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Swedish long-term experimental sites for studying nutrient losses, nutrient turnover and model developments

Flygfoto över Lanna försöksgård år 2000

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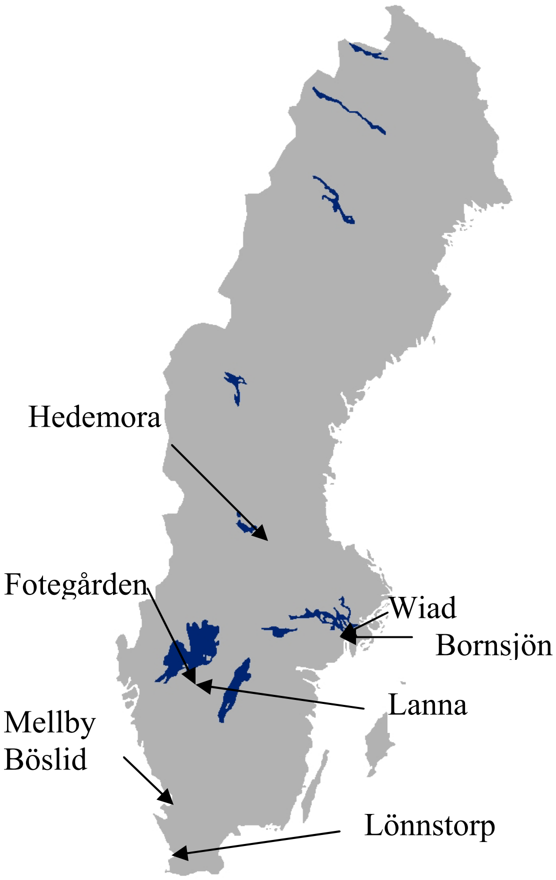
Background

The long-term experimental sites provide an irreplaceable resource for evaluating biogeochemical, environmental and biological dimensions of agricultural sustainability in conjunction with process studies for validating model performance and for predicting future changes. The long-term field experiments can identify management practices capable of maintaining crop yield and soil quality. They make up a temporal and spatial database for determining the impact of ecosystem changes. In addition to the original purposes of defining the immediate effects of crop management on yield, several unforeseen functions, such as trends in atmospheric deposition, may be derived in the future. In addition, archived soil samples permit estimates of changes in soil concentrations of hazardous substances and compounds that may be analysed with new techniques in the future.



Hedemora. Phosphorus, nitrogen and erosion via surface runoff from this silty soil have been monitored in different tillage systems.

Wiad is situated on a silty clay loam in Central Sweden. Factors such as application of solid manure and production of perennial ley have been studied.

Bornsjön. This is a new site specially designed to study phosphorus losses to the Baltic Sea from a marine clay soil.

Lanna. This clay soil carries long-term experiments focusing on phosphorus and nitrogen losses to drainage waters from both conventional and organic systems.

Fotegården. The studies on this sandy soil form an important complement to the findings from the Mellby site.

Mellby. Leaching studies from this sandy soil at Laholm Bay, which is exposed to high precipitation, started in 1984. The studies have focused on the impact of catch crops and slurry incorporation on nutrient leaching in both conventional and organic farming systems.

Böslid. This is a more loamy sand than at Mellby and without iron mottles in the soil profile.

Lönnstorp. This soil is a loamy soil in the most southern part of Sweden and experiments are focused on more locally important crops, e.g. sugar beat.

Figure 1. Geographical distribution of Swedish sites with experimental plots used for leaching and nutrient turnover studies.

Table 1. *International soil classification, vegetation, hardiness zone (H) and average concentrations in drainage water (mg l^{-1}) of total nitrogen (TotN), nitrate nitrogen (NO_3N), total phosphorus (TotP) and dissolved reactive phosphorus (DRP)*

Site	Soil classification	Vegetation zone	H	TotN	NO_3N	TotP	DRP
Hedemora	Silt loam	Southern boreal	5	2.8	2.3	0.35	0.02
Wiad**	Silty clay loam	Boreo-nemoral	6	6.1	5.5	0.15	0.05
Bornsjön	Slay	Boreo-nemoral	6	2.8	2.1	0.14	0.03
Lanna	Silty clay loam	Boreo-nemoral	7	3.8	2.8	0.10	0.04
Fotegården	Sandy clay loam	Boreo-nemoral	7	10	8.6	0.015	0.003
Böslid	Sandy loam	Nemoral	7	6.8	5.6	0.011	0.005
Mellby	Sandy loam	Nemoral	7	10	9	0.10	0.05
Lönnstorp	Sandy loamy	Boreo-nemoral	7	12	11	0.02	0.01

Losses of nutrients, pesticides and other constituents from arable soil in Sweden are complex functions of climate, topography, soil type and land management. The long-term experimental sites used for studies of leaching, nutrient turnover and other environmental effects are spread over the country (Figure 1). They represent different types of soils, vegetation zones and levels of nutrient concentrations in the drainage water (Table 1).

The Swedish agricultural areas belong to the cold climate temperate zone, semi-humid in the south-west and dryer in the rest of the country. There are usually several freeze-thaw events during the winter. Both temperature and precipitation differ between the experimental sites, as does the amount of drainage water (Table 2). The sites also represent a range of soil textures, soil physical and soil chemical conditions (Appendix 1).

The network of experimental sites has successively been established in step with available funding. The main sources of such funding have been:

SJB The National Board of Agriculture; SJFR/FORMAS Swedish Council of Forestry and Agriculture Research; FLAMM Foundation of Oscar and Lili Lamm, SEPA Swedish Environment Protection Agency; SLF Swedish Farmers' Research Council; MISTRA Environmental Strategic Funding; SLU University resources; RTK Stockholm County Council

Table 2. *Average temperature and precipitation at the sites during winter (November-April) and summer (May-October) for 1961-1990. The 'Drainage' column shows average water flow through the drainage system for the sub-period specified*

Site	Temperature (^oC)		Precipitation (mm)		Drainage (mm)	
	Winter	Summer	Winter	Summer	Yearly	Period
Hedemora	-2.3	+11.7	204	352	-*	1992-2004
Wiad	-0.5	+12.7	252	333	170	1999-2004
Bornsjön	-0.4	+12.7	245	329	220	1992-2005
Lanna	-0.2	+12.3	217	343	310**	1997-2003
Fotegården	-0.4	+12.2	228	327	150	1993-2002
Böslid	+1.4	+13.1	357	446	500[##]	2003-2004
Mellby	+1.4	+13.1	357	446	370[#]	1997-2003
Lönnstorp	+2.1	+13.7	305	349	200	1993-2000

*Only surface runoff; **Plots 1-26; [#]Average of the 4 sub-sites (plots 1-9, 10-23, 24-37, 38-50); [##]Potato production and irrigation

The funding is primarily national, and up to now the end-users have mainly been national. However, the farming industries and authorities have now asked for results for direct use. In addition to the results from the experimental plots being adapted for farmers and environmental advisors, they are also being used to develop risk indices and models. In addition to publishing the results in national reports research of a more fundamental nature has been carried out at the sites and reported in international publications. Several soils of the long-term experiments are included in the European soil database HYPRES (Hydraulic PRoperties of European Soils) used for standardising the hydraulic properties of soil profiles. The clay soil at Lanna has also been used for international tests of pesticide leaching and the characteristics of this soil are described in reports from the Nordic Council of Ministers.

