Long-term field experiments
- a unique research platform

Proceedings of NJF Seminar 407
Askov Experimental Station and Sandbjerg Estate
16-18 June, 2008, Denmark

Bent T. Christensen, Jens Petersen & Margit Schacht (eds.)
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Faculty of Agricultural Sciences ( DJF )
Department of Agroecology and Environment

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The nordic Association of Agricultural Scientists ( NJF )
and
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Preface

This report contains abstracts of oral and poster presentations given at the NJF-seminar 407: *Long-term field experiments - a unique research platform*, held in Denmark at Askov Experimental Station and Sandbjerg Estate on the 16th-18th June 2008. The seminar has been organized by a working group appointed by *Section I (Soil, Water and Environment)* of the *Nordic Association of Agricultural Scientists* (NJF; [www.njf.nu](http://www.njf.nu)). The seminar is financially supported by *Norden – The Nordic Council of Ministers* ([www.norden.org](http://www.norden.org)) through a project grant from the section *Environment Strategies in Agriculture & Forestry* (MJS; [www.norden.org/mjs](http://www.norden.org/mjs)).

The members of the seminar working group were:
Lennart Mattsson, Swedish University of Agricultural Sciences (SLU), Faculty of Natural Resources and Agricultural Sciences, Department of Soil and Environment, Uppsala,
Hugh Riley, Norwegian Institute for Agricultural and Environmental Research (Bioforsk), Arable Crops Division, Apelsvoll,
Tapio Salo, MTT - Agrifood Research Finland, Jokioinen,
Gudni Thorvaldsson, Agricultural University of Iceland, Kednaholt, and
Bent T. Christensen (chairman), University of Aarhus, Faculty of Agricultural Sciences (DJF), Department of Agroecology and Environment, Foulum.

The seminar secretariat included Margit Schacht and Jens Petersen from the Department of Agroecology and Environment. Their excellent management and organizing talents are gratefully acknowledged.

Bent T. Christensen
Department of Agroecology and Environment
Foulum
May 2008
Long-Term Experiments at Askov Experimental Station

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Introduction
The experimental station at Askov was founded in 1885 as one of the first two agricultural research stations in Denmark. The station is located in the South of Jutland (55°28'N, 09°07'E) with an annual precipitation of 862 mm and a mean annual temperature of 7.7 °C. During the previous 123 years, the station has hosted a number of field experiments with treatments that were kept unchanged for decades. As research funding became more and more reliant on short-term contracts, field experiments of long-term nature were reduced in number. However, provided that good records have been kept, previous experiments may maintain great relevance, and historic results have played a key role in research performed long after experiments have been closed down (e.g. Christensen & Johnston, 1997; Bruun et al., 2003). Today, Askov Experimental Station accommodates three experiments of long-term nature, the most widely known one being The Askov Long-Term Experiments on Animal Manure and Mineral Fertilizers. The two others are a field experiment with different levels of cereal straw incorporation (The Straw Experiment), and a small-plot experiment with continuous silage maize (The Maize Experiment). This paper provides a short presentation of their core treatments and references to some of the projects that have drawn on these experiments.

The Askov Long-Term Experiments on Animal Manure and Mineral Fertilizers (Askov-LTE)
The Askov-LTE was initiated in 1894 on two sites, only a kilometre apart but with contrasting soil texture: Sandmarken with a sand soil enriched in fine sand, and Lermarken with a sandy loam soil. The overall objective of the experiments was to test crop responses to different levels of nutrients (0, ½, 1, 1½, 2) added in animal manure (AM) or in mineral fertilizers (NPK). Plots given N, P and K individually or in combinations of two or three were included. Each site includes four fields in a four-course crop rotation of winter cereals, row crops, spring cereals and grass/legumes. Christensen et al. (1994) describe in detail the experiments, the adjustments in experimental layout, and present selected results for the period 1894-1994. The basic principle of the rotation has been kept since 1894, while individual crops in the rotation have changed over time. However, one major change was introduced in Sandmarken in 1997, when the site was converted into permanent grassland and the nutrient additions were stopped. The herbage is now cut annually and left on the plots, and the soil is sampled every fourth year.

The Lermarken site has also been subject to adjustments. In 2005, silage maize replaced turnips and beet roots as row crop in the rotation. A more substantial change occurred in 1996 when some of the treatments in the B4-field at Lermarken were reverted and when treatments with mineral fertilizers (NPK) were replaced by treatments with farmyard manure in order to...
compare the effect of solid+liquid manure with that of animal manure slurry. Also, semi-
permanent grass strips were introduced to reduce tillage mediated transfer of soil between
plots. These more recent adjustments at the Lermarken site are detailed by Christensen et al.
(2006). Table 1 gives an account of the current treatments at the Lermarken site (for the B4-
field until 1996). Historically, the B2-field has been divided into two sections (B2e, B2w).

### Table 1. Lermarken: The current treatments and the number of replicates in each field
(block)

<table>
<thead>
<tr>
<th>Code in field plan</th>
<th>Treatment and year of establishment</th>
<th>B2e</th>
<th>B2w</th>
<th>B3</th>
<th>B4”)</th>
<th>B5</th>
<th>All fields</th>
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</thead>
<tbody>
<tr>
<td>a</td>
<td>0 (Unmanured) 1893</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>3</td>
<td>5</td>
<td>21</td>
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<tr>
<td>b</td>
<td>½ AM 1894</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td>3</td>
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<td>11</td>
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<tr>
<td>c</td>
<td>1 AM 1894</td>
<td>6</td>
<td>4</td>
<td>5</td>
<td>2</td>
<td>4</td>
<td>21</td>
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<tr>
<td>d</td>
<td>1½ AM 1894</td>
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<td>4</td>
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<td>2</td>
<td>3</td>
<td>17</td>
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<tr>
<td>s</td>
<td>2 AM 1923</td>
<td>3</td>
<td></td>
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<td>p</td>
<td>½ NPK 1923</td>
<td>5</td>
<td>4</td>
<td>2</td>
<td>4</td>
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<td>15</td>
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<tr>
<td>k</td>
<td>1 NPK 1894</td>
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<td>3</td>
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<tr>
<td>r</td>
<td>1½ NPK 1923</td>
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<td>1</td>
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<td>4</td>
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<tr>
<td>l</td>
<td>1 NP 1894</td>
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<td>2</td>
<td>2</td>
<td>2</td>
<td>10</td>
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<tr>
<td>f</td>
<td>1 NK 1935</td>
<td>2</td>
<td>3</td>
<td>3</td>
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<td>10</td>
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<tr>
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<td>4</td>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

In total 48 28 35 28 25 174

”) Only valid for the B4-field until 1996

Soil samples are retrieved from every plot every fourth year and analyzed for C and N, while
crop yields are determined annually. Every four years (following a complete rotation), crop
samples from each treatment (bulked across plot replicates and fields) are analyzed for N, P and
K. The soil archive contains samples back to 1923, while systematic archiving of crop samples
was initiated in 1949. The data archive contains records of yields back to 1894 and of crop
analyses back to 1949. Climate data are also available. The experiments have supported
numerous studies and have for long functioned as a research platform. Christensen et al. (2006)
provide a description of the data storage system and a list of publications related to the
experiments (>120 publications from 1906 to 2005). A more recent research activity is presented
by Petersen et al. (this volume).

### The Straw Experiment

This field experiment was initiated in 1981 in the O1-field next to the Askov-LTE Lermarken
site. Spring barley dressed with mineral fertilizers is grown every year (except for 2000-2002).
At harvest, the straw is baled and removed from the field, leaving only the stubbles behind. Then
0, 4, 8 or 12 t straw (85 % DM)/ha is returned and incorporated in main plots. During 1981-1988
straw incorporation was combined with additions of pig slurry (35 t/ha) in subplots, either shortly
after harvest or late in the autumn. In 1989, cultivation of a nitrate catch crop of ryegrass (under-
sown in spring) replaced the treatment with slurry given shortly after harvest. Catch crop was also introduced in plots given slurry in the late autumn. The residual effects of the treatments were tested during 2000 to 2002, where three consecutive crops of winter wheat were grown. During this period, straw incorporation, slurry addition and catch cropping was abandoned. The yield of wheat was tested at four levels of mineral fertilizers. Soil sampled before (in 1999) and after the test phase (in 2002) was analyzed for contents of C and N (Figure 1). Results from this test phase are presented by Thomsen and Christensen (2004).

![Figure 1. Amounts of C and N in soil (0-20 cm) in 1999 and in 2002 as a function of the C and N inputs in straw during 1981-1998 (Thomsen & Christensen, 2004).](image)

In 2003, the experimental plan reverted to that used before the wheat test phase, but adjustments were made: a catch crop of grass/clover replaced that of ryegrass with pig slurry, and all subplots were split into two: autumn plowing and spring ploughing by a strip-subplot design.

Studies recently hosted by this experiment are reported by Luxhøi et al. (2007) and Thomsen et al. (2008). In 2008, the experiment serves as research platform for the ERA-net COREOrganic project: AGTEC-Org (see Ingrid K. Thomsen this volume, and http://agtec.coreportal.org).

**The Maize Experiment**

The different abundance of $^{13}$C in C3- and C4-crop residues represents a valuable tool for studies on C turnover in soils, where cropping with C3-plants have been replaced with C4-plants. Based on this concept, a maize experiment (Section A) was established in 1988 in Askov using four different soils placed outdoors in large open-ended cylinders (diameter 0.7 m; depth 0.5 m) that were inserted 45 cm into the ground. Two of the soils (ASK, LUN) had no previous record of C4-crops while the two other soils (ROS, RØN) had been under silage maize for 8 years before the start of the experiment. Silage maize has been grown every year since 1988, the aboveground maize biomass being whole-crop harvested (leaving 4 cm of stubbles), usually by mid-October (growth stage BBCH 75). The experiment includes two treatments: incorporation of stubbles, and incorporation of stubbles + 8 t DM/ha of chopped aboveground maize biomass. Kristiansen et al. (2005) provides a detailed description of the experiment and results on the turnover of maize-derived and pre-maize soil C during the first
14 years. Hofmann et al. (this volume) provides results from a study on lignin dynamics in the soils over an 18 year period.

The Section A maize experiment was amended with a separate Section B in 1996. Section B involves two soils (ASK, LUN) and grows silage maize every year with the treatments: stubbles only, stubbles + 8 t DM/ha in chopped aboveground maize biomass, and stubbles + 8 t DM/ha in feces from sheep fed exclusively on silage maize.

Crop yields are determined every year and samples kept in the archive. Soils are sampled every 2-3 years and archived. The soil archive includes initial soil samples from before maize growing was started. Ongoing studies analyze the annual variation in the $^{13}$C signature of the maize biomass during 1988-2006, and of the retention in soil of $^{13}$C from the maize biomass and the maize-derived sheep feces.

**Conclusions**
The long-term experiments at Askov have been and remain a resource of tremendous value for plant, soil and environmental research. The most widely known experiment (Askov-LTE) has been included in the SOMNET and the Duke University databases on long-term experiments. The three experiments outlined in this contribution have been included as DK-2, DK-5 and DK-1, respectively, in the recently established inventory of Nordic long-term agricultural experiments (see Petersen this volume).

**References**


The CRUCIAL facility: A long-term field trial with urban fertilizers – is recycling of nutrients from urban areas to peri-urban areas detrimental to the environment or the production system integrity?

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Thorvaldsensvej 40, DK-1871, Frederiksberg
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After a period of consultations and discussions among researchers and organic farmers, it was decided to establish the CRUCIAL project, which included a long-term urban fertilizer trial. This facility is to be used for basic research on soil quality issues, as well as a reference system for addressing the possible detrimental effects of recycling of urban fertilizers to the environment or the production system integrity.

A key rationale for establishment of the CRUCIAL facility was that by approaching the known limits for a number of heavy metals below which no profound disturbance should be observed on key soil ecological functions, it should be possible to discern if some of the many unknown components in the composite urban waste based fertilizers have measurable impacts on these functions. Subsequent calculations indicated that with ‘normal’ applications rates of average quality sludge or compost of MSW it would take 30-40 years or even longer in order to approach the eco-toxicological soil quality criteria for heavy metals which should be well below the problem concentrations. This was somewhat surprising to us, since literature reports from long-term experiments with sewage sludge indicated a rather fast increase of heavy metal concentration, but in fact due to changes in society which is increasingly ‘post-industrial’ the metal content of Danish sludge and organic waste has been reduced dramatically over the past 30 years. Therefore we decided that it would be pertinent to include accelerated treatments with sludge and MSW compost, and furthermore a reference organic treatment with cattle dung, in order to emulate high loading of nutrient rich organic matter as a possible control treatment for the accelerated urban fertilizer plots. When looking at the calculations for the accelerated treatments the eco-toxicological limits can be approached over 7-10 years which was considered to be acceptable in terms of longevity of the trials and the uncertainty concerning the ensuing funding commitments.

The facility is located 20 km west of Copenhagen (the Copenhagen University experimental Farm), Denmark (55° 40’ N, 12° 18’ E). It consists of 39 large plots of approximately 900 m² each, allowing for production of quantities of feed or fodder sufficient to allow experiments with small-to-medium animals or even humans. After discussions with the Danish Agricultural Advisory service we have split these plots (in 2008) so half of each will receive herbicide treatments, in order to provide a ‘realistic’ yield level for conventional farmers,

η Closing the Rural-Urban Nutrient Cycle - Investigation of Urban Fertiliser pre-treatments, Agronomic research on Urban Fertiliser turnover in soil and impact on Crop growth, and Initiation of a Monitoring Programme on Soil Quality changes wrought by using Urban Fertilisers in Long-term Field Trials
while still allowing a time frame for the weed management in the rotation, which is appropriate for annual applications of fertilizers, but unlike normal organic rotations, which in our part of Europe would normally include several years of clover grass leys.

The sequence of crops grown in the period 2002-2007 was: spring wheat, oats, spring barley (for silage) and spring oil seed rape. Between each of these main crops, grass-clover was grown each autumn as a green manure, which was ploughed down the next spring before establishing the subsequent crop.

The facility has received increasing interest among research groups interested in environmental microbiology and pharmacology. In the presentation we will focus on ongoing studies, some preliminary results and possibilities for further development of the facility for international collaboration.
Long-term tillage and nitrogen fertilisation effects on maize yield and soil quality under rainfed Mediterranean conditions: a critical perspective

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2 Land Lab, Scuola Superiore Sant’Anna-Pisa, Piazza Martiri della Libertà n. 33, 56127 Pisa, Italy
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Long-term agroecosystem experiments are essential for determining sustainable cropping systems thanks to their capacity to highlight the long-term effect on crop productivity, in relations to different climatic conditions, and on soil fertility. The aim of this study was to evaluate the effect of tillage and N fertilisation on maize productivity and on SOM content in a silt-loam soil (Typic Xerofluvents) in Central Italy. A long-term rainfed continuous maize (Zea mays L.) experiment comparing five tillage techniques [deep ploughing (50 cm) - DP, shallow ploughing (25 cm) - SP, shallow ploughing (25 cm) plus chiseling (25 cm) - SPC, chiseling (50 cm) - CP and minimum tillage (disk harrowing 10-15 cm) - MT] and three N rates (0-200-300 kg ha⁻¹) was established in 1990 at the “Enrico Avanzi” Interdepartmental Centre for Agro-Environmental Research of the University of Pisa, Italy. Nitrogen fertilisation increased maize grain yield up to the highest rate (300 kg N ha⁻¹). During the 16-yr period the lowest yields were obtained under deep ploughing while the higher yields were obtained under CP, SP and SPC, followed by MT. Looking at the entire soil tillage layer (0-45 cm), lower SOM contents have been observed under CP and DP (the deeper soil tillage systems) respect to other treatments; this was particularly evident in 2004 when DP showed the lowest SOM value (1.44%).

Introduction

The effect of tillage and nitrogen fertiliser management on maize yield (Zea mays L.) and soil quality has been studied extensively over many years. Long-term studies that include a wider range of soil and climate conditions can provide useful data to draw more general conclusions on the effects of tillage systems and/or N rate on maize productivity and soil fertility. Recent concerns over environmental quality, energy conservation, and economics have increased the need to reduce tillage practices (Lal, 1991; West and Post, 2002; Holland, 2004) and maximise crop utilisation of N fertiliser (Olson and Swallow, 1984). However, in Italy, ploughing is usually quite deep: 40-50 cm is common for summer crops (e.g. maize and sugar-beet), 30-35 is usual for winter cereals. The reduction of ploughing depth and/or its substitution by other tillage techniques (e.g. chiselling or disk harrowing) can be useful to reduce farming costs and maintaining or increasing soil organic matter (SOM) in the upper layer of soil without affecting crop yields significantly (Mazzoncini et al., 2001). The aim of this study was to evaluate the effects of various tillage systems and N fertilisation rates on rainfed continuous maize productivity and soil organic matter conservation in a long-term...
experiment (16-yr) carried out in Central Italy in order to suggest alternative solutions to Italian farmers.

**Material and Methods**

A long-term rainfed field experiment was established in 1981 on alluvial poorly drained silt-loam soil (Typic Xerofluvents with sand 457 g kg\(^{-1}\), silt 404 g kg\(^{-1}\) and clay 139 g kg\(^{-1}\)) at the “Enrico Avanzi” Interdepartmental Centre for Agro-Environmental Research (CIRAA) of the University of Pisa, located in the Pisa coastal plain (43°40’ N lat; 10°19’ E long, with 1 m a.s.l. and 0% slope). Climatic conditions at the experimental site are typically Mediterranean, characterised by rainfall in the coldest months of the year, with a greater frequency in autumn and early spring, and with a few rain events in summer. Rainfall ranges from 400 to 1000 mm yr\(^{-1}\) and rainfall events are often of such a high intensity that they strongly reduce the chance for an efficient water storage which, on the other hand, should be favoured by the occurrence of such events in the period of lowest evapotranspiration rate. This climate results in moderate stress for rainfed summer crops (e.g. maize). The experiment was carried out to compare five tillage treatments [deep ploughing (50 cm) - DP, shallow ploughing (25 cm) -SP, shallow ploughing (25 cm) plus chiselling (25 cm) - SPC, chiselling (50 cm) - CP and minimum tillage (disk harrowing 10-15 cm) - MT] in a two year sunflower-wheat rotation. From 1990 onwards, soybean-wheat rotation was replaced by continuous maize. From 1991 onwards three N rates (0-200-300 kg ha\(^{-1}\)) were applied. A split-plot experimental design, with four replications, was used with N fertiliser rates as main plots and tillage systems as subplots. A split-plot design combined over years (considering years as a randomized variable) was used to analyze maize grain yield. A randomized complete block design with four replications was used to analyze soil organic matter. Soil data were transformed according to arc sine value. LSD at \( P \leq 0.05 \) was used to test the significance of differences between treatment means (Gómez & Gómez, 1984). Data were analysed using SAS system (SAS Inst. 1997).

**Results and discussion**

**Effects of tillage and N fertilisation rate on maize grain yield**

Significance of main effects and interactions effects on grain yield are presented in table 1.

**Table 1. Analysis of variance. Maize grain yield (1991-2006).**

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>Years</th>
<th>91</th>
<th>92</th>
<th>93</th>
<th>94</th>
<th>95</th>
<th>96</th>
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<td>Tillage</td>
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<td>ns</td>
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<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
</tbody>
</table>

*, ** and ns refer to significant treatment effect in ANOVA at \( P \leq 0.05 \), \( P \leq 0.01 \) and not significant, respectively.

**Nitrogen rate effects**— Over the 16-yr period, rate of applied N fertilisation significantly influenced maize grain yield (tables 1 and 2, fig. 1). According to the 16-yr average data, in most cases (ten out of the sixteen seasons) the 300 N rate significantly improved yield respect to the 200 N rate. However, in five out of the sixteen seasons there was no yield benefit in applying the maximum N rate compared with the 200 N rate.
**Tillage practices effects**- Tillage significantly influenced maize grain yield (tables 1 and 2). The 16-yr average data show that among tillage systems there were significantly differences. Grain yield in the DP system compared with other four treatments was significantly lower. The higher grain yields were obtained under CP, SP and SPC while MT provided intermediate yields.

### Table 2. Main effect of N fertilizer rate and tillage systems on maize grain and straw yield (Mg ha⁻¹) (1991-2006).

<table>
<thead>
<tr>
<th>Years</th>
<th>91</th>
<th>92</th>
<th>93</th>
<th>94</th>
<th>95</th>
<th>96</th>
<th>97</th>
<th>98</th>
<th>99</th>
<th>00</th>
<th>01</th>
<th>02</th>
<th>03</th>
<th>04</th>
<th>05</th>
<th>06</th>
<th>mean</th>
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<tbody>
<tr>
<td>Grain yield (Mg ha⁻¹)</td>
<td>0.05</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N rate 200</td>
<td>6.64</td>
<td>3.32</td>
<td>4.22</td>
<td>3.30</td>
<td>2.57</td>
<td>3.14</td>
<td>2.67</td>
<td>1.86</td>
<td>2.42</td>
<td>1.48</td>
<td>0.82</td>
<td>2.66</td>
<td>1.23</td>
<td>1.40</td>
<td>0.43</td>
<td>1.57</td>
<td>2.48</td>
</tr>
<tr>
<td>300</td>
<td>11.29</td>
<td>6.35</td>
<td>5.31</td>
<td>9.06</td>
<td>6.19</td>
<td>7.42</td>
<td>7.08</td>
<td>6.96</td>
<td>8.55</td>
<td>5.32</td>
<td>3.50</td>
<td>12.33</td>
<td>3.61</td>
<td>7.45</td>
<td>2.37</td>
<td>5.66</td>
<td>6.78</td>
</tr>
<tr>
<td>LSD</td>
<td>0.05</td>
<td>1.08</td>
<td>0.48</td>
<td>0.58</td>
<td>0.70</td>
<td>1.37</td>
<td>0.64</td>
<td>0.64</td>
<td>0.72</td>
<td>1.01</td>
<td>1.05</td>
<td>0.84</td>
<td>1.51</td>
<td>1.13</td>
<td>1.09</td>
<td>0.82</td>
<td>1.34</td>
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<tr>
<td>DP</td>
<td>8.89</td>
<td>5.99</td>
<td>3.54</td>
<td>6.90</td>
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<td>5.24</td>
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<td>3.37</td>
<td>1.67</td>
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<tr>
<td>SPC</td>
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<td>7.07</td>
<td>4.92</td>
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<td>6.45</td>
<td>2.45</td>
<td>5.92</td>
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<tr>
<td>CP</td>
<td>10.72</td>
<td>6.81</td>
<td>6.01</td>
<td>8.39</td>
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<td>7.22</td>
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<td>6.05</td>
<td>2.25</td>
<td>5.65</td>
<td>6.27</td>
</tr>
<tr>
<td>MT</td>
<td>9.55</td>
<td>5.72</td>
<td>4.94</td>
<td>7.02</td>
<td>5.74</td>
<td>7.01</td>
<td>5.91</td>
<td>4.93</td>
<td>6.39</td>
<td>4.81</td>
<td>3.45</td>
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<td>7.28</td>
<td>1.98</td>
<td>4.74</td>
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<tr>
<td>LSD</td>
<td>0.05</td>
<td>0.79</td>
<td>0.41</td>
<td>0.43</td>
<td>0.74</td>
<td>0.75</td>
<td>1.01</td>
<td>0.72</td>
<td>0.86</td>
<td>1.00</td>
<td>0.89</td>
<td>0.59</td>
<td>ns</td>
<td>0.91</td>
<td>1.00</td>
<td>0.48</td>
<td>0.98</td>
</tr>
</tbody>
</table>

Means in the same column are significantly different at the 0.05 level by LSD test; ns: not significant.

**Interaction “Nitrogen x tillage”** - Interaction effects between factors are usually more important than the main effects associated with individual factors. Such was the case in this study where there was significant interaction between N and tillage factors both using the 16-yr average data and data from nine out of the sixteen seasons; in seven out of the sixteen seasons grain yield were not affected by the interaction N x Tillage. On average DP system was less sensitive to N rates respect to the other techniques (except MT under unfertilized soil). Differences among CP, SP, SPC and MT were insignificant at each N rates. This finding indicates that, under DP system, other limiting factors able to reduce the effect of N on maize grain yield may arise (e.g. soil moisture) or that soil nitrogen availability was lower. This last speculation is based on the well known negative effect of the soil tillage on soil organic matter conservation, especially using DP year after year for a long period.

