

Technical Annex

Scientific description of the project

Title: The effect of cropping systems on production and the environment (CROPSYS)

Acronym: **CROPSYS**

Duration: 4.5 years **From:** Jan 2006 **to:** Jun 2009

Participating scientists:

(Titles, names and brief institutional affiliations of scientists in the project. Head of project is written in bold, participants responsible for work packages are underlined).

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English summary

Modern agricultural systems greatly influence the environment, and there is a particular emphasis in Denmark on nitrate leaching and greenhouse gas emissions from agriculture. Sustainable agricultural systems also need to fulfil the requirements for quantity and quality of the agricultural produce. Crop production in organic farming systems relies to a large extent on soil fertility for nutrient supply. The soil fertility must be maintained via choice of crop rotation and (green) manuring practices. A proper management of this to improve crop yields and reduce emissions to the environment requires an in-depth understanding of soil processes and nutrient dynamics, and their effects on crops and weeds.

A long-term organic crop rotation (CRO) experiment was initiated in 1997 at three different locations in Denmark; in 2005 it is modified to include also a conventional system. The three locations represent typical soils (sand, loamy sand and sandy loam) and climates for Danish agriculture. The design of the currently 8-year old rotations allows for effects of manure application and catch crops to be distinguished, and for effects of soil type and climate to be quantified. Thus, a differentiated analysis of management strategies can be conducted. The project will exploit this unique long-term experiment for an integrated study of the productivity and nitrogen (N) flows in organic cropping systems.

The project will quantify productivity and environmental impacts of different organic and conventional cropping systems across a range of soil and climatic conditions, and identify management measures, which contribute significantly to a sustainable development of the individual cropping systems. This will be achieved through an integrated experimental and modelling programme, where measurements of key indicators of productivity and environmental impact and of the underlying processes and dynamic soil properties are carried out in the CRO experiment. A simulation model (FASSET) and a life cycle analysis (LCA) model will be used to analyse different management scenarios. The output of the work is guidelines for improving the sustainable development of organic crop production systems in Denmark.

WP1 will coordinate the project and ensure the communication between partners and with stakeholders. A common measurement and management protocol for the CRO experiment will be maintained. All data from the CRO experiment will be stored in a database for access by all partners.

WP2 will manage the CRO experiment. The experiment includes three 4-year crop rotations representing an organic green manure/cash crop rotation, an organic cash crop rotation and a conventional cash crop rotation. A factorial design is used, which includes two manure treatments and two catch crops treatments. With two replicate plots for each system combination, a total of 64 field plots are managed at each site. Crop yield and biomass of crops and weeds will be measured. The crop N uptake will be measured and the N_2 -fixation will be measured in legume crops and catch crops.

WP3 will measure nitrate leaching of all cropping systems of the CRO experiment. This enables an interpretation of short- and long-term effects of management and location on the nitrate leaching. The leaching of dissolved organic nitrogen (DON) will be measured in a campaign coordinated with measurements of topsoil DON in WP5. The potential uptake of N by roots in soil layers below the installed suction cups will be analysed from measurements of root development using minirhizotrons and modelling (WP6).

WP4 will measure nitrous oxide emissions from four selected treatments in the CRO experiment during a 12 month period at two of the locations. Samples of the topsoil will be taken at the sandy loam site to investigate cropping systems effects on denitrification and the ratio of $N_2O:N_2$ production. Soil samples will be collected in autumn 2008 at two depths for measurements of total carbon (C) and N to analyse trends in soil C and N storage.

WP5 will quantify the effects of contrasting cropping systems on a range of soil attributes (including pore size distribution, air permeability, soil workability, soil mineral N, DON, microbial biomass N). Measurements will be taken during two years in the CRO experiment. Some of the measurements will be taken in all systems. However, the majority of the effort will focus on the four contrasting systems and the two sites also used in WP4. In addition, soil samples will be analysed for net N mineralisation and for microbial biomass pools.

WP6 will use statistical methods, simulation modelling (FASSET) and life cycle analyses (LCA) to generalise the results of the CRO experiment (WP2 to WP5) to other climatic and soil conditions and to other management strategies. This will include an assessment of the environmental impact of the whole product chain for both organic and conventional farming systems. These results will be used for quantifying management measures that may contribute significantly to a sustainable development of organic farming systems.

A.1 Introduction, state of the art and objectives of the project

Modern agricultural systems greatly influence the environment both locally and globally. In Denmark, nitrate leaching from agriculture is particularly important due to its negative impact on aquatic ecosystems, and nitrate leaching must be reduced to comply with the EU Water Framework Directive (Anonymous, 2003). On a global scale, nitrous oxide (N_2O) is a major contributor to the emission of greenhouse gases (Mosier et al., 1998), and in Denmark agriculture is by far the largest emitter of N_2O (Olesen et al., 2004). Denmark has a commitment under the Kyoto Protocol to reduce greenhouse gas emissions by 21% in 2010, and so options to mitigate N_2O emissions should also be explored. Sustainable agricultural systems should not only be environmentally benign, but also fulfil the needs for high quantity and quality of agricultural products. Organic farming have some benefits in this area, but there is also scope for improvements (Berntsen et al., 2004; Olesen et al., 2005b).

Crop production in organic farming systems relies to a large extent on soil fertility for nutrient supply. The soil fertility must be maintained via choice of crop rotation and (green) manuring practices. Fertility building by such means requires a long-term integrated approach, rather than the short-term and targeted solutions common in conventional agriculture (Watson et al., 2002). It follows that, for studies of management effects on soil fertility, long-term cropping experiments are indispensable.

Crop yields and product quality must meet the demands of farmers and consumers, respectively, without jeopardizing air and water quality. This requires an in-depth understanding of soil processes and nutrient dynamics during and outside the growing season (Mäder et al., 2002; Stockdale et al., 2000). In the Swiss long-term DOC-crop rotation experiment, Mäder et al. (2002) found enhanced soil fertility

in organic compared with conventional treatments. This may increase crop yields, but also nitrate leaching and nitrous oxide (N₂O) emissions (Robertson et al., 2000; Berntsen et al., 2004). To ensure a sustainable development of organic crop production systems, there is a need to evaluate and contrast effects of organic and conventional rotations on yields and environmental impact. Such an analysis should address the interests of all stake-holders, i.e., farmers, consumers, politicians and authorities.

A long-term organic crop rotation (CRO) experiment was initiated in 1997 at three different locations in Denmark (Olesen et al., 2000); in 2005 it is modified to include also a conventional system. The design of the currently 8-year old rotations allows for effects of rotation, manure application and catch crops to be distinguished, and for effects of soil type and climate to be quantified. This project aims to exploit this unique long-term experiment for an integrated study of the productivity and nitrogen flows in organic cropping systems as compared with conventional systems.

State of the art

Management effects will not manifest themselves immediately, but only over the course of several years. This temporal aspect is of particular importance in organic farming, where the systems rely on soil fertility (Shepherd et al., 2002; Stockdale et al., 2002). Soil fertility integrates a wide range of soil physical, chemical and biological properties, and the performance of cropping systems and their contribution to a sustainable development can therefore most effectively be evaluated through monitoring of key indicators (Vereijken, 1997; Rigby et al., 2001). For this project we have selected indicators for crop production (yield), environmental impact (N leaching and greenhouse gas emissions) and resource use (use of fossil energy and other non-renewable resources). The cropping system and management will affect the key indicators directly and in-directly through a number of inter-linked processes and dynamic soil and crop properties (Figure 1).

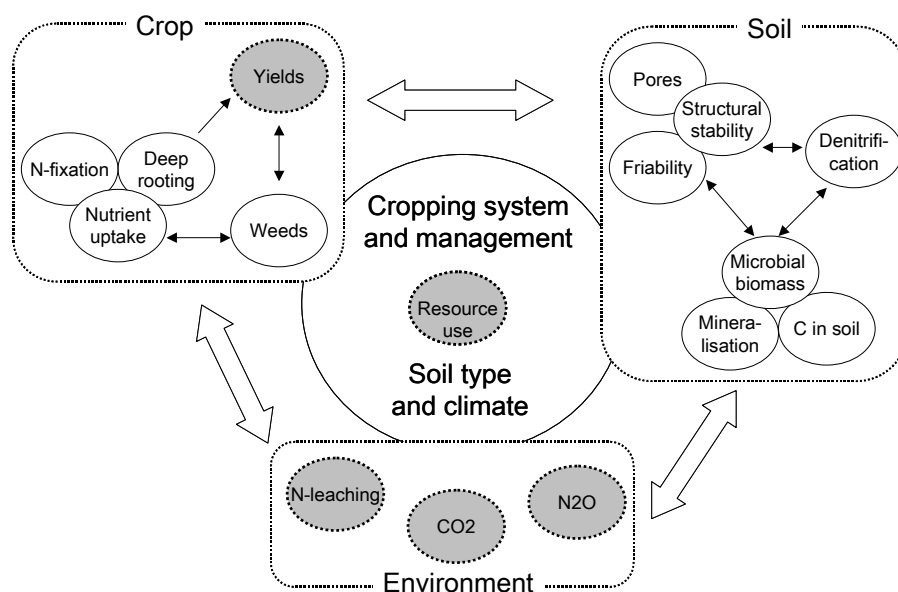


Figure 1. Key processes and dynamical properties (white) and their influence on key indicators (grey).

Crop yields and weed control. Crop yields in arable organic farming are mainly affected by N supply and weed control (Berry et al., 2002; Olesen et al., 2005a). These factors are in turn affected by management and local soil and climatic conditions (Rasmussen et al., 2005b). The CRO experiments have thus shown significant effects of location, crop rotation, catch crops and manure on yields (Olesen et al., 2002). There were indications of changes of some of these effects over time as a result of the ‘buffering power’ of grass-clover, where the N₂-fixation is affected by crop management and soil fertility (Askegaard et al., 2005b). This buffering power will probably not only affect yields but also the risk of N losses, and there is a need to further investigate possibilities of controlling N supply to the crops better through improved use of green manure crops, catch crops and manure at the crop rotation level.

Perennial weeds (especially *Cirsium arvense* and *Elymus repens*) have proliferated severely in the CRO experiment at two of the three locations during the experimental period, and these weeds may seriously reduce yields in organic arable farming. Direct control of perennial weeds is typically carried out by

stubble cultivation in autumn, reducing the possibilities for growing catch crops. The energy use, as well as the elevated risk for nutrient leaching, jeopardizes the sustainability of this practice, and therefore cultivation should be avoided (Rasmussen et al., 2005a). The CRO experiment has shown that the occurrence of these weeds is significantly affected by the choice of crops and catch crops, and by the addition of manure (Askegaard et al., 2004). However, this needs to be further substantiated, and the effects of weed infestation on yields, as well as the interaction with fertility level needs to be quantified.

Catch crops and N leaching. In the CRO experiment, catch crops have reduced nitrate leaching significantly on two sandy soils, but not on a sandy loam, where the initial soil fertility was low (Schjønning et al., 2004b; Askegaard et al., 2005a). The ability of catch crops to retain mineral N depends both on plant species and (sub)soil type. Large differences between catch crop types with respect to root depth and ability to absorb N from below 1 meter have been found on a sandy loam soil (Kristensen and Thorup-Kristensen, 2004). On a coarse sandy soil, the root depth of several catch crop types screened did not exceed 75 cm depth (Askegaard, unpublished results). Nitrate concentrations of the soil water at 1 m depth are normally assumed to reflect those of drainage water, so there is a need to estimate the N uptake of catch crops from below 1 m depth on loamy sand and sandy loam soils. This will affect estimates of N leaching and total N balances. Leaching of dissolved organic N (DON) is not usually included in estimates of N leaching. However, significant leaching losses of dissolved organic matter have been observed after grasslands (Vinther et al., 2005). Such leaching losses may be particularly high in organic farming systems with large inputs of organic matter, and there is a need to include this fraction in estimates of N-leaching losses.

Grass-clover green manure is widely used to increase soil fertility via N_2 -fixation. However, large leaching losses may take place after ploughing-in on sandy soils (Djurhuus and Olsen, 1997; Askegaard et al., 2005a). Nitrogen-fixing legume catch crops also supply N to the crop rotations, and they reduce nitrate concentrations in the soil solution, although not as effectively as non-fixing catch crops (Askegaard, unpublished results). Substituting a grass-clover green manure crop with a legume catch crop on sandy soils could reduce N leaching, while ensuring the N supply for subsequent cash crops.

Atmospheric emissions. Soil aeration is a key factor for N losses to the atmosphere. Soil aeration is influenced by soil diffusivity, which is a function of soil structure rather than texture (Schjønning et al., 1999). Oxygen can also be depleted around manure or crop residues due to intense decomposer activity (Højberg et al., 1994; Petersen et al., 1996). Accordingly, management practices are likely to have a significant influence on the potential for atmospheric N losses (Vinther et al., 2004). The end product of denitrification is dinitrogen (N_2), whereas the intermediate nitrous oxide (N_2O) is mainly released during transition from aerobic to anaerobic conditions (Firestone and Davidson, 1989). However, soil is an extremely heterogeneous environment where oxygen availability fluctuates after rainfall, and gradients of oxygen are found in soil aggregates and around manure particles and crop residues. Therefore, N_2O emissions may represent a significant part of total soil denitrification (Aulakh et al., 1984).