In addition to the current sites, we are finding it necessary to extend the long-term experiments. Several national reports (The Sea Commission; SEPA statements of environmental targets) point out the need to study measures to combat phosphorus losses from arable land. This was also the conclusion from the international expert evaluation *The Eutrophication of the Seas Surrounding Sweden* in 2005. An experimental area with 30 drained plots will be constructed in the coming season (2006) on a marine clay soil south of Stockholm, where there are serious problems with high phosphorus losses.

GENERAL METHODS

The experimental sites are particularly designed for measurements of leaching losses. Measurements are mostly made in experimental plots, which are independently tile-drained for individual measurements of water flow and quality. In order to evaluate nutrient flows in crops and mineral N flows in the soil, nutrients in harvested products and in growing crops and ammonia emissions are also made (Figure 2).

Water flow measurements, water sampling and water analysis
In most cases the drainage or surface water flows are measured by tilting vessels connected to a data logger (CR10 or CR10X from Campbell Scientific). Runoff is usually stored as daily values (mm per day) or in some cases as hourly values. Data stored in the logger are retrieved monthly. Most of the sites are equipped for flow proportional water sampling, controlled by

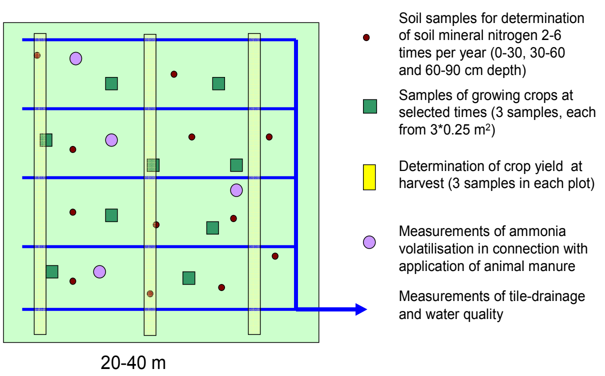


Figure 2. Sampling procedures in field leaching experiments.

the data logger. The samples are taken as bulk samples during a time of 2 weeks, or as individual samples using ISCO samplers. All sampling equipment and water bottles are stored cool and in darkness at the measuring station before transport to the laboratory. The water samples are analysed in accordance with EU Standards and, in addition, according to the Swedish Board for Accreditation and Conformity Assessment.

Mineral nitrogen in soil profile
Soil samples for determination of soil mineral nitrogen are taken from 2-3 up to 5-6 times per year depending on the type of study, the crop grown and the financial situation. Basic time points for sampling are: early spring (April), yellow ripeness in cereals (or comparable) and late autumn (October-November). The soil profile is typically divided into three layers: 0-30 cm, 30-60 cm and 60-90 cm depth. Eight to sixteen sub-samples, depending on soil and sampling equipment, are taken from each layer and pooled for that layer. Samples are stored deep-frozen (-20˚C) before analysis. For nitrogen analyses, 100 g thawed moist soil is extracted with 250 ml 2 M KCl. The extract is analysed for NO_3-N and NH_4-N, and the values are converted to kg per ha by using measured (or estimated) bulk density and actual gravimetric water content.

Harvested products
The amounts of harvested products and their content of nutrients are measured by conventional experimental methods. On the rather large plots (>= 900 m^2), the measurements are usually repeated three times on each plot. However, on smaller plots or when funding is lacking, only one measurement is made on each plot. Each measurement covers an area of 20-30 m^2. In most cases both grain and straw in cereals are measured and sampled (one from each measurement) for analysis of total N, P, K, and (mostly on straw) total-C. To get a better overview of the total aboveground N uptake in the crop, stubble and weeds (or undersown crop) are often sampled after harvest (see below). If sampling is followed by incorporation, the C content is also analysed.

Nutrient content in growing crops
Winter crops are sampled in late autumn and/or in early spring to determine N uptake in aboveground plant parts. Catch crops, green manure, leys and weeds are sampled just before incorporation to estimate C and N content in incorporated aboveground crop material.
Nine sub-samples (0.25 m^2 each) are cut near the soil surface and pooled into three replicate samples per plot. In plots used particularly for phosphorus studies, P content may be measured in living and dead material before the winter period.

Production in green manure leys
The green manure leys are cut 2-3 times during summer and early autumn and all crop material is left on the soil surface. At each time, the growth and N content of the growing green manure are measured in the same way as for harvested leys i.e. by three replicate measurements and samples per plot. Samples are mostly analysed only for N, except for the last measurement before incorporation, when the C content is also analysed. Sometimes P and K have also been analysed for specific purposes.

Ammonia emission after manure application
On several of the experimental fields liquid poultry or cattle manure is applied at different times and under different soil surface conditions. These occasions have often been used to obtain information about ammonia emissions in a cost-effective way. The emissions are measured by the PDS (Passive Diffusion Sampler) method (Svensson, 1993).

Net nitrogen mineralization under field conditions

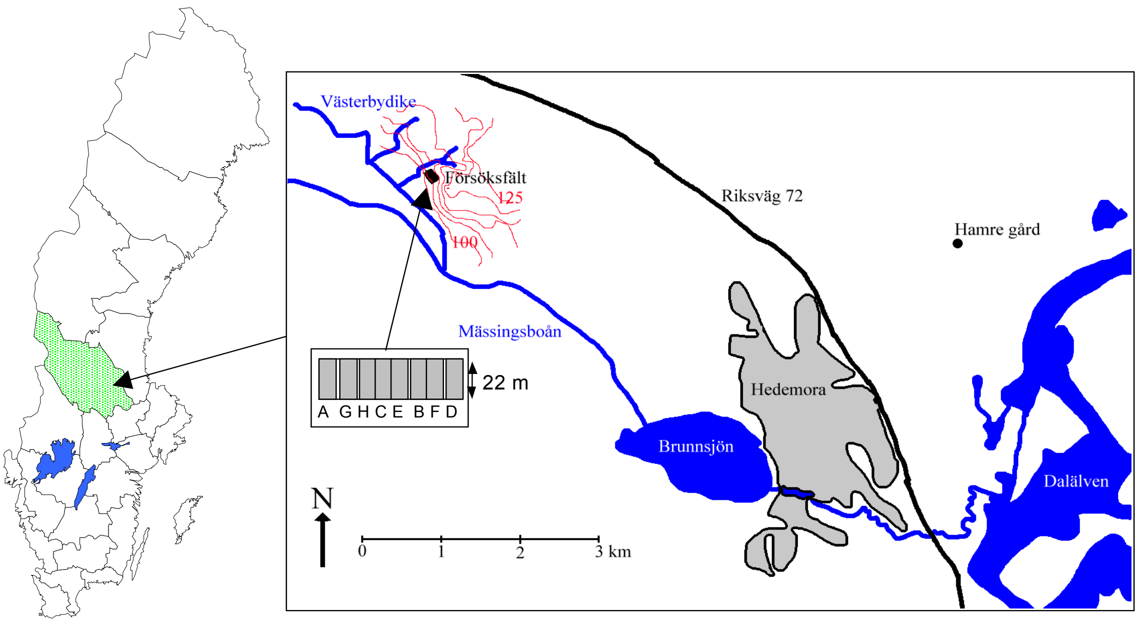
The net contribution of mineral N from organic soil material to crop uptake and leaching is estimated on some of the sites. This is done by establishing small unfertilised (no N fertiliser) plots inside the main plots. On these plots the N uptake in the crop, net change in soil mineral N and leaching (measured leaching from the main plot) are used to estimate the net release of N during different time periods of the year. These periods are generally early spring to yellow ripeness; yellow ripeness to late autumn; and late autumn to early spring the next year.

