Technical Annex 1

Scientific description of the project

Title: Grass-clover in organic dairy farming - options to reduce costs and improve nutrient utilization

Acronym: OrgGrass

Duration: From: 2007 to: 2011

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(Head of project is written in bold, participants responsible for work packages are underlined).

English summary

On organic dairy farms, grass-clover leys are essential for animal welfare, feed supply and soil fertility building. The proportion of grass-clover in the crop rotations increases on Danish organic dairy farms and, in combination with a general increase in farm sizes, this leads to high grassland frequencies near the farms. The main reason is that uniform grazing of all cropped land becomes inexpedient due to long distance to the milking facilities. This development has got implications for a number of aspects: accumulation and loss of nutrients, loss of productivity and quality in grass-clover mixtures of longer duration, and increasing problems of establishing white clover. However, the longer duration of grasslands may also provide an opportunity to control nutrient losses due to less frequent grassland cultivation.

The theme of this project is grass-clover leys as an integrated part of organic dairy farms. The focus is on management strategies with the purpose of overcoming the above-stipulated shortcomings by manipulating grassland frequency, grazing intensity (and nutrient load), species richness, and arable crop sequence following grassland cultivation. The management strategies will be evaluated on the basis of nutrient use efficiency, productivity, feed quality and biodiversity at the field and crop rotation level and in a whole farm economic and environmental perspective The aim is to propose strategies for a cost-efficient feed production and efficient nutrient utilization in organic dairy production systems.

The research consists of six interrelated work packages (WPs). WP1-2, which are also the primary experimental units, deal with production and nutrient utilization aspects at the crop rotation level. WP3-5 deal with aspects of biodiversity in relation to production and nutrient utilization. Finally, WP6 deals with production, nutrient utilization and economics of whole farming systems.

Specifically, WP1 evaluates different strategies for mixed crop rotation composition and grassland management regarding productivity and environmental impact in a factorial designed field experiment on loamy sand that represents a very wide range of dairy farms from intensive to very extensive. This is

done by quantifying grassland performance, nitrogen leaching from grassland and the residual effects and nitrogen leaching following cultivation. WP2 focus on grazed grassland of longer duration on a coarse sandy soil under private farm conditions. The effect of grazed grassland management on productivity and nitrate leaching is determined and the effect of fertilizer and catch crop use in maize following grassland cultivation is investigated. WP3 aims at developing multi species grass-clover mixtures, also including herbs, with high persistence and herbage quality through species composition and management. The soil-plant processes leading to an efficient use of multi-species mixtures is the subject of a Ph.D. study including quantification of nitrogen transfer and deposition, nutrient uptake efficiency and competition for individual nutrients in multi species mixtures and related to effects on herbage quality. WP4 will seek methods to avoid the increasing problems of establishing white clover on near-farm clover rich areas. The growth and the disease carrying by other crops, including legumes, will be investigated on clover fatigue soil. WP5 studies the influence of earthworm burrows on nitrate-N loss via macropore flow and how this is affected by management practices, such as cattle grazing, and duration of grass-clover leys. Finally, WP6 evaluates the management strategies and combinations of crop rotations investigated in WP1-3 in a whole farm perspective. This is carried out by optimizing representative whole farm prototypes regarding production, self-sufficiency, farm economics and environmental load and by creating scenarios for organic dairy farms using an economic model.

The aim is that results from this project will help ensuring a production on large organic dairy farms that presents a real alternative to conventional dairy farming by being environmentally attractive, in agreement with the organic principles and economically viable.

A.0 Introduction, state of the art and objectives of the project (max. 3 pages):

Introduction

On organic dairy farms, grass-clover leys are essential for grazing, feed supply and soil fertility building, all key elements in the organic principles of animal welfare, high quality crops and self-sufficiency. It is expected that the proportion of grassland will increase due to the changes in the EU common agricultural policy (CAP) where de-coupling of subsidies for arable crops makes grass-clover compete economically better with other feedstuff sources. Historically, a large part of organic milk has been produced on smaller farms with maximum integration of animal husbandry and plant production through grazing of the entire crop rotation. An increased proportion of grass-clover in combination with an ongoing structural development in the size of dairy farms, conventional as well as organic, lead to high grassland frequencies near the farms as uniform grazing of all cropped land becomes inexpedient due to long distance to the milking facilities. On organic dairy farms we already experience grass-intensive crop rotations located close to farm buildings with grass-clover pastures of longer duration than the 2-3 years that have been common.

This development has got implications for a number of aspects. A concentration of grazed grassland near the farm creates loss of fertility furthest from the farm and accumulation of nutrients near the farm, to an extend that may increase losses of e.g. nitrogen if not efficiently utilized. This is especially important in areas with sandy soils and high winter rainfall where a large proportion of organic dairy farms are located. Furthermore, the widely used mixture of white clover (*Trifolium repens*) and perennial ryegrass (*Lolium perenne*) often suffers from loss of productivity and quality when grown for longer duration and increasing problems have been recognised in establishing white clover in crop rotations with large proportions of grass-clover leys. However, the longer duration of grasslands may also provide an opportunity to control nutrient losses due to less frequent grassland cultivation. The theme of this project is grass-clover leys as an integrated part of organic dairy farms. The focus is on management strategies with the purpose of overcoming the above-stipulated shortcomings by manipulating grassland frequency, grazing intensity (and nutrient load), species richness, and arable crop sequence following grassland cultivation. The management strategies will be evaluated on the basis of N use efficiency, productivity, feed quality and biodiversity at the field and crop rotation level and in a whole farm economic and environmental perspective. The aim is to propose strategies for a cost-efficient feed production and efficient nutrient utilization in organic dairy production systems. The development towards increasing farm size is not necessarily in conflict with the organic principles of stable and harmonic production systems although there is a risk that elements hereof are neglected. To present a real alternative to conventional production it must be ensured that production on large organic farms is environmentally attractive and in agreement with the basic organic principles, and at the same time economically viable.

State-of-the-art

Utilizing grassland nitrogen

Over the last decades, research has greatly improved the opportunities for optimising N utilisation in agriculture. However, grassland farming and especially intensive dairy farming still has particularly low N use efficiencies at field level (Davies 2000, Jarvis 2000, Jarvis & Aarts 2000). This is mainly due to grazing. Whereas cut grassland systems without animal grazing usually have high N use efficiency and consequently low nitrate leaching (Simmelsgaard 1998) the introduction of grazing animals increases the N loss potential dramatically (Jarvis 2000). This is because ruminants excrete 75-95% of the N-intake (Whitehead 1995) with the main part deposited during grazing. Thus, a considerable build-up of N takes place in grazed grassland.

As a consequence, ploughing-out of grazed leys is succeeded by large increases in N mineralization (Francis 1995, Eriksen et al. 1999, Søegaard et al. 2002). Therefore, careful management during the ploughing-out phase is required in all intensive grassland systems including organic farming (Goulding 2000, Hansen et al. 2001, Haas et al. 2001, Stockdale et al. 2001). It is well-known that ploughing-out in late winter or spring (Francis et al. 1992, Djurhuus & Olsen 1997, Shepherd et al. 2001) and the use of efficient catch crops after ploughing (Köpke 1995, Francis 1995) are 'good management practices' for decreasing nitrate leaching losses from ploughed grass swards. Furthermore, it is important to adjust the application of animal manure to the succeeding crops (Nevens & Reheul 2002, Eriksen 2001). Eriksen (2001) has shown that the use of such good management practices upon grassland cultivation, reduced nitrate concentrations in leachates to below the EU Drinking Water Directive upper limit of 50 mg/l. It appears that further improvements of the utilization of grassland N following cultivation are limited when the current knowledge has been implemented.

If the N use efficiency of dairy farming systems is to be further improved the N-management in the pasture phase must be considered. This includes manure application to the grass-clover leys, feeding of the dairy cows, stocking density, time of grazing and the botanical composition of the sward (Cuttle & Scholefield 1995, Høgh-Jensen & Schjoerring 2001, Kristensen et al. 2005). In addition, the age of the leys have been identified to be significant for the potential N-leaching losses (Eriksen et al. 2004). During grazing ruminants distribute the dung and urine unevenly. Urine patches from larger ruminants may apply amounts equivalent to 800 kg N ha^{-1} in only one urination (Haynes & Williams, 1993) and much of the nitrate leached from pastures during the winter originates from urine patches deposited during the autumn where grass the productivity is low (Cuttle & Bourne 1993). Thus, autumn grazing needs to be included in the management measures for controlling N leaching losses.

Multi-species mixtures for increase long-term productivity and quality

On intensive organic dairy farms in Denmark the maintenance of productivity in grass-clover leys older than 2-3 year is difficult. Grassland management, particularly in autumn, is considered to influence the sward and its productivity in the subsequent year. However, the knowledge about the possibilities for maintaining the production level is relatively low (Søegaard et al. 2004a). The Danish organic and conventional grasslands are dominated by perennial ryegrass and white clover and not by species with higher persistence. The high proportion of forage crops in the feed ration for the organic dairy cows lead to a request of high herbage quality in the grass-clover sward, and if changing the present seed mixtures towards higher persistence it is necessary to meet this demand. Recently festulolium (*x festulolium*) and kura clover (*Trifolium ambiguum*) have come into focus, although the knowledge about persistence and herbage quality is limited.

There is a growing awareness of some shortcomings of the perennial ryegrass/white clover system, including poor tolerance to limited water supply, low content of minerals and increasing establishing problem due to clover soil fatigue. The interest for including other species in the sward is considerable among organic farmers, but is also a demand for milk contractors to one Danish organic dairy (Naturmælk). The potential species have different traits; as high content of minerals (Sanderson et al., 2003), expected effect on the milk flavour (Carpino et al. 2004), high growth rate at sufficient nutrient supplies, complementary growth pattern to ryegrass/white clover swards, decreasing the degradability of protein in the rumen given a higherby-pass protein (Min et al., 2003), reducing bloat risk and reducing the level of endoparasitism (Niezen et al., 1995). From nature point of view a multi-species sward would also increase the number of biotopes for grassland fauna. However, the potential of the single herb species in Danish swards for cutting and grazing is unknown with regard to proportion, persistence and palatability.

Clover soil fatigue

In recent years a new constraint - clover soil fatigue - has appeared for the establishment of white clover, which is the mostly used grassland legume on organic dairy farms. Increasing dairy farm sizes have led to more clover intensive crop rotation schemes in the grazing areas located at logistically convenient distances from stables. It has become a common practice to establish new grass-clover in the fields just after ploughing-out the grass-clover swards, and soil fatigue has become more common. On fatigued land the clover plants emerge, then stunt and eventually disappear the same year. The problem tends to cover the entire area of the fields. Obviously, this is a major constraint in organic dairy farming, because of the importance of N-inputs derived from symbiotic fixation. This serious establishing problem has not been reported elsewhere and seems until now to be a specific Danish problem. Preliminary experiments in 2004 have indicated, that the reason is an early attack of clover cyst nematodes (*Heterodera trifolii*), but an unknown factor may have triggered hatching of cysts and subsequent attacks at the very beginning of plant germination. The number of cyst was not higher on the fatigue soils (Søegaard et al. 2004b).

To overcome this fatigue problem the challenge is to find legumes, which do not maintain the fatigue, and to develop grass-clover rich crop rotation systems, which can avoid clover soil fatigue and reduce existing problems if any.

Influence of earthworms and earthworm macropores on leaching of N

The use of semi-permanent grass-clover pastures in organic dairy crop rotations is greatly stimulating earthworm populations. Thus, extremely high densities of earthworms are known from Danish organically farmed soils, up to 800 individuals m^{-2} (Christensen & Mather 1997). Earthworms can by their tunnelling through the soil significantly increase soil porosity and average pore size (Edwards & Shipitalo 1998). Moreover, anecic species such as *Lumbricus terrestris*, which are particularly favoured by organic farming and in pastures, creates persistent vertical burrow systems that penetrate to deep soil layers. Several studies have shown that infiltration rates are increased by the presence of earthworm burrows (Lachnicht et al. 1997, Shipitalo & Butt 1999, Schuster et al. 2003).

However, many macropores do not necessarily give much macropore flow. The initiation of macropore flow depends to a large degree on the near-saturated hydraulic conductivity of the soil matrix and the rain intensity. Water will only flow from the soil matrix out into the non-capillary macropores if the soil matrix hydraulic conductivity is exceeded and the soil therefore gets water saturated (Larsbo & Jarvis 2003). This is a situation mostly occurring in the period from autumn to spring. The cattle will still be grazing in the autumn and there is a high potential for leaching of nitrate from the urine patches at this time a year (Cuttle & Bourne 1993). Macropore flow can cause the rain water to bypass large parts of the bulk soil where higher concentrations of nitrate are found and therefore delay leaching.