**Effects of tillage on soil organic matter**

There were significant differences in SOM content due to tillage method. SOM content in the 0-15 cm soil depth under MT was significantly higher than the other four tillage systems in 1990, 1994 and 2004 (fig. 2). The capacity of minimum tillage to conserve or increase SOM in the surface layer of the soil has been widely reported in temperate and tropical environments (Lal, 1989). Looking at the entire soil tillage layer (0-45 cm), in 1990 and 1994 it is possible to observe insignificant differences amongst the SP, SPC and MT while lower SOM contents have been observed under CP and DP (the deeper soil tillage systems) respect to other treatments; this was particularly evident in 2004 when DP showed the lowest SOM
value. That confirms the accelerated mineralization rate of SOM under conventional tillage regimes (Lal, 1991; Holland, 2004).

Figure 1. Effect of N fertilisation rate on maize grain yields. ** indicates significant.

Figure 2. Tillage effects on soil organic carbon content (%) for different depths. Columns followed by the same letter for each depth interval indicated were not significantly different at $P \leq 0.05$.

Conclusion

Results show that during the experimental period (1991-2006) DP tended to have both lower grain yield and soil organic matter content relative to the other treatments. This trend suggests that in the tested conditions it is possible to reduce ploughing depth without maize yield decrease and SOM reduction. The productive advantages obtained under CP and MT were associated to a significant reduction in farming costs (90 and 115 € ha$^{-1}$, respectively).

References


Thirty years of growing cereal without P and K fertilization

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Introduction
The aim of a field experiment in southern Finland was to investigate how long it would take before a deficiency of the major nutrients phosphorus and potassium occurred under conditions associated with traditional crop production methods. In order to intensify the uptake both grain and straw of cereals were harvested.

Material and methods
The field experiment was established on a farm in southern Finland (60° 47’ N, 24° 55’ E, 110 m asl) in 1978 and it is still continuing. The field slopes to the south-east at c. 6%. At the beginning of the experiment the organic carbon concentration in the topsoil was 2.8% and its pH(H2O) was 7.7. The soil had been cultivated conventionally for decades before the experiment started. More details are given in Jaakkola et al. (1997).

The design of the experiment consists of two factors with two levels each: without and with PK fertilizer (36 and 70 kg ha⁻¹ a⁻¹, respectively) as well as without and with an extra superphosphate application (P 36 kg ha⁻¹ a⁻¹). The treatments were replicated at least 4 times. They were arranged in plots of 20 by 15 m or 5 by 15 m (extra superphosphate). Nitrogen has been applied at 100 kg ha⁻¹ yearly. The fertilizers were placed at depths of 6-8 cm as calcium ammonium nitrate (NH₄:NO₃ = 1:1) or NPK compound fertilizer (NH₄:NO₃ ≈ 2:1).

Spring cereals were grown each year except for ryegrass for two years. Grain and straw were harvested plotwise. So was the ryegrass stand (one cutting per year). The plant samples were analyzed for N, P and K. The topsoil (plough layer, 0 – 25 cm) was sampled plotwise after harvest in certain years. In some years the subsoil (25-40 and 40-60 cm) was also sampled. Most samples were analyzed for pH and P, K, Ca, Mg extractable in acid ammonium acetate (Ac, pH 4.65, Finnish routine method).

Results and discussion
The total dry matter yield (grain + straw) decreased from about 5000 kg ha⁻¹ to a level of 3000 kg ha⁻¹ when only N was applied (Fig. 1). After 30 years of NP fertilizer the yield level was 4000 kg ha⁻¹. NPK application kept the yield level almost constant. The surplus annual P rate of 70 kg ha⁻¹ seemed to increase the yield a little more. However, the variations between years, and even in the 5-year moving averages, were rather high for all treatments.

It is obvious that yield-reducing deficiency of potassium began to take effect in the latest 10 years. However, missing NK treatments might hide the simultaneous appearance of P deficiency.
The P balance (applied – crop uptake) over 29 years was strongly negative (Fig. 2) when no P was applied. Extractable P in topsoil decreased about 50%. A surplus of 500 kg ha\(^{-1}\) accumulated at an annual application rate of 36 kg ha\(^{-1}\). At this rate no significant change in extractable topsoil P occurred. When a doubled rate was applied the surplus increased to 1500 kg ha\(^{-1}\) and the extractable P in the topsoil increased by 50%.

Without K fertilization its balance was strongly negative (Fig. 3). The extractable K in topsoil was reduced by 70%. The annual application rate of 70 kg ha\(^{-1}\) coincided with the crop uptake but the reduction in topsoil extractable K was still very clear, about 50%.

In 2005 soil samples were taken from the topsoil (0-25 cm) and two depths of subsoil (25-40 and 40-60 cm) (Table 1). The P concentrations in all the treatments were not detectable below 40 cm. Mixing with topsoil rather than leaching might have caused the increase due to P application in the 25-40 cm soil layer. No evidence of K leaching was detected, so the decrease of K balance in K amended soil remained inexplicable.
Figure 3. Cumulative K balance (added – uptake, on the left) and KAc in topsoil (right) with no K fertilizer (-K) and at the rate of 70 kg ha\(^{-1}\) a\(^{-1}\) (+K).

Table 1. PAc and KAc at different depths in 2005.

<table>
<thead>
<tr>
<th>Depth, cm</th>
<th>P added, kg ha(^{-1}) a(^{-1})</th>
<th>K added, hg ha(^{-1}) a(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-25</td>
<td>13.2</td>
<td>56.3</td>
</tr>
<tr>
<td>25-40</td>
<td>7.4</td>
<td>10.6</td>
</tr>
<tr>
<td>40-60</td>
<td>&lt;3.5</td>
<td>&lt;3.5</td>
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</tbody>
</table>

Conclusions
Over thirty years a significant depletion of P and K in soil occurred when they were not given in fertilizers. This caused a reduction in crop yield. An abundant P application exceeding the crop uptake very clearly prevented the yield reduction but did not raise the extractable P concentration in the soil. Severe K deficiency did not start to appear until 20 years of growing cereal without fertilizer K. K application compensating for the uptake by the crop did not prevent the decrease of its extractable concentration in this soil, but this decrease did not affect crop yield.

References
Long-term experiments as unique resources for research on local and global carbon cycling

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Background
Most current long-term experiments (LTEs) were not originally designed as long-term, but rather to address practical issues of importance at the time they were started. For example, the oldest experiments at Rothamsted were initiated in the mid 19th century as a basis for unbiased advice to farmers on plant nutrition (Johnston, 1994). The Sanborn Field Experiment in Missouri, USA, started in 1880, had a similar rationale (Brown, 1994). The main agronomic results, and the management practices derived from them, were often established within the first decade. But, fortunately for later generations, scientists running the experiments had the foresight to realise that additional, and perhaps different, information could be obtained by continuing for longer. Indeed, the conference held in 1993 to mark the 150th anniversary of Rothamsted was entitled “Insight from Foresight” (Leigh and Johnston, 1994).

In temperate climates many soil properties, including soil organic carbon (SOC) content, change slowly over periods of years or decades so LTEs are especially valuable as resources in soil science research. There are several key considerations regarding the future viability and scientific value of existing LTEs:
(1) their use for addressing new research issues;
(2) the need for modifications in order to increase their value as scientific resources;
(3) the value of archiving soil and crop samples so that new analyses can be applied;
(4) the importance of good data organisation.

Types of long-term study
The majority of long-term studies on land management comprise manipulative experiments comparing different land uses and practices involving crop rotations, fertilizers, manures, tillage, crop residue management, irrigation, pesticides, etc. Richter et al (2007) reviewed the different types of long-term experimentation and, especially, how treatment-based LTEs can provide the basis for new research. Chronosequences, sometimes termed “space-for-time substitutions”, provide one alternative if an experiment with contrasting treatments established at the start is not available. An example is a study of SOC changes in Amazonia following clearing of tropical rainforest for establishment of grazed pasture (Cerri et al, 2003). The authors identified 20 sites, on the same soil type, where native forest had been cleared between 2 and 88 years previously. Using this “space-for-time substitution” they found that SOC in the 0-30 cm layer (after taking account of bulk density changes) initially declined by about 5 t ha$^{-1}$ from the 34 t ha$^{-1}$ under forest but, under well managed pasture, recovered to this level within about 10 years. After 88 years of pasture SOC was >50 t ha$^{-1}$, an
increase of at least 16 t ha\(^{-1}\) compared to the initial value – though even this SOC accumulation did not offset the initial loss of C from trees estimated to be at least 100 t ha\(^{-1}\).

Another approach to quantifying SOC changes over time is to sample non-experimental regions at different times – termed “repeated soil surveys” by Richter et al. (2007). Bellamy et al. (2005) is an example of this approach for the UK which showed a loss of SOC in many (though not all) soils over a 20 year period between two soil surveys based on about 2000 sampling sites. A benefit of this approach is that it provides data over a large area and for soils under “normal” management, as opposed to experimental sites. However, the disadvantage is that detailed information on land management practices is usually lacking so interpretation of observed trends can be uncertain. A combination of data from LTEs and other approaches is ideal.

**Soil carbon content – moving between equilibrium values**

A fundamental concept shown by data from LTEs, and reflected in models based on them, is that of SOC equilibration. Thus, following a change in management, SOC content moves from one equilibrium value to another – it does not increase or decrease linearly or indefinitely. This can be seen in the Broadbalk experiment at Rothamsted (Fig. 1) and other LTEs (Johnston and Poulton, 2005). In temperate climates it may take over 100 years for a new equilibrium value to be attained after a major change in management or land use; though, as shown in Fig. 1, SOC may reach 50% or more of the final value within about 25 years. In tropical environments changes may be four times faster. In non-experimental situations, multiple changes in agricultural management over time will often mean that the ultimate equilibrium value is never reached and so not be seen in repeated surveys of farmers’ fields.

![Graph showing changes in soil organic carbon content in some treatments of the Broadbalk Experiment at Rothamsted, UK.](image)

**Modelling soil C dynamics**

Models of SOC dynamics are invaluable tools for predicting soil C trends under different scenarios of management practice or land use. As mentioned above, SOC content changes slowly so, to develop or test models to be used predictively, long-term datasets are required. Provided soil samples have been archived, so they can be analysed by currently acceptable methods, LTEs can provide such data. Smith et al. (1997) report the results of a model evaluation in which SOC data from seven different LTEs was used to test nine models. More

Soil carbon and climate change – making it better or worse?
At the global scale the quantity of C held in soil organic matter is very large, estimated at about 1500 Gt, twice the amount in atmospheric carbon dioxide and three times that in global vegetation (Batjes, 1996). Thus even small changes in SOC stock, if reproduced over a large area, could have significant impacts on the global carbon cycle and influence climate change. If SOC content can be increased through appropriate management, it may be possible to achieve a net transfer of C from atmosphere to soil, thus sequestering C and slowing climate change. A possible mechanism might be by slowing decomposition through reduced tillage; though the magnitude of this effect has often been over-stated (Baker et al, 2006). Another mechanism is through increased input of organic C to soil; this might be achieved through reducing periods under fallow (e.g. by avoiding the fallow year in wheat-fallow rotations practiced in some dry regions if practicable in view of water conservation constraints) or by converting some arable land to grassland or forest. Various studies have sought to quantify the C mitigation possible through land management change (e.g. Freibauer et al, 2004) but recent studies for Europe indicate that the actual magnitude achievable is far less than the potential because current trends in land use tend in the opposite direction; more rather than less land being required for agriculture. Similarly, in a study of four regions in the world (Brazil, Kenya, Jordan, India), changes in land use driven by economic and demographic trends, are expected to lead to decreased SOC stocks and a net release of C from soil to atmosphere, e.g. through deforestation and ploughing up of grasslands (Milne et al, 2007). In addition, climate change itself is likely to cause an overall loss of C from soils, though the trends vary between regions (Jones et al, 2005).

Influence of soil C on soil properties and functions
Although total SOC content changes slowly, fractions within the total change more rapidly in response to changes in management or organic C inputs. Individual groups of soil microorganisms may change following a single input of crop residue or manure. Changes in the size of the soil microbial biomass following a change in management can be detected within a few years, much faster than a change in total soil C (e.g. Powlson et al, 1987). There is evidence that small changes in SOC resulting from differences in management can have a disproportionately large influence on a range of soil physical properties. This is probably because of changes in specific SOC fractions that influence microbial activities or aggregate formation and properties, even where changes in total C content are small. Examples illustrating this have been found, using the Broadbalk Experiment, showing differences between treatments in plough draught (Watts et al, 2006) and in water infiltration rate and aggregate stability (Blair et al, 2006). Long term experiments provide ideal resources for detailed studies on mechanisms and for testing hypotheses regarding the influence of management practices on soil properties and processes, including those connected with organic matter content. However, for some studies, shorter term experiments are also valuable where SOC (or related soil properties) have not reached an equilibrium value and are still undergoing change.
References


Organic matter stability in two soils under continuous maize: results obtained from the DFG Priority Program "Soils as source and sinks of CO₂"

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Preliminary note
The results presented in this paper have been obtained by numerous teams working in the Priority Program 1090 of the German Research Foundation "Soils as a source and sink for CO₂" (DFG-SPP 1090), which was co-ordinated by Ingrid Kögel-Knabner. Starting in the year 2000 the German Research Foundation provided funding for a six-years period with the main goal to increase our understanding on the potential of temperate soils to stabilise carbon (C) over long time scales (i.e., decades to centuries). The results of the individual working groups have been synthesised in a series of review articles published in Journal of Plant Nutrition and Soil Science, 2008, 171(1). An introduction to that is given by Kögel-Knabner et al. (2008). My report strongly relates to these synthesis papers, in particular to that of Flessa et al. (2008). All participants of the Priority Programme should be credited for this presentation.

Introduction
Soil organic matter (SOM) represents the largest terrestrial C pool, being almost 3 times as large as that of the plant biomass. The amount of C stored in a soils is determined by a dynamic equilibrium between organic carbon (OC) inputs from primary biomass production and by anthropogenic activities (e.g., application of organic manure, deposition) and C outputs by mineralisation. Stabilisation of organic matter by (1) selective preservation of recalcitrant compounds, (2) spatial inaccessibility to decomposer organisms, and (3) interactions of OM with minerals and metal ions reduce the mineralisation rate. However, the relative importance of different stabilisation mechanisms in different soils is still poorly investigated. Within the Priority Program "Soils as source and sink for CO₂" a quantitative evaluation of the different stabilisation mechanisms should be achieved for different soils and land use.

When investigating the effects of stabilisation processes on OC turnover in soil, the time scales under investigation are long. Therefore, well documented long-term field experiments and associated sample archives provide valuable sources for such studies. Within the Priority Program, we have chosen three agricultural long-term field experiments and two forest sites for our experiments. Here, focus will be given on two agricultural sites where the following topics have been addressed: (1) storage of OC in different SOM fractions, (2) function of these fraction with respect to OC stabilisation, (3) importance of fossil C for OC storage, (4) rates of OC stabilisation as assessed by compound-specific isotope analysis.
Long-term field sites
One long-term experiment is located at Rotthalmünster in the "Tertiär-Hügelland" of south Bavaria. The soil type was an (Endo-)stagnic Cutanic Luvisol. The soil texture was a silty loam consisting of 11% sand, 73% silt, and 16% clay. The dominating minerals of the clay fraction were illite > kaolinite > vermiculite. In 1979, the continuous maize-cropping experiment was established. Fertilisation was exclusively with NPK, and only the grains were harvested. The mean amount of maize C input by aboveground residues and roots was estimated to 0.63 kg m\(^{-1}\) yr\(^{-1}\). An adjacent soil with continuous wheat cropping was used as reference site for the determination of the amount of young, maize-derived C and older C from C\(_3\) vegetation.

The other site was the long-term experiment "Eternal Rye" in Halle, having a Luvic Phaeozem derived from sandy loess. The texture of the soil was a loamy sand consisting of 70% sand, 20% silt, and 10% clay. The dominating minerals of the clay fraction were illite and smectite. The experiment was established in 1878 and comprise three cropping systems with three different treatments - unfertilised, NPK fertiliser, and farmyard manure. Until 1961, winter rye was grown in monoculture on all plots. In 1961, parts of the plots were transformed to maize monoculture. Maize was produced for silage-making with mineral NPK fertilisation (NPK) and without fertilisation. Maize residue input to soil was approx. 0.08 kg m\(^{-2}\) yr\(^{-1}\), which is much less than that at Rotthalmünster because only short maize stubbles and roots were incorporated to the soil. Adjacent plots remaining under rye cropping were used as reference sites for the \(^{13}\)C natural abundance approach. The experiment in Halle is located in an industrial area where inputs to the soil by coal dust and coal combustion products (soot from nearby industry, fossil fuel-based power plants, residential heating) were large in the past.

Methodological approach
Turnover of OC was determined by a combination of \(^{13}\)C analysis, where the apparent turnover time of OC was calculated from the change of the C\(_3\) - and C\(_4\)-derived OC with time, and by \(^{14}\)C measurements. In the Halle Phaeozem, the contribution of fossil C containing no \(^{14}\)C to total OC was estimated by simple mass-balance calculation assuming a modern \(^{14}\)C age of OC derived from vegetation in the Ap horizon, as it was found in Rotthalmünster. In order to relate different stabilisation mechanisms to OC turnover, functional soil fractions were obtained. The fractionation procedures included different physical and chemical fractionation techniques as well as isolation of extractable phospholipid fatty acids and the determination of black C. The \(^{13}\)C and \(^{14}\)C analyses were also employed on these fractions.

Results and discussion
The mean apparent turnover time of the isolated OC fraction varied from 10 years for large free particulate OM to >500 years for OC resistant to oxidation by H\(_2\)O\(_2\) or Na\(_2\)S\(_2\)O\(_8\) and black carbon. Hence, the different fractionation procedures allowed the separation of SOM fractions with turnover times in the range of the active fraction (<10 years), the intermediate fraction (ca. 20 to 200 years, which is about the range of the bulk soil OC), and the passive fraction (>200 years).
In the Rotthalmünster Luvisol, SOM fractions with faster turnover times than the bulk soil represented 13-20% of total OC, depending on the fractionation procedure. Also, compound-specific δ¹³C analysis revealed that the turnover of the individual substances was less than that of the bulk OC. This is a strong argument that primary recalcitrance does not contribute to the formation of stable SOM. The predominant part of OC (70-80%) had intermediate turnover times of about 50 to 100 years. This part is represented by OM associated with fine- and medium-silt and clay and by OM resistant to acid hydrolysis. The passive OC represented 7-10% of total OC, and was isolated from the mineral-bound OM by different oxidation procedures (H₂O₂, Na₂S₂O₈).

In the Halle Phaeozem, ¹⁴C data indicated that fossil C contributed to about 50% of OC in the Ap horizon. Increasing radiocarbon concentration with soil depth reflected primarily the decreasing contamination with fossil C. Partitioning of OC with crop residues and of fossil C differed mainly as a function of their bioavailability. Turnover rates of maize-derived C in the different fractions showed a similar pattern to that in the Luvisols. Also fossil C was found in all fractions, but it accumulated primarily in the occluded particulate OM and in OC of coarse particle-size fractions. Accumulation of fossil C in the soil may be partly explained by its refractory aromatic structure. But association with mineral-bound OM and its high stability against chemical oxidation also suggests that surface oxidation (as it is also observed for black carbon) and formation of strong chemical bondings may stabilise fossil C. However, high ¹⁴C concentrations in phospholipid fatty acids also showed that some of the fossil C entered the microbial C cycle. By this process old C (i.e., ¹⁴C dead C) gets incorporated into organic molecules that may turn over rapidly.

Despite the fractionation methods produced reasonable results, it has to be clearly stated that they were not specific with respect to the different stabilisation mechanisms mentioned in the introduction. Two or maybe all three stabilisation mechanisms may work simultaneously in the stabilisation of OM molecules. E.g., black carbon is resistant to decomposition due to its highly aromatic structure. Surface oxidation may further stabilise black carbon by interaction with soil minerals, that may, depending on their location in the soil matrix, occluded within aggregates. Further, the fractions still represent SOM pools with different composition and turnover times. Despite these restrictions, the studies provide valuable information about dominating stabilisation mechanisms in arable soils, and identified reasonable measurable fractions with different functions for soil OC stabilisation. These fractionation procedures may be also a valuable tool for evaluating the accuracy of simulation models (e.g., Ludwig et al., 2008) and may be a good basis for the development of process-based OC turnover models.

References


Tracking the fate of lignin in $^{13}$C-labelled arable soils

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Introduction

Lignin is a plant-derived carbon-rich macromolecule that contributes to organic carbon pools in soils and has long been considered one of the most stable components of soil organic matter (e.g. Kögel-Knabner, 2002). However, in recent studies of field experiments with naturally $^{13}$C-labelled lignin, relatively short lignin turnover times of 10 – 40 years were calculated for arable soils, assuming single exponential decay (Dignac et al., 2005; Heim & Schmidt, 2007). In the context of carbon sequestration the proposed decadal time scales of lignin turnover in soils need to be confirmed. This can be achieved by tracking lignin in long-term (several decades) $^{13}$C-labelling field experiments that include multiple sampling dates. The $^{13}$C-labelling technique uses the difference in natural abundance of the stable carbon isotope $^{13}$C between plants of the C₃ and C₄ photosynthetic pathway (Balesdent et al., 1987). The label transfers from biomass onto soil organic carbon when the plants decompose in soil. In arable soil systems the label can be introduced by continuous cropping of C₄ plants (e.g. maize) after previous cropping of C₃ plants (e.g. barley, wheat). After the conversion to C₄ plants, no more C₃-derived lignin is added to the soil and consequently old C₃-derived lignin can be stabilised or degraded only. Management practices like fertilisation with mineral nitrogen or the return of plant residues might affect the stabilisation or degradation of lignin due to negative or positive priming effects (Kuzyakov et al., 2000).

Thus, the objective of our study was tracking lignin in $^{13}$C-labelled long-term field experiments that include different nitrogen and crop residue return levels as treatments.

The results might improve our understanding of the role of lignin in soil organic carbon storage.

Material and Methods

Soils

We analysed archived soil samples from two long-term field experiments with continuous maize cropping after C₃-vegetation: (i) Askov, Denmark (Kristiansen et al., 2005) and (ii) Cadriano, University of Bologna, Italy. Treatments include (i) two levels of aboveground maize biomass returned to the soils after harvest (zero or 0.8 kg dry matter m$^{-2}$ a$^{-1}$, Askov) or
Lignin analysis
Lignin was extracted from soil by cupric oxide oxidation (Hedges & Ertel, 1982; Goñi & Montgomery, 2000), which is a standard method for lignin analysis in soils and sediments. The oxidation products – vanillyl (V), syringyl (S) and cinnamyl (C) phenols - were quantified in the extracts by gas chromatography using a flame ionisation detector (GC-FID). The oxidation products are lignin-specific and their sum can therefore be used as an indicator for lignin (VSC lignin). The stable carbon isotope composition ($\delta^{13}C$) of lignin was determined in the extracts by gas chromatography-combustion-isotope ratio mass spectrometry (GC-C-IRMS; Goñi & Eglinton, 1996).

Results and discussion
Lignin degradation
In the Askov experiment initial C$_3$-derived lignin concentrations were on average 0.24 mg lignin carbon (CVSC) g$^{-1}$ soil or 13.4 mg CVSC g$^{-1}$ SOC. In the period of 18 years on average 33 ± 18 % (mean ± s.e.m., n = 4) of the initial lignin concentration degraded (Hofmann et al., submitted). In the Cadriano soil the initial lignin concentration was 0.13 mg CVSC g$^{-1}$ soil or 15.1 mg CVSC g$^{-1}$ SOC. In the period of 35 years on average 57 ± 10 % (mean ± s.e.m., n = 2) of the initial C$_3$-derived lignin concentration degraded.