Nitrous oxide emissions are currently estimated using a fixed emission factor that is applied to inputs of N via fertilizers, N_2 -fixation and residues, but statistical analyses have indicated that the emission factor is higher for manure (and presumably crop residues) than for mineral fertilizers (Lægread and Aastveit, 2002). A comparison of N_2O emissions in systems with contrasting inputs of N and organic matter could help resolve this question. The greenhouse gas balance of a crop rotation is also influenced by net changes in soil carbon stocks (Smith, 2004), and crop rotations accumulating soil C therefore contribute positively to the mitigation of greenhouse gas emission.

Soil quality indicators. The identification of universal thresholds for soil quality indicators has proved to be difficult due to the variation among soil types (Seybold et al., 1998; Sojka et al., 2003). Schjønning et al. (2004a) proposed to focus on site-specific *management thresholds*, i.e., the most severe disturbance a system can tolerate without lasting effects on soil properties. Both soil physical properties and nutrient transformations are relevant due to their influence on crop yields, and on soil C- and N-balances. We need to identify the specific management measures that assist a desired development in soil attributes and functions, including the soil's ability to enhance crop development and optimize N use efficiency.

The workability of soils is strongly influenced by the soil friability. Measurements have shown that the Flakkebjerg location of the CRO experiment initially had a very poor friability due to previous cultivation of monocultures, but a tendency to greater soil friability was seen following only 5-6 years with a more versatile crop rotation (Schjønning et al., 2004b). Munkholm et al. (2002) showed that a soil dressed with animal manure was more friable than a soil supplied with mineral fertilizers. It is important to determine the relative importance of management tools (crop rotation, catch crops, manure) for improvement and maintenance of soil workability.

The soil tillage may affect root proliferation and in turn crop uptake of soil N, and the physical distribution of the pore network in the bulk soil determines aerobicity in soil microhabitats, which affects atmospheric losses. Schjønning et al. (2002b) showed that an organically managed soil had a tortuous network of soil pores in contrast to a soil that for decades have been grown with small grain cereals and not supplied with animal manure.

The timing of plant residue, manure and soil organic matter decomposition is crucial for the fate of mineralised N, which may be leached or lost to the atmosphere if not synchronized with the crop N demand. Organic farming systems would greatly benefit from a better understanding of the timing of N release from labile pools in the soil. Decomposer activity and thus N-mineralisation is mainly associated with the microbial biomass (bacteria and fungi) (de Ruiter et al., 1993). The microbial biomass potentially makes a significant contribution to the crop N supply, as net releases of 25 to 50 kg N ha⁻¹ has been observed between early spring and harvest of small-grain crops (Soon et al., 2001; Petersen et al., 2003). Whether such dynamics are caused by underlying patterns of C/N availability to microorganisms or by shifts in the ratio between bacteria and fungi is not clear, but an improved understanding of these mechanisms are likely to influence the choice of management strategy for improving the crop N supply.

Systems analysis. Comparisons of different farming systems can be based either on experimental results (e.g., Robertson et al., 2000; Mäder et al., 2002; Eltun et al., 2002) or on modelling (e.g., Hansen et al., 2000; Cederberg and Mattson, 2000; Haas et al., 2001; De Boer, 2003; Berntsen et al., 2004). Experiments are typically limited due to the comparison of only a few systems or treatments, and the results depend to some extent on the design of the systems or experiments. The use of models allows more systems to be compared. The FASSET whole-farm model has been used for comparing selected organic and conventional farming practices with respect to crop production and nitrate leaching (Berntsen et al., 2004; Knudsen et al., 2005). The model has also been used to evaluate effects of management strategies for N₂O emissions (Chatskikh et al., 2005) and to evaluate the cost-effectiveness of different ways of regulating nitrate leaching from farming systems (Berntsen et al., 2003).

Analyses of cropping systems often focus on the productivity or the environmental impact per unit of land area. However, the land area to produce a given amount will vary with productivity, which makes it relevant to evaluate cropping systems in terms of their impact per unit of product produced. This is particularly the case for environmental impacts that have global effects, such as greenhouse gas emissions and use of non-renewable resources (Olesen et al., 2005b). Such effects are best analysed using life cycle assessments (LCA), which aggregate emissions through a product chain (Dalgaard et al., 2004; Halberg et al. 2004; Basset-Mens & van der Werf, 2005).

Objectives

The overall goal is to quantify productivity and environmental impacts of different organic and conventional cropping systems across a range of soil and climatic conditions, and to identify management measures which contribute significantly to a sustainable development of the individual cropping systems. The basic hypothesis is that organic cropping systems can be maintained with high productivity at low environmental impact through better crop rotation design and management, as modified by soil type and climate. This will be achieved through a better description of the role of soil N dynamics, soil properties and crop and weed dynamics in the different systems, and using modelling and scenario analyses to integrate and evaluate production-related and environmental indicators of sustainability.

A.1 Technical content of the research activity

A.2.1 Organization of the work packages

The project is organized as six work packages with project management in WP1, experiments in WP2 to WP5 and scenario analyses and synthesis in WP6 (Figure 2). WP2 will manage the long-term crop rotation (CRO) experiment (described below) and measure the productivity of different organic and conventional cropping systems. The CRO experiment constitutes the experimental platform for the other work packages in the project. WP3 will determine N leaching losses, and WP4 nitrous oxide emissions and C balances from contrasting cropping systems. WP5 will measure parameters related to soil quality of the different cropping systems with a particular emphasis on N transformations, and this WP will co-operate with both WP3 and WP4. WP6 will use two different modelling approaches (simulation modelling and life cycle analysis) to describe the different cropping systems, using the experimental results from WP2-5 for validating and improving the models, and generalising to other climates, soil types and management strategies. The project seeks to improve the understanding of how management influences the selected key indicators for sustainable development (Figure 1), and the links between management, soil and crop characteristics and the sustainability indicators will be dealt with in a synthesis conducted by all partners within WP6 on the basis of statistical analyses and modelling.

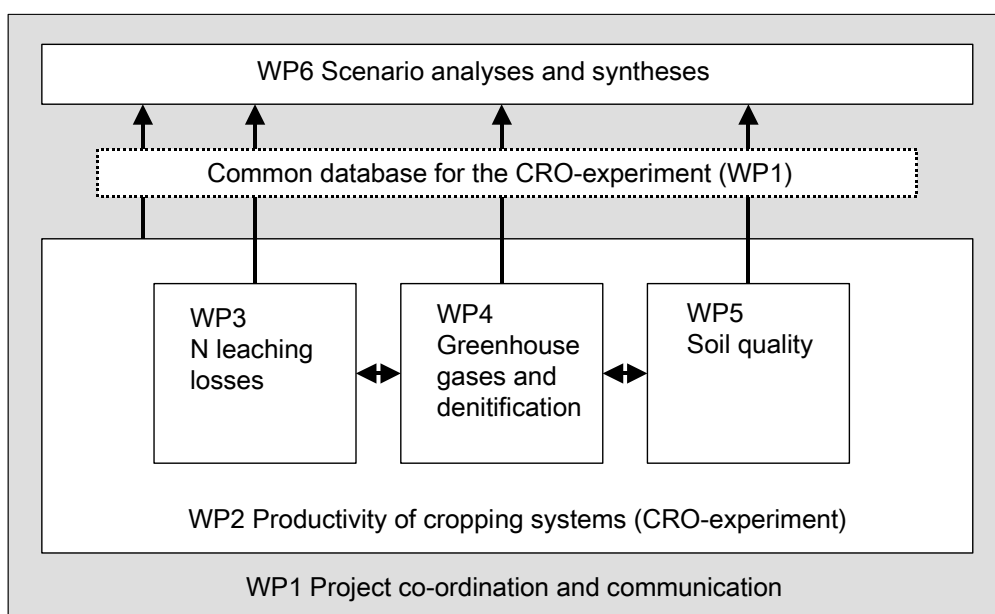


Figure 2. The relation between work packages in the CROPSYS project.

The project period runs from January 2006 to June 2010. The CRO experiment was initiated in 1997. In 2005, prior to the project start, the CRO experiment will be modified and results essential for the project will be sampled and stored for analysis in 2006. Table 1 shows the timetable for each work package and task.

Table 1. Timetable for the work packages and tasks.

WP	2006	2007	2008	2009	2010
1.1 Project management	◆	◆	◆	◆	◆
1.2 Data management		◆	◆	◆	
2.1 Management of CRO exp					
2.2 Yield measurements				◆	
2.3 Weed measurements				◆	
2.4 N uptake and N-fixation				◆	
2.5 Soil analyses					◆
3.1 Nitrate leaching losses				◆	
3.2 Leaching of DON					◆
3.3 Root depth of catch crops				◆	
4.1 Nitrous oxide emissions		◆	◆		
4.2 Denitrification			◆		
4.3 Soil total C and N				◆	
5.1 Measurement of soil quality				◆	
5.2 Soil microbial biomass pools				◆	
6.1 Test of FASSET model				◆	
6.2 Scenario analyses					◆
6.3 Empirical analyses					◆
6.4 Systems synthesis					◆

◆: Milestone

A.2.2 Design of the CRO experiment

The CRO experiment represents an ideal platform for investigation of production and environmental effects of different cropping and management systems. Different levels of fertility has been build up over 8 years, and this provides the opportunity to study long-term effects of different cropping systems on crop production and environmental impacts. The experimental treatments were initiated in 1997 at three sites representing typical Danish soil types. Jyndevad is located in Southern Jutland on a coarse sandy soil with an average annual rainfall of 964 mm, Foulum is located in Central Jutland on a loamy sand with an annual rainfall of 704 mm, and Flakkebjerg is located in Western Zealand on a sandy loam with an annual rainfall of 626 mm.

The experimental factors were 1) proportion of N₂-fixing crops in the crop rotation, 2) with (+CC) and without (-CC) catch crop, and 3) with (+M) and without (-M) animal manure. Three 4-year crop rotations were compared (Table 2). Measurements of yields, nutrient leaching, weed infestation, attack of pests and diseases, nutrient content of the harvested plant material, crop development etc. have been carried out. In 1996, prior to the experiment, an extended programme for soil chemical and physical characterisation was carried out and described in Djurhuus and Olesen (2000). Soil has been sampled every four years for chemical analyses. Sub-samples from soil tests and harvested grain and pulse crops have been stored. All data sampled during the eight years are systematically organized in a database, and all management treatments and guidelines are systematically described in annual protocols.

All crops in all rotations are represented every year in two replicates (blocks) giving a total of 64 randomised plots at each site. The plot size is 378, 216 and 169 m² at Jyndevad, Foulum and Flakkebjerg, respectively. Each plot is subdivided into 4-5 subplots. Two of the subplots are harvested for determination of crop yield. The other subplots are used for plant and soil sampling, and for experiments. All samplings are conducted in 1 m² miniplots. The position of plots and miniplots are fixed through the use of permanently installed iron tubes in guard rows between all plots. Short-cut grass borders separate all plots to avoid soil movement between plots. A soil border, which is kept bare throughout the growing season, separates the crop of each plot from the grass border.

From 2005 the design will be slightly changed (Table 2): 1) conventional cropping systems will be included, 2) there will be similar crop rotations at all three sites, and 3) a row crop (e.g potatoes or oilseed rape), will be introduced in all rotations. At Foulum and Flakkebjerg the rotations O2

and O4 will be maintained. At Jyndevad rotation O1 will be converted to O4. This implies that crop rotations with a green manure crop can be compared with rotations without green manure at all sites. The -CC/-M combination will be discontinued and the available plots will be converted to conventional systems (C4). The conventional crop rotation will be similar to the organic O4. This makes it possible to compare the effects of organic and conventional cropping systems. Crop rotation 3, which is terminated in 2005, was an extra rotation only existing in a limited version (+CC/+M) at Flakkebjerg only.

The combinations of treatments from 2005 are presented in Table 3. In O2/+M the animal manure application will be based on the principles of recirculation, where nutrients in cuts from the grass-clover green manure via anaerobic digestion are redistributed to the row crop and the cereals in the rotation. In the O2/-M treatment all plant material in the green manure crop will be left in the plot. In the O4/+M treatments the manure application are based on import from conventional farms. The nutrients in the C4 systems will be applied as mineral fertilisers. Catch crops in the organic systems will include N-fixing species, whereas in the conventional system they will be non-leguminous.

Table 2. Structure of the crop rotations.

	Field	O1	O2	O4	C4
1 st course 1997-2000	1	S. barley:ley	S. barley:ley	Spring oat ^{CC}	
	2	Grass-clover	Grass-clover	Winter wheat ^{CC}	
	3	Spring wheat ^{CC}	Winter wheat ^{CC}	Winter cereal ^{CC}	
	4	Lupin ^{CC}	Peas/barley ^{CC}	Peas/barley ^{CC}	
2 nd course 2001-2004	1	S. barley:ley	S. barley:ley	Winter wheat ^{CC}	
	2	Grass-clover	Grass-clover	Spring oat ^{CC}	
	3	Spring oat ^{CC}	Winter cereal ^{CC}	S. barley ^{CC}	
	4	Peas/barley ^{CC}	Lupin ^{CC}	Lupin	
Locations		Jyndevad	Jyndevad	Foulum	
			Foulum	Flakkebjerg	
			Flakkebjerg	Flakkebjerg	
3 rd course 2005-2008	1	Discontinued	S. barley:ley	S. barley ^{CC}	S. barley ^{CC}
	2		Grass-clover	Pea/barley ^{CC}	Pea/barley ^{CC}
	3		Row crop	Row crop	Row crop
	4		Winter wheat ^{CC}	Winter wheat ^{CC}	Winter wheat ^{CC}
Locations			Jyndevad	Jyndevad	Jyndevad
			Foulum	Foulum	Foulum
			Flakkebjerg	Flakkebjerg	Flakkebjerg

^{CC}Catch crop in the +CC-treatments.