Lamandé et al. (2003) found that the upper 10 cm were compacted on a 9 year old pasture due to cattle trampling. This caused a lower near-saturated conductivity compared to the pasture rotation plot giving a higher probability to initiate macropore flow at the surface.

Optimization on dairy farms

The complexity in farm structure and differences in management skills makes it difficult to estimate the effect at farm level of partial changes in parts of the farming system, especially in a situation aiming after a high degree of self supply with feed and manure. Type, quality and amount of roughage are in general accepted as some of the most dominating elements for the variation in productivity of the organic dairy farm (Mogensen & Kristensen 2005). Furthermore grassland management and incorporation of grassland in the crop rotation has major impact on the N balance. Thus, farm planning and optimization calls for a system approach, which can combine experimental knowledge, farm data and modelling, as shown by Mogensen & Kristensen (2000) and used by Kristensen & Kristensen (1997) in modelling of three different farming systems at the organic experimental station "Rugballegård". For this type of modelling are used quite simple static models keeping track of the in- and output and the internal balance between crop production and feed demand (Keulen et al. 2000).

Objectives

The main hypothesis is that we through grass-clover ley management on large grass intensive organic dairy farms can achieve cost-efficient feed production and efficient nutrient utilization. The overall objective is to produce results that can form the basis of this development by:

- Determination of grassland residual effects and nitrogen leaching when manipulating the grassland frequency in the crop rotation, grassland utilization and grazing intensity, and nutrient load.
- Investigating nutrient use efficiency of grassland N in high-risk areas regarding nitrate leaching (coarse sandy soil).
- Investigating the use of multi-species mixtures to increase long-term productivity, feed quality, biodiversity and nature value and improve clover establishment.
- Investigating how management practises of grass-clover fields influence the leaching losses of N in the autumn as influenced by earthworms and macropores.
- Optimizing representative whole farm prototypes regarding production, self-sufficiency, farm economics and environmental load.

A.1 **Relevance for DARCOF III and argumentation for the subject** (max. ½ page):

The project addresses theme 3.3.1 'Grass-clover - options to reduce costs and improve nutrient utilization' and the project seeks to cover all topics mentioned within this theme.

A.2 Technical content of the research activity

Project structure

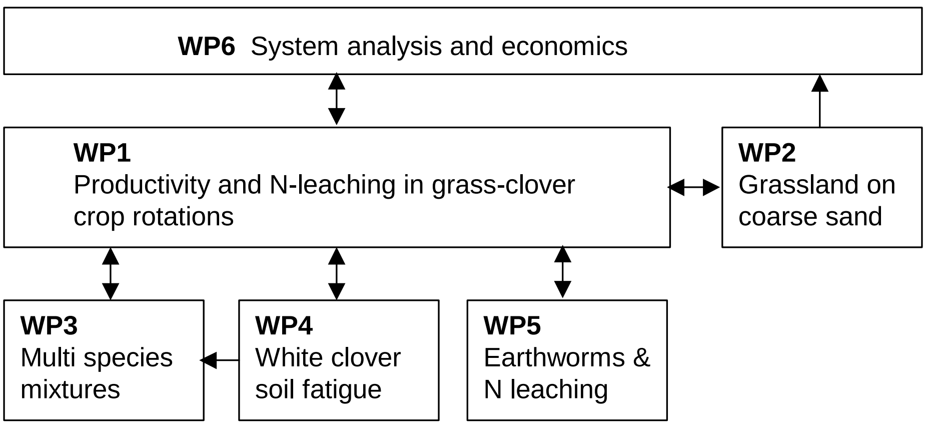
(graphical overview of the project and a timetable is given below)

The workpackages in the OrgGrass project are divided into three main groups (horizontal layers in the graphical illustration). WP1 and WP2 deal with production and nutrient utilization aspects at the crop rotation level. WP3, WP4 and WP5 deal with aspects of biodiversity in relation to production and nutrient utilization. Finally, WP6 deals with production, nutrient utilization and economics of whole farming systems.

WP1 and WP2 include the primary experimental units. WP1 is the heart of the project with studies within the widest possible range of farming systems from quite intensive to very extensive in a factorial design experiment and in permanent grassland. The detailed quantitative design of treatments in WP1 awaits an initial prototyping exercise in WP6. WP2 contains a study directly focussed on strategies for the grass-intensive part of the crop rotation near the farm on low nitrate retentive soil and is important for the generalisation of results in WP1. The experimental work in WP3, WP4 and WP5 is either fully or partly utilizing the WP1 experimental setup. WP3 investigates possibilities for exploiting functional diversity in organic grasslands by using multi species legume/grass/herb mixtures and parts of this work is carried out on commercial farms. The research in WP3 has considerable novelty and includes a Ph.D. study focussing on the plant nutrition, physiology and ecology that is the basis for developing multi species mixtures. WP4 addresses the important question of how white clover soil fatigue, having a detrimental effect on organic grassland farming, may be overcome and will be linked to the work in WP3. WP5 studies how the earthworm population is affected by grass-clover leys of longer duration and this is related to leaching of nitrate through soil macropores – also a novel approach and of importance for interpretations in WP1.

WP's 1-5 may be seen as individual scientific projects which will provide basic elements in the understanding of the dynamics of grass-clover as an integrated part of organic dairy crop rotations. They also contribute to the systems analysis in WP6, where WP1 and WP2 will provide primary data. Thus resources are used in each WP on relating results to the whole farm perspective and as such the system analysis is a larger activity than indicated by the WP6 budget. Although equally important, project management (WP7) has not been included in the diagram.

Graphical overview of OrgGrass:



Timetable of OrgGrass:

WP	Task	2007	2008	2009	2010	2011
1.1	Dairy crop rotation experiment					
1.2	Productivity and residual effects					
1.3	Nitrogen leaching					
1.4	Synthesis and implementation					
2.1	Grassland: N leaching, productivity					
2.2	Maize: Residual effects and leaching					
3.1	Multi species grassland					
3.2	Herbs in pastures on dairy farms					
3.3	Processes behind (Ph.D. study)					
4	White clover soil fatigue					
5	Earthworms, macropores & leaching					
6.1	Extending and testing Ø-plan					
6.2	Defining scenarios					
7	Project management					

Work Package list

WP No.	WP title	Responsible scientist	Budget DKK	Start	End	Deliverable No.
1	Productivity and N-leaching in grass-clover crop rotations	J. Eriksen	5.3 mill.	2-2007	6-2011	D1.1-D1.8
2	Grassland N management on coarse sandy soil	E.M. Hansen	1.7 mill.	2-2007	12-2010	D2.1-D2.4
3	Multi species grass-clover with high persistence	K. Søegaard	3.1 mill.	2-2007	6-2011	D3.1-D3.9
4	White clover soil fatigue – an establishment problem	K. Søegaard	0.9 mill.	2-2007	9-2009	D4.1-D4.3
5	Earthworms, macropores and N leaching	M. Holmstrup	1.5 mill.	6-2007	6-2010	D.5.1-D5.3
6	System analysis and economics	T. Kristensen	1.0 mill.	10-2007	6-2011	D6.1-D6.3
7	Project management	J. Eriksen	0.5 mill.	1-2007	12-2011	D7.1-7.7
Total			14 mill.			

Deliverables list

Deliveable No	Deliverable title	Lead scientist	Delivery date	Allocated scientific person months	Type of deliverable
D1.1	Refereed scientific paper on grassland productivity as affected by crop rotation, grassland management and nutrient load	MA	Jun 2011	9	S
D1.2	Refereed scientific paper on nitrogen leaching as affected by crop rotation, grassland management and nutrient load	JE	Jun 2011	9	S
D.1.3	Refereed scientific paper on residual effects as affected by crop rotation, grassland management and nutrient load	JE	Dec 2010	9	S
D1.5	Paper for farmer journals on the optimizing of mixed crop rotations on organic dairy farms.	MA	Dec 2010	2	P
D1.6	Popular paper on nitrogen leaching losses from grassland systems	JE	Oct 2010	2	P
D1.7	Popular paper on crop productivity in mixed	JE	Mar 2011	2	P

	farming systems				
D1.8	Data for system analysis and economic modelling (WP6)	MA	Jan 2010	7	O
D2.1	Refereed scientific paper on production and nitrate leaching in the grazed grassland experiment	EMH	Dec 2009	5	S
D2.2	Popular paper on production and nitrate leaching in the grazed grassland experiment	EMH	Dec 2009	1.5	P
D2.3	Refereed scientific paper on production and nitrate leaching in the maize experiment	EMH	Dec 2010	5	S
D2.4	Popular paper on production and nitrate leaching in the maize experiment	EMH	Dec 2010	0.5	P
D3.1	Refereed scientific paper on herbs in grasslands as affected by age and management	KS	Jun 2011	5.5	S
D3.2	Popular paper on herbs in grasslands as affected by age and management	KS	Jun 2011	0.5	P
D3.3	Refereed scientific paper on grassland persistence as affected by species and management	KS	Jun 2011	4.5	S
D3.4	Popular paper on grassland persistence as affected by species and management	KS	Jun 2011	0.5	P
D3.5	Refereed scientific publication on nitrogen transfer between species using tracer methodology	HHJ	Jul 2009	8	S
D3.6	Refereed scientific publication on rhizodeposition of carbon and nitrogen in mixtures including herbs	HHJ	Dec 2009	8	S
D3.7	Refereed scientific publication on competition, effective rooting depth and nutrient uptake efficiency of intercropped ryegrass, lucerne, chicory, and great burnet.	HHJ	Dec 2009	10	S
D3.8	Refereed scientific paper on herbage quality of intercropped ryegrass, Lucerne, chicory, and great burnet over three growth seasons.	HHJ	Dec 2009	10	S
D4.1	Refereed scientific paper on white clover soil fatigue	KS	Jun 2009	4.2	S
D4.2	Popular paper and information on Internet concerning clover soil fatigue	KS	Jun 2009	0.5	P
D4.3	Popular paper on optimizing crop rotation	KS	Jun 2009	0.5	P
D5.1	Refereed scientific paper on potential nitrate loss via preferential flow through macropores	OHJ	Dec 2009	5	S
D5.2	Refereed scientific paper the influence of earthworms on leaching of N	MHO	Jun 2010	4.5	S
D5.3	Refereed scientific paper on the influence of cattle trampling on macropores and leaching of N	OHJ	Jun 2010	4	S
D6.1	Prototyping of different strategies in a farm perspective	TK	Feb 2007	2.5	O
D6.2	Ø-PLAN Dairy. A whole farm model	NT	Nov 2010	6	R
D6.3	Refereed scientific paper on farm productivity and economic return in relation to grassland management and crop rotation on organic dairy farms	TK	Nov 2011	7.5	S

D7.1-D7.4	Annual reports	JE	Oct 07-10	1	R
D7.5	Project web site	JE	Jun 2007	1.5	O
D7.6	Workshop publication	JE	Feb 2010	1.5	R
D7.7	Final report	JE	Apr 2011	1	R

(The nature of the deliverables must be indicated by S = publication in scientific journal with peer review; P = publication in journals without peer review; R = reports; C = presentation at meetings and congresses or O = other types of deliverables, e.g., prototypes, models, websites, etc.).

Milestones list

Milestone No	Milestone title	Lead scientist	Delivery date
M1.1	Crop rotation experiment fully established	MA	Apr 2007
M1.2	Productivity of grassland systems evaluated	MA	Jun 2011
M1.3	Environmental impact of grassland systems evaluated	JE	Dec 2010
M2.1	Establishment of the grazed grassland experiment	EMH	May 2006
M2.2	Establishment of the maize experiment	EMH	May 2007
M2.3	Evaluation of production and nitrate leaching in the grazed grassland experiment	EMH	Sep 2009
M2.4	Evaluation of production and nitrate leaching in the maize experiment	EMH	Sep 2009
M3.1	Contracts with organic farmers on establishing herbs and registrations in their pastures	KS	Dec 2007
M3.2	Discussions of results from farms with farmers and advisors	KS	Dec 2009
M3.3	PhD study initiated	HHJ	Oct 2007
M3.4	Mezotrons inserted in established field trials (WP3.3) with multiple grassland species at clayey loam and coarse sandy soils	HHJ	Feb 2007
M3.5	Description of transfer and nutrient dynamics in multiple grassland species	HHJ	Oct 2008
M3.6	Field trails established to investigate nutrient uptake efficiency in multiple species grassland mixtures and tracers positioned	HHJ	May 2008
M3.7	Description of nutrient uptake efficiency by intercropped multiple grassland species	HHJ	Dec 2009
M3.8	Analysis of samples from 3 growth seasons on-farm multiple grassland mixtures for macro- and microelement completed	HHJ	Jun 2009
M3.9	Finalisation of PhD study	HHJ	Oct 2010
M4.1	Select the plant species used in the experiment, and point out soils on organic dairy farms for the experiment	KS	Mar 2007
M4.2	Evaluate necessity of changes in methods after the first experimental year	KS	Jan 2008
M5.1	First assessment of leaching through macropores in the field	OHJ	Nov 2008
M5.2	Assessment of earthworm density and biomass in field experiment	MH	Jun 2009
M6.1	Ø-PLAN extended and tested by expert panel	NT	Apr 2010
M6.2	Scenarios for modelling defined	TK	May 2011
M7.1	Fulfilment of overall project objectives	JE	Dec 2011

Description of work packages

WP No. 1:	**Productivity and N-leaching in grass-clover crop rotations**

	Start date or starting event: February 2007								
Partner id.	DIAS-AE								
Person-months per participant	40 VIP 16.3 TAP								
Total PM:	**56.3**								

Objectives:

- To evaluate different strategies for mixed crop rotation composition and grassland management regarding productivity and environmental impact by quantifying grassland performance, nitrogen leaching from grassland and the residual effect and nitrogen leaching following cultivation.
- To serve as the experimental unit for WP3, WP4 and WP5, and provide data input to systems analyses and economic modelling in WP6.