Both experiments show that even after almost two or four decades still considerable amounts of old C$_3$-derived lignin remained in the soils which may point to an effective stabilisation of a part of old lignin moieties. This result would contrast the relatively fast lignin turnover times calculated by Heim & Schmidt (2007) and Dignac et al. (2005) and questions the assumption of single exponential decay. However, the low degradation of old lignin found in our study has to be considered in the context of an equally slow mineralisation of bulk C$_3$-derived SOC (23 ± 3 % of initial C$_3$-SOC for Askov and 25 ± 5 % for Cadriano). A possible explanation for the slow mineralisation could be intensive cropping of the soils before the experiments were initiated. Intensive cropping could have resulted in mineralisation of most carbon inputs, leaving solely C$_3$-SOC (and C$_3$-lignin) that was already stabilised.

The results for mineralisation also provide further evidence that lignin generally degrades faster than bulk SOC and thus is not preferentially retained in soil.

Effect of management practices
The time series approach with six measurement points each would allow to detect and verify possible effects of the treatments along the duration of the experiment.

For the management practice (i), return of aboveground maize biomass (zero or 0.8 kg dry matter m$^{-2}$ a$^{-1}$, Askov), we could not detect significant differences in lignin degradation over time. No priming effect occurred, neither for lignin nor for SOC when additional biomass was added. On the other hand, total CVSC concentrations doubled during 18 years with the
incorporation of aboveground biomass while zero input of aboveground biomass (input only from stubbles and belowground biomass like roots and rhizodeposits) led to only small increase in soil lignin carbon concentrations (Hofmann et al., submitted).

For the management practice (ii), mineral nitrogen fertilization (zero mineral nitrogen or 200-300 kg N ha\(^{-1}\) a\(^{-1}\), Cadriano), lignin degradation also seemed to be independent of the treatment. No consistent effect of mineral nitrogen fertilisation on lignin degradation could be found over time. In comparison to lignin, SOC degradation seemed to be affected by fertilisation. We could find a trend of slightly higher SOC losses when the soil was fertilised. This is in agreement with the findings of Kahn et al. (2007), who could show that high mineral nitrogen fertilisation (in comparison to no fertilisation) led to significant losses of soil organic carbon during 51 years of continuous maize at the Morrow plots (Illinois, USA). Our result suggests that the degradation of lignin and bulk SOC was affected differently in the case of nitrogen addition.

**Conclusions**

1. Lignin degradation was slower than expected, after 18 and 35 years two thirds or half of the initial lignin concentrations were still retained by the soils. We currently investigate the underlying stabilisation mechanisms (e.g. chemical recalcitrance or occlusion in aggregates, Christensen, 1996) for lignin in a combined size and density fractionation study.

2. The management practices (i) crop residue return and (ii) nitrogen fertilization seemed not to affect degradation of lignin. No long-term priming effects could be detected.

**References**


Kögel-Knabner, I. (2002). The macromolecular organic composition of plant and microbial residues as inputs to soil organic matter. Soil Biology and Biochemistry 34, 139-162.


Residual effects of inorganic fertilizer and animal manure in two long-term fertilizer trials in Norway

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Introduction
The use of mineral NPK fertilizer and animal manure has been compared since 1922 in two fertilizer trials on a relatively fertile morainic loam soil at Møystad, near Hamar, SE Norway. One of the main original aims of these trials was to establish whether farmyard manure and inorganic fertilizer are equally beneficial in the long term, both for soil structure, crop yields, economic returns, animal feed and human health. Many findings on soil fertility and crop productivity have been reported. Topics studied in recent years have included organic matter, cadmium, mycorrhiza, phosphorus, sulphur and earthworms. Levels of nutrients applied were adjusted in 1983. Yield results for the period 1983-2003 (three rotation cycles) were reported by Riley (2007). In order to study possible residual effects, no manure was applied from 2004 to 2007, and inorganic fertilizer has been withheld from one NPK treatment in each trial.

Methods
Residual effects are evaluated in relation to control plots that have remained unfertilized since 1922, and to plots that have received NPK in mineral fertilizer each year, also after 2003. The treatments selected for this study are described in Table 1. Each treatment has four replicates. The farmyard manure (FYM) applied in the period 1983-2003 was composted cattle manure. Cropping was 2nd-4th year timothy/meadow fescue ley in 2004-2006 followed by oats in 2007.

Table 1. Nutrients supplied during the previous 21 years (1983-2003) in the treatments selected for this study (kg ha⁻¹ yr⁻¹). No nutrients supplied in 2004-'07 to treatments named ‘residual’

<table>
<thead>
<tr>
<th></th>
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<th></th>
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</thead>
<tbody>
<tr>
<td>Unfertilized control</td>
<td>None since 1922</td>
<td>None since 1922</td>
</tr>
<tr>
<td>Mineral fertilizer residual</td>
<td>100 N: 45 P: 140² K</td>
<td>150 N: 25 P: 120 K</td>
</tr>
<tr>
<td>20 Mg ha⁻¹ FYM residual</td>
<td>80 N: 20 P: 70 K</td>
<td>80 N: 20 P: 70 K</td>
</tr>
<tr>
<td>40 Mg ha⁻¹ FYM residual</td>
<td>160 N: 40 P: 140 K</td>
<td>160 N: 40 P: 140 K</td>
</tr>
<tr>
<td>60 Mg ha⁻¹ FYM residual</td>
<td>Not included in this trial</td>
<td>240 N: 60 P: 210 K</td>
</tr>
<tr>
<td>Mineral fertilizer control¹</td>
<td>100 N: 25 P: 120 K</td>
<td>100 N: 25 P: 120 K</td>
</tr>
</tbody>
</table>

¹ same rate applied in 2004-'07 in this treatment. ² 115 kg K applied until 1992, 165 thereafter

Results
Over the period 1983-2003, mean yields in the unfertilized control treatment were in both trials 46% of that obtained with the mineral fertilizer treatment that received 100 kg N, 25 kg P and 120 kg K ha⁻¹. Yields with 20 and 40 Mg FYM ha⁻¹ were 87% and 93%, respectively,
of the latter treatment in E-trial, whilst in F-trial they were 79% and 83% at these FYM rates and 92% with the use of 60 Mg FYM ha\(^{-1}\). Approximate balance between the supply and takeoff of N, P and K was achieved at the lowest FYM rate, but higher manure rates resulted in large surpluses of all three nutrients. This is illustrated in Fig. 1, which is based on data for 10 representative years for which FYM analyses were available. N surpluses were almost 90 kg ha\(^{-1}\) yr\(^{-1}\) at the medium FYM rate and over 150 kg ha\(^{-1}\) yr\(^{-1}\) at the high rate.

**Figure 1.** Nutrient surpluses (applied – removed) at three levels of FYM, compared with using 100 kg N ha\(^{-1}\) in two NPK treatments. Mean of 4 cereal, 4 ley and 2 potato crops.

DM yields obtained during the residual measurement period 2004-2007 are shown in Fig. 2. The decline in grass yield was due to sward ageing. Grain DM yield only is shown for 2007.

**Figure 2.** DM yields obtained in 2004-2007. Residual responses to fertilizer and FYM, compared to control treatments with no fertilizer and mineral fertilizer each year.
No significant residual effect of the mineral fertilizer treatment was found in either trial, relative to the unfertilized control. Previous use of manure, on the other hand, gave large residual effects, with only a slight decline over the four study years, relative to the fertilized control. In E-trial, the plots previously treated with 20 and 40 Mg FYM ha\(^{-1}\) yielded on average 83% and 94%, respectively, of the mineral fertilizer control, whilst the unfertilized control yielded 50%. In F-trial, the corresponding figures were 75%, 83% and 85% with 20, 40 and 60 Mg FYM ha\(^{-1}\), and 39% for the unfertilized control. Thus in both trials, the residual responses were approximately the same as when annual manure applications had been made.

A broadly similar pattern was seen in nutrient uptake responses. On FYM-treated plots, plant concentrations of the mineral nutrients measured (N, P, K, Ca, Mg, S) were in most cases close to the levels found with the mineral fertilizer treatment, whereas concentrations were consistently lower in the unfertilized control and mineral fertilizer residual treatments. Total uptakes of N, P and K are shown in Fig. 3, averaged over the residual period 2004-2007.

![Figure 3](image_url)

**Figure 3.** Mean uptakes of N, P and K (kg ha\(^{-1}\) yr\(^{-1}\)) in the residual years 2004-2007.

Large residual increases in nutrient uptakes were found after manure use, but not after mineral fertilizer (Table 2). At high manure rates they approached uptakes with current fertilizer use.

<table>
<thead>
<tr>
<th></th>
<th>Min. fert. residual</th>
<th>20 Mg ha(^{-1}) FYM residual</th>
<th>40 Mg ha(^{-1}) FYM residual</th>
<th>60 Mg ha(^{-1}) FYM residual</th>
<th>Min. fert. currently</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>E-trial</td>
<td>3.6</td>
<td>42.0</td>
<td>61.2</td>
<td>nd</td>
</tr>
<tr>
<td></td>
<td>F-trial</td>
<td>-1.8</td>
<td>40.3</td>
<td>59.6</td>
<td>61.7</td>
</tr>
<tr>
<td>P</td>
<td>E-trial</td>
<td>1.3</td>
<td>6.6</td>
<td>9.9</td>
<td>nd</td>
</tr>
<tr>
<td></td>
<td>F-trial</td>
<td>1.0</td>
<td>7.2</td>
<td>9.9</td>
<td>10.1</td>
</tr>
<tr>
<td>K</td>
<td>E-trial</td>
<td>2.5</td>
<td>47.1</td>
<td>69.8</td>
<td>nd</td>
</tr>
<tr>
<td></td>
<td>F-trial</td>
<td>6.3</td>
<td>50.4</td>
<td>77.2</td>
<td>71.8</td>
</tr>
</tbody>
</table>

*Table 2. Increases (2004-2007) in uptakes of N, P and K (kg ha\(^{-1}\) yr\(^{-1}\)) derived from the use of mineral fertilizer and farmyard manure prior to 2004, and from the current use of mineral fertilizer (100:25:120 NPK), relative to the long-term unfertilized controls.*
At the low FYM level, increases in residual uptake use were well above the annual surpluses (Fig. 1), but they were below them at higher FYM levels. The increased fertility afforded by previous manure use is probably very long-lasting, and is an important factor when comparing FYM with mineral fertilizers, which, despite high initial effectiveness, give no residual effect. A further residual benefit of manure was seen in the ley years, as it gave higher digestibility and slightly lower risk of grass tetany than did the use of mineral fertilizer (data not shown).

A complicating factor in this study was that, although no clover was sown originally, a small amount of red clover was observed on the FYM plots, presumably due to seeds present in the manure. Some white clover also appeared on the unfertilized control plots. At the first cut in 2006, clover was hand-sorted on all plots. Red clover amounted in E-trial to 18% and 21% of total DM at low and medium FYM levels, whilst in E-trial, 11% was found at the low FYM level and 16% at medium and high levels. On the unfertilized control plots, white clover amounted to 5-6% of total DM in both trials.

Uptakes of N in clover were calculated on the basis of analyses of clover material, assuming a linear increase in the amount of clover from zero in 2003 up to the levels recorded in 2006. The mean uptake values are shown in Table 3. They represented 6-7% of the total N uptake on unfertilized control plots and between 15% and 23% of the total N uptake on FYM plots. The increases in N uptake attributed to manure are therefore overestimated to a minor extent.

### Table 3. Mean N uptakes in clover material (kg ha\(^{-1}\) yr\(^{-1}\)) calculated for the years 2004-6.

<table>
<thead>
<tr>
<th></th>
<th>Unfert. control</th>
<th>20 Mg ha(^{-1}) FYM</th>
<th>40 Mg ha(^{-1}) FYM</th>
<th>60 Mg ha(^{-1}) FYM</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-trial</td>
<td>5.7</td>
<td>10.0</td>
<td>12.6</td>
<td>-</td>
</tr>
<tr>
<td>F-trial</td>
<td>4.4</td>
<td>9.2</td>
<td>11.4</td>
<td>11.8</td>
</tr>
</tbody>
</table>

**Discussion and conclusion**

In terms of the productivity of nutrient inputs, these trials show that mineral fertilizer is more efficient than farmyard manure in the year of its application. In contrast to manure, however, it showed no residual effect on crop yield or nutrient uptake when its use was discontinued. Thus it seems to have little lasting effect on soil fertility, even though its use has increased soil organic matter and nutrient contents, relative to the unfertilized control (Riley, 2007).

The low FYM level gave almost as high residual benefits as did the higher FYM levels, with little of the environmental risk associated with the latter due to nutrient surpluses. Manure use affords further fertility benefits in terms of raising soil pH, micronutrient levels and biological activity, as well as making likely improvements to soil structure, infiltration and workability.

**Reference**

Crop response to sustained reductions in annual nitrogen fertilizer rates using long-term experiments as research platform

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Abstract
Referring to the current Danish debate on measures and legislation regarding prescribed nitrogen (N) rates, long-term field experiments (LTEs) hosting a short-term study have proven their value as research platforms to generate estimates that would otherwise be impossible to obtain.

Introduction
The residual effect of organic amendments on soil N fertility is reasonably well-known for incorporation of crop residues and applications of animal manures. Mineral N fertilizers may, beyond their direct first year effect on crop productivity, also have a residual effect on soil N fertility mainly caused by crop residues left in the soil. Although this effect of fertilizer N rate may be minor, the annual effects may accumulate over time. Thus the long-term effect of fertilizer N rate becomes interesting not only from a theoretical point of view, but also in terms of evaluating soil organic N dynamics and adjusting fertilizer N rates.

The long-term effect of a sustained reduction in fertilizer N rate on yield, N off-take and quality has become an issue in the Danish environmental debate. To meet the Nitrate Directive, the Danish legislation prescribes maximum N-rates corresponding to c. 90% of the normative N-rate for economically optimal yields (Mikkelsen et al., 2005). This presentation discusses how LTEs may be applied in the evaluation of the long-term effect of sustained reductions in N-rates.

Materials and methods
Data on the interactions between previous rate of N application (Nprev) and annual rates of N (Nnew) was obtained from a series of LTEs hosting short-term N-response experiments. LTEs were located at Askov, Ronhave, and Jyndevad Experimental Stations in Denmark, and at Orup and Fjärdingslöv sites in South Sweden. The results of the experiment at Ronhave have been reported by Thomsen et al. (2003) and data from the other sites are reported by Petersen et al. (in prep.). Spring barley was used at all sites as test crop for the short-term experiments. The LTEs at Askov and Jyndevad and in Sweden are included in the inventory of on ongoing Nordic LTEs as DK-2, DK-3 and SE-9001, respectively (Petersen et al., 2008), while the Ronhave site has been closed.
The main N\textsubscript{prev} plots in the LTEs were divided into subplots of 2-4 m\textsuperscript{2} (gross size) where increasing levels of N\textsubscript{new} were established for the short-term study using applications of calcium ammonium nitrate (CAN) at rates of 0-150 kg N ha\textsuperscript{-1} in steps of 30 kg N ha\textsuperscript{-1}. A full crop stand surrounding the net subplots was kept until harvest.

Grain yield, grain N concentration, grain N\textsubscript{offtake}, total N\textsubscript{offtake} (grain+straw) and grain weight responses of spring barley to combinations of N\textsubscript{prev} and N\textsubscript{new} were recorded. A common statistical model including the linear and quadratic effect of previous (N\textsubscript{prev}) and recent (N\textsubscript{new}) N fertilizer application as well as the interaction effect was applied by site:

\[ Y_{\text{common}} = \alpha + \beta N_{\text{prev}} + (\gamma N_{\text{prev}}^2) + \delta N_{\text{new}} + \varphi N_{\text{new}}^2 + \gamma N_{\text{prev}} N_{\text{new}} + B + \epsilon \]  

(1)

Due to differences in the LTE experimental lay-out, the common model was adjusted to include variations in the design of individual LTE.

From the predicted response surface estimated by eqn. (1) two response curves were extracted. The one-year N response was represented by the curve (full line) for which N\textsubscript{prev} is constant and N\textsubscript{new} \in [0..150 kg N ha\textsuperscript{-1}]. The response including the long-term effect was represented by the curve (dashed line) where N\textsubscript{new} = N\textsubscript{prev} corresponding to the diagonal of the response surface. The two types of curves are estimated and plotted for comparison at each site and year (not shown). The schematic figure on the left illustrates the two response curves. The complete number of estimates and their interpretation are presented by Petersen et al. (in prep.).

**Results**

Grain yield decreased by 8×10\textsuperscript{-3} ton/ha (kg N/ha)\textsuperscript{-1} [= 8 kg grain (kg N)\textsuperscript{-1}] and total N\textsubscript{offtake} by 86 g/ha (kg N/ha)\textsuperscript{-1} [= 86 g (kg N)\textsuperscript{-1}] for an annual decrease in N\textsubscript{prev} accumulated during >35 years using mineral fertilizers as source for N\textsubscript{prev}. When the N source for N\textsubscript{prev} was animal manure, the N\textsubscript{prev}×N\textsubscript{new} interaction was significant, but for N\textsubscript{new}=100 kg N/ha the effect of N\textsubscript{prev} is greater than for mineral fertilizer, particularly regarding the N\textsubscript{offtake}. In contrast, the quality parameters grain N concentration and grain weight were not clearly affected by N\textsubscript{prev}.

**Discussion**

**Concept of LTEs hosting short-term experiments**

The selected LTEs have all been running for more than 35 years, and the size of the main net-plot allows division into subplots of varying N-rates without or with only a minor interruption of the LTE plan. To overcome the problem with tillage-caused dispersion between main plots (Sibbesen et al., 2000), the size and shape of the gross subplots were designed to fit into the long-term main net-plot for each of the selected LTEs. The net subplots were guarded by at
least 25 cm border with a full crop stand to counteract edge effects. This was assumed to prevent inter-plot competition for applied N (N_{new}) (Petersen, 2005) and thus the net subplot is regarded as fully representative for the N-rate treatment in the short-term experiment.

Although differences in soil C and N contents within the individual LTE were small (Petersen et al., in prep.), the differences established by 3 or 4 different N-rates at each individual LTE during more than 35 years represent a unique platform for testing the effect of N_{prev} within a normal range of N-rates for N_{new}. In addition, subdivision of the main net-plot into subplots treated with increasing rates of mineral fertilizer N in the short-term experiments allows us to investigate the N_{prev}×N_{new} interaction, an opportunity that we could not otherwise achieve.

Limitations of LTE in estimating N_{prev} and N_{new}
The LTEs used in the short-term study by Petersen et al. (in prep.) are designed for estimation of the N_{prev} effect and the N_{prev}×N_{new} interaction within a reasonable range around the economically optimal fertilizer N rate. Using LTEs with ranges for N_{prev} may be regarded as a much better basis for estimation of the long-term effect of reduced N rate than interpolations using recordings of yields in long-term unfertilized treatments that are far from the relevant range of fertilizer N rates. Although the Nitrate Directive aims to protect the aquatic environment against pollution caused by nitrates from agricultural sources, the community still needs feed and food. Therefore measures reducing the nitrogen loading will not exclude the use of fertilizer N, making the long-term unfertilized case irrelevant in predicting the effect of N_{prev}. Thus, only LTEs with more than two N-rates of N_{prev} within a reasonable range are qualified for estimating the effect of N_{prev}.

The datasets we used originate from five experimental sites due to the limited numbers of LTEs suitable for our short-term study. Also the number of years for the short-term experiments was limited, as we have to respect the LTE plans and crop rotations. The choice of spring barley as a test crop was in accordance with the crop rotation in the LTEs. Thus the short-term study was guest at the LTEs and the design had to be adapted to this circumstance (e.g. with respect to the size of subplots), particularly not to disable the treatments in LTEs. In consequence, repeating of the short-term experiment may be postponed until next time spring barley is represented in crop rotation.

In LTEs with continuously grown spring barley (Jyndevad and Rønhave) the short-term experiment was repeated once in the following year. The prerequisite of an experimental design with a clear separation of the effects of N_{prev} and N_{new} excludes continuously repeating of the short-term study as several consecutive experimental years would accumulate the effect of N_{new}, introducing a new effect neither related to N_{prev} nor N_{new}. To increase the number of datasets useful for calculations of the N_{prev}×N_{new} interaction needs involving of other LTEs.

Estimates of N_{prev} and N_{new}
The general insignificance of the N_{prev}×N_{new} interaction for LTEs using mineral fertilizer as a source for N_{prev} means that the effects are additive which makes interpretation simpler, but for the Askov-LTE using animal manure as a source for N_{prev}, the N_{prev}×N_{new} interaction effects were significant. When the effects are additive, the size of the estimates for N_{prev} may be related to the linear term of N_{new}. In all cases, the effect of N_{prev} on yield and N_{offtake} was
significant but smaller, and often much smaller, than the effect of N_{new}. In contrast, the grain N concentration and grain weight, which are regarded as quality parameters, were unaffected by the long-term effect of reduced N-rate.

**Causality – interactions with experimental conditions**
The effect of N_{prev} may include interactions and confoundings requiring interpretation of the effect in relation to conditions at the experimental sites. Relevant issues are climate, soil type including the C:N ratio, residual organic matter, other accompanying nutrients proportional to the N_{prev} rate, nutrient source of N used for N_{new}, and finally the age of the LTE. Although a complete separation of interactions and confounding is impossible, an attempt has been done to indicate certain causalities for N_{prev} effects (Petersen et al., in prep.). In balancing the arguments, however, the effect of N_{prev} obtained at Askov may clearly be overestimated due to the accompanying nutrients with the animal manure used, and also, but to a lesser extent, the longer previous period of accumulation due to the age of this LTE.

**Conclusion**
LTEs as a research platform are a valuable resource in answering questions raised by the present debate on measures and legislation for current agricultural problems. Based on the predicted curves (Petersen et al., in prep.), it was concluded that the fertilizer N rate has to be reduced with more than 30 kg N ha^{-1} in more than 30 years before a significant long-term effect of sustained reduction in N rate on grain yield and N off-take may be recognized in agricultural practice. In addition, a long-term effect of sustained reduction in N rate on grain quality expressed as grain N concentration and grain weight was clearly insignificant.

**References**
Carbon sequestration and residual effect of differently aged grass leys

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Abstract
Grass leys are often found to improve soil fertility e.g. by enhancing soil organic matter content and improving soil structure. To quantify soil carbon (C) pool build-up and the residual effect from ryegrass leys, we determined grain and straw yields in three test crops of spring barley after plough-in of zero to five years old mixed-grass leys. The soil C content was measured: at grass establishment, at grass plough-in, and after three years of spring barley. Soil C pools tended to increase with the age of grass leys. The residual effect was significantly greater after five years grass leys compared to younger leys only in the first test crop. In the second and third test crop no significant yield effect from age of grass leys was found. Furthermore in all three test crops, adding N-fertilizers erased the residual effect from the grass leys. Thus the residual effect after mixed-grass leys was mainly an effect of stored and immediately released N, in contrast to grass-clover or organic fertilizer based systems, where residual effects usually are longer lasting.

Introduction
In arable cropping, grass crops are used for grazing, for cutting, and for production of silage. They may serve as an effective nitrate catch crop during the autumn and winter period and when included in arable crop rotations, grass leys are found to play an important role in maintaining or increasing the soil carbon (C) pool, and in enhancing the soil nitrogen (N) mineralization potential for the benefit of subsequent arable crops.

The impact of fertilization on C and N accumulation in leys results not only from the positive effects that addition of plant nutrients exerts on below- and above-ground biomass production. Compared to grass-only leys, the inclusion of legumes with N$_2$-fixing capacity will lead to an increased N mineralization potential when the ley is ploughed under. Thus the effect of rotational leys on soil C sequestration and N mineralization capacity mostly results from several different mechanisms that in most field experiments remain confounded. In this study we examine C sequestration and residual N effect of grass leys without legumes and grazing animals in order to understand the basic processes under grass lands. Based on the hypotheses that increasing grass ley age i) enhances soil fertility by e.g. improving the soil structure and increasing the organic carbon content, and ii) increases soil N pools, the aim of this study was to determine the residual effect of grass leys of increasing age and quantify soil carbon pool build-up. Details of the experiment are given in Rasmussen et al. (in prep.).

Materials and Methods
The experimental area was located at Askov Experimental Station in Jutland, Denmark. The soil is a light sandy loam classified as an Alfisol (Typic Hapludalf) with the Ap-horizon (0-25
cm) containing 10% clay, 11% silt, 44% fine sand, and 35% coarse sand. The mean annual
temperature and precipitation of the site are 7.6°C and 862 mm, respectively (1961-1990).
The experimental area had a history of cereal cropping.