Table 3. Treatments

Crop rotation	Production system	-CC	+CC	+CC
		+M	-M	+M
O2	Green manure-cash crop-organic	X	X	X
O4	Cash crop-organic	X	X	X
C4	Cash crop-conventional	X		X

M: animal manure (organic) or mineral fertilizer (conventional).

CC: catch crop, '+' is with catch crop and '-' is without catch crop.

A.2.3 Use of the CRO experiment in the work packages

Table 4 shows how the different work packages will use the CRO experiment with respect to crop rotations, treatments, locations and period. Crop production and some of the other indicators will be measured in all systems and treatments, whereas more detailed measurements will only be carried out in selected treatments. In particular the treatments O2/+CC/+M, O4/-CC/+M, O4/+CC/+M and C4/-CC/+M are selected for measurements of soil quality and greenhouse gas emissions, since these treat-

ments contain contrasting effects of both organic and mineral fertiliser management systems, use of green manure versus cash crops and use of catch crops.

Table 4. The experimental use of the different cropping systems and treatments in the project

	O2			O4			C4		Sites	Period
	-CC +M	+CC -M	+CC +M	-CC +M	+CC -M	+CC +M	-CC +M	+CC +M		
WP2										
Yields and weed biomass	■	■	■	■	■	■	■	■	JY, FO, FL	2005-8
N ₂ -fixation									JY, FO, FL	2006-8
N-uptake in crops									JY, FO, FL	2006-8
Soil analyses									JY, FO, FL	2008
WP3										
Nitrate leaching	■	■	■	■	■	■	■	■	JY, FO, FL	2005-8
DON leaching									JY, FO, FL	2008
Root depth									FO, FL	2006-7
WP4										
Nitrous oxide emissions			■	■		■	■		FO, FL	2008
Denitrification									FL	2007-8
Total C and N									FO, FL	2008
WP5										
Air permability studies	■	■	■	■	■	■	■	■	FO, FL	2007-8
Pore size distribution									FO, FL	2007-8
Friability studies									FL	2007-8
N-Mineralization studies									JY, FO, FL	2007-8

JY=Jyndevad, FO=Foulum, FL=Flakkebjerg.

Work Package list

WP No.	WP title	Responsible scientist	Budget DKK	Start	End	Deliverables
1	Project management and communication	JEO	632,200	2006-01	2010-06	D1.1-D1.5
2	Productivity of cropping systems	MAS	5,029,608	2006-01	2009-12	D2.1-D2.4
3	N leaching losses	MAS	2,432,308	2006-01	2009-12	D3.1-D3.3
4	Greenhouse gases and denitrification	SOP	1,957,196	2007-01	2009-12	D4.1-D4.3
5	Soil quality	PSC	2,451,780	2007-01	2009-12	D5.1-D5.3
6	Scenario analyses and synthesis	JEO	1,488,517	2008-10	2010-06	D6.1-D6.5
Total			13,991,609			

Deliverables list

Deliverable No	Deliverable title	Lead scientist	Delivery date	Allocated scientific months	Type
D1.1	Annual reports	JEO	200x-09	1.0	R
D1.2	Common protocols for conducting the CRO experiment	JEO	2006-02	1.0	R
D1.3	Field days for farmers and advisors at the field experimental sites	JEO	200x-06	0.5	O
D1.4	Project web-site	JEO	2006-03	0.5	O
D1.5	Papers on general results of the project in agricultural and other Danish journals	JEO	2006:2010	1.0	P
D2.1	Refereed paper on crop yields as affected by crop rotation, nutrient application, catch crops and site	JEO	2009-12	6.0	S
D2.2	Refereed paper on weed propagation in different organic cropping systems	IAR	2009-12	5.5	S
D2.3	Refereed paper on the yield – weed – nitrogen dynamics in different organic cropping systems	MAS	2009-12	5.5	S
D2.4	Papers for farmer journals on crop production in organic farming systems	IAR	2009-06	2.0	P
D3.1	Refereed paper on nitrate leaching as affected by crop rotation, nutrient application, catch crops and site	MAS	2009-10	5.0	S
D3.2	Refereed paper on N flows and losses in legume based cropping systems	MAS	2009-12	5.0	S
D3.3	Papers for farmer journals on N leaching from organic and conventional cropping systems	MAS	2009-12	1.0	S
D4.1	Refereed paper on N ₂ O monitoring program	PAM	2009-12	10.0	S
D4.2	Refereed paper on laboratory study of N ₂ O and denitrification	SOP	2008-12	10.0	S
D4.3	Papers for farmers and advisors on soil C/N pools as influenced by crop rotation and management	SOP	2009-12	1.5	P
D5.1	Refereed paper on the effect of cropping systems on soil quality attributes	PSC	2009-08	14.5	S
D5.2	Refereed paper on the structure and function of organism groups responsible for N-mineralization	SCH	2009-10	3.5	S
D5.3	Papers for farmers on effect of cropping systems on soil quality	PSC	2009-11	1.5	P
D6.1	Refereed paper on validation and scenario analysis with the FASSET model	JBE	2009-12	4.0	S
D6.2	Refereed paper on the LCA of organic and conventional crop farms	NHA	2009-12	4.0	S
D6.3	Refereed paper on the link between soil functioning and indicators	JEO	2010-03	6.0	S
D6.4	Refereed paper on management effects on sustainability indicators	JEO	2010-07	6.0	S
D6.5	Papers for Danish journals on improved guidelines for organic crop production systems in Denmark	JEO	2010-05	2.0	P

Milestones list

Milestone No	Milestone title	Lead scientist	Delivery date
M1.1	Revised database for CRO experiment	JEO	2006-04
M1.2	Database updated with results of previous years experimental data	JEO	200x-01
M1.3	Meeting with all involved scientists and technicians and invited stakeholders	JEO	200x-01
M1.4	Meeting at the CRO experiments with involved scientists and technicians	JEO	200x-06
M2.1	All crop production results in the database	JEO	2009-01
M2.2	The natural abundance ¹⁵ N analyses finished	MAS	2009-01
M2.3	Soil analyses stored in the database	MAS	2009-06
M3.1	The deep root investigation finished	MAS	2008-12
M3.2	All nitrate concentrations in the database	MAS	2009-06
M3.3	DON concentrations in the database	MAS	2009-07
M4.1	Preparation of new chamber units completed	SOP	2007-06
M4.2	Nitrous oxide monitoring program completed	PAM	2008-08
M4.3	Laboratory study completed	SOP	2007-12
M4.4	Analyses of soil C and N completed	SOP	2009-03
M5.1	Data on soil quality attributes stored in database	PSC	2009-02
M5.2	Data on microbial biomass pools stored in database	PSC	2009-02
M6.1	Link between CRO experiment database and FASSET model updated	JBE	2009-01
M6.2	Typical organic and conventional crop rotations defined	JEO	2009-06
M6.3	Statistical analyses completed	KKR	2009-10
M6.4	Project workshop to discuss management effects on sustainable development	JEO	2009-11

Description of work packages

WP1 Project management and communication

	Start date or starting event: January 2006									
Partner id.	P1									
Person-months per participant	4.0 VIP 4.4 TAP									
Total PM:	8.4									

Objectives:

- To coordinate the project plans, measurement protocols, reporting and publication between the different tasks in the project.
- To manage a database with all data from the long-term cropping systems (CRO) experiment
- To communicate results to farmers and the general public in Denmark

Description of work:

The project involves running a long-term cropping systems (CRO) experiment combined with detailed measurements in the CRO experiment and use of modelling and scenario analyses to understand and predict effects of different cropping systems on a range of indicators of sustainable development. The project management will ensure that the CRO experiment is managed and used effectively for the detailed measurements and experimentation and that data from the experiment will be available for modelling in proper time. There is also a need to coordinate the use of the CRO experiment with other projects that wish to make use of this experimental facility. The project management will thus need to ensure an effective internal and external communication.

Task 1.1. Project management

Standards for description of measurement protocols and schedules for crop and soil management in the CRO experiment will be set up based on the experience achieved previously in the crop rotation experiment (Olesen et al., 2000). These protocols will be coordinated with other projects using the crop rotation experiment to ensure that different experiments and measurements do not negatively influence each other. These standards and the results of the project will be presented and discussed at annual meetings in the project group. It is anticipated to have two annual meetings of the project group, a meeting during winter to discuss results and plans, and a meeting in June. The winter meeting will be organised as a two-day event, where external experts and stakeholders will be invited to participate.

Fields days open to farmers and advisors will be held in June every year at all sites, if possible. These field days will be organised in collaboration with other field day activities organised by DIAS. In addition, the project will communicate the results to farmers and the general public through journals, magazines and the internet.

Task 1.2. Data management

All data from the CRO experiment will be stored in an ACCESS-database for use by all projects involved in this long-term experiment. The database will be updated in January with results from the previous year. The project will maintain a web-site with general information on the project and its results. Part of the web-site will have restricted access to facilitate communication between the project partners and with other projects involved in the CRO experiment.

Deliverables:

- D1.1 Annual reports (Sep 200x)
- D1.2 Common protocols for conducting the CRO experiments (Feb 2006)
- D1.3 Field days for farmers and advisors at the field experimental sites (Jun 200x)
- D1.4 Project web-site (Mar 2006)

D1.5 Papers on general results of the project in agricultural and other Danish journals (2006-2010)

Milestones:

M1.1 Revised database for CRO experiment (Apr 2006)

M1.2 Database updated with results of previous years experimental data (Jan 200x)

M1.3 Meeting with all involved scientists and technicians and invited stakeholders (Jan 200x)

M1.4 Meeting at the CRO experiments with involved scientists and technicians (Jun 200x)

WP2 Productivity of cropping systems

	Start date or starting event: January 2006								
Partner id.	P1	P2	P3						
Person-months per participant	10.5 VIP 4.7 TAP	7.5 VIP 19.8 VIP	1.0 VIP						
Total PM:	43.5								

- Objectives:**
- To measure crop productivity in different crop rotations as affected by crop rotational design, use of catch crops, plant protection, fertilization, and soil type and climate.
 - To measure the competition between the crops and weeds in the different cropping systems.
 - To measure nitrogen uptake and fixation, and changes in soil nutrient availability.
 - To serve as the experimental unit for the other work packages in the project.

Description of work:

Crop yields is one of the key indicators for sustainability and nitrogen (N) is a main yield-limiting nutrient in organic arable farms (Berry et al., 2002). The N-input through fixation therefore becomes an important element for a sustainable organic crop production. The productivity depends on crop rotation design and its content of N₂-fixing crops, nutrient application, and use of catch crops (Olesen et al., 2002). Contrary to the conventional crop production, where the management factors can often be optimized separately, many factors and their interactions must be considered when designing organic crop rotations. The management of the organic crop rotations must focus on the prevention of problems rather than curing the problem. Weed control is a main problem in Danish organic crop production, and also in the CRO experiment, especially of perennial weeds (Rasmussen et al, 2005). A better understanding of the crop-weed ecology and its management is essential for weed control in organic farming systems (Stockdale et al, 2000). This WP investigates the crop production and the interactions with N-input and weed infestation under different management and soil/climate regimes. Other macronutrients than N will be considered, because they may also turn out to be yield limiting (Askegaard et al., 2004).

Task 2.1. Management of the crop rotation experiment

Design, treatments and history of the CRO experiment are described in A.2.2. All cereal, pulse and row crops will be harvested at maturity, and straw and other organic residues are left in the plots. The crop varieties will be selected according to defined criteria with main priority on disease resistance and weed competition properties. In the organic +M treatments the manure application will be in agreement with the regulations for organic agriculture in Denmark. In the conventional systems the application of mineral fertilizers will follow the guidelines from the Danish Plant Directorate, and the use of pesticides will follow the guidelines in the web-based decision support system [PlanteværnOnline/Pl@nteInfo](#). Weed control in the organic cropping systems will be based on preventive measures and weed harrowing and/or row and hand hoeing in the crops. Perennial weeds will be controlled by stubble harrowing in the systems without catch crops.

Potassium will be applied in an approved salt to the unfertilized organic treatments at Jyndevad (Askegaard et al., 2003). This is allowed according to the organic regulations, when deficiencies have been documented. Application of essential nutrients to miniplots in selected treatments will expose problems, which might arise with deficiency of other nutrients than N. Magnesium can be applied in dolomite-lime, sulphur in gypsum and phosphorous in raw-phosphate, all allowed according to the organic regulations. Inputs of nutrients (N, P, K, Mg and Cu) in manure and mineral fertilizers will be analyzed.

All actions and criteria will be described in the experimental protocol, and all data will be stored in the database described in WP1.

Task 2.2. Yield measurements

Cereals, pulse crops and row crops will be harvested at maturity in all crop rotations and treatments at all locations. Dry matter content will be measured in two subplots per plot and N content (crude protein) determined on a bulked sample from the two subplots. In barley and winter wheat near-infrared transmittance technology (NIT) will be used for the DM and N determinations. Drying and chemical N-analysis will be used for the other crops. Sub-samples from each harvested plot will be stored for possible further analyses.