EXPERIMENTAL SITES

HEDEMORA

General

The experimental site (60°N, 16°E) is situated on a slope near the town of Hedemora (Figure 3). The soil is an *Eutric Regosol Typic Udordent* (FAO-UNESCO, 1998). An *Ochrich* A-horizon overlies deeper horizons. The soil is silty and has a low resistance to erosion, due to poor cohesive forces between the soil particles, and to friction. In addition, the soil has a low soil organic matter content and surface erosion may be visible as rills.



A	Conventional autumn ploughing
C	No tilling, except disc harrowing, autumn
E	Deep cultivation 3 times each autumn
H	Extra organic material added to the soil, no till
G	Ley/winter wheat and autumn tilling
B	Conventional spring ploughing
F	Conventional spring ploughing and catch crops
D	Direct sowing, spring

Figure 3. Long-term experimental plots at Hedemora.

Experimental plots

Surface runoff plots (22 m long, 10% slope) with 8 different treatments (Figure 3) were established in 1992. The soil in the different plots was demonstrated to have very comparable texture, aggregate stability and P concentration before the experiment started. The same agricultural treatments were repeated each year. The experiment was a principle design without replicates. Gerlach vessels were carefully interred into the soil every autumn. The amounts of surface runoff have been quantified by tilting vessels placed in measuring wells. Runoff water from the plots was collected manually from the Gerlach vessels and analysed for nitrogen, phosphorus fractions and erosion.

Completed projects (*source/s* of funding; number of plots in brackets)

1992-1997 Soil tillage impact on crop production, nitrogen utilisation and risk of nutrient losses (*SFL, SJB;* 8 plots).
1992-1997 Surface runoff of nutrients from a silty soil in the south of the county Dalecarlia (*SJB and local finance sources;* 8 plots).
1998-2001 Linking a hydrological river-basin model and field-scale models for phosphorus transport (*SEPA;* 8 plots).
2001-2004 Changed erosion during repeated tilling and cropping managements. (*SLF;* 8 plots).

WIAD

General

The experimental site Wiad is situated south-west of the town Södertälje, south of Stockholm. The soil is medium clay with a relatively high concentration of organic matter. Water infiltration is slower than at the Lanna experimental station (see below) and the soil has much less tendency to form cracks than at the Bornsjön site.

Experimental plots

The plot experiment was installed in 1977. It covers eight separately drained plots (0.33 ha). The field is sloping (Figure 4) and inlets conduct surface water together with tile-drain water to the measuring station. Water flow is measured by tilting vessels and mechanical counters. Water is sampled manually.

Completed projects (*source/s* of funding; number of plots in brackets)

1977-1981 Nutrient leaching after slurry application in autumn and spring (*SLU;* 8 plots).
1982-1986 Nutrient leaching and turnover after different time points for ploughing a ley (*SLU;* 8 plots).

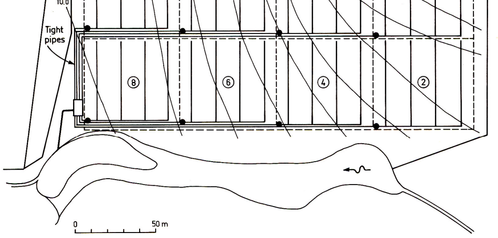


Figure 4. Experimental plots at Wiad.

1988-1991 Nutrient leaching and turnover from organic production without livestock (*SJFR;* 8 plots).
1997-2000 Nutrient leaching and turnover after autumn/spring application of solid manure (*SJB;* 8 plots).
2002-2004 Nutrient leaching and nutrient turnover after early and late autumn and spring application of solid manure (*SLU+RTK;* 8 plots).

Ongoing project

2006- Leaching of phosphorus and nitrogen from soils taken out of production. Unfertilised ley will be compared to cereal production with fertilisation and ploughing in order to better estimate a background level of P losses for models and environmental plans.

BORNSJÖN

General

The new experimental site (co-ordinates 1607 304 12; 6570 037 67) is situated 30 km south of Stockholm and 20 m above sea level in a flat landscape class 1 according to FAO-UNESCO (1988). The soil is classified as a *Eutric Cambisol* according to the same classification system. At a depth of 0.22 cm there is a distinct boundary between the topsoil and the grey horizon underneath. Under the second horizon at 0.43 m the soil is olive grey under moist conditions and there are streaks of gley. Large aggregates with clear sharp-edged prismatic structures have been observed at a profile depth of 0.2-1 m. Several coarse as well as fine macropores are often observed at a depth of 0.43-1 m. The soil profile has a similar appearance over the entire area, with a solid layer at a depth of approximately 85 cm. Above this level there are oxidised ferric mottles but without divalent ferrous ions in soil. The general ability of the soil to sorb dissolved orthophosphate based on concentrations of iron and aluminium extracted in acid lactate is typical for the region. The soil texture, with a high clay content, has a small spatial variation in both topsoil and subsoil. In addition, pH and soil concentrations of phosphorus are evenly distributed over the future experimental area that will be completed in 2006. The nutrient status of the soil meets the recommendations of the Swedish Board of Agriculture and soil physical characteristics such as bulk density and porosity are typical for Swedish soils. Soil compaction is evident in the form of a plough pan layer and there is poor hydraulic conductivity in this layer. Such compaction is often found and alters the soil hydrology, with impacts for P losses from soil.

Experimental plots

The tile drained experimental plots will be relatively small, since water flow to the depth of the drains is good. In order to adapt the plots to farm machinery, the plot dimensions will be 30 m x 20 m, surrounded by grassed headlands (Figure 5). The water flows to a measuring station and will be recorded with tilting vessels and data loggers. The loggers can control the proportion of flow sampled by means of small tube-pumps. Daily precipitation, temperature, wind speed, global radiation and relative humidity have been measured at a meteorological station at the experimental site since 1988.

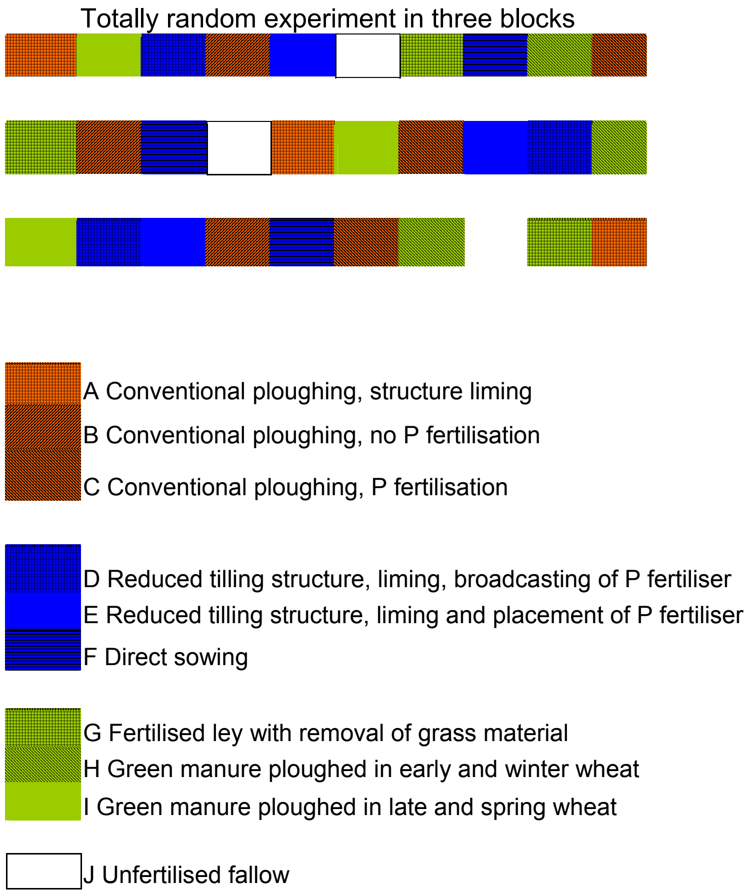


Figure 5. Proposed experimental design at Bornsjön.