In spring 1996 the first plots were established with a grass mixture of perennial ryegrass
(Lolium perenne L.), meadow fescue (Festuca pratensis Huds.), timothy (Phleum pratense L.)
and smooth meadow grass (Poa pratensis L.) undersown in spring barley (Hordeum vulgare
L.). Each year until 2001 new grass plots were established in the same way. Until grass ley
establishment plots were maintained under spring barley. Plots under grass leys were subject
to three to four cuttings in each production year (1997 to 2001). During this period, the leys
received an annual dressing of mineral fertilizer (225 kg N, 48 kg P and 288 kg K pr. ha).

The test phase (2002-2004): spring barley with a grass catch crop
In March 2002 all leys were ploughed under and sown to spring barley with an under-seed of
perennial ryegrass (8 kg seed/ha), employed as a nitrate catch crop. In the test phase (2002-
2004), the plots received an annual dressing of 32 kg P and 168 kg K per ha. In spring 2003,
and 2004, the catch crop was ploughed in and spring barley (under-sown with ryegrass) was
sown again. In the test phase, each of the previous grass ley plots was divided randomly into
six subplots (each 6m x 9m) to test a range of annual N fertilizer applications (0, 30, 60, 90,
120 and 150 kg N/ha). The barley was harvested at maturity with a plot combiner allowing
grain and straw dry matter and N yields to be determined separately. The straw was removed.

The nitrate leaching loss experiment (1996-2004)
A nitrate leaching loss experiment was established in an adjacent field with similar soil
properties similar as found in the main experiment. In 1988 twelve porous ceramic suction
cups had been installed at 1 m soil depth retrieving percolates from an experimental plot of 50
m x 50 m. In spring 1996 the plot was ploughed and sown to spring barley with an under-seed
of a grass mixture similar to that used in the main experiment. The fertilization and grass
cutting regime was similar to that applied to the grass ley plots established in 1996. In March
2002, the then six years old grass ley was ploughed under and received similar treatments as
the main experiment until 2004. The spring barley received 120 kg N ha⁻¹ in mineral fertilizer.
From autumn 1996 to spring 2004, percolates were sampled from the ceramic suction cups
and analysed of nitrate concentrations.

Soil sampling
During 1996 to 2001, bulk soil (composed of 20 sub-samples) was taken in spring from the 0-
20 cm depth before a given plot was sown to grass. All plots were re-sampled in spring 2002
before the grass leys were ploughed under and again in autumn 2004 following the last test
crop of spring barley. The soil samples were analysed for total C.

Results and Discussion
Nitrate leaching and N balances for the grass and test phases
Introduction of a grass ley markedly reduced the NO₃-N leaching (Figure 1). Concentrations
of NO₃-N at least halved under grass compared to the years before and after the grass phase
where the soil was cultivated. The N balance for the grass phase (1996-2001) showed that the
N input as mineral fertilizer was quantitatively taken up and carried away in grass cuts. In the test phase (2002-2004) all but the highest fertilizer application (150 kg N ha⁻¹) showed negative N balances.

![Nitrate concentration graph](image1)

**Figure 1.** Nitrate concentration (mg NO₃⁻ N l⁻¹) measured in water sampled by ceramic suction cups from the adjacent field with similar management as the plots with grass establishment in 1996.

**Soil organic carbon content**

In 2002, the first year after the grass leys, yield of spring barley grain with no N fertilization followed the order expected from the grass ley ages; cf. the oldest grass leys resulting in the highest grain yield and so forth (Figure 3). This trend was similarly reflected in the straw yield. Adding mineral N fertilizers gradually erased the grain yield differences found when no N fertilizer was added. In 2003 and 2004 no significant differences in neither grain nor straw yields were found between the different grass ley ages (Data not shown).

![Total C content graph](image2)

**Figure 2.** Total C content (g C 100 g⁻¹) in the 0 – 20 cm soil layer before the grass phase, after the grass phase and after the test phase. Mean and S.E. calculations based on three replicates.
The organic C content in the upper 20 cm averaged 2.33g 100g\(^{-1}\) (S.E. ± 0.02, n = 18) at establishment of the grass leys from 1996 to 2001 (Figure 2). The C content in the soil at grass establishment was stable with no significant differences in the C content between the six grass establishment years. In 2002 at plough-in of the grass leys there was a trend, although not significant, of higher C contents in the soil under the older leys than the younger leys corresponding to an annual average build-up of 0.036 g C 100g\(^{-1}\) or 1116 kg C ha\(^{-1}\).

Spring barley grain and straw yield in the test phase

![Graph showing grain yield vs. nitrogen applied](image)

Figure 3. Yields of grain (hkg ha\(^{-1}\) at 15% water content) in the first test crop of spring barley (2002) following mixed-grass established in the years 1996 - 2001. Mean and Standard Error (S.E.) calculations based on three replicates.

In contrast to other pasture studies including clover and grazing animals an enhanced residual effect from the older grass was only present in the first year of spring barley in the present study. Also in contrast to the previous studies was the finding that addition of mineral N fertilizers completely erased the pre-crop effect in the grain yield of the cereal crop. These findings showed that the short-term residual effect in the present study was mainly due to an increase in plant available N in the older the grass leys which stresses the importance of clover or organic fertilizers in improving longer-term soil fertility under grass leys.

**Conclusion**

In spite of lower NO\(_3\)-N loss during the grass phase, well-balanced N inputs, and C pool build-up no lasting residual effect could be observed after mixed-grass. In the present experiment the first year residual effect seemed to relate to stored and immediately released N, indicating that mixed-grass and inorganic fertilizers cannot increase longer-term soil fertility alone. Therefore the present study stresses the importance of forage legumes, organic fertilizers and grazing animals in soil fertility build-up.

**References**

The two experiments are located on the same hayfield. The soil is a peat soil (Histosol) and before the land was broken loss on ignition was just over 70%, bulk density about 0.15 g/cm³ and the degree of decompositions 2 on the v. Post scale.

The bog was drained by open ditches, 50m apart, in 1965. In 1969 the land was broken and hived. Experiment 299-70 started a year later with sowing and fertilisation. Experiment 437-77 is in the same field, 200 m apart. The land was broken at the same time but with final cultivation and sowing a year or two later. In both cases the grasses sown included Phleum pratense, Festuca rubra and Poa pratense. However the two last species were of varieties that disappeared during the first few years. Experience had shown that this peat soil had a high affinity for phosphor and so large application rates were used (60 to 70 kg/ha) upon sowing. When experiment 437-77 started the P status had normalised after a few years of normally fertilized lay. However the experiment 299-70 was laid out on the freshly broken bog soil without previous sowing and without extra P in the seedling year. Neither of the two experiments was designed as a long term experiments.

Both experiments have 7 treatments and 4 complete blocks. The plots were 4x9 m² and the parts harvested were ca. 20 m². The mineral fertilisers were ammonium nitrate (33% N), triple phosphate (19.7% P) and potassium chloride (49.8% K). Sheep dung is a mixture of faeces and urine under slatted floor and varies from year to year in composition. A common range of nutrients is 0.8-0.9% N, thereof 0.25-0.30% as ammonia, 0.25-0.30% P, 0.6% K, 0.3% Ca and 0.12% Mg. The mineral fertilisers were applied in spring with onset of growth, usually May 15-20th and the sheep dung was applied in April on a day with favourable weather condition. Experimental error was generally low with CV around 5%.

Experiment 299-70
The experiment was set up as a demonstration trial where N, P and K deficiency would be visible for the students and farmers. The differences were from the beginning large for a grass trial and the experiment had the additional function of demonstrating how a field experiment should be laid out.

The treatments are as follows:

<table>
<thead>
<tr>
<th>Treatment</th>
<th>kg N</th>
<th>kg P</th>
<th>kg K</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>0</td>
<td>30</td>
<td>100</td>
</tr>
<tr>
<td>b</td>
<td>50</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>c</td>
<td>50</td>
<td>30</td>
<td>0</td>
</tr>
<tr>
<td>d</td>
<td>100</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>e</td>
<td>100</td>
<td>30</td>
<td>0</td>
</tr>
<tr>
<td>f</td>
<td>100</td>
<td>30</td>
<td>100</td>
</tr>
<tr>
<td>g</td>
<td>100</td>
<td>30</td>
<td>100 + 10 t lime 1970</td>
</tr>
</tbody>
</table>

The pH in 0-5 cm depth was 4.5 to 4.7 in 1971 apart from the g-treatment where it was 5.8.
During the first years until 1977 the experiment was cut twice. From 1979-1987 the yield was not measured although the treatments were fertilised according to the plan and the grass mowed once a year and the hay removed. From 1988 the plots yield has been measured, apart from 1990. It was cut once a year at the end of July or the beginning of August. Samples for analysis have always been collected when the yield was measured.

Yield
For the first couple of years some of the sown grasses survived in the 0P and 0K plots but after 5 years they have disappeared from 0P plots witch became almost barren. Gradually some vegetation came in, *Carex*, *Eriophurum*, *Calluna* and increasingly *Festuca vivipara* which has been dominant since ca. 2000. Yields was accordingly small but has increased in the last few years to about 2 t/ha dry matter. The sown grasses survived somewhat longer in the 0K plots but there a moss mat developed and *Carex* species became dominant. In the other treatments the sown grasses, in particular the timothy survived and is still the dominant grass species. The DM yield for each treatment is shown in fig. 1.

It is interesting to note that N-application had no effect on the 0K and 0P treatments but on the other hand that 0N plots, which did not produce any considerable yield for the first 5 years have now recovered and from 1990 there yield is approaching the 100 N plots.

![Figure 1. DM yield in experiment 299-79.](image)

It is also of interest to see how the N-yield of 0N plots has developed over the years, indicating mineralization of the freshly drained bog.

![Figure 2. N removed by yield from three treatments of the experiment 299-70.](image)

Soil samples were taken at the beginning of the experiments and since then at irregular intervals. In a recent unpublished MS thesis (Gudmundsson, 2007) the P budget of plots d and f were studied. The soluble P-AL in the top 5 cm was 25 mg/kg on d-plots but 231 mg/kg in f-plots. The P-AL in 5-10 cm was much lower, and treatment effect was much smaller. In the d-plots treatments the P balance was negative, 34 kg P/ha had been removed from 1971.
whereas in the f-plots treatment the balance was positive, 480 kg P/ha had been added to the soil and had been bound in the inorganic part, rather than in the organic matter of the top soil.

**Experiment 437-77**

The idea behind this experiment was that using the winter temperature one could to a certain extent predict the grass growth the following summer and that one could reduce the uncertainty in hay yield by using different amounts of fertiliser. Basically the experiment was testing increasing N and K (a-d) including a treatment (g) were N and K was decided from winter temperature. The fertilisation on plots g varied thus from year to year but was generally about 100 N and 80 K until 1991. Additionally there are two treatments using sheep dung. The one (e) follows the handbook recommendation and was expected to give 60 kg available N/ha and sufficient P and K. More recent analysis indicates that the N-content was overestimated and 45 kg N/ha would be more correct. In the second treatment involving sheep dung (f) mineral N was added to give equal N application as in the g-treatment. From 1993 treatments b and g have had the same application rates and f has obtained 40 N as an additional N fertiliser to the sheep dung. The g-treatment is omitted in this paper. The experiment has been treated after common practice and mowed twice a year, however a few years only once.

The treatments are as follows in kg/ha:

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Fertilizer</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>30 kg P 60 kg N 60 kg K</td>
</tr>
<tr>
<td>b</td>
<td>30 kg P 100 kg N 80 kg K</td>
</tr>
<tr>
<td>c</td>
<td>30 kg P 140 kg N 100 kg K</td>
</tr>
<tr>
<td>d</td>
<td>30 kg P 180 kg N 120 kg K</td>
</tr>
<tr>
<td>e</td>
<td>15 t sheep dung</td>
</tr>
<tr>
<td>f</td>
<td>15 t sheep dung + 40 kg N</td>
</tr>
<tr>
<td>g</td>
<td>30 kg P 100 kg N 80 kg K (since 1993)</td>
</tr>
</tbody>
</table>

In the autumn 1991 a heavy implement drove over the experiment and it was thought that it had been spoilt and in spring 1992 all plots got a moderate fertiliser application. The damage was less than it appeared at first and from 1993 the experiment has continued.

**Yield**

The yield varies very much from year to year as can be seen in fig. 3 where the mean of a-d can be regarded as yield indicator for each year. There was no correlation between yield level each year and the effect of sheep manure. This effect is further demonstrated in fig. 4, which shows the difference e-(a+b+c+d)/4 and f-(a+b+c+d)/4. The difference between bars each year indicates the effect of additional N to sheep dung.

![Figure 3. Average yield of treatment a-d and manure](image_url)
The yield of plots e and f in the first year is as could be expected from the amount of nutrients applied the first years. But from 1982 it is higher or similar than from plots receiving considerably higher doses of nutrients. The only exception is 1993, following year with commercial fertilizer only. The first obvious explanation for this great effect is that it is due to N-accumulation, but this is contradicted by plots e and f always being paler then even plots a.

**Chemical content**

Mineral content of yield in 1st cut 2007 and total yield of N, P and K is shown in table 1 as a typical example. As the pale colour indicates the N-content in yield from manured plots is relatively low, but the same plots are very height in Ca and Mg. N-release in treatment a is about 85 kg/ha and the release in e-plots is 100 kg or more.

**Table 1. Chemical content in 1st. cut and total yield of macro nutrient 2007.**

<table>
<thead>
<tr>
<th>Treatm.</th>
<th>% in DM, 1st cut 2007</th>
<th>Total yield 2007, kg/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>2.30 0.29 0.34 0.24 0.89 0.32 145 17.3 54</td>
<td></td>
</tr>
<tr>
<td>b</td>
<td>2.38 0.27 0.35 0.26 1.02 0.29 174 18.6 70</td>
<td></td>
</tr>
<tr>
<td>c</td>
<td>2.39 0.26 0.30 0.23 1.19 0.29 195 20.3 90</td>
<td></td>
</tr>
<tr>
<td>d</td>
<td>2.45 0.26 0.26 0.22 1.48 0.23 205 21.1 115</td>
<td></td>
</tr>
<tr>
<td>e</td>
<td>2.05 0.28 0.48 0.41 1.01 0.29 158 20.7 73</td>
<td></td>
</tr>
<tr>
<td>f</td>
<td>2.14 0.23 0.48 0.39 0.85 0.35 136 17.3 60</td>
<td></td>
</tr>
<tr>
<td>g</td>
<td>2.35 0.25 0.28 0.21 0.98 0.25 175 17.9 67</td>
<td></td>
</tr>
</tbody>
</table>

Soil samples have been taken occasionally. In 2005 the pH is highest on plots e and f (5.3 and 5.0 respectively) but commercial fertilizers had lowered pH (pH 4.6 on plots a and 4.1 on plots d). Accordantly Ca-AL and Mg-AL in considerably higher in e and f plots. Higher pH on plots e and f has led to increased amount of dicots in vegetation, which may in part explain higher Ca-content in yield from these plots.

Soil respiration was measured in 2000 and highest respiration rate was found in manured plots, as well in situ as in laboratory.

**References**

Long-term effects of fertiliser treatments on botanical composition on permanent grassland in Iceland

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Introduction
All long-term experiments in Iceland were located on permanent grassland. The experimental plots got same fertilisation year after year resulting in changes in soil pH and nutritional status (Gudmundsson et al. 2008). The most visible effects of changing soil conditions following shortage or overdoses of fertilisers are changes in botanical composition of the grassland. In this paper we present results of botanical analyses in 2006 and 2007 on eight experiments in Southern Iceland shortly after their termination.

Material and methods
Icelandic soils are formed on volcanic materials, giving them the properties of Andic soils to a greater or lesser extent. Three of the eight experiments that are subject of this study were on freely drained Andosols, other three on sandy soil (Vitric Andosol) and two were on drained peat with high input of volcanic ash and other mineral material (Histic Andosol).

Seven of the experiments were designed to test the fertiliser effects of a single nutrient each, N, P, or K, with three or four non-zero levels and all but two included a zero level (Table 1). One experiment compared nitrogen fertilisers which had different effects on the soil reaction and nutrient status. It also included a zero and a high N-level (Gudmundsson et al. 2008). During the experimental period the plots of four experiments were split. In three of them two N-levels were applied to the sub-plots and in one experiment the P-treatment of the sub-plots differed. After the splitting of plots the plot size in the experiments ranged from 18-50 m².

The botanical composition was estimated visually in 2006 to 2007 as the percentage cover of each species for each plot as a whole.

Table 1. Subject, duration and soil types of the experiments.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Duration</th>
<th>Soil type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Different N fertilisers</td>
<td>1945-2005</td>
<td>Silandic Andosol</td>
</tr>
<tr>
<td>Ammonium nitrate, 60–240 kg N/ha</td>
<td>1964-2005</td>
<td>Silandic Andosol</td>
</tr>
<tr>
<td>Ammonium nitrate, 50 – 200 kg N/ha</td>
<td>1959-2007</td>
<td>Vitric Andosol</td>
</tr>
<tr>
<td>Potassium chloride, 0 – 99 kg K/ha</td>
<td>1950-2004</td>
<td>Histic Andosol</td>
</tr>
<tr>
<td>Potassium chloride, 0 – 99 kg K/ha</td>
<td>1959-2007</td>
<td>Vitric Andosol</td>
</tr>
<tr>
<td>Residual effects of P fertilisers</td>
<td>1938-2005</td>
<td>Silandic Andosol</td>
</tr>
<tr>
<td>Triple superphosphate, 0–39 kg P/ha</td>
<td>1950-2004</td>
<td>Histic Andosol</td>
</tr>
<tr>
<td>Triple superphosphate, 0–39 (-78) kg P/ha</td>
<td>1959-2007</td>
<td>Vitric Andosol</td>
</tr>
</tbody>
</table>
Table 2. Soil analyses in 0-5 cm, range of treatment means. Cations cmolc /kg, P mg/100g.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Year</th>
<th>pH</th>
<th>Ca</th>
<th>Mg</th>
<th>K</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Different types of N fertiliser</td>
<td>1945-2005</td>
<td>4.3-5.6</td>
<td>2.1-22.8</td>
<td>1.3-3.4</td>
<td>0.29-1.44</td>
<td>5.9-64</td>
</tr>
<tr>
<td>Increasing N</td>
<td>1964-2005</td>
<td>4.9-5.5</td>
<td>3.6-9.0</td>
<td>1.4-2.9</td>
<td>0.39-0.74</td>
<td>5.7-8.1</td>
</tr>
<tr>
<td>Increasing N</td>
<td>1959-2007</td>
<td>4.9-5.2</td>
<td>5.9-10.3</td>
<td>3.0-4.0</td>
<td>1.5-2.7</td>
<td>50-76</td>
</tr>
<tr>
<td>Increasing K</td>
<td>1950-2004</td>
<td>5.1-5.3</td>
<td>7.8-10.7</td>
<td>2.4-3.3</td>
<td>0.33-0.87</td>
<td>11-21</td>
</tr>
<tr>
<td>Increasing K</td>
<td>1959-2007</td>
<td>4.8-5.2</td>
<td>5.2-10.4</td>
<td>1.8-3.5</td>
<td>0.25-2.6</td>
<td>72-112</td>
</tr>
<tr>
<td>Residual effects of P</td>
<td>1938-2005</td>
<td>5.4-5.5</td>
<td>4.7-7.6</td>
<td>2.0-2.5</td>
<td>0.58-0.94</td>
<td>0.28-7.6</td>
</tr>
<tr>
<td>Increasing P</td>
<td>1950-2004</td>
<td>5.0-5.2</td>
<td>3.8-8.9</td>
<td>1.9-2.9</td>
<td>0.39-0.95</td>
<td>0.97-24</td>
</tr>
<tr>
<td>Increasing P</td>
<td>1959-2007</td>
<td>4.8-6.2</td>
<td>2.2-10.7</td>
<td>1.4-3.5</td>
<td>0.99-2.2</td>
<td>2.5-80</td>
</tr>
</tbody>
</table>

Results

The most common species in the experiments were red fescue (*Festuca rubra*), common bent (*Agrostis capillaries*), Kentucky bluegrass (*Poa pratensis*), meadow foxtail (*Alopecurus pratensis*) and dandelion (*Taraxacum officinale*). The average total cover of these species was 87%. Altogether 33 species were found in the experiments.

Although repeatedly estimated during the experimental period, the botanical composition at the start of the experiments is not well known. At that time seed mixtures commonly contained many species, among them meadow foxtail and orchard grass (*Dactylis glomerata*), and probably also red fescue, Kentucky bluegrass and common bent grass, but these species are also very common in the Icelandic nature. Since the plant cover is estimated such that total adds to 100% the results for the different species are highly interdependent, making the interpretation of results complicated. The decline of a species as a result of improved soil conditions may often be the result of the increased competitiveness of other species rather than a preference of the species for low nutrient levels or intermediate or low soil reaction.

*Poa pratensis*

Kentucky bluegrass (*Poa pratensis*) was found in all experiments with 23% cover on average, ranging from 0.2 to 68% in the different experiments. The cover was rather low on the more fertile Andosol and peaty Histic Andosol but very high on the sandy soil. Generally, the cover of *Poa pratensis* increased with higher nitrogen levels. Potassium or phosphorus fertilisation did not affect the cover of Kentucky bluegrass except in the experiment on sandy soil that was very poor of phosphorus. In that experiment Poa pratensis favoured P fertilisation.

*Agrostis capillaris*

Common bent (*Agrostis capillaris*) was found in seven experiments with 23% cover on average, ranging from 1 to 56% between experiments and it was 86% in the most acid treatment plots. The cover in sandy soil was low (0-9%). Common bent tends to become dominating in the sward at low pH resulting from the use of ammonium sulphate or high levels of ammonium nitrate. Significant effects of potassium or phosphorus on the cover of this species were not found.

*Festuca rubra*

Red fescue (*Festuca rubra*) was found in all experiments with 20% cover on average, ranging from 4-34% between experiments, and it was up to 50% in certain treatments. The greatest
cover was found in plots with low or zero nitrogen and on plots with low potassium levels whereas it was not affected by phosphorus fertilisation. The cover was less on plots with high pH values after fertilisation with calcium nitrate than on plots with moderate or low pH.

**Alopecurus pratensis**
Meadow foxtail (*Alopecurus pratensis*) was found in all experiments with an average cover of 13%, ranging from 1-38% between experiments, and it was up to 65% in certain treatments. Meadow foxtail was sensitive to low soil pH, but it was favoured by nitrogen at moderate pH. It was also favoured by potassium and phosphorus in some experiments.

**Taraxacum officinale**
Dandelion (*Taraxacum officinale*) was found in all experiments with an average cover of 8%, ranging from 1-20% between experiments and it was 43% in one treatment. Like meadow foxtail it was favoured by high pH values and by nitrogen as well as potassium, but unlike the foxtail it was favoured by zero phosphorus.

**Dactylis glomerata**
Orchard grass (*Dactylis glomerata*) was found in three experiments and it was highly favoured by high soil pH.

**Anthoxanthum nipponicum**
*Anthoxanthum nipponicum* was found in five experiments and it seemed to be favoured by low nitrogen and phosphorus application.

**Festuca ovina**
*Festuca ovina* was found in the sandy soil experiments and it was favoured by low nitrogen application and zero phosphorus application.

**Deschampsia caespitosa**
Tufted hair grass (*Deschampsia caespitosa*) was found in six experiments but no significant effects of fertilisation on its cover were found.

**Carex nigra**
*Carex nigra* was found in the peat soil and it was favoured by low phosphorus application. Potassium did not show any effect on the proportion of *Carex nigra*.

**Equisetum palustre**
*Equisetum palustre* was found in the potassium experiment in the peat soil. No significant effects of potassium fertiliser was found.

**Achillea millefolium**
*Achillea millefolium* was found in the three experiments on the sandy soil. The fertiliser effects were not significant.

**Galium verum**
*Galium verum* was found in all experiments except those on the peat soil. It was found in all plots but most common in plots with no phosphorus fertilisation.
Leontodon autumnalis
Leontodon autumnalis was found in four experiments and only in plots getting high doses of phosphorus.