Task 2.3. Weed measurements

The biomass of weeds, divided into annual and perennial weeds, and the biomass of the crop, divided into crop and catch crop, will be measured in three quadrates of 0.25 m² per plot at the time of anthesis of the cereals in all cereal, pulse and row crops in all crop rotations and treatments at all locations. Dry matter of each fraction will be determined. In systems, which are heavily infested with perennial weeds, measurements will be carried out to determine the competitiveness of the weeds and crops in the different cropping systems. This will be done in miniplots with naturally different densities of the perennial weeds and in miniplots, where the perennial weeds have been weeded away during the growing season.

Task 2.4. Nitrogen uptake and N₂-fixation

To determine the amount of above-ground crop residues returned to the soil, samples of total biomass will be taken in 1 m² sample areas in each plot at growth stage 85, 1-2 weeks before yellow maturity of the main crops. The samples will be analyzed for DM and N content. The amount of re-circulated N can be calculated after subtraction of N in harvested seed and grains. Dry matter amount and N content of grass-clover will be determined after each cut. Samples of the catch crops including weeds and volunteers will be taken about 1st November for DM and N analyses. All these plant samples will be carried out at all locations, in all treatments and in all years.

Dinitrogen-fixation will be determined at Foulum and Flakkebjerg in all years in pea, grass-clover and catch crops by means of the ¹⁵N natural abundance method (Unkovich and Pate, 2001), where the proportional dependence of a legume on atmospheric and soil N is estimated by comparing the natural ¹⁵N content of legume biomass with that of an adjacent non-legume reference plant. The determination will use grain and seed samples from the barley/pea mixture in the O4 and C4 rotations, clover and grass fractions from the cuts in the O2 rotations, and clover and grass samples from the catch crops in the O4 systems. N₂-fixation will be determined at Jyndevad by means of an empiric model (Høgh-Jensen et al., 2004) instead of the ¹⁵N natural abundance method. In the DAR-COFII project 'Genesis' we found that the ¹⁵N natural abundance of the soil at Jyndevad was too weak for determination of the N₂-fixation (Ambus and Askegaard, pers. comm.).

Task 2.5. Soil analyses

Soil samples are taken in the plough layer of each plot in October/November at the end of the experiment to evaluate the development and the effects of treatments on soil pH and the phosphorus, potassium, magnesium and copper status. Lime will be applied to plots when a defined threshold value of the soil pH is reached for the individual plot.

Deliverables:	
D2.1	A refereed paper on crop yields as affected by crop rotation, nutrient application, catch crops and site (Dec 2009)
D2.2	A refereed paper on weed propagation in different organic cropping systems (Dec 2009)
D2.3	A refereed paper on the yield – weed – nitrogen dynamics in different organic cropping systems (Dec 2009)
D2.4	Papers for farmer journals on crop production in organic farming systems (Jun 2009)

Milestones:	
M2.1	All crop production results in the database (Jan 2009)
M2.2	The natural abundance ¹⁵ N analyses finished (January 2009)
M2.3	Soil analyses stored in the database (Jun 2009)

WP3 N leaching losses

	Start date or starting event:								January 2006	
Partner id.	P1	P2	P3							
Person-months per participant	10.0 VIP 8.0 TAP	19.8 TAP	1.0 VIP							
Total PM:	26.0									

Objectives:	
•	To measure nitrate leaching in different crop rotations as affected by crop rotational design, use of catch crops, fertilizer application, and soil type and climate.
•	To quantify leaching losses of dissolved organic nitrogen (DON) in selected cropping systems.
•	To investigate the ability of catch crops to take up subsoil-N.

Description of work:
Nitrate leaching is one of the factors identified as a key factor for sustainability. This WP measures nitrate leaching at all three locations and in all crop rotations and treatment combinations of the CRO experiment. This enables an interpretation of long-term (the organic rotations) and short-term (the conventional rotations) effects of management and location (soil type and climate) on the nitrate leaching losses. Because dissolved organic nitrogen (DON) is exposed to leaching (Jones et al. 2004; Vinther et al. 2005), this work package will include a campaign where both nitrate and DON are measured. The campaign will be coordinated with measurements of topsoil DON in WP5. There may be a problem in the interpretation of leaching losses from the CRO experiment due to possible uptake of N by roots in soil layers below the installed suction cups. Measurements will therefore be taken of root depths of different catch crops. The nitrate and DON leaching results and a possible rectification for root depth will be included in the model based analyses in WP6.

Task 3.1. Nitrate leaching losses
Leaching of nitrogen will be estimated according to the method in Askegaard et al. (2005a) using the ceramic suction cups that were permanently installed in the CRO experiment in 1996/97. Four suction cups per plot are installed at 80 cm depth at Jyndevad and at 100 cm depth at Foulum and Flakkebjerg. The suction cups are installed in the plots that constituted field 1 in each rotation and treatment combination when the experiment was initiated in 1997 (Table 2). Suction cups are furthermore installed in fields 2, 3 and 4 in the O2/-CC/+M system at Foulum, Flakkebjerg and Jyndevad. This gives 22 plots with suction cups per location. Leaching will be measured at all sites in all field 1 plots. All crops in the 4-course rotations will during the 4-year period 2005-2009 pass field 1 and the rotational leaching losses can be estimated. Soil water will be sampled in 2005 prior to the project period and analysed in 2006. Additional measurements of nitrate leaching in the fields 2, 3 and 4 with installed suction cups will be

carried out. This enables the effect of crop and year on nitrate leaching to be measured. Every one to four weeks, depending on site and precipitation, a suction of approximately 80 kPa will be applied three days prior to sampling. The samples will be bulked with equal sample volume from each of the four suction cups per plot before nitrate analysis and further estimates of nitrate leaching. In 2005, prior to initiation of the project, water samples from the suction cups will be collected and frozen for later analyses. This enables leaching determinations on a full 4-course rotation.

Task 3.2. Leaching of DON

A campaign measuring leaching losses of dissolved organic nitrogen (DON) will be carried out at all three locations in 2008/9 (1st April 2008 to 31st March 2009) in winter wheat (field 1) in the four cropping systems O2/+CC/+M, O4/+CC/+M, O4/-CC/+M, C4/-CC/+M. These systems represent a considerable variation in soil fertility and are the same systems selected for topsoil DON measurements in WP5. A comparison between topsoil and subsoil concentrations of DON will be carried out to elucidate the DON flow and the possible dependence on the cropping system. The investigation will use the installed ceramic suction cups and analyses of nitrate (Task 3.1). Measurements of total-N and NH₄-N will be carried out on the soil water samples. The DON fraction will be estimated as the difference between total-N and the mineral N-fractions. The leaching of DON will be estimated using the same assumptions as for nitrate leaching (Vinther et al., 2005).

Task 3.3. Root depth of catch crops

The winter wheat plots in O2/+CC/+M at Foulum and Flakkebjerg will be subdivided in spring 2006 and 2007, and two different types of catch crops will be sown; a ryegrass representing shallow root depth and a chicory type representing deep root development. A winter oilseed rape from the same rotation will also be included in the investigation representing a deep-rooted crucifer catch crop. The minirhizotron technique described by Thorup-Kristensen (2001) will be used to investigate the root development and depth. Three minirhizotrones per plot in six plots (three catch crop types and two replicates) will be inserted in mid-summer 2006 and 2007 into 2-2.5 m depth at Foulum and Flakkebjerg and the root development of catch crops will be recorded three times by means of video filming until November. Soil samples will be collected at the same time as the video filming in September, October and November to 2 m depth and analyzed for mineral-N content (nitrate and ammonia) for each 0.25 m layer. Plant samples will be collected early November and analysed for DM and N content.

Deliverables:

- D3.1 Refereed paper on nitrate leaching as affected by crop rotation, nutrient application, catch crops and site (Oct 2009).
- D3.2 Refereed paper on N flows and losses in legume based cropping systems (Dec 2009)
- D3.3 Papers for farmer journals on N leaching from organic and conventional cropping systems (Dec 2009)

Milestones:

- M3.1 The deep root investigation finished (Dec 2008)
- M3.2 All nitrate concentrations in the database (Jun 2009)
- M3.3 DON concentrations in the database (Jul 2009)

WP No. 4: Greenhouse gases and denitrification

	Start date or starting event: January 2007							
Partner id.	P1	P4						
Person-months per participant	12.0 VIP 8.7 TAP	9.5 VIP 4.0 TAP						
Total PM:	34.2							

Objectives:

To estimate nitrous oxide emissions from winter wheat in contrasting organic and conventional crop rotations

- To determine system effects on soil properties, as reflected in denitrification and nitrous oxide emissions at well-defined soil water potentials
- To evaluate the carbon sequestration potential of a range of crop rotations differing in N supply and crop residues

Description of work:

Arable soils are an important source of nitrous oxide (N₂O). Emissions are influenced by soil structure, as well as by organic inputs and N availability, and N₂O therefore integrates several aspects of a cropping system (rotation, fertilization, return of crop residues, manure application).

Nitrous oxide is an intermediate of denitrification, but may account for a significant part of total denitrification in the soil. Detailed understanding of the interactions between crop rotation, soil properties and denitrification activity requires that intact samples are studied in a contained system where both N₂O emission and total denitrification can be estimated under well-defined conditions and subsequently characterized with respect to physical and chemical properties. Effects of management can be further accentuated by studying the emissions at different soil water potentials.

The soil carbon balance, like N₂O emissions, affects the total greenhouse gas balance of a crop rotation. The well-established crop rotations on three contrasting soil types represent a unique opportunity for studying the potential of crop rotations to accumulate soil carbon.

Task 4.1. Nitrous oxide emissions

Nitrous oxide emissions will be determined over an approximately 12-month period (c. 1.9.2007 until harvest 2008) at two locations (Flakkebjerg and Foulum). Monitoring will take place in winter wheat of the four rotations O2/+CC/+M, O4/+CC/+M, O4/-CC/+M and C4/-CC/+M.

Two sampling positions will be selected near the sampling positions for soil quality studies (cf. WP5) in each of the two blocks, giving a total of 16 measurement points per location (4 systems × 2 blocks × 2 sampling positions). Approximately 30 sampling dates are planned during the monitoring period. Measurements will be conducted using a static chamber method based on 75×75 cm² chambers with a permanent base and an insulated cover (Petersen, 1999). At least four individual gas samples are taken during chamber deployment for determination of N₂O flux rates. Gas samples will be analyzed by gas chromatography. A number of new chamber units needs to be acquired and prepared to carry out this monitoring program.

Task 4.2. Denitrification

At Flakkebjerg, undisturbed 100-cm³ soil cores will be sampled in 2007 and 2008 from 6-10 cm depth as described by Schjøning et al. (2002a). Sampling will be coordinated with soil sampling for WP5 studies to save resources and performed in the four rotations selected for this study. Soil cores will be adjusted to one of three water potentials (-0.003, -0.01 and -0.1 MPa), the soil diffusivity determined, and then the samples will be pre-incubated for effects of sampling and handling to cease. Individual cores are then incubated for determination of N₂O emissions, followed by estimation of denitrification activity using the acetylene inhibition method. Gas samples are taken after 24 h for N₂O emissions, and after an additional 24 h for total denitrification. Soil samples will subsequently be extracted for determination of mineral N pools. The procedure and methodology has been established in 2004 in connection with an ongoing project (NITUSE) funded by DIAS.

Task 4.3. Soil total C and N

Towards the end of the third project year, soil samples for determination of soil C and N will be collected at two depths (0-25 og 25-50 cm) in all fields of the four rotations selected for this study. A preliminary study will determine the number of subsamples needed based on a statistical evaluation of

variability (Wollum, 1994). Analytical methods will be identical to those used in 1996 and 2004 (Leco Corp. Application Bull., 1987), so that the development over time can be determined.

Deliverables:

- D4.1 Refereed paper on N₂O monitoring program (Dec 2009)
- D4.2 Refereed paper on laboratory study (Dec 2008)
- D4.3 Paper for farmers and advisors on soil C/N pools as influenced by crop rotation and management (Dec 2009)

Milestones:

- M4.1 Preparation of new chamber units completed (Jun 2007)
- M4.2 Nitrous oxide monitoring program completed (Aug 2008)
- M4.3 Laboratory study completed (Dec 2007)
- M4.4 Analyses of soil C and N completed (Mar 2009)

WP No.: 5 Soil Quality

	Start date or starting event:								
	January 2007								
Partner id.	P1	P5							
Person-months per participant	16.0 VIP 19.5 TAP	3.1 VIP 8.0 TAP							
Total PM:	46.6								

Objectives:

- To quantify a number of soil attributes of importance for crop establishment and growth (including soil tilth characteristics), N use efficiency (plant uptake and emissions) and C sequestration
- To identify management effects and interactions among these upon the selected soil quality attributes
- To investigate the relative importance of microbial biomass pools for the mineralization of N in different cropping systems

Description of work:

We have identified a number of soil properties, which may influence crop yields, water and air pollution, and carbon fluxes. The soil quality attributes have been carefully selected in order to reflect 'how well the soil does what we want it to do' (Schjøning et al., 2004a), rather than focusing on them as soil quality indicators *per se*. The choice of soil quality attributes is based on discussions in the project group, the criteria for their selection being a hypothesis that they integrate effects of soil properties and management of key importance to the identified key indicators of sustainability (crop yield and environmental impacts).