LANNA

General

Lanna experimental station (58°21'N, 13°08'E) is situated in south-west Sweden on the largest agricultural plain in the country (Västgöta plain). The soil is classified as an *Uderic Haploboroll* (USDA) with two diagnostic horizons: a *Mollic epipedon* and a *Cambic horizon*. The clay content increases with depth, from an average of 47% at 0-30 cm to 61% in the 60-100 cm layer. Daily precipitation and temperature is measured at a meteorological station at the experimental site. The site slope is less than 1%, and therefore surface runoff is negligible. The tile-drainage flow normally occurs from November to April.

Experimental plots

All plots used for leaching studies have tile-drains at 13.5 m spacing and 0.9 m depth. Two or three tiles in each plot discharge into one sealed pipe leading to a measuring station or to separate measuring wells (plots 1-7). From some of the plots (8-39), tipping vessels are used to measure the discharge. The number of tilts is recorded by data-logger and the exact volumes of the water in the vessels are calibrated annually. From plots 1-7, the discharge is measured using separate pumps and water measuring instruments installed in each measuring well. The measuring stations are equipped with peristaltic pumps for water sampling, and ISCO-samplers are used in the wells. All sampling devices are connected to data loggers and receive flow-based impulses from the loggers. The oldest experimental plots (1-7, Figure 6)

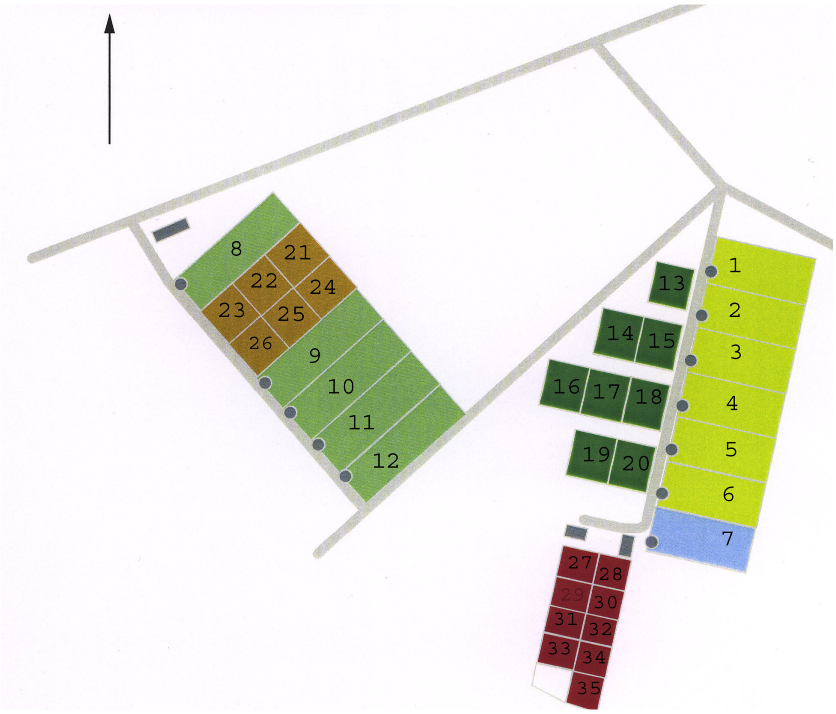


Figure 6. Drained plots at Lanna used for leaching experiments.

also named R2-8409, were drained in 1935 and used for lime experiments during the 1960s. Nitrogen leaching experiments started in 1973. In 1991-1993, monitoring of phosphorus losses started more intensively and the plots became fully equipped to measure episodic transport by flow-proportional sampling. Five plots (8-12) belong to a long-term experiment that started in 1979 with the aim of monitoring nitrogen turnover in some production systems with different crop rotations (R3-0056). These plots (size 0.45 ha) were drained in 1932. In 1996, the drainage pipes in two of the former plots of these experiments (representing a legume-based system and a monoculture loaded with pig manure) were cut off and connected in such a way that 6 smaller separate drainage systems were formed (21-26). The new plots (0.15 ha in size) are hydrologically isolated through drainage pipes surrounding the plots. Simultaneously, eight similar hydrologically isolated plots (size 42x40 m) were constructed (13-20) of which two are currently unused. In addition, nine plots in two rows with a size of 24x33 m were drained and fully equipped for flow-proportional sampling in 2001-2002 under the direction of the Division of Precision Farming, Department of Soil Science, SLU.

Water sampling

Until 1977 only manual sampling was used, but since 1997 all plots have been equipped for flow-proportional water sampling. During 1997-1999, water was collected so that each sample consisted of 10 consecutive sub-samples corresponding to 0.25 mm of drainage from several plots. For economic reasons, the number of samples had to be limited. From July 1 2000, all flow-proportional pumped water samples are pooled into a bi-weekly composite sample. However, every pumped sub-sample still corresponds to 0.25 mm discharge.

Completed projects (*source/s* of funding; number of plots in brackets)

1975-1983 Nitrogen leaching with different application rates of mineral nitrogen fertilisation. (*SJB;* plots 1-6).

1988-1989 Leaching of clopyralid (*Dow chemical company* plots).

1988-1989 Leaching of fluroxypyr (*Dow chemical company* plots).