Other species
The following species were also found in the experiments: Acetosa pratensis, Agrostis stolonifera, Alchemilla vulgaris, Alopecurus geniculatus, Botrychium lunaria, Cardamine nymanii, Cerastium fontanum, Equisetum pratense, Galium normanii, Luzula multiflora, Myosotis arvensis, Phleum pratense, Pilosella islandica, Poa trivialis, Pseudorchis albida, Ranunculus acris, Thymus praeced, Trifolium repens og Vicia cracca.

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Changes of yield responses and soil test values in Finnish soils in relation to cumulative phosphorus and potassium balances

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Agro-environmental soil testing by acid ammonium acetate extraction

An acid ammonium acetate method has been used in Finland since the early 1950s. The soil test phosphorus values (STP) determined by this method (PAc) are closely correlated with Morgan P: PAc = 1.4 * Morgan P (and PAc, mg dm⁻³, ~ PAl, mg 100 g⁻¹). The potassium values of this method (KAc, STK) represent the quickly exchangeable pool of K⁺ cations (~ 85% of total exchangeable). Current interpretations of the test values are mainly based on the long-term field experiments carried out at 24 sites in 1977-1994. The amounts of P allowed by the Agro-Environmental program are slightly below the long-term agricultural optimum.

Sippola and Saarela (1992) determined the limits of excessively high STP values on the basis of the equilibrium concentration of P in 0.005 M CaCl₂ suspension (EPC, estimate of DRP) and found that the critical EPC value of 0.5 mg dm⁻³ corresponded to the STP values of 14, 53 and 70 mg dm⁻³ in organic soils, coarse mineral soils and clay soils, respectively.

According to the amounts of DRP leaching, water flow and STP measured in Finnish fields (Saarela, 2007, unpublished calculations), the DRP/STP slope of 0.5/50 or 0.01 is typical for weakly acid mineral soils. The equation derived from chemical extractions by Uusitalo and Jansson (2002), DRP = 0.021 * STP – 0.015, and applied to estimate the losses of DRP from agricultural soils (Ekholm et al., 2005) gives too high estimates of DRP leaching.

Yield responses to P fertilisation increased from year to year

Field experiments with five rates of annual P fertilisation were carried out at 24 sites in Finland in 1977-1994 (Saarela et al., 1995, 2004, 2006a,b). A summary of the yield results was calculated on the basis of the amounts of P recommended to cereals according to STP in early 1990s (Saarela et al., 1995): 20 kg P ha⁻¹ in the STP class satisfactory (8-16 mg P dm⁻³), 30 kg ha⁻¹ in the class fair (4-8 mg dm⁻³) and 40 kg P ha⁻¹ in poorer classes. The actual limits of the classes differed by soil type. The yields obtained with these and 10 kg ha⁻¹ larger or 10-30 kg ha⁻¹ smaller amounts of P (-30 only in a part of the sites) were related to the yields produced with the highest rate of P, 60 or 45 kg ha⁻¹ (Fig. 1).

Figure 1. Relative grain yields at 1992-1995 recommended P rates (mean 27 kg/ha) and lower or higher rates of P. 227 harvest years, STP 0-16 mg dm⁻³ (Saarela et al., 1995).
The statistically significant equations (Fig 1) show that the difference to the maximal yield increased even by applying the amounts of P recommended in the early 1990s. The efficiency of repeated P fertilisation increased from year to year because the control yield and even the yield obtained with the smallest amount of P, 15 kg ha\(^{-1}\), decreased in many soils. The improved supply of P from the soil by the highest rates also increased the responses. Even if the P fertiliser was applied by the placement method, its P was utilised rather inefficiently.

The amounts of P allowed to be used by the Finnish Agri-Environmental Program, which are about 10 kg ha\(^{-1}\) less than recommended in the early 1990s, decreased the yields by five per cent in ten years. The changes appear less dramatic when calculated as relative yields. The value of the -10 line is 97.8\% in year 1 and 92.5\% in year 15, while the difference from the maximum was 2.2\% in year 1 and 7.5\% in year 15. The amounts of grain corresponding to these relative values were 80 kg ha\(^{-1}\) for the initial 2.2\% and 270 kg ha\(^{-1}\) for the final 7.5\%.

Examination of the results showed that the supply of P to cereal crops during the most critical stages of development in the early summer was sensitive to the physical conditions of the soil. Unstable silty soils, from silty clay to silty fine sand, which were compacted by showers, dried by evaporation and rooted poorly, required large rates of P to produce good grain yields (Saarela et al., 2006a,b). In the sandy soils prevailing in the inland regions of Finland the concentration of water-extractable P was low in relation to acetate-extractable P. The low water-solubility or low intensity of soil P appeared to be caused by high concentrations of sorption active aluminium in relation to iron. In the poorest soils the physical properties of silty soils were combined with the poor chemistry of coarse-textured acid soils. In the glacial clays prevailing in the southern coastal regions the main sorption agent of P was iron and the supply of P in relation to acetate-extractable P was better.

**Changes of STP values with time and P balance**

The changes of STP at the zero balance and the surpluses required to maintain the initial value were statistically calculated from the relationships of the initial and final values (Saarela et al., 2004). For this presentation the STP values corresponding to the zero balance of the 4 to 6 samplings of each experiment were determined and regressed against the experimental years. The results are presented as relative changes in Fig. 2.

![Figure 2. Annual changes of STP values at 24 sites in Finland at the P balance zero.](image)

According to the logarithmic curve (Fig. 2), the STP value remained at the initial level at 5 mg dm\(^{-3}\) and decreased 0.82\% annually at 12 mg dm\(^{-3}\). As one unit of STP corresponded to 67
kg P ha\(^{-1}\) in the P balance at STP 12 mg dm\(^{-3}\) (and 256, 133 and 41 kg ha\(^{-1}\) at STP 2, 5 and 25, Saarela et al., 2004), the initial STP value 12 mg dm\(^{-3}\) was maintained with the annual balance surplus of 6.6 kg P ha\(^{-1}\). This is slightly less than the earlier estimation by Saarela et al. (2004) and substantially less than the corresponding value by the equation of Ekholm et al. (2005) used to predict the changes of STP at the national level (Uusitalo et al., 2007).

P balance and changes of STP in Finnish soils from the 1950s

The amounts of P applied in manure and fertilisers have been larger than the amount removed in crops since the late 1940s, but the countrywide mean of the STP values began to increase not until in the late 1960s (Kähäri et al., 1987). The delay was certainly a result of an increase of the volume of fertilised soil both in the horizontal and vertical directions. The mean depth of the ploughed topsoil was 17 cm in the 1950s (Juusela and Wäre, 1956), approximately 15 cm in the 1940s and 22 to 25 cm since the late 1970s. The weight of the ploughed layer of typical mineral soil has been about 1500 tonnes ha\(^{-1}\) in the 1940s and about 2300 to 2600 tonnes or 70 % more since the late 1970s. Surface soils have extended over the open ditches of subdrained fields and to the swamps and forests cleared for cultivation.

The quick increase of the amount of fertilised soil from the 1940s to the 1960s is a key factor to understand the dissimilar changes of the mean STP value of Finnish soils in relation to the P balance until the middle 1960s and since that turning point. The strong apparent fixation of soluble P during the 1950s and early 1960s was largely caused by the mixing of the thin layer of surface soil with large proportions of infertile subsurface soil. In some experiments suggesting a strong continuous fixation of extractable soil P the initial value may have been inexact (Larpes, 1981) or the depth of the fertilised soil was still increasing (Yli-Halla, 1989, Saarela et al., 2004). The STP values decrease steeply with pH at the level from 7.3 to 6.0 (Lakanen and Vuorinen, 1963), which is an obvious reason for a quick drop of STP values observed in some soils in Finland.

Freshly applied P becomes less and less extractable from year to year, but a major part of the residual P of Finnish soils has aged for decades and is changing slowly now. Increases of the easily extractable pool of P in Finnish mineral soils are efficiently buffered because of fixation, but that does not necessarily mean any continuous losses at the zero balance.

Grain yields decreased little with STK values

The effects of repeated K fertilisation were studied at 21 sites in 1977-1994, (Saarela et al., 1778). The yield responses remained small because the K reserves of the soils together with the returned straw maintained a relatively good supply of K from the soil. The changes of the STK values at the zero balance were calculated from the initial and final values (Fig. 3). High STK values of coarse-textured soils decreased quickly in the first six years but slowly or not at all between the last samplings (Saarela et al., 1998). Then a relatively small pool of soil K, not only in the surface layer but deeper, was probably used repeatedly by successive crops.

The STK values responded to the cumulative K balances most quantitatively in light clay soils. The large quickly-exchangeable pools of K in the heavy clay soils were probably efficiently buffered by the slowly exchangeable reserves of interlayer K. In coarse-textured mineral soils the leaching losses of extractable soil K increased so steeply with the balance surpluses that he differences in the STK value remained small. In several soils the final STK values were below the earlier target levels by all treatments, but even a small rate of K, 20-40 kg ha\(^{-1}\) seemed to be sufficient for sustainable and efficient grain production. The rates earlier
recommended for cereals were optimal or slightly excessive for barley and considerably over
the optimum for other cereals.

Figure 3. Annual changes of STK values at 21 sites in Finland at the K balance zero.

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Long-term effects of liming and phosphorus fertilisation on soil properties

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Introduction
Acid sandy soils are frequent in the western parts of Denmark. To augment their natural low fertility, when they are used for agricultural production, lime and P fertilisers are continuously added to these soils and the applications of lime and nutrients have pronounced effects on crop yields as well as on soil properties.

The long-term effects and interactions of liming and P fertilisation on an arable sandy soil are elucidated in a permanent field experiment established on an acid sandy soil, containing less than 5% clay at St. Jyndevad Experimental Station, Denmark in 1942. Initially the main output from this permanent field experiment was the responses in yield and crop P off-take to liming and P fertilisation (Dorph Petersen, 1953), but nowadays research in this experiment primarily focuses on the effects of liming and phosphorus fertilisation on various soil properties.

The St. Jyndevad long-term field experiment on liming and P fertilisation
The experiment includes all combinations of four levels of liming and four levels of P fertilisation (Table 1). The experiment comprises three neighbouring fields each having the 16 treatments replicated in three blocks. Within each block, the lime treatments are laid out as main plot factors and the four P fertilisation treatments are split-plot factors within the lime treatments. Plot arrangement is systematic.

During the first decade yield was recorded for each plot yearly. During the following decades the treatments with lime and P fertiliser were carried out as planned, but yields were not recorded and soils samples were only rarely taken and analysed. Since 1994 soils have been sampled and analysed regularly and yields have been recorded from each plot yearly from one field (V2). The crop has with few exceptions been spring barley. In one field (V3) arable cropping was stopped in 1996 and this field is now maintained as set-aside grassland, without additions of nutrients and lime. The third field (V1) is used as a soil archive, meaning that researchers, who wish to use larger amounts soil with well described differences in pH or soil P status generally get permission to remove soil from the plots in this field permanently.
Table 1. Treatments in the field experiment how they are labelled.

<table>
<thead>
<tr>
<th>Phosphorus treatments*</th>
<th>Lime treatments**</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 kg</td>
</tr>
<tr>
<td>No P application</td>
<td>a</td>
</tr>
<tr>
<td>15.6 kg P ha⁻¹ year⁻¹</td>
<td>b</td>
</tr>
<tr>
<td>156 kg P ha⁻¹ initially</td>
<td>c</td>
</tr>
<tr>
<td>156 kg P ha⁻¹ initially and 15.6 kg P ha⁻¹ year⁻¹</td>
<td>d</td>
</tr>
</tbody>
</table>

*The lime treatments are repeated every 6-9 years. They aim at maintaining soil pH (in CaCl₂) at 5.4 in the 4000 kg treatment, 6.2 in the 8000 kg treatment and 6.7 in the 12000 kg treatment, while the unlimed treatment are allowed to acidify.

** P is given as super-phosphate. 15.6 kg P ha⁻¹ corresponds to 200 kg super-phosphate.

Results

Soil pH in the topsoil of the un-limed plots has dropped from initially 4.5 in 1944-47 to 3.5 in 1994 (table 1). The 4000 kg lime treatments have more or less been able to maintain soil pH at the initial level in the top soil, while 8000 and 12000 kg lime treatment has resulted in increased soil pH levels (data partially shown in table 1). The contrasting liming strategies have resulted in significantly higher soil pH levels in the limed treatments down to the 85-95 cm soil layer and highest at all depths in the most productive treatment, which has received maximum doses of both lime and P (Table 2).

Table 2. Soil pH in 1994 at four depths in the “four extreme treatments” (a, d, m and p in table 1). For each depth, figures followed by the same letter are not significantly different (P<0.05).

<table>
<thead>
<tr>
<th>Depth</th>
<th>Treatment</th>
<th>a</th>
<th>d</th>
<th>m</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-20 cm</td>
<td>“0 lime, 0 P”</td>
<td>3.5ᵃ</td>
<td>3.6ᵃ</td>
<td>5.2ᵇ</td>
<td>5.3ᵇ</td>
</tr>
<tr>
<td>30-40 cm</td>
<td>“0 lime, max P”</td>
<td>4.2ᵃ</td>
<td>4.3ᵃ</td>
<td>5.5ᵇ</td>
<td>5.7ᵇ</td>
</tr>
<tr>
<td>50-70 cm</td>
<td>“max lime, 0 P”</td>
<td>4.4ᵃ</td>
<td>4.4ᵃ</td>
<td>4.7ᵇ</td>
<td>5.4ᶜ</td>
</tr>
<tr>
<td>85-95 cm</td>
<td>“max lime, max P”</td>
<td>4.3ᵃᵇ</td>
<td>4.3ᵃᵇ</td>
<td>4.6ᵇ</td>
<td>5.2ᶜ</td>
</tr>
</tbody>
</table>

Measurements of total P contents at four soil depths in the four “extreme treatments” in 1994 (figure 1) revealed that the 30-40 cm layer in the treatment receiving maximum inputs of lime and P and having the highest productivity (treatment ‘p’) was enriched in P in the 30-40 cm soil layer compared to the “other extreme treatments” (the a, d and m treatments). The enrichment with P in this layer coincided with an enrichment with carbon (data not shown), indicating that the enrichment may be related to the higher biological production in this treatment compared to the other extreme treatments.
Traditional crop production is not possible in the unlimed treatments (a, b, c, and d, table 1), since the barley seedlings die a few weeks after emergence. Crop production is also severely inhibited in the treatments receiving 4000 kg lime regularly, and reduced in the 8000 kg lime treatments compared to the 12000 kg lime treatments. In the two treatments where crops are produced there are also significant differences in yield between the phosphorus treatments (data not shown). Reliable P balance sheets for the experimental treatments cannot be made, since P export with crops is not recorded for a long period from the 1960s up to 1994 and soil tillage is performed across plot borders resulting in soil exchange between the plots (Sibbesen et al., 2000). However, the total P measurements made in 1994 in the top 20 cm of all plots give an indication the differentiation in P status caused by the treatments (fig 2).

Figure 2 also shows how Olsen P (Olsen et al., 1954) increases with increasing P additions. Originally the Olsen P method was developed for alkaline agricultural soils. It is, however, frequently used on acid and neutral soils as well and in Denmark it has been the routine soil test used by farmers since 1987. Figure 2 also indicates that Olsen P on this acid sandy soil depends substantially on soil pH and liming status especially at very low soil pH levels.

Outlook
Because of the well-established gradients in soil pH and P status embedded in the field plots of this experiment, it often serves as a research platform for other studies, where gradients in soil pH and/or P status are needed. There is therefore already a strong tradition for using this experiment as a research platform and new ideas for further studies are more than welcome. Among the obvious ideas for further studies is using this for elucidation of what happens to carbon storage in soil, composition of the flora and soil fauna, when soil with contrasting liming and P fertilisation history is brought back to semi-natural set-aside conditions.
Figure 2. Olsen P in soil (Olsen et al., 1954) in 1998 at the four lime treatments receiving either no P (treatment a, e, i and m in table 1) or a yearly dose of 15.6 kg P ha\textsuperscript{-1} year\textsuperscript{-1}. (b, f, j and n in table 1).

References


Long-term usage of Phosphorus in permanent grassland in Iceland

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Abstract
The soils studied are Silandic Andosol and Histic Andosol at Sámsstaðir and Hemic Histosol at Hvanneyri. They are a part of long-term fertilization experiments on permanent grassland that started in 1949, 1950 and 1970 respectively. Surplus of P increased inorganic P in the soil measured as, $P_{\text{Al}}$, $P_{\text{inorg}}$, $P_{\text{ox}}$ or $P_{\text{an}}$. The largest application (39 kg P/ha) in more than 50 years has led to degree of phosphorus saturation (DPS) value of 27% at 0-5 cm, resulting in a easily available P-pool of more than 380 kg P/ha. Surplus of applied P is mainly associated with inorganic forms and can all be accounted for by the $P_{\text{ox}}$-pool. Application of P lowers $P_{\text{org}}$ as a proportion of $P_{\text{tot}}$, indicating low adsorption to organic matter. Maximum sorption is between 6.9 and 24.0 g P/kg.

Introduction
Icelandic soil has always been considered phosphorus deficient and that was based on many fertiliser experiments in the first half of the 20th century. Experience has showed that land taken under cultivation needs large quantities of P applied for cultivation to be successful (Helgason, 2002). When comparing cultivated land and land in natural state Sigvaldason (1992) found that $P_{\text{Al}}$ in cultivated grassland was considerably higher than in nearby native land, or 27-79 mg P/kg and 8-19 mg P/kg respectively.

Helgason (2002) measured organic P (0.5 M H$_2$SO$_4$) in soils in West- and South- Iceland. In freely drained grassland $P_{\text{org}}$ ranged from 0.0 to 2.36 g P/kg and from 0.41 to 1.71 g P/kg in poorly drained fields. In non-cultivated virgin soils in the south-western Iceland (Landnám Ingólfs) the range was 0.0-1.71 g P/kg with a mean percentage of 53% of the total soil-P measured in 0.5 M H$_2$SO$_4$.

Phosphorus is very limited in drained bogs or wetlands in West-Iceland. In the drained peat at Hvanneyri vegetation does not thrive without P application except occasionally *Equisetum sp.* and *Festuca vivipara* (Pálmason and Óskarsson, 1966).

General recommendation of P application for permanent grassland in Iceland are 25-40 kg P/ha when $P_{\text{Al}}$ is $<50$ mg/kg, 10-25 kg P/ha when $P_{\text{Al}}$ 50-100 mg/kg and 0-10 kg P/ha when $P_{\text{Al}}$ is $>100$ mg/kg.

Only 1.3% of Iceland is cultivated land. The low density of population and the small proportion of cultivated land have resulted in little interest being paid to the negative effect of excess fertilizing. Little or no evidence has been reported of negative effect of fertiliser in the Icelandic environment. That might have led to the general rule which can be called “to be on the safe side” regarding yield requirements, instead of strategic use of fertiliser.
Material and methods

All the soils used in this study are from cultivated permanent grasslands or hayfields in Iceland. Annually they have been fertilized with mineral fertiliser and harvested, further informations can be found in Gudmundsson (2007).

Experiments 1-49 and 9-50 are at Sámsstaðir in Fljótshlíð in south Iceland 63°44’ N, 20°06’ W. Experiment 299-70 is at Hvanneyri in Borgarfjörður in west Iceland 64°34’N, 21°44’W.

**Experiment 1-49** was established in 1949, the experiment was laid out on cultivated grassland originally sowed in 1936 with *Phleum pretense, Poa pratense, Festuca rubra* and *Trifolium repens*. The plots have never received organic fertiliser. The soil is Brown Andosol (Arnalds, 2004) or Silandic Andosol (WRB, 2006) well drained. From 1938 to 1949 the plots were used in an experiment for comparing different kind of P-fertiliser. Plot a has not received P-fertiliser since 1938.

**Experiment 9-50** was established in 1950 the experiment is on drained bog and was laid out on well maintained cultivated grassland originally sowed in 1945 with *Poa pratense, Phleum pratense Festuca rubra* and *Agrostis spp.* along with small amount of *Trifolium repens*. The soil is Gleyic Andosol (Arnalds, 2004) or Histic Andosol (WRB, 2006). The field was drained in 1935 with open ditches and ploughed drain channels. The drainage was never perfect and evidence of oxidation/reduction can been seen in the top 20 cm of the soil.

**Experiment 299-70** was established in 1970 the experiment is on drained bog and was laid out the first year of cultivation in 1970 and sowed with *Phleum pratense, Poa pratense and Festuca rubra*. The soil is Histosol (Arnalds, 2004) or Hemic Histosol (WRB, 2006).

For comparison samples were taken outside the experimental area, adjacent to the plots (named untr.). This area has not received any fertiliser, but has been harvested annually.

### Table 1. Field treatment description.

<table>
<thead>
<tr>
<th>Experiment / treatment</th>
<th>Soil type</th>
<th>Location</th>
<th>Annually applied</th>
<th>Depth</th>
<th>Sample year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>N</td>
<td>P</td>
<td>K</td>
</tr>
<tr>
<td>1-49 a</td>
<td>Silandic Andosol</td>
<td>Sámsst.</td>
<td>70</td>
<td>0.0</td>
<td>62.3</td>
</tr>
<tr>
<td>1-49 b</td>
<td>Silandic Andosol</td>
<td>Sámsst.</td>
<td>70</td>
<td>0.0</td>
<td>62.3</td>
</tr>
<tr>
<td>1-49 c</td>
<td>Silandic Andosol</td>
<td>Sámsst.</td>
<td>70</td>
<td>26.2</td>
<td>62.3</td>
</tr>
<tr>
<td>1-49 untr.</td>
<td>Silandic Andosol</td>
<td>Sámsst.</td>
<td>0</td>
<td>0.0</td>
<td>0</td>
</tr>
<tr>
<td>9-50 a</td>
<td>Histic Andosol</td>
<td>Sámsst.</td>
<td>70</td>
<td>0.0</td>
<td>74.7</td>
</tr>
<tr>
<td>9-50 b</td>
<td>Histic Andosol</td>
<td>Sámsst.</td>
<td>70</td>
<td>13.1</td>
<td>74.7</td>
</tr>
<tr>
<td>9-50 c</td>
<td>Histic Andosol</td>
<td>Sámsst.</td>
<td>70</td>
<td>21.9</td>
<td>74.7</td>
</tr>
<tr>
<td>9-50 d</td>
<td>Histic Andosol</td>
<td>Sámsst.</td>
<td>70</td>
<td>30.6</td>
<td>74.7</td>
</tr>
<tr>
<td>9-50 e</td>
<td>Histic Andosol</td>
<td>Sámsst.</td>
<td>70</td>
<td>39.3</td>
<td>74.7</td>
</tr>
<tr>
<td>9-50 untr.</td>
<td>Histic Andosol</td>
<td>Sámsst.</td>
<td>0</td>
<td>0.0</td>
<td>0</td>
</tr>
<tr>
<td>299-70 d</td>
<td>Hemic Histosol</td>
<td>Hvanneyri</td>
<td>100</td>
<td>0.0</td>
<td>100</td>
</tr>
<tr>
<td>299-70 f</td>
<td>Hemic Histosol</td>
<td>Hvanneyri</td>
<td>100</td>
<td>30</td>
<td>100</td>
</tr>
</tbody>
</table>

| 1) (WRB, 2006) |

All samples were extracted with ammonium lactate (P$_{Al}$) after Egner et al. (1960). Total (P$_{tot}$) and organic P (P$_{org}$) was determined by dissolution in H$_2$SO$_4$ based on Olsen and Sommers (1982) before and after ignition. Iron, Al, Si, Mn and P (P$_{ox}$) was dissolved in acid ammonium
oxalate using the description of Burt (2004). Adsorption of phosphorus were done based on Graetz and Nair (2000). Using the linear Langmuir equation to calculate the P sorption maximum ($S_{\text{max}}$). Determination of resin extractable P ($P_{\text{An}}$) was based on Sibbesen (1978). Degree of phosphorus saturation (DPS) is calculated by formula (1) (Schoumans, 2000).

$$\text{DPS} = \frac{P_{\text{ox}}}{0.5 \times (A_{\text{ox}} + Fe_{\text{ox}})} \times 100$$

The samples were air-dried and sieved (2mm) and stored at room temperature until analysis. For the H$_2$SO$_4$ extraction and NH$_4$ oxalate extraction a sub sample was taken and ground by hand in a ceramic mortel to homogenize the soil. Mean bulk density can be seen in table 2.