Description of work:

This study focuses on nutrient dynamics and feed production in dairy crop rotations with internal differences in grazing-intensity and proportion of leys. The experimental work will be established as a factorial design field experiment that represents a very wide range of dairy farms from quite intensive to very extensive. The experiment is situated within the dairy crop rotation on loamy sand at the experimental area of DIAS at Foulum. The six-field crop rotation, converted to organic practice in 1987, is among the oldest organic experimental areas in Denmark. Since 1987 the crop rotation has included two years of grass-clover and by now more than three rotations have passed over all fields. Measurements of yields and nitrate leaching have been carried out in the crop rotation from 1994 to 2002 (Askegaard et al. 1999; Eriksen et al. 1999; Eriksen et al. 2004), which gives the opportunity to apply a longer-term perspective on the interpretation of results.

The work package provides the experimental frame for experiments outlined in WP3-5, and will provide the main part of data input for systems analysis and economic modelling in WP 6.

<u>Task 1. Design and management of the dairy crop rotation experiment</u>

Each of the six fields was until 2004 divided into four blocks, which again was divided into four 270 m^2 plots. This gives a total of 96 large plots. From 2005 the four blocks per field will be divided into sets of two blocks leaving the possibility to investigate two crop rotations instead of one. One of the crop rotations will represent the situation close to the farm buildings (crop rotation near farm) and the other will represent the situation further away from the buildings (crop rotation distant to farm). The crop rotations are shown in the table below. Following a crop rotation conversion period in 2005 the experiment will be fully established with 1 to 4-year-old grass-clover leys in 2006, which provides a unique facility for investigating the issues of this proposal.

The dairy crop rotation at DIAS Foulum.

	1987-2004	From 2006	
		Distant to farm	Near farm
1	Barley/grass-clover	Barley/grass-clover	Barley/grass-clover
2	1st yr grass-clover	1st yr grass-clover	1st yr grass-clover
3	2nd yr grass-clover	2nd yr grass-clover	2nd yr grass-clover
4	Barley/catch crop	Barley/catch crop	3rd yr grass-clover
5	Oat/catch crop	Maize/catch crop	4th yr grass-clover
6	Maize/catch crop	Lupin/catch crop	Barley/catch crop

In each of the crop rotations is made five grassland grazing/manure treatments varying in nutrient load per unit area and grassland management.

Grassland grazing/manure treatments

Treatment no.	Grazing/manure
1	Grazing regime with manure application
2	Grazing regime without manure application
3	Cutting and grazing regime
4	Cutting regime with manure application
5	Cutting regime without manure application.

Each combination of crop rotation, crop and grazing/manure treatment is present in duplicate each year in 15x18 m plots for grazing and 15x9 m plots for cutting (a full plot divided into manured and unmanured halfs). The detailed quantitative design of treatments in WP1 awaits an initial prototyping exercise in WP6. From the expected random variability in measured parameters, the two replicates in the design, the three replicates of years where all ages of grass-clover fields are presented, and the factorial design of the grazing/manure treatments should provide the statistical power to detect significant differences.

The crop rotations and grazing/manure treatments can be combined into 35 different "farming systems"; 10 systems where the two parts of the crop rotation separately represent the crop rotation of a farm, plus 25 which are the combinations of the grazing/manure treatments in the two crop rotations and thus representing systems with divided rotations. Some of these "theoretical" farming systems are outside what can be found on private farms but are necessary for identifying biological and economical boundaries.

Adjacent to the crop rotations, permanent grassland established in 1993 will be used as a reference with the five grassland manure treatments established. Parts of the permanent grassland will be ploughed-out in spring 2008 similar to grass-clover leys in the two rotation sections.

Large heifers will be used for grazing throughout the experimental period 2006-2009. From an experimental point of view the advantages of heifers being feed only by grazing gives a better control of N deposition as milking cows excrete an unknown amount indoor during feeding and milking. Previous calculations showed approximately equally net depositions from heifers and milking cows (Askegaard, unpublished results).

The crop species will be selected according to defined criteria with main priority on disease resistance and weed competition properties. Weed control is based on preventive measures and weed harrowing and/or row and hand hoeing in the crops. All manure will be applied in imported dairy cattle slurry. No slurry will be applied to the spring barley following the grass-clover and the lupine, but both maize and spring barley with undersown grass-clover will receive manure. The grazing strategies and manure application will be decided in collaboration with WP4 and based on the prototyping in WP6. Catch crops will de used widely in the rotation to reduce the N-leaching. The grass-clover leys will consist of a mixture of perennial ryegrass and white clover. General status of other soil nutrients than N will be monitored through occasional soil sampling in the plough layer and analysis for P, K and Mg.

<u>Task 2: Crop productivity and residual effects</u>

Dry matter production and N content will be measured in all harvested grass-clover plots, and the botanical composition (grass and clover) will be determined. In the grazed plots the production will be measured in rest periods by fencing off an area in the same periods as cut 1 (spring growth) and cut 3 (regrowth 2) in the cutting plots. Before fencing off the area at regrowth 2 the plots will be topped, the sward height measured by a plate-raising meter, and the yield will be measured to the same height after the rest period.

The release of N from grass-clover residues means that N application to subsequent cereals can be reduced or even eliminated in the first succeeding crop (Watson et al. 2005). However, to reduce N fertiliser input to cereals following grass without losing yield, it is necessary to determine more precisely what factors in the grassland management that control the quantity of N released following ploughing-out. The treatments (grazing strategies and manure application) are carried out in the grass-clover leys only and other crops in the crop rotations will be used as indicators of residual effects. The residual effects of the broad spectre of grass-clover treatments will be measured in the un-manured green harvested spring barley with an Italian ryegrass catch crop undersown. It has been reported that this crop combination is very efficient in capturing nutrient release upon ploughing (Hansen et al., 2004). The green harvested spring barley will follow both the 2nd and the 4th year grass-clover leys. A similar determination of the residual effect of the five grass-clover treatments in the permanent ley will be carried out after ploughing-out in spring 2008. From these data it is possible to evaluate what controls the release of N following grassland cultivation.

The barley undersown with grass-clover and the lupine will be harvested at maturity. The barley straw will be removed and the lupine stalks will be left in the plots. The maize will be harvested as a whole crop. Dry matter production and N will de determined in all fractions.

Task 3: Nitrogen leaching

Leaching of nitrogen will be estimated after the commonly used method described in e.g. Eriksen et al. (2004) and Askegaard et al. (2005) where soil water are sampled by means of installed ceramic suction cups and the accumulated nitrate leaching is calculated after modelling the water balance. This method has been identified as the best practicable method for freely drained, structureless soils (Goulding 2000), which makes it suitable for this soil type. Three suctions cups were permanently installed in each of the 96 plots in 1993 at a depth of 1 m with a distance of 2 m between each cup, and additional new cups will be installed in the half plots with 'cut grass with manure'. A test of old and new ceramic cups showed that the nitrate uptake capacity is similar (Askegaard, unpublished results). Every one to four weeks, depending on precipitation, suction will be applied a few days prior to sampling. The samples will be bulked with equal sample volume from each of the three suction cups per plot before nitrate analysis and further estimates of nitrate leaching. Occasionally, soil water from individual cups will be analyzed to examine spatial variability.

Nitrate leaching will be determined in all plots in three experimental years (2006/7-2008/9). 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 the earthworm and macropore studies in WP5. The DON measurements will only be carried out in the treatments with old ceramic suction cups because new cups contrary to older cups appears to retain dilute organic matter (Guggenberger & Zech 1992).

Task 4: Synthesis and implementation

The total N balances and N-use efficiencies for the grassland, the succeeding crop and for the crop rotations as a whole are calculated for all combinations of crop rotation, grazing strategy and manure applications. N_2-fixation is calculated by the equations of Høgh-Jensen et al. (2004) from the clover N content in the grass-clover leys. Gaseous losses (ammonia and nitrous oxide) will be estimated from available literature. Nutrient balances for macronutrients P, K and S will be carried out in selected crops (including the green harvested barley) and treatments. Based on these calculations, and inputs from WP2-5, the many treatment combinations will be grouped according to the degree of productivity and environmental effects, and guidelines for improved grass crop productivity with regard to the whole crop rotation and the environment will be established.

Deliverables:

D1.1	Refereed scientific paper on grassland productivity as affected by crop rotation, grassland management and nutrient load
D1.2	Refereed scientific paper on nitrogen leaching as affected by crop rotation, grassland management and nutrient load
D1.3	Refereed scientific paper on residual effects as affected by crop rotation, grassland management and nutrient load
D1.4	Paper for farmer journals on the optimizing of mixed crop rotations on organic dairy farms
D1.5	Popular paper on nitrogen leaching losses from grassland systems
D1.6	Popular paper on crop productivity in mixed farming systems
D1.7	Data for system analysis and economic modelling (WP6)

Milestones:
M1.1 Crop rotation experiment fully established (4-2007)
M1.2 Productivity of grassland systems evaluated (6-2011)
M1.3 Environmental impact of grassland systems evaluated (12-2010)

WP No. 2: Grassland N management on coarse sandy soil

	Start date or starting event: 2-2007								
Partner id.	DIAS-AE								
Person-months per participant	12 VIP 1.8 TAP								
Total PM:	**13.8**								

Objectives:
To evaluate, on coarse sandy soil and under private farm conditions:

- the effect of different management of grazed grassland on grassland productivity and nitrate leaching
- the effect of fertilizer/catch crop strategies in maize grown after ploughing of the grassland on yield of maize and nitrate leaching

Description of work:
Although a major part of organic dairy farms in Denmark are located on coarse sandy soil only little experimental work has been carried out in relation to grassland N management on this soil type. Therefore, experimental work is needed on this soil type in addition to the studies carried out in WP1 on the loamy sand at Foulum. Results from projects within the DARCOF framework have indicated that nitrate leaching on coarse sandy soils may constitute a substantial problem in relation to the cultivation of grassland. However, one report has shown the extreme importance of catch crop strategy for reducing nitrate leaching in this situation (Hansen et al. 2004). It is our expectation, that this investigation will provide a better possibility for generalising results from sandy soils.

This WP will focus on grazed grassland of longer duration close to the farm before and after cultivation of the grassland. During the grassland phase the focus will be on the duration of cattle grazing because much of the nitrate leached from pastures during the winter originates from urine deposited, especially in the later part of the growing season (Cuttle & Bourne 1993). Following cultivation, focus will be on maize cropping. On these farms grassland cultivation is often followed by maize because of low weed pressure after grassland. However, as maize accumulates nitrogen for a relatively short period it is probably necessary to have an efficient catch crop strategy to retain nitrogen mineralised late in the season. The catch crop cannot be established until end of mechanical weed control in late June and there is a need to investigate how maize with catch crops may improve nitrogen utilization in grass intensive crop rotations.

Experimental: The experiment is carried out on a private farm on coarse sandy soil in 2006-2008 in the 4^{th} and 5^{th} year of grassland followed by maize. The farm is situated near St. Jyndevad experimental station and all experimental work will be carried out by experienced technicians, thus combining the advantages of controlled experimentation and the real-farm situation. The experiment is established in a split-plot design with grazing time in grass-clover as main plot factor (grazed grassland experiment) and fertilizer/catch crop strategy in maize as subplot factor (maize experiment). Grazing times are selected to represent current practises (treatment 1 and 2) and an option to reduce nitrate leaching through autumn grazing (treatment 3).