1989-1990 Leaching of nitrate from monoliths (*SNV, SJFR* 5 lysimeters from Lanna and 8 from Mellby).
1989-1990 Leaching of dichlorprop, bentazon and ^{36}Cl in field lysimeters (*SNV, SJFR* 5 lysimeters from Lanna and 8 from Mellby).
1989-1991 Catch crops, direct drilling and split nitrogen fertilisation - studies of nitrogen turnover and leaching (*SJB;* plots 1-6).
1991 Prediction of Nitrate leaching using SOILN (*SLU*, all plots at Lanna).
1992-2000 Leaching with increasing loads of nitrogen fertilisers with and without catch crops and with direct drilling (*SJB;* plots 1-6).
1996-1999 Phosphorus leaching from leys in clay soil areas (*SJB;* 9 plots).
1996-1999 Analysis and improvement of existing models of field-scale transport through the vadose zone of differently textured soils, with special reference to preferential flow (*EC;* plot 1 and 6).
1996-1997 Development of a model to predict losses of nitrogen in an aggregated clay soil (*SEPA;* plot 1).
1996-1999 Macropore flow and P losses – processes and impact of different management practices (*SJFR;* 5 lysimeters extracted from Lanna site and 3 lysimeters from the Mellby site).
2002-2004 Nitrogen leaching from cereals with different strategies for plant disease control (*SJB;* plots 27-35).
1995-1998 Modelling phosphorus losses with the GLEAMS model (*FLAMM;* plots 3-5).
1996 Temperature dependence of linuron sorption to three different agricultural soils. (*SLU, SEPA;* soils from Lanna and Mellby).
1996 Leaching of linuron and bentazon in field lysimeters (*SEPA;* 4 lysimeters extracted from Lanna site and 3 lysimeters from Mellby site).
1997-2001. FOCUS surface water scenarios in the EU evaluation process under 91/414/EEC. *(EC*; plot 6)
1998 Areal extent of preferential flow (SLU 5 lysimeters from the Lanna site and 6 from Mellby).
1998-2001. Tillage practices and incorporation of phosphorus fertilisers (*MISTRA;* 9 lysimeters extracted from Lanna site).
1997-2003 Phosphorus and nitrogen leaching under different crop rotations (*FORMAS;* 12 plots).

Table 3. *Actual crop sequences in the organic cropping systems at Lanna. Only 3 crops in each system are grown the same year (in 2 replicates)*

Crop sequences	Cattle slurry		Undersowing / catch crop	Cultivation
	Time point	P kg ha^{-1}		(after crop)
Cropping system with livestock				
Ley I				-
Ley II				1 August
Winter rape	Early spring	25		Feb.-Mars
Winter wheat	Early spring	25		Feb.-Mars
Horse bean		-		Feb.-Mars
Green fodder+undersown Ley	Spring (incorporated)	20	Grass + clover (wh.+ red)	-
Cropping system without livestock				
Green manure	-	-		1 August
Winter rape	-	-		Feb.-Mars
Winter wheat+ undersown Ley	Early spring*	80	Grass + clover (wh.+ red)	-
Green manure	-	-		Feb.-Mars
Spring wheat + catch crop	-	-		Feb.-Mars
Horse bean	-	-		September
Oats + undersown Ley	-	-	Grass + clover (wh.+ red)	-

Biofer 7-9-0, accepted for use in organic farming.

Table 4. Crop sequence and treatments in the winter wheat crop rotation (2 replicates)

	Crop	Commercial N, kg ha^{-1}	Commercial P, kg ha^{-1}	Cultivation in autumn	Winter crop
A	Oats	110	—	Shallow stubble cultivation before sowing of winter wheat	Winter wheat
B	Winter wheat	50+90+40	20, at sowing	Ploughing before sowing of winter wheat	Winter wheat
C	Winter wheat	50+90+40	20, in spring	Ploughing in late autumn	—

2002-2005 Modelling nutrient fluxes in arable land – development of a phosphorus model including losses through macropores (MISTRA, plots 1-5).
1997- Organic farming with and without livestock – nutrient turnover and risk of nutrient leaching from three crop rotations (*SLU, SJB;* plots 21-26, 13-18). (Table 3)
2001-2006 Leaching of N and P in a winter wheat crop rotation with different tillage strategies and different times for application of P fertiliser (*SJB;* plots 1-6). (Table 4)
1992- Leaching from EU fallow (*SJB;* 1 plot).
2005-2007 Different strategies for tillage and glyphosate treatment of undersown catch crops – impact on leaching of nitrogen, phosphorus and glyphosate (*SLF;* plots 27-35).
1997 - Nitrogen turnover in different crop rotations (*SLU;* plots 8-12).
2006 - Nutrient leaching and turnover in a crop sequence with fallows (plots 1-6 and 9-10), according to Table 5.

FOTEGÅRDEN

Experimental plots

The site is on a sandy clay loam situated in the county of Västergötland, 10 km north-west of Skara. Eight tile-drained experimental plots (30x28 m) were installed drained and equipped in 1992 (Figure 7). The water level is recorded continuously and water flow is calculated at V-notch. Water is sampled flow proportionally, guided by a data logger. This site was chosen for the purpose of studying the short- and long-term effects of undersown catch crops, different tillage strategies and application of pig slurry on nitrogen leaching and nitrogen turnover in this type of soil. Similar studies had been going on at the Mellby site in southern Sweden and more information was requested about how different management practices affect nitrogen leaching further north.

Table 5. *Crops in systems with green fallows at Lanna*

System	**Conventional Intensive 1.25N**	**Monoculture Intensive. 1.2N**	**Conventional 1N**	**Conventional 1N**	**Conventional 1N**
Plot no.	**10**	**8**	**2, 5**	**1,6**	**3,4**
2005	Oats	Barley	Oats	Winter wheat	Winter wheat
2006	Spring rape	Barley	Winter wheat	Oats	Winter wheat
2007	**Fallow**[a]	**Fallow**[a]	**Fallow**	**Fallow**	**Fallow**
2008	**Fallow**[a]	**Fallow**[a]	**Fallow**[b]	**Fallow**[c]	**Fallow**
2009	Barley	Barley	Spring rape	Spring rapes	**Fallow**[d] +spring rape
2010	Oats	Barley	Spring cereals	Spring cereals	Spring cereals
2011	Winter wheat	Barley	Spring cereals	Spring cereals d	Spring cereals

[a] Fallow cut twice and ploughed in October
[b] Fallow ploughed in October-November
[c] Fallow ploughed in August
[d] Fallow ploughed in early spring and spring rape sown

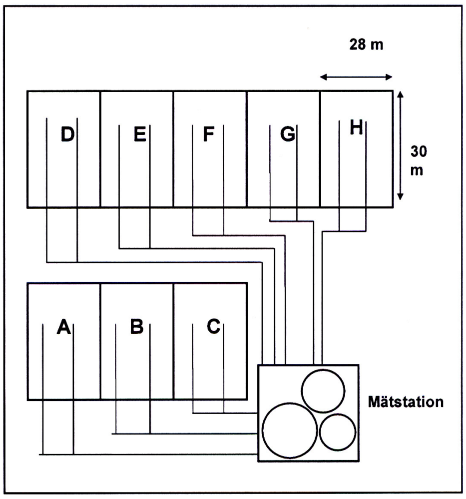


Figure 7. Experimental plots at Fotegården.

Completed projects (*source/s* of funding; number of plots in brackets)

1992-2005 Nitrogen leaching and turnover in cropping systems with undersown catch crops, different times for tillage and with/without application of pig slurry (plots A-H).

Ongoing projects

Until 2002, spring cereals, spring rape and potatoes were the only crops used. Since 2003 winter rape, winter rye and fallow have been introduced into the crop rotation.

In this ongoing project an application has been made to change the experimental design from 2006 in order to obtain replicates of all treatments in the experiment. From 2006 no application of manure will be used and there will be four experimental treatments with two replicates (Table 4).