<table>
<thead>
<tr>
<th>Depth</th>
<th>1-49</th>
<th>9-50</th>
<th>299-70</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-5 cm</td>
<td>0.57</td>
<td>0.50</td>
<td>0.31</td>
</tr>
<tr>
<td>5-10 cm (*5-15 cm)</td>
<td>0.69</td>
<td>0.60</td>
<td>* 0.33</td>
</tr>
<tr>
<td>10-20 cm</td>
<td>0.79</td>
<td>0.63</td>
<td></td>
</tr>
</tbody>
</table>

### Results

Results are presented in table 3 as means of each treatment and depth.

<table>
<thead>
<tr>
<th>1-49 0-5 cm</th>
<th>$P_{\text{Al}}$</th>
<th>$P_{\text{tot}}$</th>
<th>$P_{\text{inorg}}$</th>
<th>$P_{\text{org}}$</th>
<th>$P_{\text{ox}}$</th>
<th>$P_{\text{An}}$</th>
<th>$S_{\text{max}}$</th>
<th>DSP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Untr</td>
<td>0.011</td>
<td>1.90</td>
<td>1.00</td>
<td>0.90</td>
<td>1.30</td>
<td>0.063</td>
<td>8.9</td>
<td>6.5</td>
</tr>
<tr>
<td>a</td>
<td>0.006</td>
<td>2.38</td>
<td>0.75</td>
<td>1.63</td>
<td>1.00</td>
<td>0.046</td>
<td>9.6</td>
<td>4.8</td>
</tr>
<tr>
<td>b</td>
<td>0.002</td>
<td>1.73</td>
<td>0.80</td>
<td>0.95</td>
<td>0.98</td>
<td>-</td>
<td>-</td>
<td>5.0</td>
</tr>
<tr>
<td>c</td>
<td>0.076</td>
<td>3.85</td>
<td>2.28</td>
<td>1.55</td>
<td>2.48</td>
<td>0.310</td>
<td>7.8</td>
<td>12.6</td>
</tr>
<tr>
<td>9-50 0-5 cm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Untr</td>
<td>0.059</td>
<td>3.40</td>
<td>1.80</td>
<td>1.60</td>
<td>2.55</td>
<td>0.265</td>
<td>7.5</td>
<td>15.4</td>
</tr>
<tr>
<td>a</td>
<td>0.015</td>
<td>1.83</td>
<td>0.67</td>
<td>1.20</td>
<td>1.10</td>
<td>0.059</td>
<td>9.1</td>
<td>5.4</td>
</tr>
<tr>
<td>b</td>
<td>0.040</td>
<td>4.03</td>
<td>1.58</td>
<td>2.45</td>
<td>2.00</td>
<td>-</td>
<td>-</td>
<td>11.4</td>
</tr>
<tr>
<td>c</td>
<td>0.066</td>
<td>5.13</td>
<td>2.90</td>
<td>2.25</td>
<td>3.23</td>
<td>0.394</td>
<td>8.2</td>
<td>14.8</td>
</tr>
<tr>
<td>d</td>
<td>0.108</td>
<td>5.95</td>
<td>3.68</td>
<td>2.28</td>
<td>4.15</td>
<td>-</td>
<td>-</td>
<td>21.8</td>
</tr>
<tr>
<td>e</td>
<td>0.168</td>
<td>7.50</td>
<td>5.33</td>
<td>2.23</td>
<td>6.05</td>
<td>1.229</td>
<td>7.8</td>
<td>12.6</td>
</tr>
<tr>
<td>299-70 0-5 cm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>d</td>
<td>0.025</td>
<td>1.00</td>
<td>0.13</td>
<td>0.85</td>
<td>-</td>
<td>0.038</td>
<td>8.5</td>
<td>-</td>
</tr>
<tr>
<td>f</td>
<td>0.231</td>
<td>2.90</td>
<td>1.80</td>
<td>1.08</td>
<td>-</td>
<td>0.554</td>
<td>10.9</td>
<td>-</td>
</tr>
<tr>
<td>1-49 5-10 cm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Untr</td>
<td>0.008</td>
<td>1.80</td>
<td>0.90</td>
<td>0.90</td>
<td>1.25</td>
<td>0.045</td>
<td>8.7</td>
<td>6.5</td>
</tr>
<tr>
<td>a</td>
<td>0.003</td>
<td>2.93</td>
<td>0.93</td>
<td>2.03</td>
<td>1.00</td>
<td>0.026</td>
<td>10.7</td>
<td>4.7</td>
</tr>
<tr>
<td>b</td>
<td>0.004</td>
<td>1.65</td>
<td>0.80</td>
<td>0.85</td>
<td>1.05</td>
<td>-</td>
<td>-</td>
<td>4.9</td>
</tr>
<tr>
<td>c</td>
<td>0.029</td>
<td>3.03</td>
<td>1.55</td>
<td>1.45</td>
<td>1.93</td>
<td>0.183</td>
<td>9.0</td>
<td></td>
</tr>
<tr>
<td>9-50 5-10 cm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Untr</td>
<td>0.015</td>
<td>1.90</td>
<td>1.15</td>
<td>0.75</td>
<td>1.45</td>
<td>0.068</td>
<td>10.8</td>
<td>6.1</td>
</tr>
<tr>
<td>a</td>
<td>0.009</td>
<td>1.98</td>
<td>0.90</td>
<td>1.08</td>
<td>1.18</td>
<td>0.025</td>
<td>14</td>
<td>3.8</td>
</tr>
<tr>
<td>b</td>
<td>0.013</td>
<td>2.73</td>
<td>1.15</td>
<td>1.55</td>
<td>1.43</td>
<td>-</td>
<td>-</td>
<td>4.6</td>
</tr>
<tr>
<td>c</td>
<td>0.014</td>
<td>2.48</td>
<td>1.43</td>
<td>1.05</td>
<td>1.18</td>
<td>0.050</td>
<td>17.8</td>
<td>3.0</td>
</tr>
<tr>
<td>d</td>
<td>0.018</td>
<td>2.75</td>
<td>1.70</td>
<td>1.03</td>
<td>1.65</td>
<td>-</td>
<td>-</td>
<td>5.3</td>
</tr>
<tr>
<td>e</td>
<td>0.032</td>
<td>3.40</td>
<td>1.88</td>
<td>1.53</td>
<td>1.95</td>
<td>0.153</td>
<td>13.0</td>
<td>6.0</td>
</tr>
<tr>
<td>299-70 5-15 cm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>d</td>
<td>0.012</td>
<td>0.95</td>
<td>0.10</td>
<td>0.85</td>
<td>-</td>
<td>0.011</td>
<td>14.0</td>
<td></td>
</tr>
<tr>
<td>f</td>
<td>0.029</td>
<td>1.35</td>
<td>0.35</td>
<td>1.03</td>
<td>-</td>
<td>0.05</td>
<td>24.0</td>
<td></td>
</tr>
</tbody>
</table>
Conclusions
Application of P in excess of removal by harvest has increased the content of inorganic P in the soil measured as, $P_{AL}$, $P_{inorg}$, $P_{ox}$ or $P_{an}$. A corresponding increase in organically bound P was not observed.

With the largest application of 39 kg P/ha in experiment 9-50 in more than 50 years, the degree of phosphor saturation in the top 5 cm is 27%, resulting in an easily available P-pool of more than 380 kg P/ha measured as $P_{An}$. Surplus of applied P is mainly associated with inorganic forms and can all be accounted for at 0-20 cm depth for experiment 1-49 and at 0-5 cm for experiment 9-50 with $P_{ox}$. Surplus of P in experiment 299-70 is all accounted for in 0-15 cm with $P_{tot}$.

Sorption maxima is between 6.9 and 24.0 g P/kg for the soil studied. That indicates that totally different fertilisation strategies are needed for these soils.

References
Pálmason, F. and Óskarsson, M., (1966): Tíraunir með fosfóráburð á mýrartún á Hvanneyri. Ársrit Ræktunarfélags Norðurlands 1966:
The effect of different types of fertilisers on the nutrient status in Icelandic Andosols as found in three long-term experiments

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2 Agricultural University of Iceland, Keldnaholt, 112 Reykjavik
*E-mail: thorsteinn@lbhi.is

Introduction
The long-term effects of different types of N fertilisers were studied using three experiments under different soil and climatic conditions in Iceland. The N fertilisers were ammonium nitrate, ammonium sulphate and calcium nitrate. The experimental treatments remained mostly unchanged and the effects of long term fertiliser use on the soil can be compared at different sites. Bjarni Helgason (1975) used the same experiments to study the effects on some soil properties in 1963 and 1973, and more recently the authors of this paper investigated the effects of fertilisation for 43 years on the soil at Skriðuklaustur in more detail.

Experiments and methods
The experiments are located in East, North and South Iceland (Table 1). Two of the experiments started in 1945 (Akureyri and Sámsstaðir) and one in 1954 (Skriðuklaustur). At the end of the experiments the soils were sampled, Skriðuklaustur in 1996, Sámsstaðir in 2005 and Akureyri in 2006. Core samples were taken and divided to represent different depths. Samples were also taken just outside the experiments to make a comparison with unfertilised soils possible.

Table 1. Location and site parameters.

<table>
<thead>
<tr>
<th>Location</th>
<th>Coordinates</th>
<th>Soil type (WRB 2006)</th>
<th>Precipitation mm/year</th>
<th>Temperature °C annual mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skriðuklaustur</td>
<td>65°02' N, 14°57' W</td>
<td>Gleyic Andosol</td>
<td>501</td>
<td>4.1</td>
</tr>
<tr>
<td>Akureyri</td>
<td>65°41' N, 18°60' W</td>
<td>Silandic Andosol</td>
<td>489</td>
<td>3.6</td>
</tr>
<tr>
<td>Sámsstaðir</td>
<td>63°44' N, 20°06' W</td>
<td>Silandic Andosol</td>
<td>1236</td>
<td>4.6</td>
</tr>
</tbody>
</table>

Table 2. Fertiliser application.

<table>
<thead>
<tr>
<th></th>
<th>Skriðuklaustur</th>
<th>Akureyri</th>
<th>Sámsstaðir</th>
</tr>
</thead>
<tbody>
<tr>
<td>NH₄NO₃</td>
<td>70 and 120 N</td>
<td>55 and 88 N</td>
<td>120 and 180 N</td>
</tr>
<tr>
<td>(NH₄)₂SO₄</td>
<td>120 N</td>
<td>88 N</td>
<td>120 N</td>
</tr>
<tr>
<td>(NH₄)₂SO₄</td>
<td>120 N</td>
<td>88 N</td>
<td>120 N</td>
</tr>
<tr>
<td>P and K – all plots</td>
<td>30.6 P and 74.7 K</td>
<td>32.6 P and 79.7 K</td>
<td>29.5 P and 62.3 K</td>
</tr>
</tbody>
</table>

1 The 180 N plots received 62 N until 1960, 93 N 61-63 and 180 N from 1964

The experimental plots were square, 50 m², and arranged systematically in a knight’s move variant of the 5x5 Latin square design. The N fertilisers tested were ammonium nitrate at two
rates, ammonium sulphate and calcium nitrate and all experiments included a zero N treatment (Table 2). All treatments received a basic P and K fertilisation.

Extractable nutrients were determined by flame AAS (Ca and Mg), flame emission (K and Na) and P spectrometrically in an ammonium lactate extract, the AL method (Egner et al 1960). Organic C and total N were determined using dry combustion in a Leco apparatus. Bulk density was determined in each sample by filling a 200 cm$^3$ tin with the dried and sieved soil. Through comparison with core samples this has proved to be a good approximation.

The bulk density is generally low. As it varies both within experiments and between sites the amount of elements in the soil were calculated to a certain soil weight per area rather than soil depth. Here 650 t soil ha$^{-1}$ were used to represent approximately the top 10 cm of the soil.

**Results and discussion**

The pH was 5.3 to 5.6 in the top soil of the 0 N treatment and increased with depth at all sites irrespective of treatment (Table 2). The pH reached 7 in the lower horizons of the 0 N treatment at Skriðuklaustur but 6.0 to 6.3 at the other sites. The ammonium nitrate fertiliser had only minor effect on pH but calcium nitrate increased the pH to about 7 at Skriðuklaustur and 6.2 in the top 5 cm at the other sites.

<table>
<thead>
<tr>
<th>Skriðuklaustur</th>
<th>0 N</th>
<th>120 NH$_4$NO$_3$</th>
<th>120 (NH$_4$)$_2$SO$_4$</th>
<th>120 Ca(NO$_3$)$_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>pH</td>
<td>C/C/N</td>
<td>pH/C/C/N</td>
<td>pH/C/C/N</td>
</tr>
<tr>
<td>0-5</td>
<td>5.6</td>
<td>12.4/14</td>
<td>5.8/13.6/13</td>
<td>3.8/21.1/15</td>
</tr>
<tr>
<td>5-10</td>
<td>6.6</td>
<td>5.8/13</td>
<td>6.9/5.8/12</td>
<td>4.4/7.9/13</td>
</tr>
<tr>
<td>10-20</td>
<td>6.9</td>
<td>3.8/12</td>
<td>7.3/3.7/12</td>
<td>6.2/4.9/12</td>
</tr>
<tr>
<td>20-40</td>
<td>7.0</td>
<td>4.0/13</td>
<td>7.2/3.1/13</td>
<td>6.6/4.6/13</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Akureyri</th>
<th>0 N</th>
<th>82 NH$_4$NO$_3$</th>
<th>82 (NH$_4$)$_2$SO$_4$</th>
<th>82 Ca(NO$_3$)$_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>pH</td>
<td>C/C/N</td>
<td>pH/C/C/N</td>
<td>pH/C/C/N</td>
</tr>
<tr>
<td>0-5</td>
<td>5.3</td>
<td>11.5/12</td>
<td>5.4/12.9/12</td>
<td>4.4/22.6/15</td>
</tr>
<tr>
<td>5-10</td>
<td>5.6</td>
<td>8.5/11</td>
<td>5.8/8.8/12</td>
<td>4.6/9.8/13</td>
</tr>
<tr>
<td>10-20</td>
<td>6.1</td>
<td>6.3/11</td>
<td>6.3/7.0/11</td>
<td>5.4/6.7/11</td>
</tr>
<tr>
<td>20-40</td>
<td>6.1</td>
<td>6.3/11</td>
<td>6.5/4.2/11</td>
<td>6.1/6.1/11</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sámsstaðir</th>
<th>0 N</th>
<th>120 NH$_4$NO$_3$</th>
<th>120 (NH$_4$)$_2$SO$_4$</th>
<th>120 Ca(NO$_3$)$_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>pH</td>
<td>C/C/N</td>
<td>pH/C/C/N</td>
<td>pH/C/C/N</td>
</tr>
<tr>
<td>0-5</td>
<td>5.6</td>
<td>10.4/13</td>
<td>5.3/10.7/13</td>
<td>4.3/24.4/17</td>
</tr>
<tr>
<td>5-10</td>
<td>5.8</td>
<td>8.3/12</td>
<td>5.7/9.2/13</td>
<td>4.3/11.8/14</td>
</tr>
<tr>
<td>10-20</td>
<td>6.0</td>
<td>6.9/12</td>
<td>6.0/7.3/12</td>
<td>4.5/8.0/12</td>
</tr>
<tr>
<td>20-40</td>
<td>6.3</td>
<td>6.1/11</td>
<td>6.2/6.5/11</td>
<td>5.5/6.3/11</td>
</tr>
</tbody>
</table>

The acidifying ammonium sulphate decreased the pH to 3.8 in the top soil at Skriðuklaustur compared to 4.4 and 4.3 at Akureyri and Sámsstaðir respectively. The low pH has in all cases lead to the formation of a thick mat of poorly decomposed plant material.
The C content was generally high as is typical for Andosols and the C/N ratio was low. The highest C content was in the top 5 cm of the Gleyic Andosol as Skriðuklaustur but decreased rapidly with depth (Table 3). At the other two sites the organic C decreases more gradually with depth. In the top 10 cm of the 0 N plots it adds up to 56 to 63 t C ha\(^{-1}\) at the three sites. The C and N contents were in all cases lowest in the 0 N treatments and similar to the unfertilised area. At Skriðuklaustur and Akureyri the C contents increased significantly in the ammonium nitrate and calcium nitrate treatments compared to 0 N but not so clearly at Sámsstaðir. The largest increase in organic matter was following ammonium sulphate fertilisation. In all cases the C content exceeded 20% in the top 5 cm of the soil and there was also a marked increase at 5-10 cm depth. The increase is thus largely confined to a mat of organic matter that has accumulated on the top of the mineral soil.

In the top 10 cm there were 4.2 to 5.8 t N ha\(^{-1}\). The variation in soil N largely followed the C content. However due to an increase in the C/N ratio in the acid plots the N increased less than the C content, and in the calcium nitrate treatment at Skriðuklaustur the C/N ratio decreased leading to a relatively high N content.

In an earlier paper (Gudmundsson et al. 2004) we have shown that at Skriðuklaustur the yearly increase in C in the N fertilised plots compared to the unfertilised area ranged from about 100 to 340 kg C ha\(^{-1}\). The corresponding yearly increase in soil N was 7 to 28 kg ha\(^{-1}\).

Table 3. Ammonium lactate (AL) extractable nutrients and total C and N in the top 650 tons of soil, approximately the top 10 cm.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Ca kg ha(^{-1})</th>
<th>Mg kg ha(^{-1})</th>
<th>K kg ha(^{-1})</th>
<th>Na kg ha(^{-1})</th>
<th>P kg ha(^{-1})</th>
<th>C t ha(^{-1})</th>
<th>N t ha(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Skriðuklaustur</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 N</td>
<td>3000</td>
<td>450</td>
<td>180</td>
<td>130</td>
<td>130</td>
<td>56</td>
<td>4,2</td>
</tr>
<tr>
<td>NH(_4)NO₃</td>
<td>3600</td>
<td>420</td>
<td>74</td>
<td>160</td>
<td>120</td>
<td>61</td>
<td>4,8</td>
</tr>
<tr>
<td>(NH(_4))₂SO₄</td>
<td>1100</td>
<td>140</td>
<td>70</td>
<td>82</td>
<td>140</td>
<td>73</td>
<td>5,2</td>
</tr>
<tr>
<td>Ca(NO(_3))₂</td>
<td>6800</td>
<td>380</td>
<td>94</td>
<td>160</td>
<td>210</td>
<td>68</td>
<td>5,6</td>
</tr>
<tr>
<td>No fertiliser</td>
<td>3300</td>
<td>580</td>
<td>86</td>
<td>150</td>
<td>11</td>
<td>50</td>
<td>4,0</td>
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<tr>
<td><strong>Akureyri</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 N</td>
<td>1800</td>
<td>320</td>
<td>240</td>
<td>110</td>
<td>46</td>
<td>63</td>
<td>5,5</td>
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<tr>
<td>NH(_4)NO₃</td>
<td>2200</td>
<td>310</td>
<td>110</td>
<td>130</td>
<td>32</td>
<td>67</td>
<td>5,5</td>
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<tr>
<td>(NH(_4))₂SO₄</td>
<td>1000</td>
<td>140</td>
<td>92</td>
<td>69</td>
<td>72</td>
<td>78</td>
<td>5,8</td>
</tr>
<tr>
<td>Ca(NO(_3))₂</td>
<td>4500</td>
<td>320</td>
<td>150</td>
<td>140</td>
<td>46</td>
<td>69</td>
<td>5,7</td>
</tr>
<tr>
<td>No fertiliser</td>
<td>2500</td>
<td>560</td>
<td>110</td>
<td>110</td>
<td>8</td>
<td>65</td>
<td>5,5</td>
</tr>
<tr>
<td><strong>Sámsstaðir</strong></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 N</td>
<td>1300</td>
<td>250</td>
<td>300</td>
<td>65</td>
<td>98</td>
<td>58</td>
<td>4,7</td>
</tr>
<tr>
<td>NH(_4)NO₃</td>
<td>1100</td>
<td>160</td>
<td>78</td>
<td>97</td>
<td>40</td>
<td>62</td>
<td>4,8</td>
</tr>
<tr>
<td>(NH(_4))₂SO₄</td>
<td>150</td>
<td>44</td>
<td>102</td>
<td>59</td>
<td>160</td>
<td>87</td>
<td>5,9</td>
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<tr>
<td>Ca(NO(_3))₂</td>
<td>2900</td>
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<td>77</td>
<td>100</td>
<td>35</td>
<td>60</td>
<td>4,8</td>
</tr>
<tr>
<td>No fertiliser</td>
<td>1300</td>
<td>290</td>
<td>72</td>
<td>84</td>
<td>7</td>
<td>57</td>
<td>4,5</td>
</tr>
</tbody>
</table>

There is a marked difference in the Ca and Mg contents of the soils. The Ca and Mg contents are highest in the Andic Gleysol at Skriðuklaustur and lowest in the south at Sámsstaðir. The low values at Sámsstaðir can be associated with the high annual precipitation (Table 1).
Another cause may be higher contents of rhyolitic and andesitic ash in the South as the site is in the vicinity of the volcano Hekla. The effects of the acidifying ammonium nitrate is also most marked in the South where exchangeable Ca is about 1/9 of the Ca in the 0 N and unfertilised area and Mg has decreased from 250 to 44 t ha\(^{-1}\). The decrease in Ca and Mg at the other sites is large but not to the same extent as in the South, again indicating the higher rate of leaching in the South. The use of calcium nitrate has in all cases increased the exchangeable Ca without a marked effect on the Mg content compared to ammonium nitrate. The increase was highest in Skriðuklaustur, somewhat lower in Akureyri where the application rate was lower, and least in the South, again probably associated with more intensive leaching. Whereas the changes in Mg were marginal in the North and the East when ammonium nitrate and calcium nitrate were used the Mg contents decreased markedly when these fertilisers were used in the South. In an experiment with increasing rates of ammonium nitrate the Mg contents were most sensitive to its acidifying effects and decreased almost linearly over a wide range of N application, also at Sámsstaðir (Gudmundsson et al. 2007).

There is only a marginal difference in the K status of the three sites. The K content was always highest in the 0 N treatments but a consistent effect of different types of N fertiliser was not apparent. This may be surprising as basaltic rocks are poor in K and the soils do not contain any phyllosilicates and therefore no K fixation takes place. In an earlier work (Gudmundsson et al. 2005) we were able to show that at Skriðuklaustur K is being depleted from the soil and that the depletion can only be shown by changes in total amounts of K but not by using exchangeable or weatherable K.

The poor P status of the soils can be seen in the unfertilised areas where only 7 to 11 kg P ha\(^{-1}\) were soluble in the top 10 cm of the soil. The P application was similar all sites and the adsorption seemed lower in the Gleyic soil at Skriðuklaustur than in the dryer soils. It has been shown that the surplus P is being adsorbed by the mineral rather than in the organic material.

References


Yields and N leaching/runoff losses in a long-term cropping system experiment in SE Norway; results from the new Millennium

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Abstract
An ideal agricultural system should both maximize production and minimize undesirable effects on the environment. The long-term Apelsvoll cropping system experiment was used in this study to compare yields, leaching/runoff losses and the N loss-to-primary production ratios in six different cropping systems over a 6-year period.

Material and Methods
A 3.3 ha field experiment with tile-drained plots was established on a morainic loam in 1988/89 at the Research Centre of the Arable Crops Division in central southeast Norway (60°42’N, 10°51’E, altitude 250 m). Six cropping systems, each with 2 replicates, are practiced on twelve 1.8 ha blocks, each equipped for volume proportional sampling of drainage discharge and surface runoff. Details of soil, experimental design and analyses are given in Korsaeth (in press). The experiment includes three systems with arable (A) cash-cropping: CA1: conventional farming practice, managed as was common for the region in 1985 (e.g. autumn ploughing, whereas spring tillage was used in all other systems); CA2: improved conventional farming practice with environmentally sound management (e.g. use of catch crops, split application of fertilizer and reduced tillage), and OA: organic arable farming with 25% of the area as green manure. The other three systems representing mixed dairy production (M) with both arable and fodder crops: CM: conventional farming practice with 50 % grass-clover ley; OM1: organic farming with 50 % grass-clover ley, and OM2: organic farming with 75 % grass-clover ley. The amounts of slurry used in the mixed dairy systems are calculated from the theoretical number of cows sustained. The energy content of the primary production was calculated on the basis of measured dry matter yields and literature values for their energy content.