Treatments in the grassland phase of the experiment

Treatment no.	Grazing time in grass-clover
1	grazing only
2	spring cut and grazing
3	spring cut, grazing and autumn cut

Fertilizer/catch crop strategies in maize following grassland cultivation

Treatment no.	Fertilizer/catch crop strategy
1	unfertilized maize – no catch crop
2	unfertilized maize – ryegrass catch crop
3	fertilized maize – no catch crop
4	fertilized maize – ryegrass catch crop

Prior to ploughing of grasslands quantity and chemical composition of above- and below-ground plant material is determined by the methods described by Eriksen & Jensen (2001). As a control treatment is used unfertilized spring barley for green harvest and with an Italian ryegrass catch crop undersown. This has been recognized as being very efficient in capturing release of N following grassland cultivation (Hansen et al., 2004). The catch crop in maize is established after finishing mechanical weed control. All combinations of grazing time, fertilizer/catch crop strategy and the control are established in four replicates in plots each equipped with two suction cups in 80 cm depth. Throughout the experimental period nitrate concentrations are determined in soil water isolates and the accumulated nitrate leaching is calculated. Yield, botanical composition (grass and clover) and N-uptake is determined in all cut grassland plots and representative measures of grassland productivity are made in grazed grassland by the difference techniques and sward height measurements (see WP1). Similarly, yield and N-uptake is determined in maize and the residual effect of grasslands is determined from the uptake in unfertilized plots. As a control N-uptake is determined in four replicates of unfertilized spring barley for green harvest and with an Italian ryegrass catch crop undersown.

The nitrogen balances of the grassland and the following crop are calculated for all combinations of grazing time and strategies in maize. N_2-fixation is calculated by the equations of Høgh-Jensen et al. (2004) from the clover N content in grasslands. The results are put into a whole farm perspective by collecting available data for nutrient flows through crop and milk production on the farm. These data will also be used in WP6.

Deliverables:
D2.1 Refereed scientific paper on production and nitrate leaching in the grazed grassland experiment
D2.2 Popular paper on production and nitrate leaching in the grazed grassland experiment
D2.3 Refereed scientific paper on production and nitrate leaching in the maize experiment
D2.4 Popular paper on production and nitrate leaching in the maize experiment

Milestones:
M2.1 Establishment of the grazed grassland experiment (5-2007)
M2.2 Establishment of the maize experiment (5-2009)
M2.3 Evaluation of production and nitrate leaching in the grazed grassland experiment (9-2009)
M2.4 Evaluation of production and nitrate leaching in the maize experiment (9-2009)

WP No. 3: Multi species grass/clover with high persistence

	Start date or starting event: Feb 2007								
Partner id.	DIAS-AE	KVL-AS							
Person-months per participant	11 VIP 17.2 TAP	36 VIP							
Total PM:	**64.2**								

Objectives:

- To develop managements for grass-clover with high persistence and high herbage quality through species composition and management (grazing/cutting/slurry application)
- To develop multi-species grass-clover with different herbs
- To quantify the effects of multi-species grassland on productivity, fodder quality, and nutrient dynamics, including transfer and deposition

Description of work:

To study the possibilities to increase the persistence and the biodiversity in the grasslands a traditional seed mixture is compared with two other mixtures; one with species with different effect of growth or nutritional character and one with species of higher persistence. The interaction with the management is analysed in the dairy crop rotation experiment (WP1) and variations due to soil type and effect on biodiversity is analysed on organic farms.

The following seed mixtures will be used in the investigation:

1. Perennial ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*). Seed mixture no. 22, which is the most common used mixture for grazing in DK. The mixture will also function as a reference to earlier results in the crop rotation system, as it has been used since 1995.
2. Herb mixture: perennial ryegrass, white clover, chicory (*Cichorium intybus*), caraway (*Carum carvi*), birds-foot trefoil (*Lotus corniculatus*), great burnet (*Poterium Sanguisorba officialis*) and Lucerne (*Medicargo sativa*).
3. Mixtures with higher resistance: kura clover (Trifolium ambiguum) and festulolium (X festulolium) and white clover

The herbs chosen are all species, which can grow satisfactory under Danish conditions. The most well described species, chicory, has a high content of minerals and condensed tannins, which e.g. reduce bloat risk and improve N-utilization, but chicory can give a bitter taint in the milk with a high proportion in the feed (Barry 1998). Caraway may affect the milk quality, and birds-foot trefoil, great burnet and Lucerne are reported to have a high content of minerals and tannins.

<u>Task 1: Multi species grassland</u>

In the 'near farm' crop rotation system (cf. WP1) the three mixtures will be established in three fields:

2006	2007	2008	2009
Establising	Year 1	Year 2	Year 3
	Establishing	Year 1	Year 2
		Establishing	Year 1

The five treatments described in WP 1, concerning grazing, cutting and slurry application, will be applied for the three mixtures. One further management treatment "autumn cut" will be applied in the grazing plots. Thus, there will be 39 plots in 2007, 78 in 2008 and 117 in 2009.

Herbage production will be measured by a Haldrup plot harvester. In cut plots there will be four cuts during the growing season. In grazed plots the production will be measured in rest periods by fencing off an area in the same periods as cut 1 (spring growth) and cut 3 (regrowth 2) in the cutting plots. Before fencing off the area at regrowth 2 the plots will be topped, the sward height measured by a plate-raising meter, and the yield will be measured to the same height after the rest period.

The grazing pressure will be measured before the topping mentioned above by 30 measurements per plot with the plate-raising meter. The botanical composition will be measured in cut 1 and 3 by hand separation in all plots. The forage quality will be examined in the single species in the unfertilized cut plots at cut 1 and 3 and in the unfertilized grazed plots at the same time by hand sampling the herbage. In Year 1 the species will be analysed for IVOMD (in vitro organic matter digestibility by method of Tilley & Terry), N (Dumas) and NDF (neutral detergent fibre by method of van Soest) and the Year 2 and 3 only for N.

Task 2: Herbs in pastures on dairy farms

On five organic dairy farms (two on coarse sandy soil (JB 1) and three on clayey sand (JB 3-4)) one field, which is planned established for grazing with dairy cows in 2006, will be split in three and the three mixtures will be shown in 2006.

In 2007, 2008 and 2009 in June and August the mean botanical composition will be measured on dry matter basis on a bulked sample of six sub-samples (0,5 m^2 cut to 3 cm height). The biodiversity dynamic will be analysed with a modified Raunkjær analysis with four concentric circles. The sward structure will be analyzed by 100 sward height measurements per seed mixture.The forage quality of the species will be analyzed for N and NDF.

Task 3. Processes behind the use of multi-species mixtures in organic grassland (Ph.D. study)

To study the processes leading to an efficient use of multi-species mixtures, 3 activities will be conducted:

- Nutrient dynamics in multi-species mixtures. This approach includes individual dual plant labelling with isotopes of nitrogen (^{15}N) and carbon (^{14}C) to establish the (i) nitrogen transfer to associated species and the deposition of carbon and nitrogen in the soil. These two processes are expected to be highly influenced by soil type, soil clay content in particular, and to chance dynamically over time and soil depth. KVL has expertise in the use of dual labelling, i.e. combining ^{15}N and ^{14}C when leaf-labelling individual plants (Høgh-Jensen & Schjoerring 2000; 2001) and to follow the effects on the associated species, on the soil, and on the environments as leachates. Mezotrons will be inserted to a depth of 60 cm under field conditions after the establishment of the mixtures. A simplified version of mixture 2, described above, containing not more that four species will be used. The exact composition of the mixture could be chicory, perennial ryegrass, great burnet, and Lucerne but adjustments may take place as knowledge accumulates in the project.
- Nutrient uptake efficiency and competition for individual nutrients in multispecies mixtures and related to effects on herbage quality. The radio-tracer ^{32}P and the stable isotope ^{15}N will used under semi-field conditions, using an approach described by Hauggaard-Nielsen et al. (2001) placing pellets with these tracers at different soil depths. Through this approach, the different species utilization of mobile or non-mobile nutrients from different soil depths will be established and related to rooting pattern and uptake capability. This activity will only take place on one the coarse sand soil type.
- Temporal differences in the macro- and micromineral content of plant species as a consequence of differences in community composition. Data from a pilot study at KVL indicate that the apparent high differences in the content of several elements in chicory compared to other species may change over time. Therefore, a full element analysis (ICP-MS) will be conducted at samples from the selected longer-term field trials being established under task 1. Four species with distinct difference in rooting pattern and – depth will be followed over a period of three consecutive full production years.

Deliverables:	
D3.1	Refereed scientific paper on herbs in grasslands as affected by age and management
D3.2	Popular paper on herbs in grasslands as affected by age and management

D3.3	Refereed scientific paper on grassland persistence as affected by species and management
D3.4	Popular paper on grassland persistence as affected by species and management
D3.5	International publication on nitrogen transfer between multiple grassland species using tracer methodology
D3.6	Refereed scientific publication on rhizodeposition of carbon and nitrogen in multiple grassland mixtures including herbs
D3.7	Refereed scientific publication on competition, effective rooting depth and nutrient uptake efficiency of intercropped ryegrass, lucerne, chicory, and great burnet.
D3.8	Refereed scientific paper on herbage quality of intercropped ryegrass, Lucerne, chicory, and great burnet over three growth seasons.

Milestones:

M3.1	Contracts with organic farmers on establishing herbs and registrations in their pastures (12/2007)
M3.2	Discussions of results from farms with farmers and advisors (12/2008)
M3.3	PhD study initiated (2007/10)
M3.4	Mezotrons inserted in established field trials (WP3.3) with multiple grassland species at clayey loam and coarse sandy soils (2007/02)
M3.5	Description of transfer and nutrient dynamics in multiple grassland species (2008/10)
M3.6	Field trails established to investigate nutrient uptake efficiency in multiple species grassland mixtures and tracers positioned (2008/05)
M3.7	Description of nutrient uptake efficiency by intercropped multiple grassland species (2009/12)
M3.8	Analysis of samples from 3 growth seasons on-farm multiple grassland mixtures for macro- and microelement completed (2009/06)
M3.9	Finalisation of PhD study (2010/10)

WP No. 4: White clover soil fatigue – an establishment problem

	Start date or starting event: Feb 2007								
Partner id.	DIAS-AE	DIAS-IPM							
Person-months per participant	2.8 VIP 7 TAP	2.4 VIP 3 TAP							
Total PM:	**15.2**								

Objectives:

- To describe grassland systems without risks for clover fatigue and find methods to overcome existing fatigue
- Find alternative grassland species, which can produce satisfactory on fatigue soil without being a disease carrier and determine the necessary clover-free periods

Description of work:

To find methods to avoid the increasing establishing problems of white clover on near-farm clover rich areas, the growth and the disease carrying by other crops, including legumes, will be investigated on clover fatigue soil.

In 2004 clover fatigue was examined in a pot experiment (31 l containers) in a semifield equipment. The aim was to compare soils under comparable conditions (Søegaard et al. 2004b). This method proved useful and will therefore be used for this experiment also.

Five clover fatigue soils from organic dairy farms and one healthy reference soil from a research station will be collected in spring 2006. Five different grassland species will be grown in the soils, with six pots per species; 180 pots in total. The species are expected to be: white clover, red clover, Lucerne, Italian ryegrass and maize. The exact species will be pointed out after a screening experiment in 2005 (paid by 'Fonden for Økologisk Landbrug').

In 2007 white clover will be grown in half of the pots to examine the level of fatigue, and in the other half the same species will be grown as in 2006. In 2008 white clover will be grown in all pots. The plant growth will be followed; the appearance, top-root growth of the seedlings and the annual yield. The number of nematodes and their stage of development will be determined 4-5 weeks and 10-11 weeks after germination. Soil samples are processed by flotation and the plant samples are stained in preparation for finding nematodes in roots and stems. Cyst nematodes (Heterodera trifolii), stem nematodes (Ditylenchus dipsaci), root-lesion nematodes (Pratylenchus penetrans) are identified and counted. Some important fungi are identified.

On basis of the obtained results suggestions to viable clover rich near-farm crop rotations will be given with the aims to avoid clover fatigue and to overcome existing fatigue.

Deliverables:
D4.1 Refereed scientific paper on white clover soil fatigue
D4.2 Popular paper and information on Internet concerning clover soil fatigue
D4.3 Popular paper on optimizing crop rotation

Milestones:
M4.1 Select the plant species used in the experiment, and point out soils on organic dairy farms for the experiment (3/2007)
M4.2 Evaluate necessity of changes in methods after the first experimental year (1/2008)

WP No. 5: Earthworms, macropores and N leaching

	Start date or starting event: Jul 2007								
Partner id.	NERI	DIAS-AE							
Person-months per participant	8 VIP 5.5 TAP	5.5 VIP 5.8 TAP							
Total PM:	**24.8**								

Objectives:
The overall objective is to study how relevant management practises and duration of grass-clover fields influence the leaching losses of N in the autumn as influenced by earthworms and macropores.