This WP is closely linked to several other work packages. Hence, the soil quality data correlate to crop growth and yields monitored in WP2. The data can be related directly to N budgets and leaching losses quantified in WP2 and 3, and to greenhouse gas emissions estimated in WP4. Therefore, WP5 provides information of pivotal importance for the synthesis work to take place in WP6.

The work in WP5 is composed of two closely linked tasks. Task 5.1 covers a monitoring program of key soil attributes for two years in carefully selected management systems, while Task 5.2 combines selected monitoring results with a screening of microbial C and N dynamics in soil from the monitoring program. Fungi and bacteria have very different functions in the soil and are regulated differently (Wardle, 2002; Georgieva et al., 2005a,b). Complementary assays of microbial biomass and biomass components will be adopted, which together may help explain differences between cropping systems with respect to plant N supply from labile sources in the soil.

Task 5.1. Measurements of selected soil attributes

The measurements of soil quality attributes will primarily concentrate on four of the 8 cropping systems. All selected systems include manure or fertiliser application (see A2.2 for details): C4/-CC/+M, O4/-CC/+M, O4/+CC/+M, and O2/+CC/+M.

Samplings and measurements will take place in the winter wheat crop for all systems. Soil physical parameters will be measured on soil sampled at field capacity in the spring, while key expressions of N-dynamics are measured on soil sampled on four occasions during the growing season (Table 5).

Table 5. Overview of the measurement programme ('4' means that the measurements will take place in the four systems mentioned above, while '8' means screening in all systems).

Method / parameter	No. of sampling events per year	Number of systems studied		
		Jyndevad	Foulum	Flakkebjerg
1. Pores >30 µm + air permeability	1		8	8
2. Pore size distribution	1		4	4
3. Soil drop test, <i>in situ</i>	1			4
4. Tensile strength of aggregates	1			4
5. Clay dispersibil. + aggreg. stability	1			4
6. N _{min} * (NO ₃ and NH ₄)	4	4	4	4
7. Dissolved org. N (DON)*	4	4	4	4
8. Microbial biomass N (MBN)*	4	4	4	4

*Pre- and post-incubation values will be determined, which means that *in situ* development as well as potential net development in each of these parameters (e.g. net N mineralization) may be compared across cropping systems.

Table 5 shows that key N parameters are measured at all three locations, while at the Foulum and – in particular – the Flakkebjerg site soil structural properties will be characterized. The measurement programme will take place in 2007 as well as in 2008, so that a total of four replicate plots representing each cropping system will be included (two replicate plots each year). The time schedule of the monitoring program provides the additional benefit that the 2008 measurements will take place in the plots equipped with suction cups, where N leaching from the root zone will be measured (WP3).

Soil cores (100 cm³) and soil cubes (~650 cm³) will be sampled in undisturbed condition from the ~6-13 cm layer as described by Schjønning et al. (2002a). The soil cores will be drained to -100 hPa (method 1, see Table 1) or to a range of water potentials (-10, -30, -50, -100, -1000; method 2) for determination of water retention characteristics (Schjønning, 1985). Included in method 2 is a quantification of water retained at the -1.5 MPa matric potential (standard ceramic plate technology). Air permeability (method 1) will be measured with the steady-state method described by Iversen et al. (2001). Estimates of air-filled pore space (from total porosity and water contents) will be combined with the air permeability for calculation of the specific air permeability- an indicator of pore organization (Blackwell et al., 1990). An estimate of relative gas diffusivity will be calculated from the air-filled pore space by the pedotransfer function derived by Moldrup et al. (2000). The estimated pore size distribution allows quantification of 'protective' and 'habitable' pore space (Postma and van Veen, 1990; Hassink et al., 1993), which is considered important for the Task 5.2 evaluations. The soil drop test in situ (Table 5, method 3) includes a determination of soil fragmentation following a reproducible energy input (Schjønning et al., 2002a). Tensile strength of air-dried aggregates (Table 5, method 4) is calculated from compressive tests on individual aggregates (Dexter and Kroesbergen, 1985) with equipment described by Munkholm et al. (2001), and soil friability calculated as described by Dexter & Watts (2001). Clay dispersibility and wet stability of >250 µm aggregates (Table 5, method 5) are determined according to Pojasok & Kay (1990) as detailed by Schjønning et al. (2002a).

At least four weeks prior to the first sampling, cylinders (appr. 10 cm diameter, 20 cm height) will be inserted between rows of the winter wheat crop, leaving only a few millimeters above the soil surface. The soil in the cylinders will be kept free of growing plants, thus avoiding the influence from growing roots (e.g. Hansen and Lomstein, 1999). At four times during the growing season (*c.* April 1, May 15, July 1 and August 15), soil cores will be collected and taken to the laboratory; exact sampling

dates will take crop development into account. Replicate cores are either extracted immediately for determination of mineral N, or they are incubated for a ~6 week period at constant temperature (20 °C) in the dark (in principle as described by Thomsen et al., 2003) for determination of net N mineralization. Incubated and non-incubated soil from each sampling date will be homogenized and subsamples taken for quantification of NH₄, NO₃ and total N in principle as described by Wang et al. (2001). Dissolved organic N (DON) will then be calculated as the difference between total N and mineral N. Separate subsamples from the incubation cores are used for determination of microbial biomass N by the chloroform fumigation method (Amato and Ladd, 1988). Sub-samples from non-incubated soil cores will be used for the analyses described in Task 5.2.

Task 5.2. Soil microbial biomass pools

This task focuses on biomass assays, which reflect the active biomass or enzyme biomass. The basic technique is the substrate-induced-respiration (SIR) estimate of microbial biomass as originally introduced by Anderson and Domsch (1978), but the measurement program will be expanded to determine, whether each soil sample is N limited, and to estimate the relative contribution of fungi and bacteria to the activity recorded.

Subsamples of soil for net N mineralization measurements (Task 5.1) will be incubated under laboratory conditions with a factorial combination of C and N additions (Wamberg et al., 2003), and with or without fungal or bacterial inhibitors (Lin and Brookes, 1999).

Deliverables:

- D5.1 A refereed paper on the effect of cropping systems on soil quality attributes (Aug 2009)
- D5.2 A refereed paper on the structure and function of organism groups responsible for N-mineralization (Oct 2009)

Milestones:

- M5.1 Data on soil quality attributes stored in database (Feb 2009)
- M5.2 Data on microbial biomass pools stored in database (Feb 2009)

WP6 Scenario analyses and synthesis

	Start date or starting event:					October 2008			
Partner id.	P1	P2	P3	P4	P5				
Person-months per participant	17.5 VIP 1.6 TAP	0.5 VIP	3.0 VIP	0.5 VIP	0.5 VIP				
Total PM:	23.6								

Objectives:

- To generalise the results of the CRO experiment to other climatic, soil and management strategies
- To asses the environmental impact of the whole product chain for both organic and conventional farming systems
- To analyse the relationships between the dynamical soil and plant properties and selected indices of crop production and environmental impact.
- To quantify effects of different cropping systems on indicators for productivity and environmental impact for a range of soil and climate conditions relevant for Denmark
- To describe how management may be adjusted to ensure that organic farming systems contribute to a sustainable development based on indicators of crop production and environmental impact

Description of work:

The data collected in WP2 to WP5 will give essential data on crop production and environmental impact for a range of crop rotations at three sites in Denmark. However, these data only covers some of the possible cropping system designs and some of the possible soil and climate combinations. The experimental results will therefore be used together with model-based scenario analyses to better understand the role of cropping system management and the interaction with soils and climate. This will be used to improve guidelines for management of organic cropping systems. The analyses will focus on the selected key indicators for sustainable development and how they relate to soil and plant processes/properties and how these in turn relate to management, soils and climate. The FASSET whole farm model will be tested on the experimental data obtained from WP2-5. Based on this test the model will be used to simulate climatic, soil and management conditions that is not included in the experiment. Typical crop area distribution and manure import will be obtained from national agricultural statistics. The environmental impact of these typical farms will be evaluated with the FASSET model in combination with a life cycle assessment (LCA) analysis. This allows indicators to be calculated both per unit of land area and per product unit. The FASSET model will estimate the indicators of crop production, nitrate leaching and greenhouse gas emissions, whereas the LCA analyses will estimate the associated use of energy and non-renewable resources.

Task 6.1. Test the FASSET model on data from WP2, WP3, WP4 and WP5

Data from the existing CRO experiment during the period 1996-2001 are already included in a database that can communicate with the FASSET model. This database will be updated with new data from the CRO experiment and with new types of measurements, which will allow a better verification of the model's simulations of soil organic matter turnover. The measurements of root depth from WP3 will be used to estimate the error in simulated N leaching from using a fixed depth (0.8 to 1 m) for measurement of nitrate concentrations. The measurements of DON in WP3 and WP5 will be compared with simulated vertical transfer of organic matter to estimate the role of DON for N leaching. The model simulations will be compared with observed production (dry matter and N uptake), N mineralization and N loss from leaching, denitrification and nitrous oxide emissions.

Task 6.2. Scenario analysis of typical Danish organic and conventional arable crop rotations

Typical crop rotations for organic and conventional arable farms in Denmark will be constructed from Danish databases on crop area distribution, import of organic and inorganic fertilisers, crop and livestock production. These databases include the farm accounting data from the Institute of Food Economics and data on agricultural land use from the Central Agricultural Registers. Also data on nutrient management from the Plant Directorate will be used. A number of changes in management (e.g. alternative crop choice, catch crops and other manure/fertiliser practice) will be introduced in the scenarios for crop rotations. The production and environmental impact of the typical arable crop rotations will be evaluated with the FASSET model for a range of different soil and climatic conditions. The model output will then be used in a LCA analysis to assess differences between organic and conventional farming systems using the DIAS LCA-model (Dalgaard et al., 2004). A method will be developed to allow comparisons of crop rotations with different crops, defining a common functional unit by systems expansion and substitution in a consequential LCA (Ekvall and Weidema, 2004).

Task 6.3. Empirical analyses of soil functioning and indicators of sustainability

The experimental results from WP2-5 will be used together with previous results from the CRO experiment to analyse relationships between crop sequence, crop management, soil functioning and indicators of crop production and environmental impacts. Different statistical methods will be used to estimate the relationships efficiently. Some of the relationships may be quantified by the use of linear mixed models or generalised linear mixed models, while other may require non-linear models. In cases where the linear and non-linear models may not fit, the relationships will be sought modelled by other methods such as rank-based methods, other non-parametric methods or Bayesian networks. These relationships will be derived, where possible, to allow extrapolations to other categories of crop rota-

tions based on simple indicators such as the proportion of grass-clover and catch crops in the rotation. The relationships should also allow for the effects of differences in soil type and climates.

Task 6.4. System synthesis - crop management effects on sustainable development

The results of Tasks 6.2 and 6.3 will be used to analyse how different organic and conventional arable cropping systems affect a range of indicators of crop production, environmental impact and resource use. These results will be discussed in a workshop with all project partners and with invited stakeholders. The indicators will be analysed both per area and per product unit. The possibilities of improving several of the indicator values by changing crop rotations and management will be analysed. This will be based on the scenario results from Task 6.2 combined with the experimental results from the project and results from other studies. Emphasis will be given to evaluating differences in responses for different soil and climatic conditions. This will be used to derive guidelines for improving the sustainable development of organic crop production systems in Denmark. The results will be related to how organic farming may contribute to complying with the objectives in the EU Water Framework Directive and the Kyoto Protocol.

Deliverables:

- D6.1 Refereed paper on validation and scenario analysis with the FASSET model (Dec 2009)
- D6.2 Refereed paper on the LCA of organic and conventional crop farms (Dec. 2009)
- D6.3 Refereed paper on the link between soil functioning and indicators (Mar 2010)
- D6.4 Refereed paper on management effects on sustainability indicators (July 2010)
- D6.5 Papers for Danish journals on improved guidelines for organic crop production systems in Denmark (May 2010)

Milestones:

- M6.1 Link between CRO experiment database and FASSET model updated (Jan 2009)
- M6.2 Typical organic and conventional crop rotations defined (Jun 2009)
- M6.3 Statistical analyses completed (Oct 2009)
- M6.4 Project workshop to discuss management effects on sustainable development (Nov 2009)

A.3 Project resources and budget overview

The Danish Institute of Agricultural Sciences (DIAS) is a research institute under the Ministry of Food, Agriculture and Fisheries. With its approximately 1,100 employees of which 750 are research personnel, DIAS is one of the largest research institutions in Denmark. Three departments within DIAS participate in the CROPSYS project: Department of Agroecology [P1], Department of Integrated Pest Management [P2] and Department of Genetics and Biotechnology [P3]. P1 (JEO and MAS) and P2 (IAR) have since 1997 jointly managed the CRO experiment, and this experiment will be maintained in 2005 for core-funding from DIAS. P3 (KKR) has participated in developing the design and models for statistical analysis of the CRO experiment.