Results and discussion
There were significant yield differences between cropping systems for all crops (Fig. 1), except for potatoes (only CA1 and CA2 had potatoes in the rotation, data not shown). Largest differences were measured within the arable systems, where the organic system (OA) with green manure as its only nutrient source yielded only 42 to 54% (area corrected) of that obtained in the two conventional systems. The yield differences between the conventional and the organic systems were lower within the mixed dairy group, with organically cropped wheat and barley achieving about 76 and 85%, respectively, of the conventional yields. The reason for the lower yields with organic cropping was most likely sub-optimal plant nutrition and/or the lack of plant protection.
Drainage water was the most important pathway for field losses of N from the cropping systems, accounting for 96-99% of the water based N losses (Fig. 2). In the arable group, drainage losses were highest in CA1 and surface runoff losses were highest in OA. In CA1, all plots were ploughed in the first part of October, whereas tillage was performed in spring in the other systems. Early autumn ploughing has been found to increase the risk for N leaching, compared with spring tillage (Korsaeth et al., 2002). The larger N losses via surface runoff from OA were most likely caused by the grass-clover ley, which accumulated large amounts of fixed N that were not harvested. There is a high risk of losses to waterways associated with N-rich plant material left on the soil surface during autumn and winter (Sturite et al., 2007). The N losses to drainage water from OA were also relatively high (33.6 kg N ha$^{-1}$ yr$^{-1}$), indicating that a large share of the N released from green manure was leached. Drainage N losses were significantly larger in CA1 than in CA2. The use of catch crops in the latter, may, in addition to the use of spring harrowing instead of autumn ploughing, explain the smaller losses from CA2 relative to those from CA1. There was no significant difference in N losses between the mixed dairy systems, either in runoff or drainage. There was, however, a tendency for the organic OM1 to have larger N losses than the other mixed dairy systems. This may partly be explained by the use of autumn harrowing after wheat (following ley in the rotation) in this system in years with high pressure of perennial weeds (particularly E. repens). Such mechanical weed treatment took place in four out of the six years.
Figure 2. Losses of NO₃-N, NH₄-N and organic N via surface runoff (above) and drainage water (below), averaged over the agrohydrological years (May-April) 2001-2006. Vertical lines show standard error of means for total N (e.g. the sum of the three N fractions).

The primary energy production of the cropping systems was in the range of 32-83 GJ ha⁻¹ (Table 1). Among the arable systems, OA had the lowest primary production, achieving only 41% of that in the conventional arable systems (CA1 and CA2). This reflects partly the costs of taking 25% of the area out of production to produce green manure (OA). Among the mixed dairy systems the differences were smaller. The organic OM1 achieved 86% of the energy produced in the other two systems (CM and OM2), which had similar primary production.

Within the arable systems, CA2 had lowest N loss per unit of produced primary energy (LP-ratio, Table 1), whereas OA had the highest of all systems. Within the mixed dairy systems, OM1 had the largest LP-ratio. Comparing the primary production of cropping systems with different crops is of limited value. A more meaningful analysis of the relation between N losses and production was obtained, however, by calculating the net food production of the systems. This was beyond the scope of this paper, but is presented in detail for the years 2001-2004 in Korsaeth (in press).
Table 1. Primary energy production (MJ system\textsuperscript{-1}) and the loss-to-production ratios\textsuperscript{a} (LP-ratio; kg N GJ\textsuperscript{-1}) of the cropping systems, means for 2001-2006

<table>
<thead>
<tr>
<th>Cropping system</th>
<th>CA1</th>
<th>CA2</th>
<th>OA</th>
<th>CM</th>
<th>OM1</th>
<th>OM2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barley</td>
<td>2954</td>
<td>2805</td>
<td>1757</td>
<td>2731</td>
<td>2324</td>
<td>2304</td>
</tr>
<tr>
<td>Wheat</td>
<td>2884</td>
<td>2770</td>
<td>1588</td>
<td>2510</td>
<td>1898</td>
<td></td>
</tr>
<tr>
<td>Oats</td>
<td>3704</td>
<td>3153</td>
<td>2489</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Potato</td>
<td>5244</td>
<td>5224</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1\textsuperscript{st} year of ley</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4516</td>
<td>3928</td>
</tr>
<tr>
<td>2\textsuperscript{nd} year of ley</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5234</td>
<td>4517</td>
</tr>
<tr>
<td>3\textsuperscript{rd} year of ley</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3839</td>
</tr>
<tr>
<td>Sum (GJ ha\textsuperscript{-1})</td>
<td>82.1</td>
<td>77.5</td>
<td>32.4</td>
<td>83.3</td>
<td>70.4</td>
<td>80.5</td>
</tr>
<tr>
<td>LP-ratio (kg N GJ\textsuperscript{-1})</td>
<td>0.58</td>
<td>0.34</td>
<td>1.06</td>
<td>0.25</td>
<td>0.43</td>
<td>0.20</td>
</tr>
</tbody>
</table>

\textsuperscript{a} The ratio between total N losses in drainage + surface runoff and primary energy production.

Conclusions

- Organic arable cropping based on green manure as its only nutrient source has enhanced risks for N leaching/runoff losses and reduced productivity, whereas non-organic arable cropping may achieve a low N loss-to-production ratio by using catch crops, split application of fertilizer and reduced tillage.
- Organic mixed dairy production performs more similarly with conventional production in terms of production and N leaching/runoff losses.

References


Soil organic carbon fractions and soil aggregate associated carbon in long-term field experiments in southeastern Norway

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Abstract
The long-term effects (nearly 50 years) of fertilization and crop rotation on soil organic carbon (SOC) fractions and soil aggregate associated carbon were investigated... The experiment has three six course rotations (I) continuous spring grain, (II) spring grain for 3 years followed by root crops for 3 years, and (III) spring grain for 2 years followed by meadow for 4 years. Three fertilizer treatments compared were: (A) 30-40 kg N ha\(^{-1}\); (B) 80-120 kg N ha\(^{-1}\); and (C) a combination of B and 60 Mg ha\(^{-1}\) fram yard manure (FYM). All plots received PK fertilizer as a basal dose. Soil samples were collected from these treatment combinations at 0-10 and 10-25 cm depths and were utilized for both carbon fractionation and aggregate associated carbon..

The soil organic carbon was fractionated into humic acid (FA), fulvic acid (FA) and humin fractions. The humin fraction was further separated into black carbon. The concentration of SOC in FA, HA and humin fractions was 29, 25 and 44%, respectively. The rotation of grain + grass showed higher C in HA and humin fractions and a lower C in the FA fraction as compared to grain alone rotation. The application of FYM increased HA and humin fractions as well as black carbon more than did by chemical fertilizers. Nitrogen fertilization rates had no significant effects on SOC fractions.

Crop rotations significantly increased the stability of aggregates and the increase in stability was highest in rotation III followed by rotations I and II. Fertilizer treatment had no significant effect on water stable aggregates. Aggregate stability increased with increasing concentration of SOC \((r^2=0.53)\). The SOC and total soil N (TSN) concentrations were significantly higher in rotation III than in rotations II and I. Application of FYM increased SOC and TSN concentrations significantly in the 0-10 cm depth but no such effects between fertilizer treatments A and B were seen. The concentration of SOC and TSN generally increased with decreasing size of soil aggregate but the difference among various aggregate size fractions were significant only in few cases. The SOC and TSN concentrations were higher in >0.25 mm than in <0.25 mm aggregates. The SOC sequestration rate was 77-167 kg ha\(^{-1}\) yr\(^{-1}\) by increasing the N rate and 40-162 kg ha\(^{-1}\) yr\(^{-1}\) by applying FYM. The results suggested that incorporating meadow in crop rotation and using an appropriate combination of inorganic fertilizer and FYM increased the HA and humin fractions of SOC leading to its higher sequestration rate and in consequence reducing the rate of enrichment of atmospheric CO\(_2\).
Long term agro-ecosystem platforms for assessing biogeochemical cycles, environmental fluxes and biodiversity

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Understanding biogeochemical cycles, environmental fluxes and biodiversity is critical to sustaining agricultural productivity and environmental quality especially under future climate changes. However, the difficulty of studying and understanding biogeochemical cycles and biodiversity in the soil-vegetation systems under different land use are determined by long term processes and interactions, which have long term effects on environmental outputs. Thus the attempts to directly connect land use management of agro-ecosystems to their consequences on environmental fluxes remain often unfruitful because most individual fluxes have been studied separately in spite of their strong interdependence. As a result, the majority of environmental problems observed and measured today (organic matter losses, CO₂ fluxes, NO⁻₃ leaching…) cannot be fully explained despite tremendous research efforts devoted to it. Similarly, if we want to induce changes in land use and management systems for restoring environment and biodiversity, we need to know more precisely the time response of the whole soil-vegetation system. Moreover, climate changes will induce gradual modifications and forcing on agro-ecosystems whose effects will be observable only in long terms. Under this general trend, climate change will also increase the frequency of extreme events as severe drought or high temperature periods, the capture of the consequence of these extreme event is only possible with long term observation systems.

Indeed long-term agro-ecosystem manipulation experiments are needed to relate changes in land use and management at landscape level with their environmental consequences, which are partly determined by the fluxes, by the residence time and by the balance of major elements such as C, N and P. This will require (i) to identify and characterize the compartments of the soil organic matter playing a key role, (ii) to quantify some of the key internal fluxes and to monitor at the boundaries of the system fluxes towards atmosphere and hydrosphere, (iii) to investigate the functional role of plant, microbial and soil fauna diversity with the aim of characterising the response of the whole system to the disturbance regime induced by contrasted management systems in the long term.

To do so, a long term Observatory for Environmental Research - Agroecosystem Biogeochemical Cycles and Biodiversity (ORE-ACBB) covering three different climatic regions with different land use has been set up in France. The sites of Theix (Massif central (900 m alt) and INRA Lusignan (Poitou-Charentes) are running since 2005 whereas the third site Mons en Chaussée (Picardie region) is in preparation and will be functioning in spring 2009. These three long term experimental platforms of ORE-ACBB would allow the analysis of most the main types of agro-ecosystem: (i) natural grasslands in Theix, (ii) mixed farming systems in Lusignan, and (iii) pure arable cropping systems in Mons en Chaussée. So the
ORE-ACBB is complementary of the ORE-FORET who is devoted to different types of forest ecosystems. Each site of the ORE-ACBB is devoted to a specific question. For example in Lusignan site, the practical scientific questions that need to be answered are: would introduction of leys within arable crop rotations have an effect on C and N and soil quality for the long term? Would this effect influence the quality of drainage water and reduce greenhouse gas emission. Different rotational experimental systems were designed such as: (i) pure arable cropping; (ii) pure long term grassland; (iii) mixed grassland and cropping systems (3 year grassland – 3 year arable crop or 6 years grassland – 3 year arable crop) with contrasted level of N fertilizer inputs were designed to answer these questions. In the Theix site, the question is related to the effect of grassland management (stocking density, grazing vs cutting and N fertilizer input) on both, C and N cycles and vegetation dynamics.

Figure 1. Management practices, soil organic matter dynamics and environmental fluxes.

The main scientific hypothesis of this long-term experimental platforms, regardless of management practises, is that the evolution of the system in response to anthropogenic disturbances is governed by the dynamics of quantitative and qualitative evolution of soil organic matter (SOM) itself with a strong interaction with the dynamics of biological components of soil, and with the physical and chemical components of soil. This set of interactions represents the key scientific issue of this ORE-ACBB (Figure 1). The research strategies adopted is (i) coupling the scales of time between process with short time steps and processes with longer time steps in a dynamic analysis, ii) measuring large number of key variables and integrating different processes and iii) adjusting and validating the existing models. This becomes increasingly important as land use changes not only in reaction to contrasting management practices, but also to climate change as well.

Based on management practices, the ORE-ACBB will provide (i) the trajectories of evolution of the system and their possible divergence in terms of experimental treatments over the long term, (ii) the residence time of different organic compounds of the SOM, (iii) the quantification of fluxes to the atmosphere and hydrosphere and (iv) evaluation over the long term resilience of the system after a disturbance. Further experiments on short-term processes that determine changes in state variables will provide the ORE-ACBB an indisputable
scientific value. The data produced during the lifetime of the ORE will be managed and stored in a database.

These new experimental plate-forms for studying the long term evolution of the soil-vegetation systems submitted to contrasting management regimes should give the opportunity to connect strongly together disciplinary research on vegetation dynamics, soil biology, soil physic and chemistry, interaction which have been too often carried separately in different experiments and at different sites. For example such platforms e.g. Lusignan site will increase our understanding of the effects of temporary grassland management on the environmental outputs of mixing arable cropping grasslands systems. These include: higher sequestration capacity of C within SOM, better coupling between C and N cycling and reduction of nitrate pollution, greater activity of soil microflora and meso-fauna and enhancement of soil quality. Moreover, if a tight association between arable cropping systems and temporarily grasslands contribute to prevention of soil erosion, soil degradation and nitrate leaching, the carbon budget, carbon sinks and effects on organic matter quality in managed temporarily grassland remains unknown. All these positive effects on environment are expected to be obtained both during the period of 3 or 6 years of temporary grassland and also during the period of arable cropping.
An inventory of Nordic long continued agricultural soil experiments

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Abstract
An inventory of long continued agricultural soil experiments in the Nordic countries was established during 2007-2008. The inventory encompasses experiments initiated before 1990 and includes information on their location, their history, the experimental design and treatments, and the availability of archived samples, climatic recordings, and results from previous studies on soil and crop properties. A website has been established from which the inventory can be downloaded (www.planteinfo.dk/Nordic-LTE).

Introduction
Well managed long-term agricultural field experiments (LTEs) and their related datasets of measurements provide a unique research platform for studies on the sustainability of the soil resource. Only a few Nordic LTEs are known abroad indicating a need to introduce these experimental facilities into wider circles. The objective of this study was to identify and subsequently establish an inventory of ongoing LTEs in the Nordic countries.

Methods
A questionnaire was established to identify experiments that might qualify for the inventory of Nordic LTEs. In the present context LTEs were considered to be experiments initiated before 1990. Along with an information letter the questionnaire was distributed within each Nordic country (Iceland, Norway, Sweden, Finland and Denmark) through national contact persons plus in the Baltic countries (Estonia, Latvia and Lithuania). The structure of the questionnaire was deliberately kept simple and included entries that could be completed without consulting a large number of colleagues and without digging deep into experimental details. We asked the completed questionnaires to be returned before May 2007. In October a draft inventory was distributed to researchers who had submitted entries to provide them with the possibility of checking their entries. Supplementary information concerning climate and experimental designs was sampled during November 2007-February 2008.

Results
Completed questionnaires dealing with 38 experimental plans for LTEs were received from Norway (10), Sweden (14), Finland (5), Estonia (1) and Denmark (8). A catalogue is available
at [www.planteinfo.dk/Nordic-LTE](http://www.planteinfo.dk/Nordic-LTE) (Petersen et al., 2008b). Each experimental plan has been assigned a unique catalogue number consisting of a country code and a number together with a familiar calling name for the more widely known experiments. The information in the catalogue has been compiled in an overview report (Petersen et al., 2008a).

Only one Nordic experiment, the *Askov-LTE* (DK), is more than 100 years old, while the experiments *Møystad* (NO), *Vekselvirkningen* (DK), *Kalk-fosfor försök* (SE), *Omløpsforsøket* (NO), *Ramförsöket* (SE) and *Bördighetsförsök* (SE) all are more than 50 years old. A number of experiments were started in the 1960s and several were started around 1980. The plot size varies from less than 1 m$^2$ to more than 1000 m$^2$, but the majority of experiments have plot sizes in the range 25-250 m$^2$. There is a large variation in the number of treatments, from 2 to 48. The majority of the LTE plans include 2-4 replicates.

**Treatments**

Most LTEs include various levels of mineral fertilizer, typically as reference treatment for nutrients in organic amendments such as animal manure, sewage sludge, compost or crop residues. In other experiments mineral fertilizer treatments are combined with liming or soil cultivation, and treatments including crops and crop rotations are also represented. Some experiments include other treatments such as soil type, straight and combined NPK fertilizers, catch crops, straw, peat, sawdust, permanent fallow and buffer zones. Most often a number of treatments are combined in individual LTEs.

The experimental design is most often a split-plot design, sometimes a split-split-plot design, with an even number of replicates for all treatments. The main-plot may be soil tillage, organic amendments or liming, typically with fertilizer rate as sub-plot (or sub-sub-plot) nested and randomized within the main-plots. Practical rather than statistical considerations may have been crucial for the assignment of treatments to the main and sub-plots. The oldest experiments (*Askov-LTE, Møystad, Ramförsöket*) follow a 1-factorial design, although selected treatments may be regarded as 2-factorial, but with uneven number of replicates. Also the Finnish leaching and run-off experiments follow a 1-factorial design.

**Sampling and recordings**

The effects of treatments on soil properties and yield responses are the objective of most experiments. Turnover of C and N, as well as chemical and physical soil properties recur in several experiments. A few experiments focus on cropping sequence, leaching or heavy metals. Most of the experiments use cereal crops to test treatment responses, but grass and grass/clover are also used, particularly in experiments located at more northern latitudes. Four experiments use C4-crops either grown in monoculture or in rotation (one experiment).

Generally the crop yield is recorded annually and soil samples are typically sampled and analysed at the end of a crop rotation. A sample archive is attached to most of the LTEs, but complete archives may not be found either due to infrequent sampling or incidental loss of samples due to suboptimal storage conditions. The climate has been recorded manually until establishment of automatic weather stations, often but not always located near the experimental site.
The large variation among Nordic LTEs in experimental designs and parameters is obvious and caused by the experiments not having been coordinated. This is not necessarily a disadvantage but could be viewed as an opportunity for upcoming research projects to locate a LTE that may serve as a unique research platform.

**The catalogue**

Quantitative information from the inventory is presented in an overview report (Petersen et al., 2008a). Qualitative information not easy to tabulate may be acquired by consulting each individual catalogue entry in the web-database available at [www.planteinfo.dk/Nordic-LTE](http://www.planteinfo.dk/Nordic-LTE) (Petersen et al., 2008b). The qualitative information includes the objective of the LTEs, a sketch map indicating the location as well as the geographic position given by the longitude, latitude and altitude, characterization of the soil, references to detailed descriptions of the experimental design, references to publications that have been based on samples or data from the experiment, and contact address for the holder of the LTE.

The soil type varies significantly throughout Scandinavia, ranging from coarse sand soils with 5% clay in the South-western part of Denmark to heavy clay soils with >50% clay in Finland and the central part of Sweden. Most of the experiments are associated with universities and managed by agricultural faculties or institutes, but some experiments are managed by sector research institutes that relate to the ministry of agriculture.

**Discussion**

The information presented here provides only a general description of Nordic LTEs. However, it is clear that the diversity is high. The question is: How can this diversity best be exploited in establishing a Nordic research platform? Three main approaches may be mentioned.

**Disseminate knowledge to Nordic LTEs**

This inventory contains several LTEs that deserve more widespread attention. Using the information in the web-database, the catalogue report and the overview report (Petersen et al., 2008a,b) scientists may be able to identify 2-5 experiments of interest for their upcoming projects when looking for special features that LTEs may offer. By consulting the references for the individual entries detailed description of the design and treatments may be obtained.

**Enlarging the network between holders of LTEs**

This NJF-seminar gives the opportunity to initiate a network of researchers, who are responsible for the maintenance of Nordic LTEs and/or who have already made use of the experiments in their research. Based on the inventory reports (Petersen et al., 2008a,b) participants will be able to discuss and qualify research ideas to be embedded in the experiments included in the Nordic research platform. The web-catalogue of Nordic-LTEs will also be linked to other international LTE-network activities such as the GCTE Soil Organic Matter Network (Smith et al., 2001) and the Duke University Long Term Soil Ecosystem Studies ([http://ltse.env.duke.edu/](http://ltse.env.duke.edu/)).
Identifying research themes suitable for LTEs
This NJF-seminar will also contribute to the identification of research ideas that will benefit from the platform, including its use in the training of researchers at Master and Ph.D. level. We are finally able to discuss the potential benefits of a Nordic research platform for LTEs in terms of identifying beneficial and detrimental changes in soil quality, management thresholds for specific soil properties, and the feasibility of fixed indicator values versus prescribed managements related to the EU proposal for a Framework Directive for protection of the soil resource.

The number of studies that already have benefited from samples or data from the individual LTEs vary significantly, ranging from very few to >120. Although LTEs represent a valuable and unique research platform they are not to be abused by projects that may compromise the continuity of long continued treatments.

References
**ANAEE: an innovative concept for integrated continental biosphere research**

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**Introduction**

The continental biosphere plays an important role in global changes of the planet by means of its interactions with atmosphere and hydrosphere and also by the fact that most of the continental ecosystems are subjected to severe manipulations through human activities. These anthropogenetic actions have numerous effects on environmental issues for human societies.

Attempts to relate directly atmospheric conditions or anthropogenic management in ecosystems to their consequences on environmental fluxes have often been misleading because: (i) each individual flux (e.g. nitrate leaching, phosphorus transfer, $N_2O$ and $NH_3$ emission, $CO_2$ sequestration or emission, water flows, xenobiotic fluxes, etc…) has been studied separately from each other (disciplinary research) despite their great interdependency, (ii) the characteristic rate functions of the different processes involved in the dynamics of the system are not well known, and (iii) the residence time of the different elements (C, N, P…) within the different compartments of the ecosystem has not been well evaluated. As a consequence, some of the environmental outputs that we observe today could be the consequence of changes in land use and management that occurred several years or decades ago. Similarly, if we want to induce changes in land use and management systems for restoring and enhancing environment and biodiversity, we need to know more precisely the time response of the whole system: vegetation, soil, microbial communities and micro- and meso-fauna. For these reasons, it is necessary to develop long term integrated experimental facilities for determining baseline conditions and for studying the dynamics of evolution of different ecosystems under anthropogenic forcings.

Ecosystem sciences have often been structured around observational systems where the dynamics of populations and communities of organisms have been studied in relation to their environment. But in the absence of experimental manipulations of populations or communities and of environmental parameters, the relationships obtained are only descriptive and can rarely be interpreted as causal.

Due to the various scales and the complexity of the interactions between ecosystem processes and the environmental conditions, meeting this challenge requires a sustained research effort with various approaches closely linked. The coupling of *in silico* (theoretical and mechanistic models), *in vitro* (closed controlled facilities: ecotrons) and *in natura* experimental approaches to address these issues is then crucially needed. Theoretical and mechanistic models, powerful ‘ecosystem analysers’ and long term field experimentations are all needed to analyse, model and predict the consequences of global changes on biogeochemical fluxes and biodiversity. Such a coupling will not only provide fundamental knowledge on the
processes by which ecosystems, communities and populations of organisms respond to forcing variables, but it will also allow for valuable predictions and simulations of prospective scenarios.

These tools need a strong, concerted and innovative development across Europe. Such a development is the objective of the Infrastructure ANAEE (Analysis and Experimentation on Ecosystems). This infrastructure aims at becoming the backbone of the development of ecosystem science into modern systems biology using in silico, in vitro and in natura experiments to generate and test hypothesis and to make predictions. The ANAEE research infrastructure will therefore expand and network these complementary experimental platforms.

Ecosystem analysers (Ecotrons)
The principle of Ecotrons is to confine samples of ecosystems in closed or semi-closed environments in order to simulate a wide range of environmental conditions and to measure accurately the impact of these conditions on ecosystem processes.

Terrestrial as well as aquatic ecosystem can be studied in Ecotrons at various scales, from microcosms of a few litres to macrocosms of several tons. While most past or existing infrastructures dedicated to ecosystem experimentation were primarily equipped for environmental conditioning, a new generation of infrastructures providing more realistic environmental conditions will also stand out by their measurement capacity. State of the art instrumentation, generally not available at the level of individual laboratories or even nations, will allow new breakthrough by removing technical barriers. Integrated responses of ecosystems will be measured, in particular the components of biogeochemical cycles, as well as their underlying mechanisms at the level of organisms, populations and communities. Reconstructed, model ecosystems representing a simplification of the full complexity of natural ecosystems can also be studied in Ecotrons. It allows the study of, for example, relationships between structure and function, or the impact of complexity on ecosystem dynamics. Mathematical models can be used to link processes in model ecosystems to ecosystems in natura.