To meet with the overall objective, the following sub-objectives are defined:

- To quantify the infiltration of potassium bromide via preferential flow in macropores as a simulation of NO_3-N leaching and loss.
- To characterise and quantify the number, size and depth of macropores (primarily earthworm burrows) in the soil profile in grass-clover fields with and without grazing cattle.
- To estimate earthworm populations (number, species composition and biomass) in the soil profile in grass-clover fields with and without grazing cattle.
- To reveal the influence of earthworm burrows on nitrate-N loss via macropore flow.
- To investigate the direct and indirect influence of earthworms on nitrate-N via leaching.
- To reveal the influence of cattle trampling on macropore quality and distribution in the soil profile

Description of work:

Overall rationale

The experimental work will be carried out in the organic dairy crop rotation experiment at Foulum (WP1). In each treatment of concern we will apply potassium bromide in aqueous solution evenly to a 2-m^2 area to model nitrate originating from urine deposited during autumn grazing. This is followed by irrigation to simulate potential nitrate leaching during natural rainfall. A 1-m^2 plot will be excavated in successive layers to (1) determine the presence of earthworms (identified to species and individually weighed), (2) quantify the size and distribution of macropores (primarily earthworm burrows), and (3) determine the movement of bromide in the soil profile. These excavations will include the plowing layer, the plow pan and deeper soil layers down to a depth of 1.5 m. As a result of these investigations we will be able to quantify the potential leaching of nitrate-N under various grassland management strategies. It can then be determined if this is correlated with the density of earthworms and earthworm burrows. Furthermore, we will use suction cups in the same plots to quantify N-leaching (nitrate and organic N compounds) during a 2-month period prior to the excavation. This will enable us to reveal the influence of earthworm density and biomass on N-mineralisation and leaching. All in all this work package will give us a unique opportunity to investigate, in the same field experiment, the links between earthworms, macropores and leaching of N both by preferential flow and by percolation in a number of relevant clover/grass management practises.

Our primary investigations will be carried out in systems grazed by cattle because the highest potential of N-losses (via urine) is found here. However, we will include grass-clover without grazing for comparison in order to assess the effects of cattle trampling on earthworms and macropore flow. Our main hypothesis is that preferential flow through macropores can decrease the N-losses by leaching because less water will percolate through bulk soil. Cattle trampling may even decrease N-leaching because a lower hydraulic conductivity in the bulk soil will force even more of the rainwater to macropores and bypass the bulk soil.

Test design

With the factorial field design in the present research proposal we will be able to compare age of grass-clover field, grazing effects etc. by carrying out all assessments within a limited time period. Thus avoiding year-to-year variation in climatic conditions, sward productivity and so forth. Assessments will be made in autumn when soils are saturated and leaching potential is at its highest. Within the treatments to be investigated in this WP we will apply two sub-samples from each of the replicates. Our own previous studies have shown that this will give a sufficient statistical power to demonstrate differences of 20% with statistical significance (Holmstrup 2000).

Potassium bromide measurements

A concentrated solution of potassium bromide is applied to two 2-m^2 areas in each investigation plot to model urine patches. Two rain intensities (8 mm/hour and 20 mm/hour) will applied by a rain-simulator in a total of 20 mm. After 1 day a 1-m^2 area is excavated. Samples are taken in 0-10, 12-22, 25-35, 50-60, 70-80, 90-100 and 110-120 cm. By a cubic shovel we take 7 samples in a line in horizontal direction. Bromide is extracted in a bucket by pyrophosphate solution as described by Jacobsen & Iversen (2004). This is replicated three times in each depth. Bromide concentration is determined and mass balances for the bromide in the soil profile calculated. These bromide profiles can be used to see how the age of the pasture and how grazing versus cutting affects the degree of macropore flow quantitatively

Earthworms and macropores

Earthworm numbers, species and biomass will be determined by hand sorting of the excavated soil. By use of this technique more than 95% of earthworms and earthworm biomass is recovered (Holmstrup 2000). Earthworms will be identified to the species level in order to reveal the number and size of earthworms primarily contributing with horizontal burrow systems, and those building persistent vertical burrows to deep soil layers (*Lumbricus terrestris* and *Aporrectodea longa*).

A 1-m^2 plot will be excavated in successive layers followed by vacuuming. The surface is photographed and the number of cylindrical pores > 1 mm are recorded. Digital image analysis will be used to estimate diameter of each pore. Excavation will continue to depths where no more macropores can be found and no more potassium bromide can be traced.

Earthworm contribution to mineralisation and leaching of N

The direct excretion of N (primarily ammonium) by earthworms and turnover of earthworm biomass will be estimated from population density and known excretion rates (Curry et al. 1995, Whalen & Parmerlee 1999). We will compare these estimates with the concentrations of N in leachate collected by suction cups directly beneath the soil volume for which we quantify the earthworm population.

Deliverables:
D5.1 Refereed scientific paper on potential nitrate loss via preferential flow through macropores
D5.2 Refereed scientific paper on the influence of earthworms on leaching of N
D5.3 Refereed scientific paper on the influence of cattle trampling on macropores and leaching of N

Milestones:
M5.1 First assessment of leaching through macropores in the field (11-2008)
M5.2 Assessment of earthworm density and biomass in field experiment (6-2009)

WP No. 6: System analysis and economics

	Start date or starting event: Oct. 2007								
Partner id.	DIAS-AE	KVL-FRE							
Person-months per participant	7 VIP 1.1 TAP	9 VIP							
Total PM:	**17.1**								

Objectives:
- The objective is to evaluate the consequences in a whole farm perspective of the management strategies investigated in WP1-3. A specific task is to verify, by prototyping, the outcome of different management strategies in relation to grassland production in order to establish the best possible design of treatments in WP1
- To extent an existing model – Ø-PLAN Dairy – to work with several crop rotations within a farm and differentiation of the grassland management
- To analyse nutrient efficiency, productivity and economic results at farm level of different crop rotations and grassland strategies

Description of work:

Quantity knowledge about specific management strategies need to be evaluated in a farm perspective in order to evaluate the generality of the results and to insure an optimal introduction into commercial organic milk production. At organic dairy farms, aiming after a high integrity, there is a very complex interaction between crop production, nutrient management and productivity in the herd, which makes it difficult to estimate the results of a change made in part of the farming system. By modelling it is possible to set up several farming systems and calculate the effect on a specific farm of changes in the management strategies. Therefore modelling is used to generalize in a farm perspective the results obtained in relation to grassland management and crop rotation.

Task 1. Prototyping

The expected outcome at farm level in terms of production and nutrient efficiency of different crop rotations and grassland management strategies will be evaluated, based on existing knowledge and data from organic pilot farms[1)]. The farm data will be analysis to give realistic productions levels and managements decisions related to stocking rate and soil type, with focus on the internal relation between herd demand, crop productivity and manure allocation as first part of the prototyping. This is followed by analyses of the possibilities and obstacles for introduction of new ways of farming, with focus on the effect of proportion of grassland in the rotation and the proportion of the grassland utilized by grazing, as these elements are critical factors in the set up of the activities in WP1. Theoretical farming systems will be designed by linking farming data and expected effects of changes made in separate parts of the system. These theoretical systems will be important input to laying of the experimental work in WP1.

1) Data are available from the project "Udvikling af nye økologiske jorbrugssystemer 2000-2004" project leader TKR .

Task 2. Model extension

Ø-PLAN Dairy (Tvedegaard 2002) is a spreadsheet program that carry out the economic calculations for a six years planning period. The Ø-plan toolbox is constructed as deterministic simulation models that can simulate the expected annual economic consequences at farm level of alternative strategies with respect to e.g. investment plans, organic production rules, subsidy regimes and product and input price developments. The model framework includes sub-optimation routines in order to determine e.g. the economic best utilization of the produced manure and to maximize the economic return in plant production.

The model need to by extended in order to handle the crop rotations within a farm taken into consideration the distance between the field and the farm buildings (barn, storage of feed and slurry). This is done be adding a cost function to the model that calculates the cost (time and machinery), based on information about the distance between field and barn. Also the model need to be extended to estimate the nutrient balances and efficiency for N, P and K on herd, field and farm level according to the principles described by Sveinsson et al. (1998). The number of crops at choice including specification of productivity, quality and yield response for nutrient supply will be extended in agreement with the elements investigated in WP1-3. The model will by tested by an expert panel with four researcher (to be selected from other projects within this programme) and two organic advisors, with focus on nutrient efficiency and grassland productivity.

Task 3. Economic scenarios for organic dairy farms

The extended Ø-PLAN Dairy will be used to calculate the effect of different farming systems defined by

1) Size of the herd (60, 120 and 240 cows)
2) Stocking rate (0.8, 1.2 and 1.8 livestock unit per ha)
3) Proportion of land close to the barn (40, 80 and 100)
4) Proportion of land with grass (33, 50 and 100)
5) Proportion of grassland used for grazing (10, 40 and 60)

Results from WP1-3 will be used to specify the relation in the model and information from the national economic statistics will be used to set the relevant levels for the economic turnover. Sensitivity analyses will be made on critical technical relations and the economic figures. Output from the model will be:

1) Milk and meat production
2) Export and import of feed and crops
3) N, P and K herd, field and farm balance and efficiency.
4) Workload
5) Economic return

These results will be discussed in relation to impact in more broad terms on the environment related to the different farming system.

Deliverables:
D6.1 Prototyping of different strategies in a farm perspective
D6.2 Ø-PLAN Dairy. A whole farm model
D6.3 Refereed scientific paper on farm productivity and economic return in relation to grassland management and crop rotation on organic dairy farms

Milestones:
M6.1 Ø-PLAN extended and tested by expert panel (4-2010)
M6.2 Scenarios for modelling defined (5-2011)

WP No. 7: Project management

	Start date or starting event: Jan 2007								
Partner id.	DIAS-AE								
Person-months per participant	5 VIP 0.5 TAP								
Total PM:	**5.5**								

Objectives:
- Securing project progress through coordination of activities
- Securing communication of results
- Planning an international workshop

Description of work:
Task 1. Coordination
To coordinate research activities, two annual meetings are held with all project partners, in Feb-Mar prior to the start of fieldwork and in Aug-Sep prior to finalizing the annual report.

Task 2. Communication
An Internet web site is established and continuously updated (accessible via the DARCOF web site) for internal communication in the project and as a more popular window for others (pictures, video-clips etc.) to draw attention. Links will be made to the scientific publications available over time.

The field experiment in WP1 will be presented at annual field days for farmers, advisors and the public. This field experiment has traditionally had many visitors, both national and international.

In 2008 the project will host a meeting for national advisors and farmers, who are directly involved in the project through on-farm experiments or have a special interest in the investigated issues. The purpose is to get feedback on initiated research still having the opportunity to adjust plans.

In 2009 the project will host an international workshop possible in collaboration with the 'European Grassland Federation' working group on 'Grassland resowing and grass-arable crop rotation' including University of Kiel (Germany), Institut National de la Recherche Agronomique (France), Institute of Grassland and Environmental Science, Scottish Agricultural College, IACR-Rothamsted, ADAS (all UK), Teagasc (Ireland), Ghent University (Belgium), Research Institute for Animal Husbandry, Plant Research International, Alterra Green World Research, Applied Plant Research and Nutrient Management Institute (all The Netherlands). The results from this project will be presented and discussed at this workshop. The following scientists have agreed to act as invited speakers at the conference if this application is successful:

Prof. Dr. Michael Wachendorf, Dept. of Grassland Ecology and Forage Production, Witzenhausen (email: mwach@mail.wiz.uni-kassel.de)
Prof. Dr. Friehelm Taube, Agricultural Faculty, University of Kiel (email: ftaube@email.uni-kiel.de)
Dr. Frans Aarts Plant Research International, Wageningen (email: frans.aarts@wur.nl)
More relevant speakers will be invited in relation to the topics of multispecies mixtures and clover soil fatigue. The written outcome of the workshop is a joint publication.

Deliverables:
D7.1-7.4 Annual reports
D7.5 Project web site
D7.6 Workshop publication
D7.7 Final report

Milestones:
M7.1 Fulfilment of overall project objectives (12-2011)

A.3 Project resources and budget overview

Partners

The Danish Institute of Agricultural Sciences (DIAS) is a research institute under the Ministry of Food, Agriculture and Fisheries. It has approximately 1,100 employees of which 750 are research personnel. Department of Agroecology has since 1987 managed the organic dairy crop rotation, that is the main experimental facility of this project and the experiment will be maintained in 2005 by core-funding from DIAS. Department of Agroecology focuses its research on interactions between soil, crop production and environment, and has state-of-the-art laboratories and considerable experience in field measurements of N flows including N_2-fixation, nitrate and dissolved organic nitrogen leaching and determination of grass performance and crop production. Also the department has a strong tradition for whole farm studies and systems analysis. The department provides policy support to the Danish government concerning agriculture including evaluation of the Danish Aquatic Plans.