DIAS, Department of Agroecology [P1] focuses its research on the interaction between soils, crop production and environment. The department works at all scales from detailed experimental studies of the soil-root environment to regional, national and continental analysis using GIS (Geographical Information Systems) and modelling. The department has state-of-the-art laboratories for analyses of soil physics, soil organic matter dynamics and has considerable experience in field measurements of N flows, including N₂-fixation, crop N uptake, nitrate and DON leaching and measurements of nitrous oxide emissions and denitrification. The department has developed a range of models to analyse flows of carbon and nitrogen at field, farm and landscape scales, with particular emphasis on nitrate leaching and greenhouse gas emissions. The Department provides policy support to the Danish government concerning agriculture, including the effects of measures to regulate emissions from Danish agriculture. It also plays a key role in contributing to IPCC and the groups of the UNECE Convention on Long Range Transboundary Air Pollution.

DIAS, Department of Integrated Pest Management [P2] focuses its research on efficient and environmentally acceptable prevention and control of pests in crop production, animal husbandry and food precessing as well as in buildings and homes. An important goal for the activities is to reduce the use of pesticides in Denmark. Activities include investigation of chemical, biological and physical control methods as well as the possibilities of combining them into IPM-strategies and plant protection in organic farming. The department has considerable expertise in experiments on weed management and control, including in organic farming systems. The department provides support to the Danish Environmental Protection Agency, the Danish Medicines Agency, FAO, WHO and OECD. The department is responsible for administrating GEP (Good Experimental Practise) authorisation.

DIAS, Department of Genetics and Biotechnology, research unit on Statistics and Decision theory [P3] will contribute to the statistical analyses used to describe the relationships between soil functioning and indicators of sustainability in WP6. In addition it will act as an advisory concerning application of statistical methods in some of the other working packages. The research at the research unit focuses on statistical methods and theory for decision support system relevant for biological applications including agricultural research. By this the research unit has a state-of-the-art knowledge and contributes to the use of relevant and optimal use of statistical methods for design and analyses of biological experiments. The unit cooperates with many departments and research unit within DIAS in a large number of research projects where statistical expertise is important.

Risø National Laboratory (Risø) [P4] belongs under the Ministry of Science, Technology and Innovation. Risø carries out research in science and technology, providing the Danish society new opportunities for technological development and contributing to the development of environmentally acceptable methods for agricultural and industrial production, as well as for the generation of the energy necessary for modern society. Risø houses approx. 900 employees and seven different research departments. The Biosystems department has a staff of 100 scientists and technicians. The department has many years of experience in studies on soil chemistry, soil decomposition processes, plant nutrition, plant-microbe symbioses and risk assessment in plant and energy production. The Biosystems department has participated in numerous national and international research projects with focus on biogeochemical cycling and impacts of air pollution and energy production on terrestrial ecosystems – forest, agriculture, grass- and shrublands. The department thus has long experience in measuring atmosphere-biosphere exchange of C and N compounds and holds state-of-the art instrumentation and competences needed to accomplish these measurements.

The Biological Institute at Copenhagen University (KU) has specialised on the soil decomposer subsystem, in particular the interaction between microorganisms and the microbivorous fauna living on microorganisms. The studies deal with the effect of soil nutrient level on these interactions in cultivated as well as natural soils. We identify marked differences in the dynamics of the decomposition process when dealing with mineralisation of dead organic matter such as crop residues versus treating rhizosphere processes where the decomposers are fuelled by soluble carbon from the growing plants. Since year 2000 the applicant (SCH) has published 26 papers in internationally referred journals within this field.

Table for person month (scientific staff) allocated on WP's and partners

Partner	P1	P2	P3	P4	P5	Total
WP						
WP1	4.0					4.0
WP2	10.5	7.5	1.0			19.0
WP3	10.0		1.0			11.0
WP4	16.0			9.5		25.5
WP5	20.0				4.5	24.5
WP6	21.5	0.5	3.0	0.5	0.5	26.0
Total	82.0	8.0	5.0	10.0	5.0	110.0

Table for person month (scientific staff) allocated on WP's and partners

Partner	P1	P2	P3	P4	P5	Total
WP						
WP1	4.0					4.0
WP2	10.5	7.5	1.0			19.0
WP3	10.0		1.0			11.0
WP4	12.0			9.5		21.5
WP5	16.0				3.1	19.1
WP6	17.5	0.5	3.0	0.5	0.5	22.0
Total	70.0	8.0	5.0	10.0	3.6	9.6

Table for breakdown of total budget on partners and different cost categories (DKK)

Participating institution	Responsible scientist	Salaries		Equipment	Operational expenses	Others	Total budget DKK
		Academic	Techn. adm.				
DIAS (P1)	JEO	3,508,250	1,422,360	115,000	1,237,040	2,389,700	10,407,050
DIAS (P2)	IAR	406,600	816,500	0	443,800		2,000,600
DIAS (P3)	KKR	273,000	0	0	3,000		332,040
Risø (P4)	PAM	436,614	108,502	0	38,000		699,739
KU (P5)	SCH	144,000	240,000	0	77,400		553,680

The costs for carrying out management and measurements at Jyndevad and Foulum are covered by P1, and these cost are included under other costs according to the costing procedure of DIAS for these two experimental stations.

A.4. Dissemination of scientific results

The project will initiate a PhD study on the "Influence of cropping systems on greenhouse gas emission". This study will be linked to WP4, WP5 and WP6. The PhD study will be hosted by P1, who will co-fund the PhD study.

The primary results of the project will be published in international journals subject to peer review. Results will be presented at international conferences such as those organised by ISO FAR, European Society for Agronomy, European Soil Science Society and European Weed Research Society. In addition, information will be communicated to farmers and the general public in Denmark through journals, magazines, the internet and presentations at national conferences such as "Økologikongressen" and "Plantekongressen". The project will maintain a web-site with general information on the project and its results.

A.5. Scientific collaborations

Partners P1 and P2 have informal collaborations with the following institutes on the conduct of long-term experiments in organic farming:

- Norwegian Crop Research Institute, Norway (Apelsvoll experiment)
- FiBL, Switzerland (DOC experiment)
- SAC, UK (Cropping systems trials)
- Rodale Institute, USA (FST experiment)

It is expected that this collaboration will be further intensified within the CORE organic EU research network.

The CRO experiment is part of the ISOFAR Long Term Experiment network.

P1 is member of the management committee in COST action 627 on "Carbon storage in European grasslands". Results of the CRO experiment have previously been presented at COST627 meetings, and the further results of the experiment on soil carbon storage will be discussed within this framework.

P1 is member of the management committee in COST action 729 on "Assessing and managing nitrogen fluxes in the atmosphere-biosphere system in Europe". The methodology and methods of measuring nitrogen fluxes in the CRO experiment will be discussed at COST729 meetings.

P4 is member of the management committee of COST action 856 on "Denitrification in agriculture, air and water pollution".

The CROPSYS project will cooperate with a running project "Organic cropping systems for higher and more stable yields" at The Norwegian Crop Research Institute (Planteforsk). The Norwegian and the CROPSYS projects have much in common. As part of this cooperation, the Norwegian research group will visit DIAS (Research Centre Foulum) in August 2005, and information exchange will take place at an informal two-day workshop.

P1 and P4 participate in an integrated project called "The nitrogen cycle and its influence on the European greenhouse gas balance (NitroEurope)" under the EU FP6. The CRO experiment is part of a network of long-term experiments in this proposal, and it will be used for measuring management and environmental effects on nitrogen fluxes.

A.6 Other issues

The project will maintain a discussion with stakeholders in Denmark to ensure that the results of the project are in line with the current developments in organic farming and addresses the needs for information on productivity and environmental impacts of these systems. The stakeholders will be invited to some of the winter meetings in the project. The stakeholders include representatives from the following private and public institutions and NGO's:

- Danmarks Miljøundersøgelser (National Environmental Research Institute)
- Dansk Landbrugsrådgivning (Danish Agricultural Advisory Service)
- Økologisk Landsforening
- Danmarks Naturfredningsforening (Danish Society for Nature Conservation)
- Det Økologiske Råd (The Ecological Council)

The organic farming treatments of the CRO experiment will be managed according to the principles of organic farming, i.e. without any use of pesticides, mineral fertilisers or other products not allowed in organic farming. However, the manure used in the experiments is derived from non-organic animals and especially the degassed-slurry might not currently be acceptable in organic farming. The seed used is not seed-dressed, but is not always of organic origin.

The N-fixation will be determined in the CRO experiment using the ¹⁵N-natural abundance technique, which does not include adding any N isotopes to the soil.

The CROPSYS project will deliver plant products to BIOTRACE. The additional costs for harvesting etc. for this purpose will be covered by BIOTRACE.

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- Vereijken, P. (1997). A methodological way of prototyping integrated and ecological arable farming systems (I/EAFS) in interaction with pilot farms. *European Journal of Agronomy* 7, 235-250.
- Vinther, F.P., Hansen, E.M. & Olesen, J.E. (2004). Effects of plant residues on microbial activity including field CO₂ and N₂O fluxes and N mineralisation in unfertilised crop rotations. *Nutrient Cycling in Agroecosystems* 70, 189-199.
- Vinther, F. P., Hansen, E. M. & Eriksen, J. (2005) Leaching of soil organic carbon and nitrogen in a coarse sandy soil after cultivating grass-clover pastures. *Journal of Plant Nutrition and Soil Science* (submitted)
- Wamberg, C., Christensen S., Jakobsen I., Müller A.K. & Sørensen S.J. (2003) The mycorrhizal fungus (*Glomus intraradices*) affects microbial activity in the rhizosphere of pea plants (*Pisum sativum*) *Soil Biology and Biochemistry* 35, 1351-1359.
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A.8 Curriculum vitae

Curriculum vitae for research professor Jørgen E. Olesen

Name and birth

Jørgen E. Olesen, born 28.10.1958

Scientific degrees

M.Sc. in agriculture from Royal Veterinary and Agricultural University (KVL)

Employment record

1983-1986 Scientist, Danish Institute of Plant and Soil Science, Agrometeorological Service
1986-1991 Head of department, Danish Institute of Plant and Soil Science, Department of Agrometeorology
1991-1993 Scientist, Danish Institute of Plant and Soil Science, Department of Soil Science
1993-1994 Senior researcher, Danish Institute of Agricultural Sciences, Department of Crop Physiology and Soil Science
1994- Head of research group on Crop Production, Department of Crop Physiology and Soil Science, Danish Institute of Agricultural Sciences
2003- Research professor, Department of Agroecology, Danish Institute of Agricultural Sciences

Research areas

He was involved in initiating Danish research on agrometeorology. He has lead several interdisciplinary projects, including projects on integrated wheat production, application of remote sensing and GIS in agriculture, development of a whole-farm simulation model, and several projects on organic farming and reduced tillage. He has participated in six EU projects and concerted actions on the effect of climate change on agriculture and also contributed as an author to the third IPCC assessment report, and is a lead author for the IPCC fourth assessment report. He has participated in two EU projects on mitigation to climate change, and he currently participates in two EU projects (CARBOEUROPE and ENSEMBLES) on adaptation and mitigation to climate change.

Other activities

He is currently co-supervisor of three Ph.D. studies. Key supervisor at the research school for organic farming (SOAR). He participates in COST action 627, where he coordinates WP4 on scenarios and policy implications. He is member of the management committee of COST action 729. He is member of the editorial advisory board of European Journal of Agronomy, and vice-president of the Nordic Association of Agricultural Scientists.

Publications

He has published 62 papers in international scientific journals, 123 papers at conferences and 138 in reports and technical letters.

Berntsen, J., Jacobsen, B.H., Olesen, J.E., Petersen, B.M. & Hutchings, N.J. (2003). Evaluating nitrogen taxation scenarios using the dynamic whole farm simulation model FASSET. *Agricultural Systems* **76**, 817-839.

Olesen, J.E. & Bindi, M. (2002). Consequences of climate change for European agricultural productivity, land use and policy. *European Journal of Agronomy* **16**, 239-262.

Olesen, J.E., Rasmussen, I.A., Askegaard, M. & Kristensen, K. (2002). Whole-rotation dry matter and nitrogen grain yields from the first course of an organic farming crop rotation experiment. *Journal of Agricultural Science, Cambridge* **139**, 361-370.

Olesen, J.E., Hansen, P.K., Berntsen, J. & Christensen, S. (2004). Simulation of above-ground suppression of competing species and competition tolerance in winter wheat varieties. *Field Crops Research* **89**, 263-280.

Olesen, J.E., Rubæk, G., Heidmann, T., Hansen, S. & Børgesen, C.D. (2004). Effect of climate change on greenhouse gas emission from arable crop rotations. *Nutrient Cycling in Agroecosystems* **70**, 147-160.

Curriculum vitae for senior scientist Margrethe Askegaard

Name and birth

Margrethe Askegaard, born January 2, 1955

Scientific degrees

M.Sc. in agriculture from Royal Veterinary and Agricultural University (KVL), 1980.

Ph.d. in Plant Nutrition, Royal Veterinary and Agricultural University (KVL), 2003.

Employment record

2004-date Senior scientist, DIAS, Dept. of Agroecology.
1997-2004 Scientist, DIAS, Dept. of Agroecology (Crop Physiology and Soil Science to 2003)
1993-1997 Scientist, Danish Institute of Plant and Soil Science, Dept. of Soil Science
1983-1993 Advisor, Agricultural Extension Service
1980-1983 Instructor, Agricultural Schools

Main research activities

2000-date Participant in a project on the effect of catch crops on N and K leaching and crop production.
2000-2004 Participant in a project on the performance of grain legumes and cereals at low K levels.
1997-2004 Project leader of a project on nutrient management in an organic dairy crop rotation.
1997-2004 Participating project leader of a project on organic crop rotations for grain production
1997-2003 Ph.D. project on potassium dynamics in organic farming as main objective.
1996-2000 Project leader of a project on availability and utilisation of K, P and S.
1994-1997 Project leader of a project on plant production, nutrient management and crop protection on organic dairy farms.