Table 6. *Experimental treatments suggested for Fotegården 2006-*

Plot	Catch crop	Time of tillage	Cropping history 1992-2005
2, 6	No	Stubble cultivation in September	Liq. manure 90 total-N kg ha^{-1} y^{-1}
3, 7	Yes	Ploughing in November	Catch crop, mineral fert.90 N kg ha^{-1} y^{-1}
1, 5	No	Ploughing in spring	Mineral fert. 90 N kg ha^{-1} y^{-1}
4, 8	Yes	Ploughing in spring	Catch crop and liq. Manure 90 kg ha^{-1}

MELLBY

General

The Mellby experimental site (56°29'N, 13°0'E) is situated 25 km south of Halmstad on the south-west coast. The autumn and winters are mild and wet. Mean annual precipitation is 800 mm. The soil profile has been classified as a *Fluventic haplumbrept* (USDA) or a *Haplic Phaeozem* (FAO). Diagnostic characteristics are *Mollic* epipedon and *Cambic* horizon. The sand and clay contents in the layer 0-23 cm are 79% and 10%, respectively. Mellby sand has a weak coarse granular structure in the topsoil and is structureless in deeper layers of the sand deposits with a thickness of 90-130 cm overlying a glacifluvial clay.

Experimental plots and permanent lysimeters

At Mellby, plots 24-33 (40 x 40 m) were drained and hydrologically isolated in 1982, plots 34-37 (40 x 40 m) in 1987, plots 1-9 (30 x 30 m) in 1989, plots 10-23 (30 x 30 m) in 1989, and plots 38-50 (30 x 30 m) in 1996. At L (Figure 8), 12 permanent lysimeters plots (6 x 6 m) were constructed in 1989 by installation of rubber cloth down to the depth of 1.0 m, each with a net area of 9 m^2 (3 x 3 m). All water-flow is measured by tilting vessels and water is sampled flow-proportionally from the plots. Daily precipitation and temperature, wind speed, global radiation and relative humidity are measured at a meteorological station at the experimental site.

Completed projects (*source/s* of funding; number of plots in brackets)

1990-2002 Nutrient leaching from sandy soil - measures and new technique.

1990-1997 Nitrogen turnover and leaching in systems loaded with fertilisers or manure, with and without catch crops.

1983-1989 Nitrogen turnover and leaching from a coarse-textured soil with fertilisers or manure in the south of the county of Halland (plots 24-33).

1990-1999 Environmentally-friendly use of slurry and catch crops (plots 24-33).

1996-1999 Analysis and improvement of existing models of field-scale transport through the vadose zone of differently textured soils, with special reference to preferential flow (*EC;* plots 18 and 19).

1998-2001 VASTRA - Development and testing of the SOILNDB modelling tool (*MISTRA*; plots 24-33).

1997-2000 Losses of ammonium from cattle slurry (plots 38-39 + 44-47).

1995-1997 Nitrogen leaching from cultivation of lettuce and cabbage (*SJB;* 12 lysimeters).

1999-2000 Nitrogen leaching from cultivation of lettuce (*SJB;* 12 lysimeters).

1998-2001 Tillage practices and incorporation of phosphorus fertilisers (*MISTRA;* 9 lysimeters extracted from Mellby site).

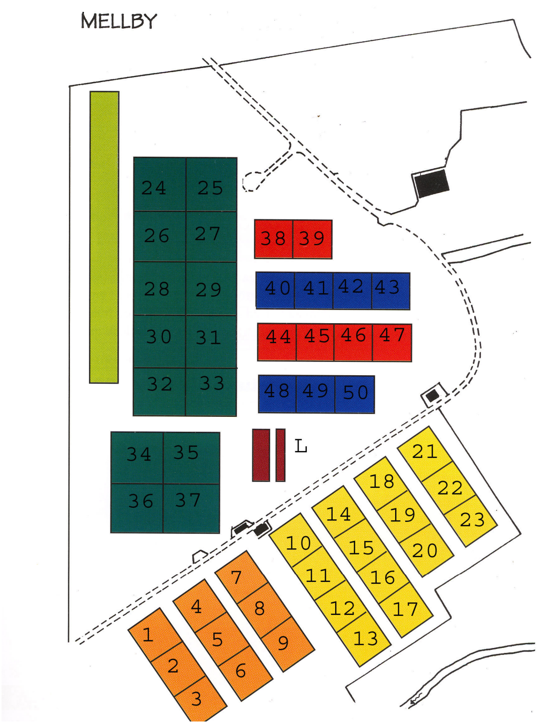


Figure 8. Experimental plots at the Mellby site.

1996 Temperature dependence of linuron sorption to three different agricultural soils. (*SLU, SEPA;* soils from Mellby and Lanna).
1996 Leaching of linuron and bentazon in field lysimeters (*SEPA;* 3 lysimeters extracted from Mellby site and 4 lysimeters from Lanna site).
1998-2000 Soil tillage and nitrogen leaching in two crop production systems (suction cups)
1996-1999 Macropore flow and P losses – processes and impact of different management practices (*SJFR*; 5 lysimeters extracted from Lanna site).
1996-1999 Macropore flow and P losses – processes and impact of different managements practices (*SJFR*, 3 lysimeters extracted from Mellby site and 5 lysimeters from Lanna site).
1992-1993 Ryegrass cover crop effects on nitrate leaching in spring barley fertilised with $^{15}NH_4{}^{15}NO_3$ (*SJFR;* 10 lysimeters extracted from Mellby site).
1992-1995 Leaching of total nitrogen from nitrogen-15-labelled poultry manure and inorganic nitrogen fertiliser (*FLAMM*; 15 lysimeters extracted from Mellby site).
2000-2002 Leaching and crop uptake of nitrogen from nitrogen-15-labelled green manure and ammonium nitrate (*FLAMM;* 12 lysimeters extracted from Mellby site).

Ongoing projects

1990- Nitrogen leaching and turnover in cropping systems with undersown catch crops and with or without application of pig slurry at different rates in spring or autumn (*SLU, SJB*, plots 24-37). (Table 7).
1991- Organic farming with livestock – nutrient turnover and risk of nutrient leaching from three crop rotations (*SLU, SJB;* 12 plots 10-17, 20-23).
1997- Organic farming without livestock – nutrient turnover and risk of nutrient leaching from three crop rotations (*SLU, SJB;* 7 plots 40-43, 48-50). (Table 8)
1997- Nitrogen-effective tillage systems (Cooperation with *Division of Soil Management, SLU*; plots 38,39, 44-47).
1990- Nutrient leaching from sandy soil - measures and new technique in conventional cropping systems with poultry respectively cattle slurry (*SLU, SJB,* plots 1-9). (Table 9)

Table 7. *Main treatments in cropping systems with undersown catch crops and with or without application of pig slurry*

Treatment	Slurry (1 STG=110 kg N ha^{-1})	Commercial N (1 N=90 kg ha^{-1})	Time for slurry application	Catch crop	Time for cultivation
A	-	0 N	-	-	Early autumn
B	-	0 N	-	Per. ryegrass	Early spring
C	-	1 N	-	-	Early autumn
D	-	1 N	-	Per. ryegrass	Early spring
E	1 STG	½ N	Early autumn	Per. ryegrass	Early spring
F	2 STG	½ N	Early autumn	Per. ryegrass	Early spring
G	1 STG	½ N	Early spring	-	Early autumn
H	1 STG	½ N	Early spring	Per. ryegrass	Early spring
I	2 STG	½ N	Early spring	-	Early autumn
J	2 STG	½ N	Early spring	Per. ryegrass	Early spring
K	-	1 N	-	-	Late autumn
L	-	1 N	-	Per. ryegrass	Late autumn