The National Environmental Research Institute, Department of Terrestrial Ecology (NERI) has long practical experience within soil ecotoxicology and ecology. NERI do basic, applied and commercial contract research on soil fauna ecology, ecophysiology and ecotoxicology. NERI provides an advisory role for national and international authorities within our areas of expertise. The main aim of the research activities is to describe and understand how different kinds of pollutants, climatic conditions and various methods of farming affect soil living animals and the ecosystems, which they are a part of. The department has a permanent staff of 20 scientists and 20 technicians and administrative personnel.

The Food and Resource Economics Institute carry out basic research and education in economics at The Royal Veterinary and Agricultural University. The Institute has approximately 120 employees. The Institute does applied research in cooperation with other research institutions, Danish authorities and International organisations such as EU, WTO and the World Bank. The topics span widely - from EU Policies, International policy and trade, WTO trade negotiations and growth and economic development in developing countries to production and distribution in agriculture, the economics of the food chain and fishery economics and management. Environmental issues and natural resources, as well as citizens' and consumers' response to and demand for foodstuffs are also among the research priorities. Quantitative economic models, statistical methodology and economic theory are furthermore important areas of research. The Production and Technology Division, involved in this project, is primarily concerned with research related to farm management, food chain management, technology assessment and production economics.

The Royal Veterinary and Agricultural University, Department of Agricultural Sciences, has as a major aim of contributing to the development of sustainable production systems. As part of this work, organic grassland has been a research focus the last 15 years starting with quantifying the biological nitrogen fixation in grass-clover leys to understanding the underlying mechanisms for co-existence and competition in multispecies grassland pastures. The Department has high quality labs equipped for tracer studies and element analysis and possesses working experience with the proposed methods and the technologies for the sample analysis. The work on multispecies grassland nutrient dynamics is related to the ongoing project "NitGrass" which is co-financing a Ph.D. about below ground C- and N dynamics in grass-clover mixtures.

Key competences and management of the project

The multidisciplinary project group consists of well qualified, and in most areas international class scientists within the specific disciplines necessary to lift the tasks of this project and many years of experience in organic farming research are present (see A8). Within the group strong expertise is present on: Nutrient cycling and nitrate leaching, forage crop productivity and quality, legume intercropping and species mixtures, ecology of soil invertebrates and nematodes, soil macropore transport, feed supply and pasture management in dairy farming, farming systems research and economic modelling. The project manager has lead several projects on aspects of nutrient utilization and grasslands within the DARCOF programs and is experienced in managing large field experiments and on-farm research, and also an experienced communicator as evidenced by numerous scientific and popular papers and national and international presentations.

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

Partner / WP	DIAS-AE	DIAS-IPM	KVL-AS	KVL-FRE	NERI	Total
WP1	40					40
WP2	12					12
WP3	11		36			47
WP4	2.8	2.4				5.2
WP5	5.5				8	13.5
WP6	7			9		16
WP7	5					5
Total	83.3	2.4	36	9	8	138.7

Table for breakdown of total budget on partners and different cost categories (1000 DKK)

Participating institution	Responsible scientist	Salaries		Equip-ment	Operational expenses	Total budget DKK
		Acade-mic	Techn. adm.			
DIAS-AE	JE	4,449	1,593	5	1,168	10,909
DIAS-IPM	LMH	104	77		62	340
KVL-AS	HHJ	984			215	1,500
KVL-FRE	NT	392			25	500
NERI	MH	397	169		59	750

A.4. Dissemination of scientific results

- **Planned education of scientists including Ph.D. and post-docs**
  - One Ph.D. student in WP3 to be enrolled in the Research School for Organic Agriculture and Food systems (SOAR).
  - Master students will be actively encouraged to associate the project. Contact will be made to universities.

- **Stays abroad, guest researchers etc**.

- **Communication of results. Publication strategy, contributions to national or international workshops etc.**
  - Dissemination of results to farmers and the advisory service will occur via direct contact to the Danish Agricultural Advisory Service, via printed media (e.g. Økologisk Jordbrug and Landbrugsavisen) and via the DARCOF electronic newsletters. Results will also be presented at special courses for advisors and authorities.
  - High priority is given to dissemination of results to the scientific community via international refereed journals and conferences. Furthermore, a workshop is planned in 2008 with a restricted number of invited participants including international experts (see WP7) to inform about research activities and receive critical feedback.
  - Finally, results will be communicated via the project web site, field days and via contact to visitors (see WP7). It must be emphasized that all project participants have a long record of communication to the scientific community, farmers and the public.

A.5. Scientific collaborations

- **Collaboration with other research institutes (national and international collaborative partners etc. please include a brief description of the collaborative scheme)**
  The project group participates in international working groups of huge relevance for this proposal:
  - European Grassland Federation (EGF) working group ”Grassland resowing and grass-arable rotations”
  - EU-COST-action 627 “Carbon Storage in European Grasslands”
  - EU-COST-action 852 “Quality Legume-Based Forage Systems for Contrasting Environments of Europe”.

- **Co-ordination with other projects (relations with other projects within the same field, which have been granted public funding)**
  Within this research programme:
  - Another DARCOF application "The effect of cropping systems on production and the environment" (CROPSYS) addresses to some extent similar aspects of organic crop production but in arable systems without grazing animals. The research is coordinated through overlap in project staff (M. Askegaard).
  - Another DARCOF application ‘Integrated supply of vitamins and minerals and non-antibitic health control in organic dairy herds (ECOVIT)’ has on pastures on dairy farms included measurements of mineral content in the plant species and selection by the dairy cows. In present application the botanical composition and the biodiversity dynamic will be measured in the same pastures (WP3 task 2 seed mixture 2). There is no financial overlap. The research is coordinated through overlap in project staff (K. Søegaard).

  Already funded:
  - The DARCOF II project I.15 NIT_GRASS (responsible J. Eriksen) deals with aspects of nitrogen dynamics in grasslands and the research is co-ordinated.

- **Collaboration with private business partners or networks (names, titles)**

Concerning white clover soil fatigue there is collaboration with Vibeke Meyer, Dansk Planteforædling (breeding company), DLF Trifolium about knowledge, fatigue soil and plant exchange.

A.6 Other issues

(E.g. special considerations concerning conducting of experiments in relation to principles of organic food and farming).

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A.8 Curriculum vitae

Curriculum Vitae
Project manager, responsible for WP1 and WP7

Name: Jørgen Eriksen

Born: 2 February 1967

Education: 1991 M.Sc. (Agric) from The Royal Vet. and Agricultural University.
1994 Ph.D. in Plant Nutrition from The Royal Vet. and Agricultural University.

Employment: 1994-96 Scientist at Dept. of Soil Science, Danish Inst. of Plant and Soil Science.
1997- Senior Scientist at Dept. of Crop Physiology and Soil Science (now Dept. of Agroecology), Danish Institute of Agricultural Sciences.

Other activities External examiner at The Royal Vet. and Agricultural University, Inst. of Agricultural Science.
Co-supervisor for students at The Royal Vet. and Agricultural University (3 M.Sc., 2 Ph.D.) and the Swedish Agricultural University (1 Ph.D.).

Main research projects:
1991-1994 Soil sulphur dynamics in relation to soil fertility (Ph.D.-project).
1995-1996 Nutrient management in organic dairy rotations.
1997-1999 Precrop effects and leaching following grass-clover. (Project leader).
1997-2000 Nutrient balances in organic pig production. (Project leader).
1998-2000 Availability and utilization of sulphur in organic farming.
1998-2000 Sulfonates in terrestrial environments (ENV4-CT-0723). (Project leader).
2000-2004 Nitrogen management for enhanced bread wheat production.
2000-2004 Use of catch crops in organic vegetable production.
2001-2004 Environmental impact of pig production systems.
2002-2006 Nitrate leaching from grasslands in dairy farming systems. (Project leader).
2005 Sulphur availability of acidified slurry.

Research interests: Research has focussed on nutrient dynamics in relation to soil fertility and environmental impact of different farming systems. The research has resulted in 130 publications (author, senior-author and co-author) of which 41 are in international, refereed scientific journals and 39 are conference proceedings.

Some recent publications

Eriksen J., Askegaard M. & Kristensen K. (2004) Nitrate leaching from an organic dairy crop rotation; the effect of manure type, N-input and improved crop rotation. Soil Use Manage. 20: 48-54.

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Berntsen J., Petersen B.M., Olesen J.E., Eriksen J. & Søegaard K. (2005) Simulation of residual effects and nitrate leaching after incorporation of different ley types. Eur. J. Agron. In press.

Hansen J.P., Eriksen J. & Jensen L.S. (2005) Residual nitrogen effect of a dairy crop rotation as influenced by grass ley management, manure type and age. Soil Use Manage. In press.

Curriculum Vitae
Responsible for WP2

Name: Elly Møller Hansen

Born: 13 August 1957

Education: 1985 Cand. Agro (M.Sc. Agricultural Sciences), The Royal Vet. and Agricultural University, Copenhagen.

Employment:
1985-87 Agricultural teacher, Riber Kjærgård Landbrugsskole, Bramming.
1987-92 Scientist, Dept. of Soil Tillage, Soil Physics and Irrigation, Jyndevad Experimental Station, Danish Institute of Agricultural Sciences (DIAS).
1992-99 Scientist, Dept. of Soil Science, Research Centre Foulum, DIAS.
1999- Senior Scientist, Dept. of Soil Science/Dept. of Agroecology, DIAS.

Other activities:
External examiner at the Swedish Agricultural University (1 Ph.D.).
Member of the task group 'Soil Tillage' under Scandinavian Association of Agricultural Scientists (NJF), 1993-1999.

Main research projects:
1987-91 Soil tillage and catch crop use in relation to nitrogen turnover and nitrogen losses.*)
1988-92 Nitrogen uptake and nitrate leaching in crop rotations with winter green fields.*)
1993-97 Models intended to evaluate crop rotations in plant production systems.*)
1994-96 The influence of low input farming on nitrate leaching.
1998-02 Increased N use efficiency of litter-rich cattle and poultry manure by adjusting the application strategy.
1999-01 Biomass for energy: Effects on the soil carbon balance in agriculture and forestry.
2002-06 Nitrate leaching from grasslands in dairy farming systems.
2002-06 Crop management and economics of non-inversion tillage systems.
*) Translated from Danish.

Research interests: Nitrate leaching measured in field experiments, including the effect of catch crops, soil tillage methods and organic amendments. Nitrogen fixation measured with the ^{15}N natural abundance technique in grazed organic grass-clover. Soil organic matter decomposition including determination of changes in the natural abundance of ^{13}C in *Miscanthus* and maize.

Relevant publications:

Hansen, E.M. & Djurhuus, J. (1996). Nitrate leaching as affected by long-term N fertilization on a coarse sand. Soil Use and Management 12, 199-204.

Hansen, E.M. & Djurhuus, J. (1997). Nitrate leaching as influenced by soil tillage and catch crop. Soil & Tillage Research 41, 203-219.

Hansen, E.M. & Djurhuus, J. (1997). Yield and N uptake as affected by soil tillage and catch crop. Soil & Tillage Research 42, 241-252.

Hansen, E.M., Djurhuus, J. & Kristensen, K. (2000). Nitrate leaching as affected by introduction or discontinuation of cover crop use. Journal of Environmental Quality 29, 1110-1116.

Hansen, E.M., Djurhuus, J. & Kristensen, K. (2000). Langvarig eller kortvarig dyrkning af rajgræs som efterafgrøde på sandjord – Udbytte og N-udvaskning. Grøn Viden, Markbrug no 221.

Hansen, E.M., Eriksen, J. & Vinther, F.P. (2004). Øget udnyttelse af kvælstof efter ompløjning af afgræsset kløvergræs. Grøn Viden, Markbrug no 300.

Hansen, E.M., Kristensen, K. & Djurhuus, J. (2000). Yield parameters as affected by introduction or discontinuation of catch crop use. Agronomy Journal 92, 909-914.

Hansen, E.M., Kyllingsbæk, A., Thomsen, I.K., Djurhuus, J., Thorup-Kristensen, K. & Jørgensen, V. (2000). Efterafgrøder. Dyrkning, kvælstofoptagelse, kvælstofudvaskning og eftervirkning. DJF rapport, Markbrug 37. 50 pp.

Hansen, E.M., Thomsen, I.K. & Hansen, M.N. (2004). Optimizing farmyard manure utilization by varying the application time and tillage strategy. Soil Use and Management 20, 173-177.

Curriculum Vitae
Responsible for WP3 and 4

Name: Karen Søegaard

Born: 15 October 1953

Education: 1980 M.Sc. (Biology) from Århus University.

Employment: 1980-87 Scientist at Dept. of Irrigation and Soil Physics.
1987-94 Scientist at Dept. of Soil Science, Danish Inst. of Plant and Soil Science.
1994- Senior Scientist at Dept. of Plant Physiology and Soil Science (now Agroecology), Danish Institute of Agricultural Sciences.

