditions during the normal period of the TRK project (Precipitation, P = 650 mm, Mean air temperature, T = 7°C) (Johnsson and Mårtens-

Table 4-6. Runoff and precipitation for the period 030701–040630 at Skilleby and Solmarka and at different gauging stations from the Swedish Meteorological and Hydrological Institute (SMHI). The SMHI stations are located ~16 km from the investigation sites. Coordinates are given in local Swedish Grid (RT90, 2.5g W).

Location		Runoff (mm)	Location		Precipitation (mm)
Skilleby	6548195 N 1602410 E	110	Skilleby	6548195 N 1602410 E	495
Trosaån	6554410 N 1589910 E	165	Gnesta	6553550 N 1586690 E	634
Saxbroån	6556690 N 1614570 E	172	Södertälje	6563670 N 1603480 E	634
Solmarka	6270230 N 1520380 E	50	Solmarka	6270230 N 1520380 E	566
Ljungbyån	6285510 N 1520430 E	163	Kalmar	6283560 N 1529660 E	587

son, 2002). Compared to the investigation period in the BERAS project, the Skilleby region had similar conditions (Södertälje: P = 634 mm, T = 6.8°C). The Solmarka region, however, was dryer (Solmarka: P = 566, T = 7.3°C). Thus, the climatic influence on nutrient leakage is similar at Skilleby during both the TRK period and the BERAS investigation period which implies that differences in nutrient leakage solely depend on crops and the production system. At Solmarka, however, lower precipitation might cause lower nutrient leakage than during the TRK period.

Measured leakage from ERA

Water discharge, nitrogen and phosphorus concentration are shown in Figure 4-3 and 4-3. Discharge follows the usual pattern with flood events in fall and during the snow melt in spring and low discharge during summer. This results in high variability of nutrient load where large amounts can be leached during some few flood events. The difference between nutrient concentration in summer 2003 and 2004 at Skilleby

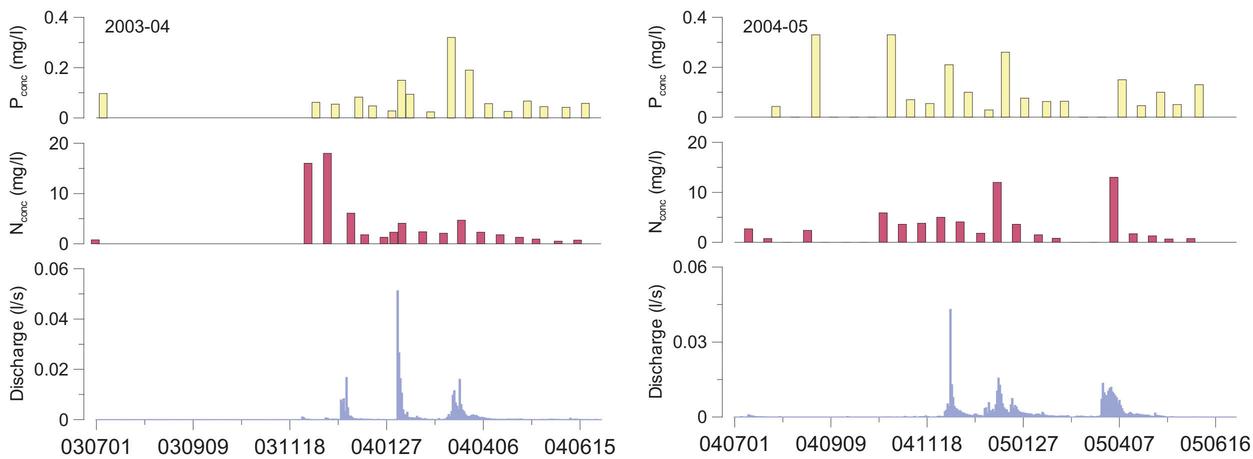

Figure 4-2. Discharge, nitrogen and phosphorus concentration, Skilleby 2003–2005.

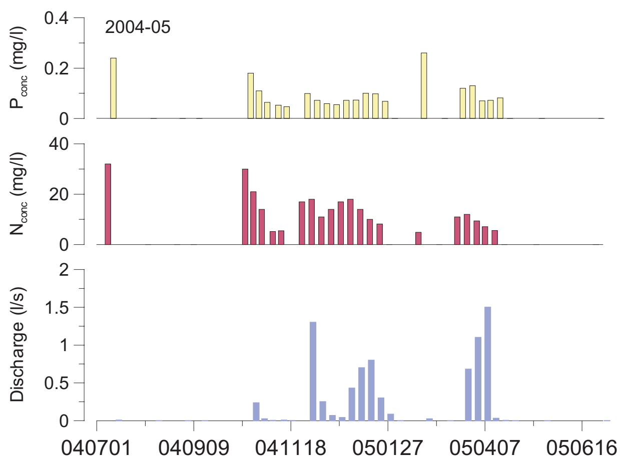

Figure 4-3. Discharge, nitrogen and phosphorus concentration, Solmarka 2004–2005.

were due to dry conditions in 2003, where no samples were taken. However, nutrient load is not affected significantly as discharge is low during summer.