Other tasks

Member of the Foundation for Organic Agriculture, Ministry of Agriculture and Fisheries.

Key qualifications

Her main competence is on cropping systems and nutrient management, with detailed knowledge about both conventional and organic crop production. She includes practical management approaches as well as scientific approaches in her work. This broad technical approach to crop production and management facilitates the identification of weak links in cropping systems with respect to production and environmental effects.

Publications

She has published 15 papers in international scientific journals, 30 papers at conferences and 21 reports and technical letters.

- Askegaard M., Eriksen J. and Johnston A.E. 2004. Sustainable Management of Potassium. In: Schjøning, P., Elmholt, S. and Christensen, B.T. (eds.) *Managing Soil Quality – challenges in modern agriculture*. CAB International, Wallingford, UK, Chap. 6, 85-102
- Askegaard M., Eriksen J. & Olesen J.E. 2003. Exchangeable potassium and potassium balances in organic crop rotations on a coarse sand. *Soil Use and Management* 19 (2) 96-103.
- Askegaard M., Olesen J.E. and Kristensen, K. Nitrate leaching from organic arable crop rotations: effects of location, manure and catch crop. 2005. *Soil Use and Management*. In press.
- Eriksen, J., Askegaard, M. and Kristensen, K. 2004. Nitrate leaching from an organic dairy crop rotation; the effect of manure type, N-input and improved crop rotation. *Soil Use and Management* 19, 96-103.
- Olesen J.E., Rasmussen I. A., Askegaard M. og Kristensen K. 2002. Whole-rotation dry matter and nitrogen grain yields from the first course of an organic farming crop rotation experiment. *Journal of Agricultural Science*, 139, 361-370.

Curriculum vitae for senior scientist Per Schjønning

Name and birth

Per Schjønning, born 22.10.1953

Scientific degrees

M.Sc. in agriculture from Royal Veterinary and Agricultural University (KVL)

Employment record

1980-1988 Scientist, Danish Institute of Plant and Soil Science, Department Soil Tillage and Soil Physics

1988-1994 Senior Soil Scientist, Danish Institute of Plant and Soil Science, Department of Soil Physics, Soil Tillage and Irrigation

1994- Senior Soil Scientist, Danish Institute of Agricultural Sciences, Department of Crop Physiology and Soil Science / Department of Agroecology

Research areas

Per Schjønning (PS) has been involved in numerous national and international projects on soil physics as related to agricultural management of soils. In the 1980's he was given as a main task the building up of a soil physical laboratory for general use within DIAS. In this context he constructed and implemented several methods for soil physical measurements (e.g. air permeability, air diffusivity). In recent years, PS has increased his research in multidisciplinary approaches for understanding the effects of soil physical properties on biological processes. PS is currently coordinating a DARCOF project 'ROMAPAC' on soil quality as related to organic farming management.

Other activities

PS is member of the Executive Committee of the European Society for Soil Conservation (ESSC) and in this context responsible for ESSC task force on 'Soil Quality'. Member of ISTRO (International Soil Tillage Research Organization). Serving as a referee for several international Journals. He has served as DIAS supervisor for several Ph.D.- and M.Sc. students.

Publications

PS has authored or co-authored more than 160 publications of which 59 papers are in international scientific journals or books, and 42 are conference contributions.

Selected, recent publications:

Schjønning, P., Elmholt, S. & Christensen, B.T. (Eds.) 2004. *Managing Soil Quality: Challenges in Modern Agriculture*. CABI Publishing, Wallingford, UK, 368 pp.

Larsen, T., Schjønning, P. & Axelsen, J.A. 2004. The impact of soil compaction on euedaphic Collembola. *Applied Soil Ecology* 26, 273-281.

Moldrup, P., Olesen, T., Komatsu, T. Yoshikawa, S., Schjønning, P. and Rolston, D.E. 2003. Modeling diffusion and reaction in soils: X. A unifying model for solute and gas diffusivity in unsaturated soil. *Soil Science* 168, 321-337.

Schjønning, P., Thomsen, I.K., Moldrup, P. & Christensen, B.T. 2003. Linking soil microbial activity to water- and air-phase contents and diffusivities. *Soil Science Society of America Journal* 67, 156-165.

Thomsen, I.K. & Schjønning, P. 2003. Evaluation of a non-destructive technique for inorganic soil N measurement. *Geoderma* 113, 147-160.

Thomsen, I.K., Schjønning, P., Olesen, J.E. & Christensen, B.T. 2003. C and N turnover in structurally intact soils of different texture. *Soil Biology and Biochemistry* 35, 765-774.

Ball, B.C. & Schjønning, P. 2002. *Air permeability*. In: J.H. Dane and G.C. Topp (eds.) *Methods of Soil Analysis*, pp. 1141-1158, Part 1. 3rd ed., Agronomy Monograph, ASA and SSSA, Madison, WI.

Schjønning, P., Elmholt, S., Munkholm, L.J. & Deboosz, K. 2002. Soil quality aspects of humid sandy loams as influenced by organic and conventional long-term management. *Agriculture, Ecosystems & Environment* 88, 195-214.

Schjønning, P., Munkholm, L.J., Moldrup, P. & Jacobsen, O.H. 2002. Modelling soil pore characteristics from measurements of air exchange: the long-term effects of fertilization and crop rotation. *European Journal of Soil Science* 53, 331-339.

Curriculum vitae for senior scientist Søren O. Petersen

Name and birth

Søren O. Petersen, born 17.2.1960

Scientific degrees

M.Sc. in biology from University of Aarhus (1988)

Ph.D. in microbial ecology, University of Aalborg (1991)

Employment record

1991-1994 Post doc, University of Aalborg, Dept. Water, Soil and Environmental Engineering

1992-1993 Post doc, Michigan State University, Center for Microbial Ecology

1994- Senior researcher, Danish Institute of Agricultural Sciences, Department of Crop Physiology and Soil Science (now: Dept. Agroecology)

Research areas

SOP has studied microbial ecology of arable systems for >15 years, with an emphasis on C/N-cycling, microbial community structure and gaseous emissions. Environmental impacts on microbial communities, as well as on soil invertebrates, have been investigated by phospholipid fatty acid analyses. Initiated the FP5 research project 'Greenhouse gas mitigation for organic and conventional dairy production' (2001-2004) (<http://www.energetik-leipzig.de/Bioenergie/Midair.htm>). Initiated Nordic collaboration on greenhouse gas emissions from agriculture (2001-2002).

Other activities

SOP has for several years been involved, acting as secretary, in working groups re-evaluating Danish greenhouse gas inventories and identifying mitigation options. Has evaluated research proposals for Norwegian and Czech Research Councils. Referee for various journals. Co-editor of a special issue of *Agriculture, Ecosystems and Environment* on greenhouse gas mitigation strategies for agriculture.

Publications

SOP has published around 40 papers in international scientific journals since 1991. Selected publications from the five last years are given below:

- Petersen, S.O., Amon, B. and Gattinger, A. 2005. Methane oxidation in slurry storage surface crusts. *J. Environ. Qual.* 34, 455-461.
- Petersen, S.O., Roslev, P. and Bol, R. 2004. Dynamics of a pasture soil microbial community after deposition of cattle urine amended with [¹³C]urea. *Appl. Environ. Microbiol.* 70, 6363-6369.
- Sommer, S.G., Petersen, S.O. and Møller, H.B. 2004. Algorithms for calculating methane and nitrous oxide emissions from manure management. *Nutr. Cycl. Agroecosys.* 69:143-154.
- Petersen, S.O., Frohne, P.S. and Kennedy, A.C. (2002) Dynamics of a soil microbial community under spring wheat. *Soil Sci. Soc. Am. J.* 66: 826-833.
- Petersen, S.O., Henriksen, K., Mortensen, G.K., Krogh, P.H., Brandt, K.K., Sørensen, J., Madsen, T., Petersen, J. and Grøn, C. (2002) Recycling of sewage sludge and household compost to arable land: Fate and effects of organic contaminants, and impact on soil fertility. *Soil Till. Res.* 72: 139-152.
- Petersen, S.O., Kristensen, K. and Eriksen, J. (2001) Denitrification losses from outdoor piglet production: Spatial and temporal variability. *J. Environ. Qual.* 30, 1051-1058.
- Pedersen, A.R., Petersen, S.O. and Vinther, F.P. (2001) Stochastic diffusion model for estimating trace gas emissions with static chambers. *Soil Sci. Soc. Am. J.* 65, 49-58.
- Nielsen, P. and Petersen, S.O. (2000) Ester-linked polar lipid fatty acid profiles of soil microbial communities: A comparison of extraction methods and evaluation of interference from humic acids. *Soil Biol. Biochem.* 32: 1241-1249.

Curriculum vitae for senior scientist Niels Halberg

Name and birth

Niels Halberg, born 1961

Scientific degrees

M.Sc. in agriculture from Royal Veterinary and Agricultural University (KVL)

Employment record

1988-1992: Extension officer in Local farmers organisation

1992-1998: Scientist, Danish Institute of Animal Sciences

1998-present: Senior scientist: Danish Institute of Agricultural Sciences

2000-2002: Advisor, School of Agriculture Prek Leap, Cambodia (on leave).

Key qualifications

Niels Halberg has more than 14 years of experience in the study of farming systems and their resource use and environmental impact. Moreover, Dr. Halberg has experience in project management and co-ordination of multidisciplinary work between several institutions. He is presently co-ordinator of the project "Life Cycle Assessment of basic food (LCA)" (<http://www.lcafood.dk/>).

Niels has experience with international scientific collaboration and has been responsible for an international conference on Life Cycle Assessment of Food http://www.lcafood.dk/lca_conf/. He has also broad experience in planning of courses and dissemination to farmers, extension workers, scientific colleges, teachers and students and experience in the preparation of material for political decision-makers

Selected recent publications

- Halberg, N., van der Werf, H.M.G., Basset-Mens, C., Dalgaard, R. & de Boer, I.J.M., 2005. Environmental Assessment tools for the evaluation and improvement of European livestock production systems. *Livestock Production Science*. Accepted.
- Halberg, N., Verschuur, G. & Goodlass, G. 2005. Farm level environmental indicators; are they useful? An overview of green accounting systems for European farms. *Agriculture, Ecosystems and Environment*, 105, 195-212.
- Dalgaard, R., Halberg, N., Kristensen, I.S. & Larsen, I., 2004. An LC inventory based on representative and coherent farm types. In: Halberg, N. (ed). *Life Cycle Assessment in the Agri-food sector. Proceedings from the 4th International Conference, October 6-8, 2003, Bygholm, Denmark*. DIAS report (61) 98-106. Available on-line (Oct 2004) at: <http://www.lcafood.dk/lca_conf/DJFrapport_paper_2_poster.pdf>
- Goodlass, G., Halberg, N., Verschurr, G. 2003: Input output accounting systems in the European community – an appraisal of their usefulness in raising awareness of environmental problems. *European Journal of Agronomy*, 20, 17-24.
- Nielsen PH, Nielsen AM, Weidema BP, Dalgaard R and Halberg N (2003). LCA food database. Available online, 31/8 2003 at www.lcafood.dk/database.
- Stein, A.; Riley, J., Halberg, N. 2001: Issues of Scale for environmental indicators. *Agriculture, Ecosystems & Environment* 87, 215-232.
- Halberg, N. 1999. Indicators of resource use and environmental impact to be used in an ethical account for a livestock farm. *Agriculture, Ecosystems & Environment* (76,17-30).
- Refsgaard, K., Halberg, N., & Kristensen, E. Steen. 1998. Energy utilisation in crop production on organic and conventional livestock farms. *Agricultural Systems* (57) 599-630.

Curriculum vitae for scientist Jørgen Berntsen

Name and birth

Jørgen Berntsen, born 17.09.1966

Scientific degrees

B.Sc. in mathematics and computer science from University of Aarhus

M.Sc. in biology from University of Aarhus

Employment record

1996-1997 Research assistant University of Aarhus

1997-1997 Unisense A/S, Science Park Aarhus

1997- Scientist, Department of Soil Science, Department of Crop Physiology and Soil Science, Danish Institute of Agricultural Sciences

Research areas

He has worked with analysis and modelling of the plant/soil/atmosphere systems. The research has focused on plant growth and plant responses to environmental factors. These physiological responses have been used in the FASSET dynamic simulation model. Large parts of this model were developed by JBE. Root growth of several species has also been studied under different soil and environmental conditions in both lysimeters and field scale. He has participated on two DARCOF project on root growth of different spring barley varieties (BAR-OF) and modelling of organic cropping systems (BIOMOD).

Publications

He has published 11 papers in international scientific journals, 47 papers at conferences, in reports and technical letters.

Berntsen, J., Jacobsen, B.H., Olesen, J.E., Petersen, B.M. & Hutchings, N.J. (2003). Evaluating nitrogen taxation scenarios using the dynamic whole farm simulation model FASSET. *Agricultural Systems* **76**, 817-839.

Berntsen, J., Hauggard-Nielsen, H., Olesen, J.E., Petersen, B.M., Jensen, E.S. & Thomsen, A. (2004) Modelling dry matter production and resource use in intercrops of pea and barley. *Field Crops Research* **88**, 69-83.