Other activities: Member of executive committee of European Grassland Federation.
Member of board of Danish research Centre for Organic Farming.
Member of national groups concerning feed quality valuation and grassland seed mixtures respectively.

Main research projects: 2000-2005 Organic dairy production systems, DARCOF II.
2000-2005 Organic production of steers and use of bioactive forages in livestock, DARCOF II.
2000-2003 Nitrogen fertilization of grass/clover at different managements.
2001-200x Prognosis for herbage growth and quality in pastures (project leader).
2004-2005 White clover soil fatigue – what is it ?
2003-2006 Irrigation in a holistic resource perspective.
2003-2007 Development of $EFOS_{kvæg}$ method for determination of digestibility of forage crops.
2003-2006 Lower N-surplus at grazing with dairy cows (project leader).

Research interests: Main working area is forage crops, production and quality. Mostly grassland both for cutting and grazing. Management of herbage quality, quality in relation to the demand of the dairy cow and analysing methods. Environmental problems as N-losses and improved N-utilization in grasslands.

Relevant publications:

Nielsen, A.L. & Søegaard, K. (2000) Forage quality of cultivated and natural species in semi-natural grassland. Grassland Science in Europe 5, 213-215.

Sehested, J., Søegaard, K., Danielsen, V., Roepstoff, A. & Monrad, J. (2004) Grazing with heifers and sows alone or mixed: herbage quality, sward structure and animal weight gain. Livestock Production Science 88, 223-238.

Søegaard, K. (2004) Kvægbrugssædskifter. I : Muligheder for forbedret kvælstofudnyttelse i marken og for reduktion af kvælstoftab, (Ed.: U. Jørgensen), DJF-rapport Markbrug no 103, 114-127.

Søegaard, K., Hopkins, A., Bommelé, L. and Gierus, M. (2004) Effects of grassland renovation on crop and animal performance. Grassland Science in Europe 9, 523-525.

Søegaard, K, Berntsen, J., Nielsen, K.A. & Thygesen, I. (2005) Prognosis for herbage production under continuous grazing. Grassland Congress Ireland. Accepted for publication.

Søegaard, K. & Møller, K. (2005) White clover soil fatigue – an establishment problem on large and intensive dairy farms. Grassland Congress Ireland. Accepted for publication.

Curriculum Vitae
Responsible for WP5

Name:	Martin Holmstrup
Born:	14 May, 1961
Education:	1989 M.Sc. in Biology (University of Aarhus, Earthworm ecology). 1995 Ph.D. in Biology (University of Aarhus, earthworm ecophysiology). 2003 D.Sc. in Biology (University of Aarhus, soil invertebrate ecophysiology).
Employment:	1993-1996 Scientist, National Environmental Research Institute (NERI), Dept of Terrestrial Ecology. 1996-2003 Senior Scientist, NERI, Dept. of Terrestrial Ecology. 2000 External lecturer, Dept. of Zoology, University of Aarhus (Ecotoxicology). 2003- Professor, NERI, Dept. of Terrestrial Ecology and Aarhus University.
Other activities:	Reviewer of more than 100 scientific manuscripts and grant proposals. 2000-2001 Organiser of The Third International Workshop on Earthworm Ecotoxicology, University of Aarhus, 26-29 August 2001. Supervisor of 5 Ph.D. students and more than 20 M.Sc. students. External examiner at 2 Ph.D. dissertations and more than 10 M.Sc. dissertations.
Relevant research projects:	1996-1998 Effects of pesticides on earthworm reproduction in the field. 1997-2000 The role of soil invertebrates in organic farming. 2002-2004 Freeze tolerance in earthworms. 2002-2005 Evolution of stress response and stress resistance (Functional Genomics). 2004-2006 Influence of mechanic weed control on earthworms in agricultural soils. 2004-2008 Novel methods for integrated risk assessment of cumulative stressors. 2004-2008 Climate change effects on biological processes in terrestrial ecosystems.
Research interests:	My research interests include ecology, ecophysiology and ecotoxicology of soil invertebrates, especially earthworms. The work ranges from laboratory studies to field manipulation experiments assessing effects of climate change, agricultural management and pollution on soil organisms.
Recent relevant publications:	Has published more than 50 papers in peer reviewed international scientific journals with more than 5 papers per year from 1999-2004 (see full publication list at www.sofar.dk).

Holmstrup, M. (1999) Cocoon production of *Aporrectodea longa* Ude and *Aporrectodea rosea* Savigny (Oligochaeta; Lumbricidae) in a Danish grass field. Soil Biology and Biochemistry 31:957-964.

Bayley, M. and Holmstrup, M. (1999) Water vapor absorption in arthropods by accumulation of myoinositol and glucose. Science 285:1909-1911.

Holmstrup, M. (2000) Field assessment of toxic effects on reproduction in the earthworms *Aporrectodea longa* and *A. rosea*. Environmental Toxicology and Chemistry 19:1781-1787.

Holmstrup, M. (2001) Sensitivity of life history parameters in the earthworm *Aporrectodea caliginosa* to small changes in soil water potential. Soil Biology and Biochemistry 33:1217-1223.

Holmstrup, M., Bayley, M. and Ramløv, H. (2002) Supercool or dehydrate? An experimental analysis of overwintering strategies in small permeable arctic invertebrates. Proc. Natl. Acad. Sci. USA 99:5716-5720.

Holmstrup, M. (2003) Overwintering adaptations in earthworms. Pedobiologia 47:504-510.

Friis, K., Damgaard, C. and Holmstrup, M. (2004) Sublethal soil copper concentrations increase mortality during drought in the earthworm *Aporrectodea caliginosa*. Ecotoxicology and Environmental Safety 57:65-73.

Curriculum Vitae
Responsible for WP6

Name: Troels Kristensen

Born: 27. marts 1956

Education:
1983 M.Sc. Agric. The Royal Veterinary and Agricultural University of Copenhagen.
1996 Projektlederkursus I og II, forskningssekretariatet.
1998 Ph.D. The Royal Veterinary and Agricultural University of Copenhagen.

Employment:
1983 Scientist, Dep. of Research in Cattle and Sheep, Danish Institute of Animal Science.
1987 Advisor Cattle Production, Farmers Organization, Randers.
1988 Scientist, Dep. of Research in Cattle and Sheep, DIAS.
1999 Senior Scientist, Dep. of Agricultural Systems (now Dep. of Agroecology) DIAS.

Other activities
Co-supervisor for Ph.D. and Master students and ad hoc reviewer for scientific journals.
Member of the cattle network and coordination group within cattle research at DIAS.

Main research projects:
2000-2005 Organic dairy production systems, DARCOF II - project leader.
2000-2005 Organic production of steers and use of bioactive forages in livestock, DARCOF II.
2000-2004 Effektive kvægbedrifter, Dansk Kvæg, - project leader.
1999-2005 Demonstration og udvikling af nye økologiske jordbrugssystemer, DFFE - project leader.
1997-2001 Stude på marginaljord, ARL97.

Research interests:
Senior Scientist Troels Kristensen has a broad experience with farming systems research based on registration on private farms; experiments conducted on private farms and modeling. Different aspects of feed supply on organic and conventional dairy farm has been the main working topics and more specific pasture management, grazing systems and effects of supplemental feeding have been in focus in the recent years. Highly experienced in designing and analysis of on farm data with respect to production, economy and environmental aspects. Project leader and participant in several major research and demonstration projects during the last years.

Some recent publications

Børsting, C.F., Kristensen, T., Misciattelli, L., Hvelplund, T. & Weisbjerg, M.R., 2003. Reducing nitrogen surplus from dairy farms. Effects of feeding and management. Livestock Production Science 83: 165-178.

Nielsen, N.M., Kristensen, T., Nørgaard, P. & Hansen, H., 2003. The effect of low protein supplementation to dairy cows grazing clover grass during half of the day. Livestock Production Science 81: 293-306.

Nielsen, N.M. & Kristensen, T., 2001. Malkekøernes kvælstofudskillelse og udnyttelse på besætningsniveau - analyse af data fra Studielandbrug. DJF rapport, Husdyr no 33, 34 pp.

Kristensen, T., Mogensen, L. & Kristensen, I.S., 2000. Danish organic dairy cattle productionsystems – pasture utilisation and animal performance. Grassland Farming. Balancing environmental and economic demands (Edited by: K. Søegaard, C. Ohlsson, J. Sehested, N.J. Hutchings, T. Kristensen). EGF 2000, 22-25 May 2000, Aalborg Denmark, p. 564-565.

Kristensen, I.S. & Kristensen, T., 1997. Animal production and nutrient balances on organic farming systems. Prototypes. In: Proceedings ENOF workshop ”Ressource use in organic farming”. Ancona, Italy, 4-5 June. 21 pp.

Curriculum Vitae
Participant in WP1

Name:	Margrethe Askegaard
Born:	January 2, 1955
Education:	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:	2004-date Senior scientist, DIAS, Dept. of Agroecology. 1993-2004 Scientist, DIAS, Dept. of Agroecology (Crop Physiology and Soil Science 1997-2003, Dept. of Soil Science 1993-97). 1983-1993 Advisor, Agricultural Extension Service. 1980-1983 Instructor, Agricultural Schools.
Other activities	Member of the Foundation for Organic Agriculture, Ministry of Agriculture and Fisheries.
Main research projects:	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.
Research interests:	The main competence is on cropping systems and nutrient management. Both practical management approaches and scientific approaches are included in the work. This broad technical approach to crop production and management facilitates the identification of week links in cropping systems with respect to production and environmental effects.

Some recent publications

Askegaard M., Eriksen J. and Johnston A.E. 2004. Sustainable Management of Potassium. In: Schjønning 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, 96-103.

Askegaard M., Olesen J.E. and Kristensen, K. 2005. Nitrate leaching from organic arable crop rotations: effects of location, manure and catch crop. 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. and 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.

Öborn I., Andrist-Rangel Y., Askegaard M., Grant C.A., Watson, C.A. and Edwards A.C. 2005. Critical aspects of potassium management in agricultural production systems. Soil Use and Management (in press).

Curriculum Vitae
Participant in WP3

Henning Høgh Jensen, 15 April 1957;

Employment record

2000 - Associate Professor, Department of Agricultural Sciences, KVL.
1997 - 2000 Assistant Professor, Department of Agricultural Sciences, KVL.
1993 - 1997 Ph.D. scholarship, Department of Agricultural Sciences, KVL.

Research interests

My research activities have been centred around legumes, moving on levels ranging from individual plant physiology to natural resource management on systems level and the spin off that the legumes create in the surrounding natural and socio-economic spheres. I have a particular interest in developing an understanding of the nutrient and matter dynamics in low input intercropped and organic systems. Competition and facilitation processes as well as the nutrient dynamic associated with grassland mixtures has been studied.

Relevant project experience

Research Projects:

- Coordinate the research programme “Pigeonpea-based Maize Production in Semi-Arid Eastern and Southern Africa”.
- Participate in the research project: Regional groundwater protection by optimised organic farming systems.
- Participate in the international CG-centre challenge programme “HarvestPlus”.

Research Education:

- Head of the post graduate Research School in Organic Farming and Food Systems (SOAR).
- Study coordinator of the MSc Agricultural Development programme at KVL.
- Supervisor of five Ph.D. students.

Selected papers in international scientific refereed journals:

Høgh-Jensen H, Loges R, Jensen ES, Jørgensen FV & Vinther FP (2004) An empirical model for quantification of symbiotic nitrogen fixation in grass-clover mixtures. *Agricultural Systems* 82, 181-194.

Høgh-Jensen H (2003) The effects of potassium deficiency on growth and N_2-fixation in *Trifolium repens*. *Physiologia Plantarum* 119, 440-449.

Høgh-Jensen H & Pedersen MB (2003) Morphological plasticity by crop plants and their potassium use efficiency. *Journal of Plant Nutrition* 26, 969-984.

Høgh-Jensen H, Schjoerring JK & Soussana J-F (2002) The influence of phosphorus deficiency on the growth and nitrogen fixation of white clover plants. *Annals of Botany* 90, 745-753.

Hansen EM, Høgh-Jensen H & Djurhuus J (2002) Biological nitrogen fixation in a grazed grass/clover ley and correlation with herbage and soil variables. *European Journal of Agronomy* 16, 309-320.

Høgh-Jensen H, Fabricius V & Schjoerring JK (2001) Regrowth and nutrient composition of different plant organs in grass-clover canopies as affected by phosphorus and potassium availability. *Annals of Botany* 88, 153-162.

Høgh-Jensen H & Schjoerring JK (2001) Rhizodeposition of nitrogen by red clover, white clover and ryegrass leys. *Soil Biology & Biochemistry* 33, 439-448.

Høgh-Jensen H & Schjoerring JK (2000) Below-ground nitrogen transfer between different grassland species: Direct quantification by ^{15}N leaf feeding compared with indirect dilution of soil ^{15}N. *Plant and Soil* 227, 171-183.