Table 8. *Actual crop sequences in the organic cropping systems at Mellby. Only 3 crops in each system are grown the same year (in 2 or 3 replicates)*

Crop sequences	Cattle slurry Time point	P kg ha^{-1}	K* kg ha^{-1}	Undersowing / catch crop	Cultivation (after crop)
Cropping system with livestock					
Ley I	Drilled after 1:e harv.	10	50		-
Ley II	Drilled after 1:e harv.	10	50		1 August
Winter rape + catch crop	Early spring	20	25	Per. ryegrass+ wh. clover	Feb.-Mars
Spring barley + catch crop	Early spring	15	25	Per. ryegrass	Feb.-Mars
Horse bean		-	50		Feb.-Mars
Green fodder+undersown Ley	Early spring	15	25	Grass + clover (wh.+ red)	-
Cropping system without livestock					
Green manure	-	-	-		1 August
Winter rape + catch crop	-	-	50	Per. ryegrass	Feb.-Mars
Oat + undersown Ley	-	-	25	Grass + clover (wh.+ red)	-
Green manure	-	-	-		Feb.-Mars
Spring wheat + catch crop	-	-	50	Per. ryegrass	Feb.-Mars
Horse bean	-	-	50		September
Rye + undersown Ley	-	-	50	Grass + clover (wh.+ red)	-

* "Biofer-Ley", accepted for use in organic farming

Proposed projects

2006-2008 Evaluation of residual effects of undersown catch crops in combination with applications pig slurry during 15 years (plots 26-29). Residual effects are studied in small plots without application of nitrogen fertiliser. Crop uptake and measurements of soil mineral nitrogen is used to estimate net nitrogen mineralisation from soil organic matter.

2006- Long-term green fallow for studying N dynamics in permanent grassland (plots 36-37).

Table 9. *Actual crop sequences and treatments in the conventional systems with new technique*

	Crop sequences	Slurry P kg ha^{-1}	Application time	Commercial N kg ha^{-1}	Cultivation (After crop)	Catch crop / Autumn crop
Cattle						
	Green fodder	20	Spring[1]	0	-	Undersown ley
	Ley I	15+15	Drilled aft. 1:e harv. + late autumn (bands)[3]	45+0+45	-	Ley
	Ley II	15	Drilled aft. 1:e harv.[3]	90+0+45	Early spring[2]	Ley
	Fodder maize	25	Spring (in bands)[1,]	20 + 70	Early spring[2]	
Poultry						
D	Spring barley	30	Spring (in bands)[1]	0	-	Per. ryegrass /ley
E	Green fallow	-		-	Early autumn	Winter rape
F	Winter rape	20	Spring, (in bands)[3]	*140	Early autumn	Winter wheat
G	Winter wheat	25	Drilled, early spring	*120	Early spring[2,4]	Per. ryegrass
H	Potato	-	-	*120 + 30	Early autumn	Rue-wheat
I	Rye-wheat	25	Drilled, early spring[3]	*100	Early spring[2]	Per. ryegrass

*) Adapted to the actual amount ammonium-N applied by slurry.

1) Poultry manure incorporated within 4 hours; cattle manure incorporated immediately.

2) February -Mars

3) Measurements of NH_3-emissions.

Table 10. *Proposed pre-crop treatments at Böslid*

	Treatment of preceding crop, before potatoes
A	Green manure cut three times and no crop removal.
B	Ley of green manure harvested at the same time as above and crop biomass removed.
C	Undersown ley before the potatoes. Ley biomass neither harvested nor removed.
D	Undersown ley before the potatoes. Ley biomass harvested in early October.

BÖSLID

General

This site is situated 15 km north of Mellby and has the same climate as Mellby but a different soil texture. Leaching studies have revealed lower nitrogen concentrations. In addition, the responses of phosphorus will probably be different due to the different soil texture.

Experimental plots 36 plots (20 x 16 m) were drained in 2002-03 (Figure 9). These plots are hydrologically isolated from each other by plastic sheets in the subsoil and a protective drainage pipe around the plots.

Completed projects (*source/s* of funding; number of plots in brackets)

2003-2004 Techniques for maximum nitrogen utilisation and minimal leaching of nitrogen leaching under potato cropping, *(in cooperation with Division of Precision Farming, SLU Skara).*(*SLF,* 18+18 plots).

Ongoing projects (*source/s* of funding; number of plots in brackets)

2005-2007 Different strategies for tillage and glyphosate treatment of undersown catch crops - impact on leaching of nitrogen, phosphorus and glyphosate (*SLF;* 10 plots).

Proposed projects

2006- Nutrient turnover and improved environmental adaptation by cropping green manure and organic potatoes. Four treatments with randomly replicates will be investigated with the aim of producing four different preceding crops that will be ploughed into the soil (Table 10).

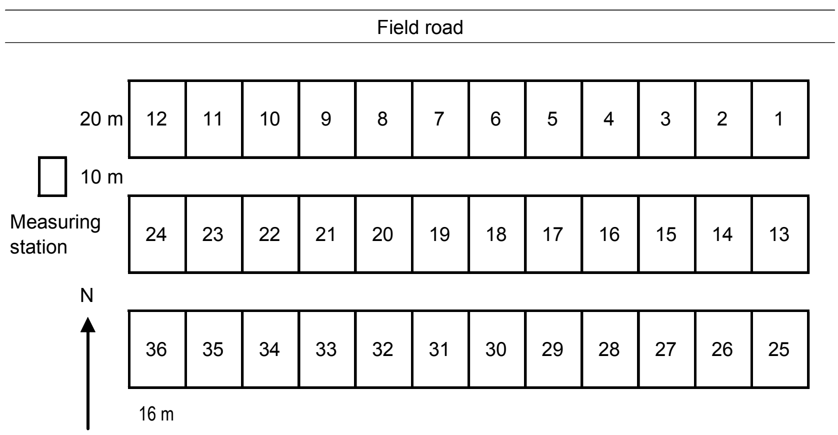


Figure 9. Experimental plots at the Böslid site.

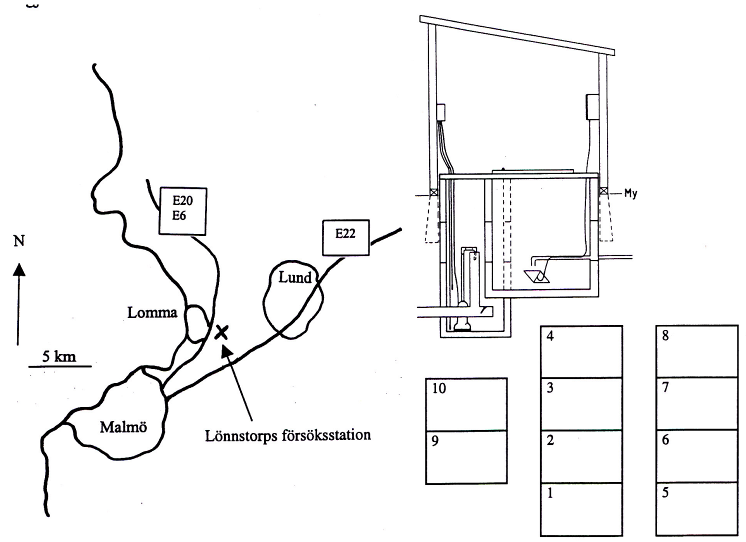


Figure 10. The experimental site Lönnstorp with drained experimental plots.