An innovative use of Ecotrons, especially when their measurement capacities are well developed, is to analyse the physiology of blocks of ecosystems which have been subjected in situ for years to various treatments within Long Term Experimental Platforms (LTEP) systems (see below). In that case, Ecotrons can been seen as ecological analysers receiving samples for analysis.

Long Term in situ Experimental Platforms (LTEP)
A network of LTEP will constitute a large-scale European-Field Laboratory with the aim of providing fundamental, mechanistic information on ecosystem structure, function and resilience.

Five thematic areas are in focus: 1) the patterns and controls of primary productivity, 2) the spatial and temporal distribution of representative populations of plants, animals and
microbes, 3) the distribution and dynamics of organic matter in soil, water or sediments, 4) the patterns of inputs and transport of inorganic nutrients and chemicals through the ecosystem, and 5) the patterns and effects of disturbances.

The role of these LTEP facilities should be:
- to maintain in the long term the different treatment by appropriate management systems;
- to insure the monitoring of all state and flux variables at appropriate time intervals;
- to construct and maintain databases with access for the scientific community;
- to create and conserve collections of samples of soil, vegetation, water, and organisms.

These platforms should be organised for hosting some complementary experiments and measurement facilities allowing the analysis of some processes and mechanisms through the use of isotope tracers, portable growth chambers, FACE systems etc. ANAEE will assist in developing existing sites across different European countries and setting up complementary ones where necessary.

**Modelling and bioinformatics facilities**

It is also crucial to develop theoretical frameworks and simulation models to help interpreting the results of the Ecotron and Long Term Experimental Platforms and to suggest new experiments. The information and knowledge gained from this research will also feed into scenario simulations to evaluate environmental hazards and impacts on functional biodiversity resulting from a wide range of contrasting land use and management systems. ANAEE will initiate a modelling platform.

The results of the research programs carried out within ANAEE must feed a common integrated data base and information system allowing exchanges and communications between different research teams of different disciplines. The handling and the exploitation of the considerable amount of data generated by these instruments as well as the high level of complexity generated by the large number of interactions and feedbacks operating in ecosystems require a large investment in computing power and informatics and the support for the development of an innovative systems biology approaches to ecosystem science. A European (Eco) Systems Biology Centre will have to be developed which will also operate a Virtual Institute for Theory and Modelling when this distributed infrastructure is established.

**Integrating the three tools**

The added value of the ANAEE distributed infrastructure is coming from the interaction and integration of the three component tools: ECOTRON, LTEP and Modelling Platform

- **ECOTRON** represents a powerful capacity for studying quantitatively processes in relation with environmental variables, but with difficulties for defining the domain of validity and the extrapolation of the relationships obtained in natural conditions;
- **LTEP** alone does not allow the separation of the effect of parameters correlated in natural environment, so the relationships obtained between variables are not directly causal;
- **Modelling Platform** will allow the integration of results obtained in ECOTRON with data collected in LTEP within a more comprehensive system biology approach.
The first impact expected by the ANAEE infrastructure is to structure the European scientific community in continental biosphere (agronomists, soil scientists, ecologists, foresters…) around shared complementary infrastructures. The three interrelated infrastructures proposed in the ANAEE concept should encourage and promote a more holistic vision of the functioning of the different agro-ecosystems constituting the continental biosphere, with a more inter-disciplinary approach.

So the emergence of ANAEE network of infrastructures in Europe would be an important opportunity for developing strong inter-disciplinary research programmes dealing with the main scientific stakes related to the interactions between soil-vegetation systems and both atmosphere and hydrosphere for the two major issues of water resources management and global climatic changes. Innovation in environmental sciences will emerge more from the coupling between different processes (genetic and community dynamics, biology and physico-chemistry, soil and vegetation etc…) than by deepening the understanding of each process in isolation. By the mean of promoting facilities for such an integrated approach the ANAEE distributed infrastructure should contribute at boosting European research potential on continental biosphere at a high international level for leading research programmes related to these problems.

Another impact of the development of ANAEE network should be the opportunity to develop in Europe a strong ecological engineering in order to valorise all the expertise accumulated within this network in term of manipulation or management of agro-ecosystem for optimising both their economic outputs and their ecological services. The Long Term Experimental Platforms could be advantageously coupled with more operational monitoring and observations for environmental survey offering then unique research services to national or regional users as environmental agencies, territorial management entities, national or regional parks etc…. Moreover, the modelling expertise and the data bases accumulated would provide unique tools for simulation of different scenarios of management of ecosystems, or association of agro-ecosystem at landscape level, and the evaluation of different environmental outputs. This would have also an impact on teaching agronomy, ecology and forestry with management perspectives by contributing to get a more holistic vision of the systems. This aspect should attract young people to scientific education courses by pointing out the strategic place of basic sciences for applications in term of management decision for sustainable development.

Moreover, this ANAEE distributed infrastructures might be extended to overseas countries in order to integrate a wider range of climates and ecosystems. Some European research institutions have close research contacts with tropical countries and existing experimental platforms could be integrated within ANAEE. So the ANAEE distributed infrastructure could initiate integrated programmes with developing countries and for education and formation of the scientific staff of these countries. In exchange this possibility would open more largely ANAEE to a worldwide scale.
Long-term experiments as a platform for monitoring bread wheat quality

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Abstract
Both winter wheat and spring wheat have the potential for producing grain of bread wheat quality under North European conditions. The two crops may due to their different growth length respond differently to previous use of green manure and to the soil organic matter content. To compare winter wheat and spring wheat for their ability to produce quality grain for bread production, both crops are included in a long-term experiment (LTE) at Askov Experimental Station. The LTE provides a unique platform for such comparison, as the two crops can be grown under identical conditions regarding previous management, soil and climate. The bread wheat experiment is part of the project AGronomical and TEChnological methods to improve ORGanic wheat quality (AGTEC-Org) funded by CORE Organic (www.coreorganic.org).

Background
It is a challenge to organic farmers, millers and bakeries to fulfil consumer expectations of healthy and safe products without impairing yield performance. The quality of organic grain can be modified by agronomic conditions such as crop management, crop rotation, and soil fertility. Food processing technologies such as the post-harvest handling of the grain and flour processing are also key factors in producing bread of high nutritional value without contaminants. AGTEC-Org focuses on the optimization of agronomic practices and grain fractionation processes in order to obtain wheat and flour with improved nutritional value, health and sensory characteristics. The project is a transnational research project with partners from ISARA, ESA, INRA in France; FiBL and ART in Switzerland; BOKU in Austria and INRAN in Italy. Further information at: http://agtec.coreportal.org

Objective
The overall objective of the AGTEC-Org project is to identify agronomic and food processing technologies that enhance the baking quality and the nutritional value of organic wheat and reduce mycotoxin contamination. Specific objectives are to:

- Evaluate the current practices for organic grain wheat production and flour-processing in Europe,
- Improve crop management strategies to enable bread-quality wheat to be produced on organic farms with and without livestock,
- Develop optimal post-harvest treatment to prevent mycotoxin contamination and enhance bread-making quality and nutritional value,
- To generalise results from experiments in order to enhance farm management strategies in diverse climates and soil types.
The aim is to enhance the quality, relevance and utilisation of resources in European research in organic food and farming through coordination and collaboration.

**Materials and methods**

Interactions between type of green manure and time of incorporation will be investigated at Askov Experimental Station in Denmark in the DK-5 experiment in the catalogue on Nordic LTEs (Petersen et al., 2008). In this LTE initiated on a sandy loam in 1981, three green manure treatments were included in 2003: ryegrass, grass-clover and none. Half of each plot is ploughed in late autumn; the other half is ploughed in spring. The standard crop in the LTE is spring barley. In the 2007/2008 growing season, winter wheat will be sown after the autumn ploughing and spring wheat after the spring ploughing. Grain of winter wheat and spring wheat will be sampled in 2008. The two wheat types will be tested for protein content, baking quality and *Fusarium* contamination.

**References**

Long term experiments in Iceland

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Introduction
Icelandic agriculture is based on the cultivation of grass fields and the use of range land for pasture. Around 80-90% of the animal fodder is in the form of hay or silage. Until 1990 most grass fields were seldom recultivated but since then it has become more common to renew them with a few years interval. In the course of time the fields are invaded by native vegetation and the proportion of sown varieties declines.

Numerous fertiliser experiments were performed on grass fields in Iceland during the years 1930-1970. Most of these experiments lasted only a few years. However, quite a few of them continued for many years and became long term experiments. These experiments were fertilised with the same amount of fertiliser every year, some of them for 50-60 years or more.

The experiments
The experiments were harvested and yield measured every year, usually twice, and the harvest sampled. The soil was sampled less frequently although surface samples were taken nearly annually in a few experiments, in some cases for more than three decades, and the botanical composition was estimated occasionally. Most of the experiments were on the experimental stations Sámsstaðir, Reykhólar, Akureyri and Skriðuklaustur and only one of these stations are still operated at a different location. Only two of these experiments are still running at the Agricultural University in Hvanneyri. However, the results of yield measurements in combination with chemical analyses of yield of soil samples are a very valuable source for detailed studies of the effect of fertilisation on soil and forage. Earlier works need to be reconsidered in the light of later results and numerous samples remain to be analysed. This work has been in progress during the past decade. Few of these experiments have been used for new experiments by division of the plots. Results from our long-term experiments are presented at this seminar in four other presentations. The most important experiments are listed in Table 1. At the moment the main emphasis in our studies on the long term experiments are:

1. Nutrient balances and the effect on nutrient status and fertility of the soils.
2. The influence of different fertilisers on C and N in the soils and testing of carbon models.
3. The fate of surplus phosphorus in the soils and its availability.
4. Investigation on the effect of fertiliser on hay yield and quality.
5. Trends in micronutrient contents.
Table 1. Subject, duration, soil types and location of the experiments.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Duration</th>
<th>Soil type</th>
<th>Location</th>
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<tr>
<td>Different forms of N fertiliser</td>
<td>1945-2005</td>
<td>Silandic Andosol</td>
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<td>1954-1996</td>
<td>Gleyic Andosol</td>
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<td>Increasing N fertiliser</td>
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<td>1954-1986</td>
<td>Gleyic Andosol</td>
<td>Skriðuklaustur</td>
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<td>Increasing K fertiliser</td>
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<td>Histic Andosol</td>
<td>Sámsstaðir</td>
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<td>Vitric Andosol</td>
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<td>Reykhlólar</td>
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<td>1958-1978</td>
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<td></td>
<td>1938-2006</td>
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<td>Akureyri</td>
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<tr>
<td>Increasing P fertiliser</td>
<td>1950-2004</td>
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<td>P and K experiments</td>
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<td>1954-1986</td>
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<td>Hvanneyri</td>
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</tr>
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<td>Organic and inorganic fertiliser</td>
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<td>Sámsstaðir</td>
</tr>
<tr>
<td>N, P and K experiments</td>
<td>1970-</td>
<td>Hemic Histosol</td>
<td>Hvanneyri</td>
</tr>
<tr>
<td>Increasing N and K + manure</td>
<td>1977-</td>
<td>Hemic Histosol</td>
<td>Hvanneyri</td>
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</table>

The soils in Reykhlólar were on an alluvial plain and included both freely and poorly drained soils.
Carbon and nitrogen balances of three different soils from a long-term experiment with vegetable crops

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Introduction
The function of plant soil systems as a carbon sink and/or source is one of the countless problems discussed recently in the context of global climatic change. Although vegetable production is only a percentage of arable land, the mechanisms of plant soil interactions are the same as in agriculture.

The aim of this presentation was to show the long-term effects of different organic and mineral N fertilization strategies on the C and N balance components within a 30-year period.

Material and methods
The data presented here result from a long-term experiment initiated in 1973 in Grossbeeren, south of Berlin (Germany). Three soils different in soil texture (5 %, 15 % and 25 % clay) were filled in concrete boxes with a surface area of 2 x 2 meters and a depth of 75 cm. Twelve different fertilization strategies (3 levels mineral N, 4 kinds of manure) were tested in quadruple replication within the vegetable crop rotation white cabbage – carrots – cucumber – leek – celery. The quantity of mean annual irrigation water amounted about 150 mm.

Measured components of the C and N balances were the element quantities applied with fertilizers, removed from the field and changed in the storages of soils. Mean annual N inputs from atmospheric deposition and from irrigation water were considered with 50 kg ha\(^{-1}\) and 15 kg ha\(^{-1}\), respectively

Results and conclusions
The results are presented exemplarily for the sand soil (5% clay).
C and N balances were calculated according to the following equation:

\[
\text{Output by plants} + \text{Changes in soil storage} - \text{Input by fertilizers (and other N sources)} = \text{Balance}
\]

The investigations showed that a) to get the maximum carbon yield of the plant soil system and b) to keep mean annual N losses less than 50 kg ha\(^{-1}\), both the C and the N input by manures is to minimize whereas the mineral N supply could increase up to the site specific potential of plant matter production. This implies that the organic matter input by harvest residues (of the treatments without manure) led to a humus content of soils allowing high plant productivity combined with low N losses under these conditions.
N balance as an indicator of N leaching in long-term leaching fields

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Introduction
Ideally, N fertilizers, manure, mineralization and biological N fixation provide sufficient N for crop and forage growth by simultaneously avoiding the risk of water and air pollution due to N surpluses. This ideal state is often not achieved, and the calculation of N balances has been identified as a priority agro-environmental indicator of the environmentally harmful N losses from agricultural fields. The aim of this study was to compare relationships between N surface balances and N leaching losses with data obtained from two long-term agricultural runoff fields in Finland.

Material and methods
The Finnish runoff data was retrieved from two experimental fields on clayey and sandy soil, reported in Salo and Turtola (2006). The experimental field on clay soil is located in Jokioinen, southern Finland (60°49'N, 23°28'E, 85 m a.s.l.). The soil is a heavy clay (> 60 % clay, 2.6 % organic C) with a mean slope of 2 % (1–4%). The experimental field on sand soil is situated in Toholampi (63°49'N, 24°09'E, 83 m a.s.l.), with a mean slope of 0.5 % (0.3–0.7%). The soil is classified as a fine sand soil (< 10 % clay, 5.0 % organic C).

Annual N balances were calculated for each plot by considering fertiliser N, manure N and estimated N fixation as the input and crop N (yield) and estimated ammonia volatilisation from the manure applications as the output. The annual N balances were then compared with the annual N leaching losses. Annual N leaching was calculated as the sum of N lost via surface and drainage runoff. In addition to the annual balances, N balances were averaged over the years of similar management and compared with the respective averaged N leaching, for accounting the delay in the leaching due to variable climatic variations.

In our previous work (Salo and Turtola, 2006), linear regression model was fitted to the Finnish datasets and now the linear-plateau model (Sieling and Kage, 2006) was used for the same datasets. N balance at the intersection of the plateau and the linear model, leaching at the plateau part of the model and the proportion of N balance leached at the linear part of the model were estimated using the NLIN procedure of SAS.

Results and discussion
In the Finnish conditions, annual N leaching from the experimental plots was not adequately estimated using the respective annual N balances, or supplementing the estimation with annual precipitation, total runoff, or drainage runoff (Salo and Turtola, 2006). Values averaged over the years improved the estimation when management included such environmentally risky managements as bare fallow or off-season application of cow slurry (Salo and Turtola, 2006).
Calculated with the linear regression (Salo and Turtola, 2006), N leaching was 20–57% of the averaged N balance (Table 1). The linear-plateau model produced higher percentage of N leaching (57%) from the averaged N balance at the linear part of the model (100 x slope in Table 1). The linear-plateau model could not directly be fitted to arable dataset since N leaching did not reach the plateau part. Then N leaching at the plateau part was set to the lowest averaged N leaching values observed at the experimental period.

Table 1. Linear and linear-plateau equations of the averaged N balance (Nb) and N leaching. N₀ is the estimate of N leaching at the plateau part of the model. Intersection is the threshold value of N balance where the linear part of the model begins. Slope is the proportion of the balance (N balance – intersection) that is leached.

<table>
<thead>
<tr>
<th>Crop rotation</th>
<th>linear equation</th>
<th>R²</th>
<th>N₀, N kg ha⁻¹</th>
<th>Intersection, Nb kg ha⁻¹</th>
<th>Slope</th>
<th>R²</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>arable</td>
<td>-13+0.57Nb</td>
<td>0.71</td>
<td>6</td>
<td>33</td>
<td>0.57</td>
<td>0.71</td>
<td>8</td>
</tr>
<tr>
<td>grass</td>
<td>5+0.20Nb</td>
<td>0.69</td>
<td>10</td>
<td>99</td>
<td>0.57</td>
<td>0.93</td>
<td>16</td>
</tr>
</tbody>
</table>

With its simplicity, N balance is a useful indicator for potential N leaching. The considerable variation between the balance values and the actual N leaching, at least in individual fields and within a few years time-scale, is obviously due to the complex turnover of N in soil resulting in delayed feedbacks of the management practices and N surpluses. The linear–plateau model seems to be a more appropriate way to describe the relationship between N balance and N leaching than the simple linear regression.

References
Introduction
Field testing of crop response to P and K application generally requires an experimental site with low available soil P or K status. However, most Danish arable soils are high in available P and K due to generous fertilisation with inorganic fertilisers and animal manures for decades.

At the Experimental Research Farm of The Royal Veterinary and Agricultural University (now a part of University of Copenhagen since 2007) the Long-term Nutrient Depletion Trial was established back in 1964 by staff at the Department of Plant Nutrition. The site did not receive any P or K containing fertilizers or manures in the period up to 1995 and in this period the field was managed with continuous cereal production. The available P and K levels decreased to relatively low values over these more than 30 years of depletion.

In 1996 a new experimental design was applied in the majority of the field, with two more varied crop rotations and seven nutrient application treatments, including both mineral fertilizers and animal manures. The overall objectives of the new experimental design were to study how soil biology, physics and chemistry and crop performance behaved when an arable soil low in P and K, receives N, P and/or K in mineral fertilizers or animal manures. Specific objectives were to study soil ability to supply crops with N, P and K and crop uptake of N, P and K, physiological response and yield for different crop species and cultivars.

Site and experiment description
The facility is located 20 km west of Copenhagen (the University of Copenhagen experimental farm), Denmark (55° 40’ N, 12° 17’ E). Average temperature is 7.5 °C (max. 15.8 and min. -0.5 °C) and annual precipitation is 610 mm. The soil type is sandy clay loam (clay 15%, silt 18%, sand 65%) with a content of 1.15 % C, 0.13 % total N, a C/N of 9, a soil pH (0.01 M CaCl2) of 5.6 and a cation exchange capacity of 8.4 cmolc. kg⁻¹ soil at pH 7.

In 1964 a test site, the Long-term Nutrient Depletion Trial, was established in an 8.5 ha field (field #33). It was managed with a continuous cereal production, which as one single treatment received mineral N fertilizer (60 kg N ha⁻¹ y⁻¹), but no P or K containing fertilizers or manures in the period until 1995. The available P and K levels decreased to relatively low values (Olsen-P of 11 mg kg⁻¹ and exch. K of 55 mg kg⁻¹) over these more than 30 years.

In 1996 the field was divided into 2 main plots (North and South), in which 2 different crop rotations were placed (Table 1). Each main plot has been divided into 2 blocks, in which 7 subplots of 18 x 100m (2 m guard zones) are placed, corresponding to the main NPK treatments, see Table 2. West of the main plots, are 4 extra subplots where the original treatment from 1964 are maintained (60N, 0P 0K).

* : In memoriam; deceased 2005
Table 1. Crop rotation in the southern and northern main plots, respectively.

<table>
<thead>
<tr>
<th>Year</th>
<th>South main plot</th>
<th>North main plot</th>
</tr>
</thead>
<tbody>
<tr>
<td>1996</td>
<td>Spring barley</td>
<td>Spring barley</td>
</tr>
<tr>
<td>1997</td>
<td>Spring barley with grass clov. undersown</td>
<td>Sugar beets</td>
</tr>
<tr>
<td>1998</td>
<td>Grass clover (for silage)</td>
<td>Sugar beets</td>
</tr>
<tr>
<td>1999</td>
<td>Grass clover (for silage)</td>
<td>Spring barley with grass clov. undersown</td>
</tr>
<tr>
<td>2000</td>
<td>Sugar beets</td>
<td>Grass clover (for silage)</td>
</tr>
<tr>
<td>2001</td>
<td>Spring barley with grass clov. undersown</td>
<td>Grass clover (for silage)</td>
</tr>
<tr>
<td>2002</td>
<td>Spring barley</td>
<td>Spring barley</td>
</tr>
<tr>
<td>2003</td>
<td>Spring barley</td>
<td>Spring barley</td>
</tr>
<tr>
<td>2004</td>
<td>Spring barley with grass clov. undersown</td>
<td>Spring barley</td>
</tr>
<tr>
<td>2005</td>
<td>Grass clover (for silage)</td>
<td>Spring barley with grass clov. undersown</td>
</tr>
<tr>
<td>2006</td>
<td>Grass clover (for silage)</td>
<td>Grass clover (for silage)</td>
</tr>
<tr>
<td>2007</td>
<td>Spring barley</td>
<td>Grass clover (for silage)</td>
</tr>
<tr>
<td>2008</td>
<td>Spring barley with grass clov. undersown</td>
<td>Spring barley</td>
</tr>
</tbody>
</table>

Table 2. Nutrient treatments, with application rates in kg ha\(^{-1}\) y\(^{-1}\) and source.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>S</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>60</td>
<td>0</td>
<td>60</td>
<td>25</td>
<td>Fertilizer</td>
</tr>
<tr>
<td>C</td>
<td>60</td>
<td>10</td>
<td>0</td>
<td>25</td>
<td>Fertilizer</td>
</tr>
<tr>
<td>D</td>
<td>60</td>
<td>10</td>
<td>60</td>
<td>25</td>
<td>Fertilizer</td>
</tr>
<tr>
<td>E</td>
<td>120</td>
<td>20</td>
<td>120</td>
<td>50</td>
<td>Fertilizer</td>
</tr>
<tr>
<td>F</td>
<td>75*</td>
<td>10</td>
<td>75</td>
<td></td>
<td>Animal slurry</td>
</tr>
<tr>
<td>G</td>
<td>150</td>
<td>20</td>
<td>150</td>
<td></td>
<td>Animal slurry</td>
</tr>
<tr>
<td>H</td>
<td>60</td>
<td>0</td>
<td>0</td>
<td>25</td>
<td>Fertilizer</td>
</tr>
</tbody>
</table>

*: 75 kg of total N for the animal slurry treatments corresponds to approximately 60 kg NH\(_4\)-N

In 1995 soil samples were taken from all plots and analysed. Crop biomass production has been determined as grain yield at harvest for cereal crops, and biomass dry matter yield for clover grass silage cut 1, 2 and sometimes 3 in years with grass. Crop samples (grains for cereals and plant samples for grass clover) have occasionally been analysed for N and in a few instances for other elements.

**Results**

Yield results are available for most years and will be summarized in the poster together with some of the data on crop nutrient uptake.

The experiment has also accommodated related studies on e.g. the relationship of root hair promoted P uptake of selected barley genotypes to the grain yields in P limiting soil (Gahoonia and Nielsen, 2004) and the ability of different catch crop species to mobilise and take up P and K from soils of low availability, as well as their ability to deliver P and K to the subsequent main crop (Jensen et al., 2005).

**References**


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Well-managed, long-term agricultural field experiments provide a unique research platform for studies on the sustainability of the soil resource. The soil can be considered a non-renewable resource, and vital economical, environmental and human health issues are intimately linked to soil properties. Soils play a key role in carbon, nutrient, and water storage, in the elimination of harmful substances and organisms originating from anthropogenic activity, and constitute a biological habitat with a unique genetic and functional biodiversity. Thus soils are crucial in the production of food, feeds and fibres, in the protection of water resources, and in the exchange of greenhouse gases with the atmosphere.

This report presents abstracts of oral and poster contributions to an international seminar on the use of long-term experiments as research platforms. One seminar priority was the identification of research areas that will benefit from platform networking on a Nordic and a wider EU scale.