Hansen B, Kristensen ES, Grant R, Høgh-Jensen H, Simmelsgaard SE & Olesen JE (2000) Nitrogen leaching from conventional versus organic farming systems – a systems modelling approach. *European Journal of Agronomy* 13, 65-82.

Eriksen J & Høgh-Jensen H (1998) Variation in the natural abundance of ^{15}N in ryegrass/white clover shoot material as influenced by cattle grazing. *Plant and Soil* 205, 67-76.

Høgh-Jensen H & Schjoerring JK (1997) Interactions between white clover and ryegrass under contrasting nitrogen availability: N_2 fixation, fertilizer recovery, N transfer, and water use efficiency. *Plant and Soil* 197, 187-199.

Høgh-Jensen H, Wollenweber B & Schjoerring JK (1997) Kinetics of nitrate and ammonium absorption and accompanying H^+ fluxed in roots of *Lolium perenne* L. and N_2-fixing *Trifolium repens* L. *Plant, Cell and Environment* 20, 1184-1192.

Curriculum Vitae

Participant in WP4

Name:	Lars Monrad Larsen
Born:	1947
Education:	1976 M.Sc. (Biology) from Århus and København University. 1979 Part of degree (Cand. polyt.), Danish Tecnical University.
Employment:	Senior scientist. Danish Institute of Agricultural Sciences, Research Centre Flakkebjerg, Department of Crop Protection, DK-4200 Slagelse (since 1980).
Other activities:	
Relevant research projects:	
Research interests:	Entomology, pests (insects, slugs, nematodes), forecasting, damage thresholds, models, insect/plant-relationship, allelochemicals in pest control, biosensors and pests.
Recent relevant publications:	Hansen, L.M., 2004. Economic damage threshold models for pollen beetles in spring oilseed rape crops. Crop Protection 23, 43-46. Hansen, L.M., 2004. Role of Dimboa in the Partial Resistance of Winter Wheat to the Grain Aphid (Sitobion avenae F.). Second European Allelopathy Symposium "Allelopathy - from understanding to application", 88-90. Hansen, L.M., 2003. A model for determination the numbers of pollen beetles (Meligethes aeneus F.) per plant in oil-seed rape crops (Brassica napus L.) by estimating per cent plants attacked by pollen beetles. Journal of Applied Entomology 127, 163-166. Hansen, L.M., 2003. Insecticide resistant pollen beetles (Meligethes aeneus F.) found in Danish oilseed rape (Brassica napus L.) fields. Pest Management Science 59, 1057-1059. Jakobsen, J. & Hansen, L.M., 2002. Nematoder som skadedyr på gulerødder. Grøn Viden, Markbrug no 254. Hansen, L. M. & Jakobsen, J. 2001. Kartoffelcystenematoder. Grøn viden, Markbrug no 240. Hansen, L.M. 2000. Establishing control threshold for bird cherry-oat aphid (Rhopalosiphum Padi L.) in spring barley (Hordeum Vulgare L.) by aphid-days. Crop Protection 19, 191-194. Hansen, L.M. & Nielsen, G.C., 2000. Havrecystenematoder i majs. 17. Danske Planteværnskonference, marts 2000, DJF rapport no 25 - Markbrug, p. 45. Jakobsen, J. & Hansen, L. M., 2000. Roecystenematoder. Grøn Viden, Markbrug no 226.

Curriculum Vitae
Participant in WP5

Name: Ole Hørbye Jacobsen

Born: 9 May 1961

Education: 1986 M.Sc. (Horticultural science) from The Royal Vet. and Agricultural University.
1991 Ph.D. in Soil Physics from The Royal Vet. and Agricultural University.

Employment: 1998-:Head of research unit of Soil Physics and Chemistry. Danish Institute of Agricultural Sciences, Department of Agroecology, Research Centre Foulum, Tjele.
1994-98:Senior Scientist at Danish Institute of Plant and Soil Science, Research Centre Foulum.
1991:Visiting Scientist at U.S. Salinity Laboratory, Riverside, California.
1987-94:Research Associate at Danish Institute of Plant and Soil Science, Højer Experimental Station, Jyndevad Experimental Station and Research Centre Foulum.

Other activities External examiner at The Technical University of Denmark, Lyngby**.**
Co-supervisor for students at The Royal Vet. and Agricultural University (1 M.Sc., 1 Ph.D.), Aalborg University (9 M.Sc., 1 Ph.D.), Roskilde University (1 M.Sc.) and KU Leuven, Belgium (2 M.Sc.).
Assoc. Editor of Journal of Environmental Quality (1997-2000) and Vand og Jord (2000-).

Main research projects:
1987-88: Determination of unsaturated hydraulic.
1988-91: Estimation of transport parameters for water and solute (Ph.D. project).
1992-96. Project leader of joint project concerning water and solute transport in heterogeneous soils. Project funded by the Danish Environmental Research Programme.
1992-96: Water and solute transport in heterogeneous soils (Project leader).
1995-98: Colloid facilitated transport of pesticides (Project leader).
1995-98: "Finger flow" in the root zone of sandy soils (Project leader).
1996-99: Pesticides and groundwater. Danish Environmental Research Programme.
1998-01: Ammonia volatilisation and soil conditions.
1998-: Concept for identifying areas vulnerable to pesticide contamination.
2002-05: Regional groundwater protection by organic farming systems. (Project leader).

Research interests: Participating and project leader in several joint projects concerning water, solute and colloid transport – mainly nitrate, phosphorus, estrogens and pesticides and especially in heterogeneous soils. The research has resulted in 106 publications (author, senior-author and co-author) of which 32 are in international, refereed scientific journals and 32 are conference proceedings.

Some recent publications

Jacobsen, O.H., Moldrup, P., Larsen, C., Konnerup, L. & Petersen, L.W. 1997. Particle transport in macropores of undisturbed soil columns. *J. Hydrol.* 196:185-203.

Sommer, S.G. & Jacobsen, O.H. 1999. Infiltration of slurry liquid and volatilization of ammonia from surface applied pig slurry as affected by soil water content. *Jour. Agric. Sci., Cambridge* 132:297-303.

Jacobsen, O.H., Poulsen, T.G., Moldrup, P. & Schjønning, P. 1999. Relating saturated and unsaturated hydraulic conductivity to gas diffusivity and the Campbel water retention model. *In* van Genucthen, M.Th. et al. (eds.) Characterization and measurements of the hydraulic properties of unsaturated porous media. Riverside. pp. 1495-1508.

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.

Iversen, B.V., Moldrup, P., Schjønning, P. & Jacobsen, O.H. 2003. Field Application of a Portable Air Permeameter to Characterize Spatial Variability in Air and Water Permeability. Vadose Zone Journal 2:618-626.

Poulsen, T.G., Moldrup, P., Wosten, H. & Jacobsen, O.H. 2004. Predicting three-region unsaturated hydraulic conductivity from three soil-water retention points. *Soil Science* 169:157-167.

de Jonge, L.W., Sommer, S.G., Jacobsen, O.H. & Djurhuus, J. 2004. Infiltration of slurry liquid and ammonia volatilization from pig and cattle slurry applied to harrowed and stubble soils. Soil Science 169:729-736.

Curriculum Vitae
Participant in WP6

Name: Niels Tvedegaard

Born: 13 November 1969

Education: 1999 M. Sc. from The Royal Vet. And Agricultural University.

Employment: 1998-2002 Research Assistant at the Institute of Food and Resource Economics.

2002- Consultant at the Production and Technology Division, KVL.

Main research projects: Since 1998 I have been working specifically with the biological relationships in organic farming systems. I have estimated the economic impact of these complex links, which includes estimations of the value of nitrogen in a organic plant production and where nitrogen optimally should be placed in relation to crop rotation. As a result of this work I have developed a dynamic model (Ø-plan), which is designed for organic farming. Existing versions of the model includes organic crop production, milk production, pig production and chicken production.

Research interests: The economy in organic farming including the conversing period. Modelling the biological connections in organic framing to the economy.

Some recent publications

Tvedegaard, N. (1999): Conversion to organic pig- and plant production - analyses of the economic consequences. In Danish: “Omlægning til økologisk svine- og planteproduktion – analyse af økonomiske konsekvenser på udvalgte bedrifter”, Working Paper no 16/1999, Statens Jordbrugs- og Fiskeriøkonomiske Institut.

Tvedegaard, N. (2000): Conversion to organic plant production – Analyses of the economic consequences on selected farms. In Danish: “Omlægning til økologisk planteavl – analyse af de økonomiske konsekvenser på udvalgte planteavlsbedrifter”, Working Paper no. 2/2000, Statens Jordbrugs- og Fiskeriøkonomiske Institut.

Tvedegaard, N. (2000): Conversion to organic chicken production – Analyses of the consequences on selected farms. In Danish: “Omlægning til økologisk slagtekyllingeproduktion – analyse af de økonomiske konsekvenser på udvalgte bedrifter”, Working Paper no 12/2000, Statens Jordbrugs- og Fiskeriøkonomiske Institut.

Tvedegaard, N. (2002): Organic milk production – economic analyses. In Danish: “Økologisk mælkeproduktion – økonomiske analyser”. Rapport no 137. Fødevareøkonomisk Institut.

Curriculum Vitae
Participant in WP6

Name: Kristensen, Ib Sillebak
Born: 5. March 1957
Education: 1982 M.Sc. (Agric) from The Royal Vet. and Agricultural University.
1993 Ph.D. in grassland production from The Royal Vet. and Agricultural University.

Employment: 1982-83 Farmer Association. Plant adviser.
1983-96 Scientist at Dept. of Research in Cattle and Sheep, Danish Inst. of Animal Science.
1996- Senior Scientist at Dept. of Agroecology, Danish Institute of Agricultural Sciences.

Other activities Co-supervisor for students at The Royal Vet. and Agricultural University (2 M.Sc., 2 Ph.D.) and the Swedish Agricultural University (1 Ph.D.).
Member of International Boards.
-European Grassland Federation working group since 2002: Grassland resowing and grass-arable crop rotation.
-European Grassland Federation working group since 2003: Member of steering committee: Dairy Farming System and environment.

Main research projects:
1983-1989 Management of roughage production on private dairy farms.
1989-1993 Growth and regrowth of perennial ryegrass for cut (PhD).
1989-1994 Plant production and nutrient utilization on organic dairy farms (Project leader).
1994-1999 Egg and plant prod. and nutrient utilization on org. egg farms (Project leader).
1996-1999 Farm gate nutrient balances on organic pig farms.
1999-2003 Plant prod. Farm gate nutrient balances on org. arable farms (Project leader).
2002-2004 Environmental impact of organic production.

Research interests: Research has focussed on roughage production and management. During later years nutrient flows between fields, farm and region and environmental impact of different farming systems has been in focus. The research has resulted in 127 publications (author, senior-author and co-author) of which 12 are in international, refereed scientific journals and 20 are conference proceedings.

Some recent publications

Halberg, N., Kristensen, E. S., and Kristensen, I. S. 1995: Nitrogen turnover on organic and conventional mixed farms. Jour. of Agric. and Env. Ethics 8, 30-51.

Halberg, N. and Kristensen, I. S. 1997: Expected crop yield loss when converting to organic dairy farming in Denmark. Biological Agric. and Hort. 14, 25-41.

Knudsen, M. T., Kristensen, I. S., Berntsen, J., Petersen, B. M., and Kristensen, E. S. 2005: The effect of organic farming on N leaching. Submitted. Jour. Agric. Sci.

Kristensen, I. S., Kelm, M., and Kristensen, T. 2004: Effects of grassland renovation on farm-gate nitrogen balances and losses. Proc. of the 20th General Meeting of the European Grassland Federation, Luzern, Switzerland, 21-24. June 2004. 756-758.

Kristensen, E. S., Høgh-Jensen, H., and Kristensen, I. S. 1995: A simple model for estimation of atmospherically-derived nitrogen in grass-clover systems. Biological Agriculture and Horticulture 12, 263-276.

Kristensen, T., Søegaard, K., and Kristensen, I. S. 2005: Management of grasslands in intensive dairy livestock farming. Accepted by Lives. Prod. Sci.

Nielsen, A. H. and Kristensen, I. S. 2005: Level of nitrogen and phosphorus surplus at Danish livestock farms in relation to farm characteristics. Accepted by Lives. Prod. Sci.

Kristensen, I. S., Halberg, N., Nielsen, A. H., and Dalgaard, R. 2003: N-turnover on Danish mixed dairy farms. Workshop: "Nutrient management on farm scale: how to attain European and national policy objectives in regions with intensive dairy farming?". 23-25 June 2003. Quimper, France. Part 2, 1-21. www.agrsci.dk/jbs/isk/DK_country_report_partII.pdf.

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