Berntsen J., Petersen B.M., Olesen J.E., Eriksen J., Søgaard K. (2005) Simulation of residual effects and nitrate leaching after incorporation of different ley types. *European Journal of Agronomy*. (in press).

Knudsen, M.T.; Kristensen, I.S., Berntsen, J., Petersen, B.M., Kristensen E.S. (2005) The effect of organic farming on N leaching loss. *Journal of Agricultural Science* (submitted)

Petersen, B.M., Berntsen, J., Hansen, S. & Jensen, L.S. 2004. CN-SIM - a model for the turnover of soil organic matter. I: Long term carbon development. *Soil Biology and Biochemistry*. **37**, 359-374.

Curriculum vitae for senior scientist Ilse A. Rasmussen

Name and birth

Ilse A. Rasmussen, born 14.07.56.

Scientific degree:

Cand. agro. (M.Sc. in agriculture) from The Royal Veterinary and Agricultural University (KVL).

Scientific positions:

1989 – 2004 Researcher at Danish Institute of Agricultural Sciences, Dept. of Integrated Pest Management, Research Group Weed Ecology

2004 - Senior Scientist at Danish Institute of Agricultural Sciences, Dept. of Integrated Pest Management, Research Group Weed Ecology.

Other positions:

1986 – 1989 Advisor in organic farming at Frederiksborg County

1984 – 1985 Teacher in organic farming at St. Restrup Højskole.

Research areas:

She has been involved with research in population dynamics of weeds, weed seed production and soil seed reserve, non-chemical weed control in cereals, pulses and oil seed rape with focus on preventive measures, organic farming - crop rotations and weed control and generally weed management in organic farming. She has been leader of several interdisciplinary projects including projects on pesticide-free production of malting barley and cultivation of cereals and pulses in organic farming. She has been workshop-coordinator, session-organiser and co-arranger of several national and international workshops, symposia and conferences including the biennial Organic Conference in Denmark 2004, the EWRS Workshop on Physical and Cultural Weed Control, Norway, 2004 and the 12th international conference on weed biology, Dijon, France, 2004.

Other activities

She is an active member of the working groups on Physical and Cultural Weed Control and Weed Seed Germination and Early Growth under the European Weed Research Society (EWRS) and the Working Group on long-term experiments under the International Society of Organic Agriculture Research (ISO FAR).

Publications

She has published 9 papers in international scientific journals or books, 24 papers at international conferences and workshops, 25 papers at national conferences and workshops and 43 in reports and technical letters.

Olesen, J.E., Askegaard, M. & Rasmussen, I.A. (2000): Design of an Organic Farming Crop-Rotation Experiment. *Acta Agriculturae Scandinavica, Sect. B, Soil and Plant Science*, 50, 13-21.

Olesen, J.E., Rasmussen, I.A., Askegaard, M. & Kristensen, K. (2002): Whole-rotation dry matter and nitrogen grain yields from the first course of an organic farming crop rotation experiment. *Journal of Agricultural Science*, 139, 361-370.

Rasmussen, I.A. 2004: Weed management in organic cropping systems. In: Goodman, R.M. (ed.): *Encyclopedia of Plant and Crop Science*. Marcel Dekker, Inc., <http://www.dekker.com/servlet/product/productid/E-EPCS>

Rasmussen, I.A. 2004: The effect of sowing date, stale seedbed, row width and mechanical weed control on weeds and yields of organic winter wheat. *Weed Research* 44, 12-20.

Rasmussen, I.A. & Holst, N. (2003): Computer model for simulating the long-term dynamics of annual weeds: from seedlings to seeds. *Aspects of Applied Biology* 69: Seedbanks: Determination, Dynamics & Management, 277-284.

Curriculum vitae for senior scientist Kristian Kristensen

Name and birth

Kristian Kristensen, born 27.4.1945

Scientific degrees

Cand. hort. Royal Veterinary and Agricultural University, Copenhagen, 1970

Ph.D. Department of Mathematics and Statistics, Royal Veterinary and Agricultural University, Copenhagen, 1980

Employment record

1970-76. Research assistant, Danish Institute of Plant and Soil Science (SP)

1976-79. Ph.D student. Department of Mathematics and Statistics, Royal Veterinary and Agricultural University, Copenhagen

1979-1987. Research assistant, SP

1987-1992. Temporary head of department, Department of Biometry and Informatics, SP

1992-1998. Scientist, SP/Danish Institute of Agricultural Sciences (DIAS)

1998- Senior scientist, DIAS.

Research areas

Many years experience in applied statistics. Especially analyses of data from crop and soil science using different kind of methods, such as linear and non-linear mixed model, generalised mixed models and other multivariate models. Participation in projects on setting up and evaluation of models for nitrogen leaching from agricultural fields (N-LES, N-LES₂ and N-LES₃). Great expertise in design of experiments.

Other activities

Participates in COST action 860, where he coordinates WP2 on biostatistics. Planned and coordinated workshops on DUS data in Kiew (2000), Mexico (2002) and Beijing (2004).

Publications

Published 25 papers in international scientific journals, 38 papers at conferences, 44 other papers and reports and more than 100 oral presentations.

Kristensen, K.; Hansen, P.K. & Kristoffersen, P. 2004. Simulation of vegetation cover on sidewalks in Denmark. *Pest Management Science* **60**, 588-594.

Kristian Kristensen, Uffe Jørgensen, Ruth Grant. 2003. Genberegning af modellen N-LES. 12 pp. Baggrundsnøtat til Grant, R. og Waagepetersen, J. 2003. Vandmiljøplan II - slutevaluering. Danmarks Miljøundersøgelser, Miljøministeriet. ISBN:87-7772-776-2. (Available at http://www.dmu.dk/1_viden/2_publicationer/3_ovrige/rapporter/VMPII/Genberegning_af_modellen_N-LES.pdf).

Kristensen, K. & Rasmussen, I.A. 2002. The use of a Bayesian network in the design of a decision support system for growing malting barley without use of pesticides. *Computers and Electronics in Agriculture*. **33**, 197-217.

Hansen, E.M., Djurhuus & Kristensen, K. 2000. Nitrate Leaching as Affected by Introduction or Discontinuation of Cover Crop Use. *Journal of Environmental Quality*. **29**, 1110-1116.

Simmelsgaard, S.E., Kristensen, K., Andersen, H.E., Grant, R., Jørgensen, J.O., Østergaard, H.S. 2000. Empirisk model til beregning af kvælstofudvaskning fra rodzonen. N-LES. Nitrate Leaching ESTimator. DJF rapport, Markbrug. **32**, 67 pp.

Eriksen, J., Askegaard, M. & Kristensen, K. 1999. Nitrate leaching in organic dairy/crop rotation as affected by organic manure type and livestock density and crop. *Soil Use and Management* **15**, 176-182.

Fomsgaard, I.S. & Kristensen, K. 1999. Influence of microbial activity, organic carbon content, soil texture and soil depth on mineralisation rates of low concentrations of ¹⁴C-mecoprop – development of a predictive model. *Ecological Modelling* **122**, 45-68.

Curriculum vitae for senior scientist Per Ambus

Name and date of birth

Per Ambus, date of birth 08.11.1959.

Address

Biosystems Department (BIO-309), Risø National Laboratory, DK-4000 Roskilde.

Tel: (+45) 4677 4152. e-mail: per.ambus@risoe.dk; www: http://www.risoe.dk/pbk/research_uk/ple.htm

Education and employment

M.Sc. (1987) in General Microbiology at Cphg Univ; Ph.D. (1992) on nitrogen dynamics in riparian areas (Cphg Univ.). Participation in training courses in HPLC and ion chromatography, health physics, hazardous waste and radio isotope training, project management and isotope ratio mass spectrometry.

1989 Visiting Graduate. Southeast Watershed Research Laboratory, USDA Georgia, USA.

1991-1993 Postdoctoral Fellow. Department of Population Biology, Copenhagen University.

1993-1994 Research Scientist. Plant Ecosystems and Nutrient Cycling, Plant Biology and Biogeochemistry Department, Risø National Laboratory.

1995-1996 Visiting Research Associate. Kellogg Biological Station, Michigan State University, USA.

1997- Research Scientist and Senior Research Scientist (1998-). Plant Ecosystems and Nutrient Cycling, Plant Biology and Biogeochemistry Department, Risø National Laboratory.

Research activities

The main focus of my research has been on biogeochemical cycling of C and N in soil-plant ecosystems, including studies at the laboratory scale and in large scale field experiments. In particular issues of plant residue decomposition and greenhouse gas emissions from soils have been investigated. Since 1998 I have been responsible for the stable isotope laboratory at Risø, and has participated in development and application of novel stable isotope techniques. I have participated as PI in several EU-projects (STEP; Nofretete; GreenGrass) as well as national projects. Coordinator of national project on greenhouse gas emissions from grass pastures (DINOG). Experience in teaching and supervising at graduate and post-graduate levels. Currently external advisor for one Ph.D. student.

Publications

Since 1991 I have published 110 publications of which 35 are printed in international, peer reviewed journals. A detailed list is available at: http://iis-03.risoe.dk/netahtml/risoe/publ_uk.htm

Ambus, P. 2005 Gross nitrogen turnover and nitrous oxide emission in organic grass-clover pastures. Nutrient Cycling in Agroecosystems. In press

Formánek, P. and Ambus, P. 2004. Assessing the use of $\delta^{13}\text{C}$ natural abundance in separation of root and microbial respiration in a Danish beech (*Fagus sylvatica* L.) forest. Rapid Communications in Mass Spectrometry. 18: 1-6.

Andersen, M.K., Hauggaard-Nielsen, H., Ambus, P. and Jensen, E.S. 2005. Biomass production, symbiotic nitrogen fixation and inorganic N use in dual and tri-component annual intercrops. Plant and Soil. 266: 273-287.

Grogan, P., Michelsen, A., Ambus, P. and Jonasson, S. 2004 Effects of differing freeze-thaw regimes on nutrient cycling and respiration in sub-arctic heath tundra. Soil Biology and Biochemistry. In press Jan 2004.

Pilegaard, K., Mikkelsen, T.N., Beier, C., Jensen, N.O., Ambus, P., and Ro-Poulsen, H. 2003. Field measurements of atmosphere-biosphere interactions in a Danish beech forest. Boreal Environment Research. 8: 315-333. ence of crop residue particle size, quality and placement. Phyton, 41(3): 7-15.

Curriculum vitae for professor Søren Christensen

Name and date of birth

Søren Christensen, born 3 November 1953.

Educational degrees:

Cand scient (M.Sc.) in biology, Univ Copenhagen, June 1978.

Lic scient, (Ph.D.) in soil biology, Univ. Copenhagen, April 1985.

Dr Scient, (D.Sc.) in soil biology, Univ. Copenhagen, October 1992.

Professional employment:

Forskningsstipendiat (Res. assistant), State Lab. for Soil and Crop Research, Lyngby, Denmark, 1979 - 1984.

Videnskabelig assistent (Res. associate), State Lab. for Soil and Crop Research, Lyngby, Denmark, 1984 - 1986.

Leave from State Lab. for Soil and Crop Research, May 1985 - Oct. 1986.

Post-doc, Dept. Plant and Soil Science, Michigan State Univ. USA, May 1985-Oct. 1986.

Lektor (assoc. professor), Univ Copenhagen, Dept. Population Biol., Oct. 1986–March 2001.

Professor, Univ. Copenhagen, Dept. Terrestrial Ecology, from April 2001.

Research activities

I deal with the dynamics of the decomposition process in soil and the interaction of the responsible organisms (bacteria, fungi, protozoa, and nematodes). Main foci are (i) the spatial pattern of organic matter and oxygen availability and (ii) importance of diversity among decomposer organisms for stability of the decomposition towards disturbance. At the population level current work is on resource allocation from plants to above- and below ground organisms. At the system level projects currently deal with increased CO₂ and rhizodeposition, as well as variability of plant residues in organic farming. Earlier work has given experience in mechanisms governing trace gas production from soil micro-organisms.

Publications

72 original research papers during 1980-2005; 2004-2005 publications:

Marzcia E.C.Techau, Bjørnlund L., Christensen S. (2004) Simulated herbivory effects on rhizosphere organisms in pea (*Pisum sativum*) depended on phosphate. Plant and Soil 264, 185-194.

Timonen S., Christensen S., Ekelund F. (2004) Distribution of protozoa in scots pine mycorrhizospheres. Soil Biology and Biochemistry 36, 1087-1093.

Vestergard M, Bjørnlund L, Christensen S (2004) Aphid effects on rhizosphere microorganisms and microfauna depend more on barley growth phase than on soil fertilization. Oecologia 141, 84-93.

Bjørnlund L., Christensen S. (2005) Gap dynamics in a semi-natural forest: How does litter quality and site heterogeneity interact on decomposer organisms? Soil Biology and Biochemistry 37, 203-213.

Georgieva S., Christensen S., Petersen H., Gjelstrup P., Thorup-Kristensen K. (2005) Early decomposer assemblages of soil organisms in litterbags with vetch or barley roots. Soil Biology and Biochemistry 37.

Georgieva S., Christensen S., and Andersen K. (2005) Nematode succession and microfauna-microorganism interactions during plant residue decomposition Soil Biology Biochemistry 37.