Annual nutrient load is summarized in Table 4-7. In Skilleby, nitrogen leakage in 2003/04 was of the same magnitude as standard leakage for this area in the TRK project, but for 2004/05 it was the double. Nitrogen load differs significantly between the two years, whereas differences in phosphorus leakage were smaller. The large N-leakage 2004/05 most probably can be explained by releasing fixed nitrogen due to ley ploughing of half of the drainage area and spreading of manure on the same area during fall 2004. Further analyses and measurements are necessary to study whether mineralization of organically fixed nitrogen in the manure can produce enough movable nitrogen during such a short time. Even in Solmarka a large part of the field area was grassland which was ploughed in fall 2004 causing large nitrogen pulses. However, results from Solmarka are uncertain due to difficulties in discharge measurements.

It is always difficult to draw conclusions about general nutrient leakage from a two year data series in a five-year crop rotation system. Nevertheless, we can try to generalise our two-year-results to a larger scale. The test fields at Skilleby farm consist of two lots, on which ley was ploughed in 2004 on one lot and in 2005 on the other one. In a five-year crop rotation on two fields there are two years of ley-ploughing and three years of non-ley-ploughing. Assuming, the 2003/04 results being representative for a non-ley-ploughing season (N_{nlp}) and the 2004/05 results for a ley-ploughing season (N_{lp}), mean nitrogen leakage (N_{mean}) can be estimated as:

$$N_{mean} = \frac{2 * N_{nlp} + 3 * N_{lp}}{5} \qquad (3)$$

Table 4-7. Nitrogen and phosphorus leakage at Skilleby and Solmarka in comparison with the standard leakage according to the TRK-project (Brandt and Ejhed, 2002). N_{TRK} was calculated according to data shown in Table 4-2 and Table 4-3. P_{TRK} was calculated according to Equation 1.

	N kg/ha year	N_{TRK} kg/ha year	P kg/ha year	P_{TRK} kg/ha year
Skilleby 2003/04	5.7	5.3	0.18	0.14
Skilleby 2004/05	11.8	5.2	0.25	0.22
Solmarka 2004/05	21.6[1]	9.2[1]	0.14[1]	0.19[1]

[1] Results are based on corrected runoff, see text for more details.

By applying this relationship, mean nitrogen leakage from the test fields at Skilleby farm was calculated to 8.14 kg/ha N.

The TRK results are calculated for respective area with its characteristic climate, soiltypes and livestock density. In the TRK area 60 (Skilleby) livestock density is 0.2 – 0.4 au/ha (Granstedt 2000) whereas Skilleby farm has a livestock density of 0.6 au/ha. Nutrient surplus is strongly depending on livestock density. As shown earlier in this report (see Chapter 2) nitrogen surplus can be decreased by 40 % by halving livestock density. The ERA farm produces ~40 % more nitrogen leakage than farms with a 50 % lower livestock density in the same area. Taking livestock density into account nitrogen leakage from ERA is of the same magnitude as the calculated standard leakage in the respective TRK area.

In the TRK area 22 (Solmarka) mean livestock density is 0.8-1 au/ha. Solmarka farm has a livestock density of 0.7 au/ha and a nitrogen leakage twice the leakage calculated in the TRK project. This is similar to the results at Skilleby during the ley-ploughing season. However, the data are limited and crop rotation is more complicated at Solmarka with several fields and crops than at Skilleby. More data is needed to draw reliable conclusions.

Phosphorus leakage from ERA is ~0.2 kg/ha year which confirms the calculated P leakage in the TRK project. The calculation of phosphorus in the TRK project depends mainly on livestock density (see Equation 1).

Comparison with nutrient balances

Mean nitrogen surplus of 36 BERAS farms was calculated in chapter 2 to 36 kg/ha year. With ammonium losses of 30 % respective 40 %, the theoretical nitrogen leakage from the ERA farms in the project were 11 respective 7 kg N/ha year, assuming that leakage and denitrification in the soil contribute with equal parts (see Figure 2-12). In addition, Skilleby farm has a livestock density of 0.6 au/ha which is similar to the mean of all BERAS farms. Mean leakage at Skilleby was calculated above to ≈8 kg/ha year. These results are, thus, in good agreement with results from the nutrient balances.

Phosphorus surplus for all BERAS farms was calculated in Chapter 2 to -1 kg/ha year. Together with a measured leakage of 0.2 kg/ha year this indicates a constant loss of phosphorus from the fields, which most probably is fed by weathering of bedrock material in the soil matrix.

Conclusions

Within the BERAS project direct measurements of nitrogen and phosphorus leakage from fields were carried out on two ERA farms in Sweden and one in Finland. The data series which is available contains two years of measurements on Skilleby farm (Stockholm County). The data series from Solmarka farm (Kalmar County) and from the Finnish test farm in Partala were too short and are not reported here. The results from the measurements from Skilleby farm lead to the following conclusions:

- Nitrogen and phosphorus leakage from the ERA farm in Stockholm County were 8 kg N/ha year and 0.2 kg P/ha year, respectively with an assumed runoff. These results are in good agreement with the official nutrient leakage calculated in the TRK project for the same area, when taking into account differences in livestock density.
- The measured nitrogen leakage supports the results from the nutrient balances in the previous chapter of this report, where nitrogen leakage is 7–10 kg/ha year depending on the magnitude of ammoniac losses.
- The measured phosphorus leakage together with the deficit in the nutrient balances indicate a constant loss of phosphorus from the soil which most probably is fed by weathering of bedrock material in the soil matrix.

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