LÖNNSTORP

Experimental plots

The soil is a slightly gravelly sandy loam (USDA) situated on a plain site in the county of Scania. The clayey fraction is glacial till. The soil has been physically described and shows great variations in saturated hydraulic conductivity. Eight experimental plots (37x26 m) were drained and equipped in 1983 and two more plots (9-10) were drained in 1992. Water flow is measured by tilting vessels (Figure 10) and water is sampled manually.

Completed projects (*source/s* of funding; number of plots in brackets)

1983 - Different loads of nitrogen fertilisers with and without manure (*SJB;* 8 plots).

Ongoing projects

1992- Long-term control of nitrogen leaching from soil covered with vegetation during autumn (*SJB;* 10 plots). Two crop rotations containing cereals, oilseed rape and sugarbeet have been studied since 1992. One of the rotations contains undersown catch crops. This experiment has been useful in providing information about nitrogen leaching in common crop rotations in the southernmost part of Sweden and in showing efficient ways to reduce losses. The effect of removal of sugarbeet tops after harvest on nitrogen leaching was studied in this project. Since 2003, fallows have also been introduced into the rotations.

Proposed projects

No new crop rotation is suggested but renewed comparisons are planned, especially between fallows and the winter rape that follows the fallow (Table 6).

Table 11. *Crop rotations at Lönnstorp 2003-*

Conventional crop rotation (plot 5-8, 10)	**Catch crop rotation (plot 1-4, ,9)**
Winter rape (reduced tillage)	Winter rape (reduced tillage)
Winter wheat (ploughing in Sep)	Winter wheat + catch crop
Sugar beets (ploughing in November)	Sugarbeet (ploughing in November)
Spring barley (no tillage)	Spring barley + catch crop (no tillage)
Bare fallow (tillage in August)	Green fallow (tillage in August)

GENERAL SITES FOR LONG-TERM STUDIES

Soils from the long-term studies with different long-term fertilisation histories have primarily been used for lysimeters or soil nutrient trials.

Completed projects (*source/s* of funding; number of plots in brackets)

1995-1997 The effect of winter vegetated soil on erosion of phosphorus (*SJB;* 15 plots).
1999-2001 Phosphorus sorption in relation to soil properties in cultivated soils (*MISTRA;* 10 sites).
1999-2002 Phosphorus leaching in relation to soil type and soil phosphorus content (*MISTRA;* 36 lysimeters, 5 sites).
2002-2004 Improved P-AL method to assess the risk of high phosphorus leaching (*SLF;* 10 sites).

Ongoing project

2005- Phosphorus leaching after fertilisation according to recommendations and with phyto-remediation (*SLF;* 41 lysimeters 6 sites).

Appendix 1

Soil physics and chemistry of the long-term experimental sites.

Table A1. *Average texture according to international (sand, silt, clay) and Swedish (Sa, Gmo, Fmo and Mj) standards. Examples of soil physical parameters - saturated hydraulic conductivity (K_{sat}, cm h^{-1}) and porosity (POR, %) either measured or estimated from nearby sites*

Site	**Layer**	**International texture classes**			**Swedish texture classes**					
		Sand 2-0.06	**Silt** 0.06-0.002	**Clay** <0.002	**Sa** 2-0.2	**Gmo** 0.2-0.06	**Fmo** 0.06-0.02	**Mj** 0.02-0.002	**K_{sat} (cm h^{-1})**	**POR (%)**
Hedemora	0-30	4	77	19	3	1	20	57	-	-
	30-60	3	75	23	2	1	18	57	-	-
	60-90	2	69	28	1	1	13	57	-	-
Wiad	0-30	12	55	33	1	11	9	25	-	-
	30-60	13	57	30	5	9	19	38	-	-
Bornsjön	0-30	3	35	62	1	2	11	25	16	56
	30-60	2	33	65	1	1	10	23	0.1	50
	60-90	3	37	60	1	2	11	26	0.2	52
Lanna	0-30	12	43	45	7	5	15	28	16	52
	30-60	5	37	58	2	3	10	27	5.5	48
	60-90	6	32	62	1	5	7	25	0.6	46
Fotegården	0-30	82	11	7	10	73	6	4	6.1	45
	30-60	87	9	4	13	75	6	2	31	37
	60-90	87	9	4	10	77	6	2	64	36
Böslid	0-30	84	5	7	11	73	2	3	2.5	41
	30-60	96	2	1	4	92	1	1	8.4	40
	60-90	97	2	1	10	87	1	1	0.1	41
Mellby	0-30	77	14	10	34	42	6	8	3.7	43
	30-60	91	7	2	27	64	5	2	7.2	38
	60-90	86	13	1	23	63	11	2	5.4	32
Lönnstorp	0-30	52	30	18	24	28	16	14	12.3	46
	30-60	53	28	19	27	26	14	14	2.4	39
	60-90	52	32	16	26	26	14	18	2.8	33

Table A2. *Soil pH (H_2O), content of organic carbon (C, %), total nitrogen (N, %) and phosphorus extracted in acid ammonium lactate (P-AL, mg 100 g^{-1} dry soil) and hydrochloric acid (P-HCl, mg 100 g^{-1} dry soil)*

Site	layer	pH	C*	N	P-AL	P-HCl	K-AL	K-HCl
					(mg 100 g soil^{-1})			
Hedemora	0-30	5.3	1.7	0.10	4	73	8.2	-
	30-60	6.1	0.7	0.07	4	48	5.2	-
	60-90	6.5	0.3	0.03	5	52	6.4	-
Wiad	0-30	6.6	2.4	-	16	67	-	-
	30-60	-	-	-	10	59	-	-
	60-90	-	-	-	12	60	-	-
Bornsjön	0-30	6.6	2.2	-	6	100	14.9	
	30-60	7.0	1.5	-	2	84	-	-
	60-90	7.2	1.0	-	3	72	-	-
Lanna	0-30	6.0	1.9	0.16	5	55	15.7	-
	30-60	6.2	0.6	0.04	11	59	16.3	-
	60-90	5.9	0.5	0.01	19	75	22.0	
Fotegården	0-30	5.7	3.3	0.17	13	49	9.8	26
	30-60	-	1.3	-	-	-	-	-
	60-90	-	0.3	-	-	-	-	-
Böslid	0-30	6.5	-	-	6	-	6.9	53
Mellby	0-30	6.2	2.3	0.16	22	74	9.1	40
	30-60	6.1	0.5	0.03	4	23	2.3	48
	60-90	5.6	0.2	0.01	2	37	2.6	48
Lönnstorp	0-30	6.7	2.1	0.2	-	-	-	-
	30-60	7.2	0.8	0.1	-	-	-	-
	60-90	8.0	0.3	0.0	-	-	-	-

*Considering 58% C in organic material for some sites

APPENDIX 2

Publications related to the long term field experiments

The letter in parenthesis refers to the experimental area: L= Lanna, M=Mellby, W=Wiad, H= Hedemora, B= Bornsjön, Lönnstorp= Lo, Fotegården=Fo, Böslid=Bö,G= General long-term experimental sites such as those used for crop management on yield,

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Kristian Persson 2001. Measurement and modelling of phosphorus transport from arable land *Ekohydrologi 58* (Licenciate). (H, B, L) Swedish University of Agricultural Sciences, Uppsala.

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